

**Agroforestry Comes of Age:
Putting Science into Practice**

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MICHAEL A. GOLD & MICHELLE M. HALL, EDS.

Editing/Page Layout: **Michelle Hall**

FOREWORD

This year, we celebrate the 20th Anniversary of the North American Agroforestry Conference (NAAC) series, originally kicked off by Andy Gordon and Peter Williams at Guelph, Ontario, Canada in 1989. Eighteen years ago, 1991, the University of Missouri hosted the 2nd NAAC. Based on discussions that took place at the 2nd NAAC, the Association for Temperate Agroforestry (AFTA) was formed in 1992 and took on the responsibility of organizing all future biennial NAACs.

AFTA's mission is to **"...promote the wider adoption of agroforestry by landowners in temperate regions of North America."** The theme of the 11th North American Agroforestry Conference (NAAC) "Agroforestry Comes of Age: Putting Science into Practice" provides support to AFTA's mission. The two keynote addresses headlining the 11th NAAC, "Sheep, Trees and Direct Marketing in British Columbia" by Chris and Jen Cunningham of the Jay Springs Lamb Company and "From the Hills of the Ozarks to the Bistros of St Louis" by Nicola McPherson of Ozark Forest Mushrooms, were deliberately chosen to remind us that the practice of agroforestry is our ultimate goal.

In the winter of 1993 the first issue of AFTA's newsletter "The Temperate Agroforester" was published. In that first issue I wrote "... the future is constrained by a climate of limited financial resources, a lack of active constituencies to support temperate agroforestry, untested and unproved technologies, and the cross disciplinary nature of agroforestry in the temperate zone."

Over the past 16 years agroforestry has expanded from a base in biophysical "tree/crop interactions" research to include a strong focus on the environmental benefits of agroforestry and an increasingly vibrant focus on the socio-economic-market, institutional-policy oriented aspects. That progress is reflected in the newly published second edition of "North American Agroforestry: An Integrated Science and Practice" and in these proceedings. U.S. policy (i.e., cost-share dollars) supporting agroforestry practices has also grown.

Looking toward the future, two challenges are evident. First, finding financial support to underwrite and provide continuity to the long-term nature of agroforestry research. Second, finding new, creative ways to support producers and achieve on-the-ground adoption of agroforestry practices. Simply put, growers trust other growers, and agroforestry needs to expand the core group of successful and dedicated practitioners to convince others to practice agroforestry. Welcome to Missouri!



Michael A. Gold

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SECTION 1

Carbon Sequestration/Carbon Markets

ESTIMATING CARBON STOCK CHANGE IN AGROFORESTRY AND FAMILY FORESTRY PRACTICES

Miles L. Merwin¹, Mark Easter², Lyn R. Townsend¹, Roel C. Vining¹ and
Greg L. Johnson¹

¹USDA Natural Resources Conservation Service, 1201 NE Lloyd Blvd., Portland, OR 97232

²Natural Resource Ecology Laboratory, Colorado State University, Ft. Collins, CO

Contact: Roel.Vining@por.usda.gov

Abstract: The Carbon Management Evaluation Tool for Voluntary Reporting (COMET-VR) is an online tool that estimates short-term carbon stock (CS) changes under different farm or forest land management systems, including temperate agroforestry practices. It was developed by the USDA Natural Resources Conservation Service in conjunction with Colorado State University. The intended audience includes private farm and forest landowners, NRCS field staff, and technical service providers. Through the online interface, users identify their location, parcel size, surface soil texture, crop rotation history and tillage intensity. The user can choose either of two methods to estimate CS change for their agroforestry practice: 1) for new or future plantings, by using standard prescriptions common to their geographic region, or 2) for a more accurate estimate of an existing planting, by using a summary of live-tree stand inventory data collected from their parcel. Above and below-ground individual tree biomass is calculated using diameter-based allometric equations generalized for tree genera groups. For existing agroforestry plantings, growth estimates are based on empirical models developed from forest inventory data specific to species and region. For new or future plantings, growth estimates were derived for standard agroforestry prescriptions using the Forest Vegetation Simulator. COMET-VR uses the Century soil carbon model to estimate CS change in soil. The output of the tool is a report estimating CS changes over the forthcoming 10 years in the above and below-ground portions of live trees and in the soil. Although specifically designed to meet the requirements of the US Dept. of Energy voluntary greenhouse gas reporting program, COMET-VR may also be applicable to other private and public sector carbon offset programs.

Key Words: carbon sequestration, biomass, allometric equations, soil carbon, greenhouse gas reporting.

INTRODUCTION

A new version of the online Carbon Management Evaluation Tool for Voluntary Reporting (COMET-VR) tool enables landowners to rapidly estimate potential changes in live tree and soil carbon stocks (CS) under different temperate agroforestry management practices in the conterminous US. These include the row-type agroforestry practices Alley Cropping (including nut orchards) and Windbreaks, and the forest-like practices Multi-Story Cropping, Riparian Buffers and Silvopasture. An additional practice, Farm Woodlots, is also included for non-industrial family forest plantings. It uses the Century Soil Organic Matter model (Century), a generalized biogeochemical ecosystem model that simulates changes in soil carbon, nitrogen and other elements (Parton et al. 1993). COMET-VR is designed to comply with the requirements for

voluntary reporting of short-term changes in CS under the US Dept. of Energy's 1605(b) program.

Work to add the reporting of agroforestry practices to COMET-VR, which was previously calibrated only for annual crop rotations and grazing on farm and range lands, began in early 2006. Merwin and Townsend (2007) described methods and expected results during an earlier stage of its development. This paper describes changes incorporated in the current (2009) version of COMET-VR that includes the agroforestry/family forestry extension.

MATERIALS AND METHODS

Carbon Pools and Tree Biomass Estimation

Since the DOE 1605(b) reporting period is only ten years, the COMET-VR agroforestry extension focuses on those components that account for most of the short-term change in CS. Smith and Heath (2008) estimated that 85% of the total net annual CS change in all US forests from 1987 to 2001 was in the live tree (66%) and forest soil (19%) pools. The remainder occurred in other pools that change more slowly: shrubs and herbaceous understory (2%), forest floor (4%) and down dead wood (8%). Technical guidelines for reporting of greenhouse gases from agroforestry projects under the DOE 1605(b) program recommend measuring and monitoring of carbon in the live tree (above and below-ground) and soil pools (US DOE 2007a). Guidelines for forest carbon sequestration projects also recommend monitoring only these three pools for agroforestry, afforestation and forest restoration projects (Pearson et al. 2007). These pools are the only ones estimated by the COMET-VR agroforestry/family forestry extension.

To estimate live tree biomass in agroforestry practices, COMET-VR uses a generalized, diameter-based allometric equation developed by the US Forest Service that predicts total above-ground and component (roots, branches, etc.) dry weight biomass of individual trees from diameter at breast height (dbh) for all US tree species divided into ten genera groups (Jenkins et al. 2003, 2004). It is designed for use at the national scale over all sites, slopes, aspects, elevations, etc.

Tree Growth Estimation

No "universal" model to predict the growth of trees in agroforestry practices in all regions of the US exists. However, it is possible to develop empirical models of individual tree growth by species from periodic inventory data collected from a large number of field plots (Lessard 2001).

The first attempt to develop an empirical growth model was to try to relate tree age with dbh (Merwin and Townsend 2007). Published data from the Forest Inventory and Analysis (FIA) program was obtained from US Forest Service. Site trees of known age and size were selected. However, due to a high level of site and genetic variation, the resulting plots of age versus dbh by species and location failed to produce realistic or useable models of tree growth. The data had too wide a scatter to fit a non-linear equation that could represent an expected (sigmoidal) tree growth pattern.

The second method tested and the one ultimately used in COMET-VR was relative diameter increment. This method relies on data from individual trees whose diameters are measured at two different points in time. It's not necessary to know the age of the tree, only its current dbh, which is a more easily-measured and accurate variable. The growth metric is diameter change over time (standardized to 10 years) relative to the starting diameter, i.e.

$$RI = ((DBH_1 - DBH_0) / DBH_0) * (10 / RemYrs)$$

where RI is relative increment, DBH_0 is the dbh at the first measurement time, DBH_1 is the dbh at the second measurement time, and RemYrs is the time intervals between measurements in years. Relative diameter increment is a common measure of tree growth (Bragg 2001, Lessard et al. 2001, Westfall 2006).

Development of growth models based on relative diameter increment for COMET-VR followed the work of Lessard et al. (2000, 2001). They created growth models using state-level FIA data that have two terms: average dbh increment and a modifier. For COMET-VR, only the average growth term was used because the modifier term requires collection of more detailed information than was deemed practical for COMET-VR users, e.g. crown ratio, basal area, etc. Therefore, the growth equation predicts growth of "average" trees on an "average" site.

The form of the growth equation used for COMET-VR is as follows,

$$ARI = a * \exp(-b * x) * (x^c)$$

where ARI is average relative increment, x is average dbh at the current age, and a, b, and c are coefficients.

Because of the relatively short, 10-year reporting period for the 1605(b) program, the tree growth estimates produced by COMET-VR assume no mortality, harvest, or significant change in growth potential due to management, microclimate or inter-tree competition during the interval.

Inventory Data and Analyses

Both published and unpublished data from FIA inventories in which trees were remeasured at least 10 years apart were obtained from FIA National Spatial Data Services for all but one of the conterminous states. The data were mainly from older periodic inventories, since the newer annual inventories conducted by FIA since 2000 only allow comparisons over short remeasurement intervals. Only live trees that were not overtopped by adjacent trees were selected. Geographic locations of tree records were identified at the level of Land Resource Region (LRR) and Major Land Resource Area (MLRA) (USDA 2006). (For COMET-VR, alphabetical subdivisions within an MLRA, e.g. 43A, B and C, were combined into one.) Data were then fit by nonlinear regression to the ARI growth equation to derive coefficients for each combination of species by MLRA and species by LRR.

In addition to the FIA forest inventory plot data available from USFS, data from windbreak trial plots are published by the Natural Resources Conservation Service (NRCS). The data are from

windbreak species evaluations monitored under the Ecological Site Inventory System (ESIS) and located in the central states. The original idea was to use FIA data to derive growth models for the forest-like agroforestry practices and Ecological Site Inventory (ESI) data to derive growth models for the row-type practices in COMET-VR (Merwin and Townsend 2007).

ESI data on tree species and dbh were accessed online (<http://esis.sc.egov.usda.gov/>). The data are averages of 10-tree row plots and can be differentiated on the availability of supplemental moisture. However, no remeasurement data are available for the same trees on the same plots over time. Therefore, it was not possible to calculate relative diameter increment. Instead, an attempt was made to correlate tree age with dbh for species by LRR combinations, using the Chapman-Richards tree growth model (Richards 1959). However, there was too much variability in the ESI data to produce a good fit to the Chapman-Richards equation. Therefore, it was decided to use only the ARI method outlined above for tree growth equations regardless of agroforestry practice.

Site Productivity Class

Potential growth of trees in agroforestry practices depends not only on genetics and microclimate, but also on site factors such as soil moisture holding capacity, slope, aspect, etc. Some of the state-level FIA files used for COMET-VR contain a rating of the Site Productivity Class of the inventory plot, which is a measure of the site's inherent capacity to grow stemwood, expressed as cubic feet/acre/year.

An attempt was made to correlate ARI with site productivity class for selected commercial species in some regions, e.g. Loblolly pine in the Southeast (Merwin and Townsend 2007). However, the analysis did not result in a consistent relationship between growth (ARI) and site class code. Also, it was decided that it would be difficult for the average COMET user to obtain their site productivity class code. Therefore, site class is not used in the current version of COMET-VR.

Agroforestry Prescriptions

Predictions of soil CS change for annual crops on farm and range lands calculated by the Century model under COMET-VR are based on agronomic crop rotations commonly used in each MLRA. These crop rotations were parameterized with the Century model to estimate soil C changes. It was therefore necessary to develop a set of standardized prescriptions for common agroforestry practices in all regions (LRRs) of the US.

From a telephone survey of NRCS foresters and a literature review, a set of 84 agroforestry prescriptions was developed for all LRRs that include different combinations of hardwood and softwood species and planting densities derived from recommended tree spacings. Using the Jenkins biomass equation and the ARI growth equation described above, the live-tree biomass growth of each prescription was modeled over a range of starting diameters (1-50 inches). These values are used to predict the change during the 10-year reporting period in dry-weight above- and below-ground biomass per tree for the standard prescriptions in each LRR.

The change in soil C during the same period is estimated by Century following parameterization of each prescription to the model. Parameterization was done by LRR and Jenkins biomass group rather than by species.

To help validate the parameterization of these prescriptions with Century, biomass growth was also modeled using selected regional variants of the Forest Vegetation Simulator (FVS) (<http://www.fs.fed.us/fmfc/fvs/index.shtml>). All but one of the FVS variants used contain the Fire and Fuels Extension (FFE) which estimates CS changes over time in different forest components; only above and below ground portions of live trees were modeled in this instance.

The interface program Suppose with the database extension was used to run FVS. A stand initiation file was constructed using National Forest sites, average site indices and potential vegetation codes that were deemed to be generally representative of each LRR. For some LRRs, e.g. DN and E, prescriptions were modeled with more than one FVS variant. Tree growth in each prescription was simulated for 60 years in 10 year cycles, starting from planting 2-year old seedlings on bare ground. The carbon submodel of FFE (based on the Jenkins biomass equation) was used to model total above and below-ground C for all live trees in the stand at each cycle end. These values were converted to dry biomass assuming that woody biomass is 50% C by weight.

RESULTS AND DISCUSSION

The inputs and outputs of an earlier version of the COMET-VR user interface were previously described by Merwin and Townsend (2007). Through the online interface, users identify their location, parcel size, surface soil texture, crop rotation history and tillage intensity.

One important change in the current released version is on the land management information page. Here the user is asked to select the agroforestry or family forestry prescription(s) which most closely match(es) their own current or future plantings from a list of regionally-appropriate choices. A choice of agroforestry practices is available for the two most recent time periods, i.e., pre-1970s to the forthcoming 10 years.

After choosing the appropriate prescription, the user is asked if they have data to enter from an inventory of their agroforestry planting. This choice-point determines which of two methods is used to estimate CS change on their parcel for the reporting period. If the user does not have inventory data, the agroforestry practice is not yet established, or the average dbh of the trees is currently less than 1 inch (25 mm), then CS estimates are based solely on pre-calculated values for the agroforestry prescription they selected for the reporting period in the previous step.

On the other hand, if they have data collected from a current inventory of their planting and wish a more accurate estimate, then the CS estimate is predicted from calculations using the biomass and growth equations for their tree species and geographic region.

For either method used to calculate CS change for an agroforestry parcel, the results are reported to the user in the form of a table. The carbon storage report presents the annual change in C for the entire parcel subtotaled by above-ground live tree, below-ground live tree and soil. For each

pool, values are given in tons C per year, tons CO₂ equivalent (CO₂e) per year and uncertainty. The uncertainty estimates for these annual CS change values are based on long-term experiments of agronomic rotations.

To guide the user through the COMET-VR interface, extensive online Help is available. This includes detailed instructions and worksheets for performing field inventories in both row-type and forest-like agroforestry practices; descriptions, photos and references for the five common agroforestry practices plus family forestry; and step by step instructions for navigating the COMET-VR interface.

CONCLUSIONS

The latest version of COMET-VR is a first attempt to provide a user-friendly carbon estimation tool for agroforestry and family forestry practices in the conterminous US. The intended audience includes private landowners, farmers, ranchers, non-industrial private forest owners, NRCS field staff, and technical service providers. In keeping with the design criteria for COMET-VR, the agroforestry extension is designed for relative ease of use, national-scale applicability, and reasonable accuracy across a wide range of site factors.

Research conducted at University of Nebraska Lincoln (UNL) on windbreak trees in some central states suggests that the Jenkins biomass equation may significantly under-estimate biomass in widely-spaced trees growing in windbreaks (Zhou et al. 2002). More research is needed on this question, involving species and regions beyond the UNL study.

FIA data used to develop the ARI growth equation was collected mainly from forest stands that may not include the lower planting densities often found in widely-spaced or linear agroforestry practices, i.e., windbreaks and alley cropping. It has been suggested that FIA incorporate more inventory plots of “working trees” on agricultural lands (Perry et al. 2009). That would allow the development of more accurate models of tree growth in row-type agroforestry plantings. Nevertheless, tree growth models derived from FIA data collected in forest stands should be a good predictor of growth in family forests and forest-like agroforestry practices, i.e., multi-story cropping, silvopasture (except widely-spaced tree rows), and riparian buffers.

Furthermore, the FIA plot data used are from older periodic inventories dating back to the 1970s in some cases. USFS has since changed to an annual program of data collection. For a future version of COMET-VR, it would be worthwhile to compile a new dataset from annual inventory data with remeasurement intervals of 10 or more years. Using more recently collected inventory data would better reflect potential tree growth responses to changing microclimates.

As mentioned above, site quality is a strong predictor of tree growth. More work is recommended to try to differentiate potential growth of selected tree species by site index or site productivity class. That would improve the accuracy of CS change estimates for users able to assess the relative site quality of their land.

COMET-VR is currently accredited for voluntary reporting of CS changes in soil under agronomic practices for the DOE 1605(b) program (US DOE 2007a). Guidelines for the use of models for reporting of CS changes in forestry projects under 1605(b) give higher ratings for models that produce estimates close to the actual values, e.g. an A rating for 90% or higher accuracy (US DOE 2007b). The latest release of COMET-VR has not yet been approved or rated by US DOE for reporting of CS changes in agroforestry or family forestry projects, and field studies are needed to compare model estimates with values obtained through direct measurements. The use of site-specific inventory data should earn the user an A or B rating, whereas estimates based only on standard prescriptions may earn a C rating.

Although it was originally designed to be used for voluntary reporting under the 1605(b) program, COMET-VR could potentially be used in existing or future greenhouse gas (GHG) trading systems. For example, Chicago Climate Exchange (CCX) protocols for monitoring of carbon pools in managed forests allow the use of models such as FVS. Field testing would be required to determine if the current release of COMET-VR could be used for monitoring and verification of agroforestry / family forestry carbon offset projects under CCX. Nevertheless, COMET-VR is useful now for planning purposes since it enables landowners to compare potential CS changes that may result from applying different agronomic, grazing, agroforestry and family forestry practices on their land.

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CARBON DYNAMICS IN AGROECOSYSTEMS WITH *PINUS PONDEROSA* (DOUGL. EX LAWS) AND NATIVE PASTURES ESTABLISHED ON DEGRADED VOLCANIC SOILS IN THE CHILEAN PATAGONIA

Francis Dube¹, Andrew M. Gordon, Naresh V. Thevathasan, Miguel Espinosa, Erick Zagal and Neal Stolpe

¹Department of Silviculture and Forest Management, Faculty of Forest Sciences, University of Concepción, Victoria 631, Casilla 160-C, Chile. Tel: (+56) 41 299-3859
Contact: fdube@udec.cl

Abstract: In the last 20 years, CO₂ emissions due to fossil fuel combustion have increased approximately 40%. According to the United Nations, the use of agroforestry systems on degraded lands could result in the global capture of 820 - 2200 x 10⁶ t C year⁻¹ over a 50-year period. Consequently, there is a growing interest to study the potential of C sequestration in agro-ecosystems worldwide, including regions such as Patagonia, where ranchers face increasing pressures to maintain the cattle-raising productivity of their land. The objective of this study is to investigate the potential to sequester C in a pine-based silvopastoral system arranged in strips, a pine plantation, and degraded grassland of the Chilean Patagonia. Tree and pasture biomass and coarse woody debris were inventoried in the field and corresponding C contents determined by dried combustion and gas chromatography. Needle fall was recollected on a monthly basis, and decomposition of needle, grass roots and cattle feces was measured using the litterbag technique. Lignin and nutrient contents in the needle litter were determined, and the carbon in soil leachates and respired CO₂ were obtained using lysimeters and gas chambers, respectively. Soil samples were analyzed to determine SOC. Preliminary results show that decomposition rates were related to soil temperature and moisture contents. Additionally, soil respiration was highest in the prairie and lowest in the pine plantation. Determination of SOC at 0-40 cm depth shows that the pasture had the highest C contents, and there was more C in the soil under pasture and pine than in the corresponding plant biomass. Pine needles contained almost four times more C than the pasture shoots, but pasture roots contained more C than pine roots. Because of the association of pine and pasture, the silvopastoral system is an interesting alternative for C sequestration and growth of plant components.

Key Words: Silvopastoral system, C sequestration, *Pinus ponderosa*, volcanic soils, decomposition, soil respiration.

CARBON SEQUESTRATION PAYMENTS FOR LANDOWNERS: CURRENT OPTIONS AND FUTURE POTENTIALS IN MINNESOTA

Diomy Zamora¹, Gary Wyatt², Dean Current³

¹University of Minnesota Extension, 322 Laurel St. Suite 21 Brainerd, MN 56401

²University of Minnesota Extension, 1961 Premier Drive, Suite 110, Mankato, MN 56001

³Center for Integrated and Natural Resources and Agricultural Management, University of Minnesota, St. Paul

Contact: zamor015@umn.edu

Abstract: The interest of reducing the level of greenhouse gasses in the atmosphere by various groups is escalating. Federal, state, county agencies and non-government organizations are looking for innovative ways to combat the effects of climate change through carbon sequestration activities. Carbon sequestration, the capture and secure storage of carbon that otherwise be emitted to or remain in the atmosphere, is a process that would not only lessen the magnitude of carbon dioxide build up in the atmosphere but it also serves as a tool to provide payment to landowners for the ecological services they render. These ecological services include sequestering carbon dioxide from the atmosphere through tree or agriculture plantings. Growing plants sequester carbon from the atmosphere and release it when they decompose unless converted. Other management practices employ by farmers with potentials to sequester carbon include agroforestry, no-till farming and grass planting. Soils in these practices serve a major depository for carbon. This presentation will focus on the current options and future potentials of carbon sequestration payments for landowners in Minnesota. We will also discuss the current extension programming on carbon credits at the University of Minnesota including implementation of perennial vegetations, agroforestry practices, forest and agricultural management practices that sequester or store carbon. The role of carbon markets will also be discussed.

SECTION 2

Water Quality

STREAM BANK EROSION RATES OF SMALL MISSOURI STREAMS

C.C. Willett¹, S.A. Berges², R.N. Lerch³, and R.C. Schultz²

¹Department of Soil, Environmental and Atmospheric Sciences, University of Missouri.

²Department of Natural Resource, Ecology and Management, Iowa State University.

³USDA-Agricultural Research Service, Cropping Systems and Water Quality Research Unit, Columbia, MO.

Contact: Bob.Lerch@ars.usda.gov

Abstract: Sedimentation of surface waters in the United States is a significant environmental concern. Investigating land use impacts on stream bank erosion rates is intended to lead to the development of improved management practices and provide the basis for targeting the placement of management practices to mitigate this problem. The overall objective of this research was to determine the effect of stream order, adjacent land use, and season on stream bank erosion rates. Study sites were established in 2007 and 2008 within Crooked and Otter Creek watersheds, two claypan watersheds located in northeast Missouri. Detailed site information was recorded, including eroded stream bank length, soil descriptions, gullies, debris dams, cattle access areas, and point bars. A factorial experimental design was implemented with four land uses (cropped, forest, pasture, and riparian forest) and three stream orders (1st, 2nd, 3rd). Each treatment was replicated three times for each stream order, except for the cropped 3rd order treatment as only one suitable treatment could be found. Erosion pins were installed based on bank height and length at each site to measure bank erosion/deposition rates. The effect of different seasons was assessed by measuring the length of the exposed pins three times per year (March, July, and November). Statistical analyses were performed to determine the effect of stream order, land use, and season on erosion rates. The results showed that the seasonal effect was highly significant, with much greater erosion rates in the winter of 2008 compared to the other seasons. Land use was significant when low magnitude deposition was observed and was not significant in any of the seasons in which erosion occurred.

Key Words: stream order, land use, claypan watersheds, erosion pins.

INTRODUCTION

Sedimentation is a significant environmental problem, with estimated mitigation costs of \$16 billion annually in North America (Wynn and Mostaghimi 2006). Stream banks contribute substantially to stream sediment (Zaimes et al. 2006; Piercy and Wynn 2008; Fox et al. 2007). Simon et al. (1996) reported that stream bank erosion accounted for up to 80% of the in-stream sedimentation in watersheds of the loess area of the Midwestern United States. Recent work utilizing stable isotopes has shown that stream bank erosion can account for the majority of suspended sediment present in streams during high flow conditions (Wilson et al. 2008). The impact of sediment on aquatic habitats and populations and the implications of soil loss on agricultural productivity have been widely recognized by state and federal conservation agencies as a major soil and water quality issue in agricultural watersheds (Wilson and Kuhnle 2006). As a result, the influences of various management practices have been extensively examined.

However, despite extensive research, a general consensus on which management practices are best for stabilizing banks and reducing sediment delivery has not emerged (Nerbonne and Vondrack 2001). In addition, because of the runoff-prone nature of claypan soils, it has been widely assumed that overland erosion from cropped fields is the primary source of sediment in the streams of claypan watersheds (Jamison et al. 1968). Therefore, no published information has been reported on stream bank erosion and its contribution to the sediment load in claypan watersheds.

As researchers and management specialists look to understand the causes and effects of these water quality issues, the need for further investigation is apparent. Investigating land use impacts on stream bank erosion rates is intended to lead to development of improved management practices and provide the basis for targeting the placement of “best management practices” (BMPs) within watersheds to mitigate stream bank erosion. The overall objectives of this study were to investigate the effects of adjacent land use, season, and stream order on stream bank erosion rates in two watersheds of the Central Claypan Region of northeastern Missouri. The results presented here include only 3rd order streams as data analysis of 1st and 2nd order streams has not been completed.

MATERIALS AND METHODS

To identify differences in stream bank erosion rates based on adjacent land use, study sites were established in Crook and Otter Creek watersheds, located in northeastern Missouri. The Crooked Creek watershed is 284 km² with 56% of the area used for cropland, followed by pasture (26.5%) and forest (14.5%). The Otter Creek watershed encompasses a 271 km² area, with 64.6% in cropland, 20.3% in pasture, and 12.6% in forest (Lerch et al. 2008). These watersheds were selected because they are representative of the intensively row-cropped claypan watersheds of Major Land Resource Area 113 (Central Claypan Region) (Lerch and Blanchard 2003; Lerch et al. 2008). A factorial experimental design was implemented to evaluate the effects of land use and season on stream bank erosion of 3rd order streams. Land use treatments included riparian forest, forest, pasture, and cropped. Data was collected three times annually. The three seasons were defined as follows: Season 1-December-March; Season 2-April-July; and Season 3–August-November. Four sets of seasonal measurements have been made since 2007. Each treatment was replicated three times with the exception of the riparian forest in the first season of measurement, during which time only a single site had been established. Additionally, one 3rd order crop site has been established so far but two other suitable treatment sites have not been located for the 3rd order crop treatment.

Site selection was based primarily on the continuous presence of a given land use treatment. All sites have a minimum of 400 m of continuous land use on both sides and had to be 3rd order based on the stream ordering system of the National Hydrography Dataset (Dewald and Roth 1998). To determine the amount of total eroded length, surveys were conducted using hand-held GPS units (Juno ST, Trimble Navigation Ltd, City, State, or Dell X51 with GlobalSat BC-337 Compact Flash GPS Receiver, Dell Computers Inc., Round Rock, TX) and Trac-Mate software (Farm Works Software, Version 12.16, CTN Data Services, Inc., Hamilton, IN) to measure distances between eroding and non-eroding sections along each bank. Eroding banks were identified based on criteria from the U.S. Department of Agriculture - Natural Resource

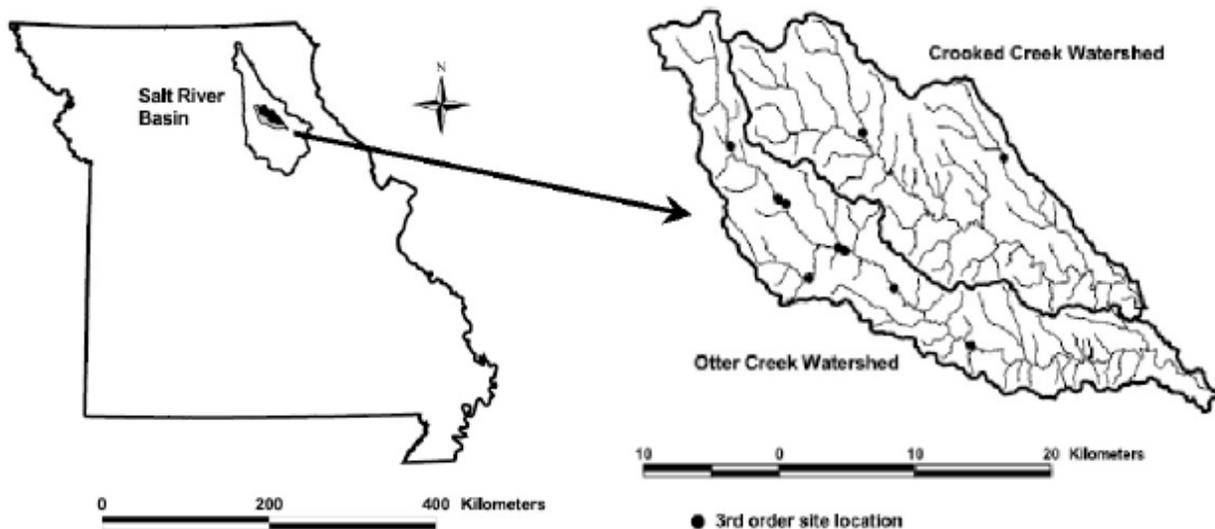


Figure 1. Third order stream site locations in Crooked and Otter Creek watersheds.

Conservation Service (USDA-NRCS) developed for calculating erosion and sediment delivery from visual inspection of stream banks and as used in previous stream bank erosion studies conducted by collaborating members from ISU (USDA-NRCS 1998; Zaines et al. 2006). Banks identified as eroded possessed one or more of the following characteristics: 2/3 of the bank face devoid of vegetative growth or roots; less than 1/3 of bank face protected by roots; overhanging vegetation with eroded undercut face; near vertical slope; and apparent bank failures, such as slumps and slides.

After surveys were conducted, each 400-m reach was sub-divided into four 100-m sub-reaches. The total eroded length for each sub-reach was then calculated using the GPS data from the survey. Erosion pins made of rolled steel (76.2 cm long and 6.2 mm diameter) were then installed perpendicular to the bank face at each site to measure stream bank erosion. Pin plot placement was randomly assigned within each sub-reach, with pins installed in at least 20% of the eroded length in that sub-reach. Arrangement of pins was based on bank height. For banks of 1 m or less, pins were placed approximately at half bank height. For banks greater than 1 m but less than 2 m, pins were placed at 1/3rd and 2/3rd bank height. Three rows of pins were installed for banks over 2 m, with rows at 1/4, 1/2, and 3/4 bank height. Laterally, pins were spaced 2 m apart. An example of pin placement on a 3rd order stream is seen in Figure 2. Pins were inserted horizontally into eroded banks with 10.2 cm of 76.2 cm left exposed and spray painted to aid in locating the pins. Each pin arrangement was recorded and each pin plot was marked with a white stake and neon flagging to aid in location of pin plots during subsequent visits. A GPS coordinate was also obtained at each white stake in the event that the stake's location was altered between visits. Pin plots were installed beginning in late June through August 2007, with one site installation during November 2007. Each pin was measured for deposition or erosion three times annually by measuring the length of the exposed pin. Bank area of each pin plot was computed based on height and length measurements. To date, four sets of seasonal data were collected: Season 3–2007; Season 1–2008; Season 2–2008; and Season 3–2008.



Figure 2. Pin arrangement on 3rd order stream. Banks are approximately 2.5m high.

Bulk density samples were taken over the course of the summer and fall 2008. Fifty percent, or a minimum of three, of the plots at each site were sampled. Bulk density cores were taken from each major soil horizon. Soil profile descriptions were recorded for each horizon from which a corresponding bulk density sample was collected. Horizon descriptions included general soil color, texture, structure, and horizon depth. Bulk density samples were dried in an oven at 110°C for a minimum of 3 days, brought to room temperature in a desiccator, and weighed. Bulk densities were computed on a depth-weighted basis for each pin plot, and then averaged over the number of plots sampled to obtain a depth-weighted average for each site

Following computation of the net pin length for a given seasonal data set, the mass of eroded or deposited bank sediment was computed based on the average net pin length (m) for an entire pin plot multiplied by the plot area (m^2) and average site bulk density ($kg\ m^{-3}$). This mass (kg) was then divided by the pin plot length (m) to give a linear erosion rate ($kg\ m^{-1}$) for each pin plot. The average linear erosion rates of the pin plots were then multiplied by the total eroded length (m) of each site (based on the initial GPS surveys described above), giving the total mass (kg) of eroded or deposited sediment for the site. The linear erosion or deposition rate of each site was then computed by dividing the total eroded or deposited mass for a site by 800 m (400-m reach with two banks per reach) to give the final linear erosion or deposition rate ($kg\ m^{-1}$) on a stream reach basis for each treatment.

Statistical analysis included a two-way analysis of variance (ANOVA) to determine the significance of the two main effects (season and land use), and their interaction, on erosion rates. Because the seasonal effect in the two-way ANOVA was significant (based on $\alpha = 0.10$), a one-way ANOVA was performed to determine the effect of land use, within each of the four seasons, on stream bank erosion rates for 3rd order streams. Missing values for the riparian treatment sites in Season 3 - 2007 were replaced with zeros in the two-way ANOVA and were left as missing in

one-way ANOVAs. The substitution of zero for the missing values in the two-way ANOVA did not change the conclusion from this analysis. Data from the crop site was not included in analysis but the data is included in tables and graphs for comparative purposes. For any significant ANOVA, the F-protected least significant difference value (F-LSD) was calculated at $\alpha = 0.05$ level of significance. This level of significance was greater than the p-value of the significant ANOVAs. The F-LSD for the season 3-2007 land use data was calculated using the ANOVA performed with missing values in the riparian treatment but assuming the same number of replications for each treatment.

RESULTS AND DISCUSSION

The seasonal effect on stream bank erosion rates was found to be highly significant for the study period ($p < 0.0001$). Seasonal means across land uses are reported in Table 1. Inspection of the graph (Figure 3) reveals that the erosion rates in Season 1-2008, which represent the erosion that occurred from December 2007 through March 2008, greatly exceeded those in other seasons. Season 1-2008 had significantly greater average erosion rates (130 kg m^{-1}) than any other season measured. Season 2-2008 (9.86 kg m^{-1}) and 3-2008 (10.3 kg m^{-1}) had moderate to low levels of erosion, while Season 3-2007 (-5.43 kg m^{-1}) showed low levels of deposition for all land uses.

Table 1. Summary of mean erosion rates (kg m^{-1}) by season and land use.

Land-Use	Season				Land-Use Mean	Between Season
	3-2007	1-2008	2-2008	3-2008		F-LSD
Forest	-3.78	33.2	13.6	9.32	13.1	—
Pasture	-12.0	171	6.23	5.91	42.8	—
Riparian Forest	-0.51	184	9.74	15.7	52.3	—
Seasonal Mean	-5.43	130	9.86	10.3	36.1	44.0
Within Season F-LSD	5.71	—	—	—	—	—
Crop*	4.32	198	56.2	-10.3	62.1	—

*Not included in ANOVA tests

The effects of season on stream bank erosion rates found in this study were consistent with past findings. Wolman (1959) observed the highest erosion rates during the winter months (December-March) and lower erosion rates in the summer. Zaines et al. (2006) report similar results with the largest magnitude erosion occurring in the spring and early summer and little erosion occurring in the fall. Wolman (1959) attributed some winter erosion to freeze thaw mechanisms but concluded that winter erosion was largely a result of high flow events occurring when the bank materials were already “thoroughly wetted.” Flow events in summer months occurred when bank materials were dry and therefore did not produce erosion rates that were as large as those seen in the winter. Even when summer flow events greatly exceeded those occurring in the winter the resulting erosion was less (Wolman, 1959). Furthermore, a study by Hooke (1979) revealed that while soil moisture was the most important factor controlling stream bank erosion, significant erosion only occurred in association with peak discharge. Zaines et al. (2006) identified precipitation pattern as a major factor contributing to the seasonal effect on

bank erosion, finding the most erosion occurred following many medium sized precipitation events or two large precipitation events that occurred close together. This pattern fits that described by Wolman (1959), where banks become “thoroughly wetted” during the first precipitation event and then were eroded during subsequent precipitation events.

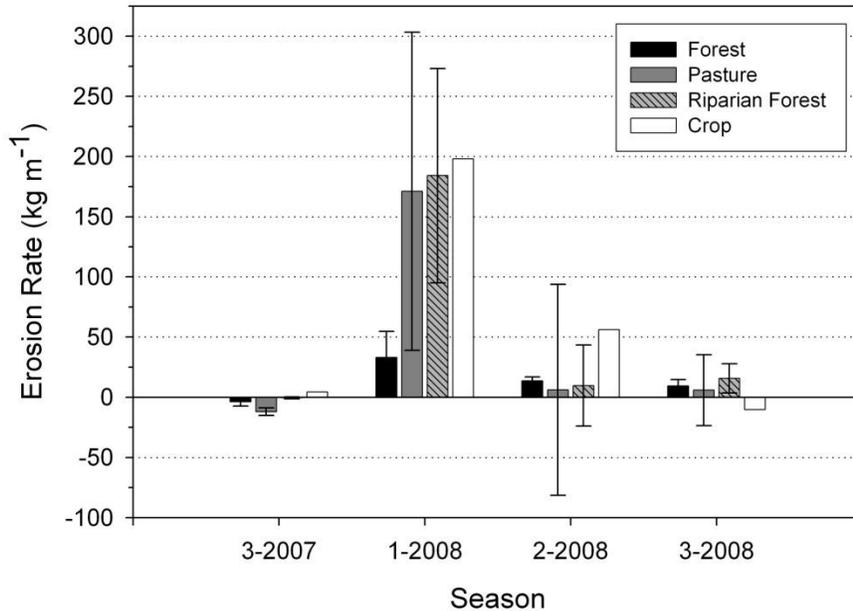


Figure 3. Mean erosion rate for each land-use during each season measured.

Considering the erosion data in light of the discharge data for Crook Creek (U.S. Geological Survey, 2009) (figure 4) reveals an extreme example of the Wolman pattern, where many moderate-sized events in February and March 2008 produced considerably more erosion than that caused by the numerous runoff events which occurred from April through September 2008. Moreover, not only were the runoff events closely spaced during this time, occurring at almost weekly intervals, three events were also of much greater magnitude than any of the erosive events that occurred during the winter of 2008. The high frequency of summer events suggested that wet bank conditions would persist through Seasons 2 and 3 of 2008, and the disparity between seasonal erosion rates was therefore not entirely explained by the Wolman pattern. Zaines et al. (2006) attributed additional seasonal differences in erosion rates to differences in vegetative cover density. They reasoned that lack of vegetation in the winter leaves banks completely exposed and vulnerable to scour, while lack of evapotranspiration prevents banks from drying. This combination maintains saturated conditions and weak cohesion of bank material, resulting in a high degree of vulnerability to erosion during the winter months. In contrast, dense vegetative cover in the summer months protects banks from scour and evapotranspiration dries bank material, mitigating the erosive effects of an exceptionally wet year that had multiple sequential flow events.

Land use was a much less important factor to stream bank erosion than the observed seasonal effect. Averaged across all seasons, the erosion rate was 13.1 kg m⁻¹ for forest, 42.8 kg m⁻¹ for pasture, 52.3 kg m⁻¹ for riparian forest, and 96.3 kg m⁻¹ for crop (Table 1). The two-way ANOVA testing the effect of season and land use on stream bank erosion rates showed that the erosion rates for different land uses were not significantly different (p=0.21). This may be

explained, in part, by the overwhelming importance of season on stream bank erosion processes which may mask land use effects within a given season. The results of the one-way ANOVAs

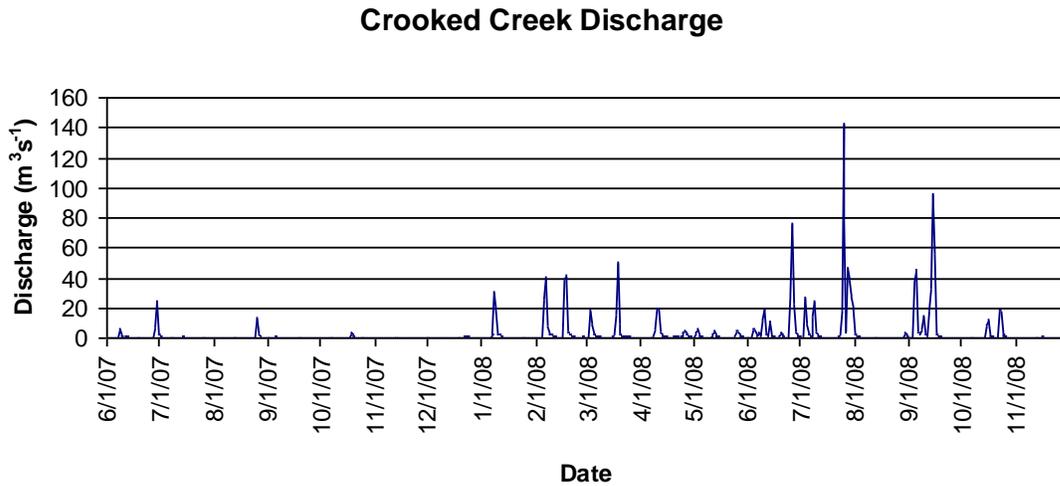


Figure 4. Average Daily Discharge of Crooked Creek from June 2007 to Dec 2008.

showed that erosion rates for the different land use treatments were significantly different only during Season 3-2007 ($p=0.06$). Subsequent seasonal measurements did not show any statistical difference between the erosion rates for the different land use treatments. These results are partly explained by the highly variable erosion rates that were measured among and within treatments, which made the variance extremely high, making it difficult to discern differences in land use treatment. Comparison of treatment means within Season 3-2007 using the F-LSD test showed the deposition rate was significantly greater in pasture than in forest or riparian forest. Erosion rates in forest and riparian forest were not statistically different.

While this study showed significant differences between land use only under depositional conditions, past studies have also found significant differences between land use treatments under eroding conditions. Zaines et al. (2004) found second order streams flanked by row-crop and pasture fields experienced higher erosion rates than those with adjacent riparian forest buffers. The presence of cattle negatively affects the ability of plant roots to hold soil and trampling on and along banks causes destabilization (Belsky et al., 1999). Pasture sites have been observed by the authors to be prone to slumping because of cattle access to the streams. Furthermore, pasture sites had few trees, and they were generally not large trees that impart stability to the stream banks. Destabilized bank material may be a sediment source during depositional conditions at pasture sites, which provides a possible explanation for the land use effects between the treatment sites in Season 3-2007. Another possible sediment source at the pasture sites was overland erosion. If overland erosion rates were greater at the pasture sites compared to the riparian forest and forest sites, then deposition of this material during low and moderate intensity runoff events could also explain the higher deposition rates of the pasture sites. In addition, sediment transported from upstream sources may also be deposited once reaching larger 3rd order streams. However, at the 3rd order scale, the effects of upstream sediment sources should be similar across the land use treatments as the upstream land use at all sites would be dominated by cropland. Stream data from 1st and 2nd order streams may also

provide insight to the impacts of upstream sediment sources as specific land use effects can more easily be isolated at these smaller scales.

CONCLUSIONS

The results of this study to date point to season as the most important factor controlling stream bank erosion rates. Erosion rates were highest for Season 1-2008 (winter months) and lowest during the summer and fall, despite frequent and high-magnitude runoff events in 2008. Land use was significant only in Season 3-2007 (August-November), when conditions resulted in net deposition across all land use treatments. Under erosive conditions, treatment differences were masked by the highly variable erosion rates within and between treatments. These results show the highly variable nature of stream bank erosion in these landscapes and bring to light the difficulty in management.

Unfortunately, seasonal weather patterns cannot be controlled, and managers must look for other ways to control stream bank processes; our preliminary results suggest that cattle access to streams can destabilize banks and provide a source of sediment to streams adjacent to this land use. Targeting the placement of BMPs may best be accomplished using in-stream assessment tools that identify eroding reaches on a site-by-site basis. For instance, the Rapid Assessment of Stream Conditions Along Length (RASCAL) survey, an in-stream GPS-based assessment tool, has been used by the Department of Natural Resources to identify stream properties such as riparian zone cover, livestock access points, bank stability, etc. for the placement of BMPs (Kiel 2008). Analysis of our complete data set to include 1st and 2nd order stream treatments may further highlight land use effects and offer more insight into targeting of practices to mitigate stream bank erosion.

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STREAMBANK EROSION FROM GRAZED PASTURES, GRASS FILTERS AND FOREST BUFFERS OVER A SIX-YEAR PERIOD

M. Tufekcioglu¹, T.M. Isenhardt², G.N. Zaimes³, R.C. Schultz⁴, J.L. Kovar⁵ and J.R. Russell⁶

¹339 Science II, Iowa State University, Natural Resource Ecology and Management
Ames, IA 50011

²215 Science II, Iowa State University, Natural Resource Ecology and Management, Ames, IA
50011

³Dept. of Natl. Res. Ecology & Management, Univ. of Arizona, 310 Bio Sciences East, Tucson,
AZ 85721

⁴215 Science II, Iowa State University, Natural Resource Ecology and Management, Ames, IA
50011

⁵USDA-ARS National Soil Tilth Laboratory, 2110 University Blvd. Ames, IA 50011-3120

⁶Animal Science, Iowa State University, 337 Kildee Hall, Ames, IA 50011

¹Contact: mtufekci@iastate.edu

Abstract: In agricultural landscapes, streambank erosion, as a source of non-point water pollution, is one of the major contributors to stream habitat degradation. Streambank erosion rates from riparian forest buffers, grass filters and grazed pastures (stocking rates ranged from 0.23 to 1.15 cow-days ha⁻¹ m⁻¹ yr), in three landform regions of Iowa, were measured. Erosion pins were measured seasonally, except in winter, over a six year period. Severely eroded streambank areas, soil bulk densities and total streambank soil-P concentrations were also measured to calculate total soil and P losses from stream banks. Buffers and grass filters had significantly lower soil loss (respectively, ranged from 4 to 20 tons km⁻¹ yr⁻¹, p= 0.002 and 0 to 73 tons km⁻¹ yr⁻¹, p= 0.001) from stream bank erosion than did grazing pasture practices (92 to 376 tons km⁻¹ yr⁻¹). Similar significant trends among these practices were also found for soil-P loss, severely eroded bank area and erosion rate as well. From the three treatments only the pasture practices had a correlation between seasonal erosion rate and amount of precipitation as it directly contributes to discharge (p= 0.0001; R² = 0.42). This suggests that precipitation recorded from the closest weather station in these pasture sites can be used to account for a significant portion of the streambank failure that took place under different frequencies and intensities that were not directly observed in this study. It can also be suggested that significant correlation between precipitation and erosion rate from grazed pastures could be an indication of low streambank soil resistance to stream discharge which, in turn, increased soil loss.

QUANTIFYING CONCENTRATED FLOW WITHIN GRASS FILTER STRIPS AND RIPARIAN FOREST BUFFERS

Keegan Kult, Thomas Isenhart, Matthew Helmers, and Richard Schultz

208 Forest Street, Polk City IA, 50226, Iowa State University

Contact: keegankult@gmail.com

Abstract: Riparian buffers have been accepted as an edge of field best management practice to improve surface water quality by reducing the sediment and nutrients transported in surface runoff. Many plot scale studies under uniform flow conditions have assessed the effectiveness of riparian buffers. The purpose of this study was to examine, at the hillslope scale and under natural rainfall conditions, the impact that concentrated flow has on riparian buffers. The study was conducted on two private farms located in the Lake Darling and Lake Rathbun watersheds. Three sites located in the Lake Rathbun Watershed consisted of one control, located at the field edge, and two sites with a 15.2 m wide grass filter treatment. The three sites located in the Lake Darling Watershed consisted of one control, located at the field edge, and two sites with a 15.2 m wide natural riparian forest buffer. Monitoring at the Lake Darling watershed was from April 2007 - October 2007. Monitoring at the Lake Rathbun watershed was from June 2007 - October 2007. There were seven natural rain events monitored at the Lake Rathbun watershed, and twelve natural rain events monitored at the Lake Darling watershed. Potential pollutants monitored were total sediment, nitrate-N, ortho-P, total-N, and total-P. The grass filter strips reduced pollutant load relative to the control in smaller rain events. However, one of the grass filter sites was not effective at reducing pollutant load during larger events. There appeared to be a threshold that is dependent upon the amount and intensity of rain, and the contributing area to effective buffer ratio. The riparian forests were less predictable for which storm events they can be considered effective. This is because there is little to no resistance to concentrated flow within the riparian forest, which allows concentrated flow to pass through the buffer.

Sediment delivery models based on plot studies have been developed to predict catchment sediment yield. The modified universal soil loss equation (MUSLE) is a modification made to the original universal soil loss equation in order to predict sediment yield applicable to individual storm events. A limitation to the MUSLE is that it does not take into account the effects of concentrated flow which leads to ephemeral gully (EG) erosion. The formation of an EG provides a direct link from the uplands to the streams which increases sediment delivered by reducing surface roughness. Two study sites were established on the Southern Iowa Drift Plain to quantify the amount of sediment loss in small catchments with ephemeral gullies at the catchment scale. The observed amount of sediment loss was then compared to the MUSLE predicted amount of sediment loss for each individual storm event. Monitoring began in April of 2007 and continued through October 2007 at the site located in the Lake Darling Watershed. A total of 12 rainfall generated runoff events were monitored. Monitoring began in June of 2007 and continued through October 2007 at the site located within the Lake Rathbun Watershed. A total of 7 rainfall generated runoff events were monitored. The MUSLE under-predicted sediment loss for all the events occurring at the site in the Lake Darling Watershed, and all but two events at the site in the Lake Rathbun Watershed. The disparity among the predicted and

observed sediment losses increased with storm size. A general weakness with the MUSLE is that rainfall events are based on 24 hour rainfall depth and not intensity which is a dominant factor in determining amount of runoff. The occurrence of ephemeral gullies also appeared to increase the amount surface runoff exiting the catchments along with the amount of sediment yield.

VETERINARY ANTIBIOTIC SORPTION TO AGROFORESTRY BUFFER, GRASS BUFFER AND CROPLAND SOILS

Bei Chu¹, Keith Goyne¹, Stephen H. Anderson¹, Ranjith P. Udawatta² and Chung-Ho Lin²

¹ Department of Soil, Environmental and Atmospheric Sciences, University of Missouri, 302 ABNR Building, Columbia, MO 65211

² Center for Agroforestry, University of Missouri, 203 ABNR, Columbia, MO 65211
Contact: bc3g7@mizzou.edu

Abstract: Veterinary antibiotics are used to treat infectious animal diseases and enhance animal growth. In Missouri, the increased growth of confined animal feeding operations (CAFOs) and the need to dispose of manure generated by CAFOS may be problematic due to co-application of antibiotics during land application of manure. Surface runoff events from claypan or claypan-like soils are relatively frequent; thus, there is a need to develop and evaluate the use of vegetative buffer strips (VBS) as management tools to reduce antibiotic transport to surface water resources. The objectives of this study were to (1) investigate oxytetracycline (OTC) and sulfadimethoxine (SDT) sorption to agroforestry (tree/grass) buffer, grass buffer, and cropland soils, (2) evaluate differences in antibiotic sorption between soils collected from different vegetative species, and (3) elucidate relationships between soil properties and antibiotic sorption. Sorption/desorption isotherms generated using batch techniques were well-fitted by the Freundlich isotherm model ($r^2 > 0.80$). Oxytetracycline was strongly adsorbed by all soils, and the antibiotic was not readily desorbed; hysteresis was observed between all adsorption and desorption isotherms. Solid-solution distribution coefficients (K_d) values of OTC are an order of magnitude greater than those of SDT. Statistical analyses indicate that OTC K_d values are significantly greater for VBS soils relative to cropland soil, and STD K_d values are significantly greater for agroforestry soils as compared to other soils studied. Regression analyses correlating antibiotic sorption to soil properties are in progress. Results indicate that agroforestry and grass buffers may effectively mitigate antibiotic loss from agroecosystems due to enhanced antibiotic sorption properties.

Key Words: Oxytetracycline (OTC); Sulfadimethoxine (SDT); Sorption/Desorption Isotherms; Vegetative Buffer Strips; Solid-Solution Distribution Coefficients (K_d).

INTRODUCTION

Antibiotics are used to treat infectious diseases and as animal feed supplements to promote growth of food-producing animals. However, significant proportion (up to 80%) of the antibiotics added to animal feed is excreted in urine or feces as the parent compound (Thiele-Bruhn 2003). Land application of manure as fertilizer is a common agricultural practice in many parts of the U.S. However, manure-amended lands may serve as a non-point source for antibiotics that enter surface and ground waters via runoff and leaching (Meyer et al. 2000; Koplín et al. 2002). The concentrations of antibiotics in manure range from trace levels to concentrations as high as 200 mg L⁻¹ (Kumar et al. 2004; 2005). In most soils, antibiotic

concentrations do not reach therapeutic levels that can inhibit bacterial growth and population, but they may still have an influence on the selection of antibiotic resistant bacteria in the environment (Nygaard et al. 1992; Kümmerer, 2003). However, in particular terrestrial settings, it is possible that antibiotics can affect the quantity and quality of the native microbial communities (Nygaard et al. 1992). The development of antibiotic-resistant microorganisms, which are difficult to treat with existing antibiotics, is also a risk if infectious bacteria are frequently exposed to antibiotics. Land application of manure containing veterinary antibiotics is one of the main reasons attributed to the development of antibiotic resistant bacteria in the environment (Thiele-Bruhn 2003; Sarmah et al. 2006). Therefore, there is a need to evaluate land management practices that may reduce the fate and transport of antibiotics in the environment.

It has been demonstrated that a well-designed vegetative buffer can be a cost-effective method to mitigate non-point sources of agricultural pollutants from crop land (Schultz et al. 1995; Lowrance et al. 1997). Vegetative buffers may be planted to trees, shrubs, grasses, or a combination of species grown within or on the edges of fields and along stream banks in riparian zones. Mechanisms of pollutant removal within vegetative buffers include physical, chemical and biological processes that can increase solute-soil interaction, improve solute uptake by the soil, and enhance degradation of organic agrochemicals (Mandelbaum et al. 1993). However, no previous studies have evaluated vegetative buffer impacts on antibiotic adsorption and transport.

The objective of this study was to investigate antibiotic sorption to cropland, grass buffer and agroforestry (tree/grass) buffer soils, evaluate differences in antibiotic sorption between soils collected from different vegetative species and elucidate relationships between soil properties and antibiotic sorption.

MATERIALS AND METHODS

Sampling Site Information

Soil samples were collected from grass and tree/grass buffers located at the University of Missouri Horticultural and Agroforestry Research Center (HARC; 39°01'N, 92°45'W), University of Missouri Greenley Memorial Research Center (GMRC; 40°01'N, 92°11'W), and University of Missouri Agricultural Experiment Station Southwest Center (SWC; 37°05'N, 93°52'W). The soil series sampled at HARC, GMRC, and SWC were Menfro silt loam (Typic Hapludalfs), Armstrong silt loam (Aquertic Hapludalfs), and Huntington silt loam (Fluventic Hapludolls), respectively. Soil (3 - 5 kg) was randomly sampled at multiple points in the vegetated areas from a 0 - 10 cm depth. In the case of sampling the tree/grass buffer soils, samples were collected from multiple trees (3 or 4) at a distance of 30 - 50 cm from the base of the tree. Cropland soil samples were collected in farmlands adjacent to these vegetative buffers. At each site, samples were bulked by vegetation type, thoroughly mixed, air-dried, sieved through a 2 mm mesh sieve, and stored in plastic bags. Soil samples < 2 mm were analyzed using standard methods of analysis (Ross 1995; Loeppert and Inskeep 1996; Burt 2004). Samples were analyzed for particle size analysis, cation exchange capacity (NH₄Cl exchangeable), base saturation, organic C content, and pH in salt and water. The soil properties are listed in table 1.

Table 1 Selected properties of the studied soils.

Soil Series	Vegetation	Clay g kg ⁻¹	Organic Carbon g kg ⁻¹	pH	CEC [†] cmol kg ⁻¹	Base Saturation %	Al _{CBD} [‡] g kg ⁻¹	Fe _{CBD} g kg ⁻¹
Armstrong	Grass	245	30	7.0	23.4	71.4	1.08	16.0
	Tree/Grass	253	23	6.7	26.8	65.1	0.97	13.8
	Corn/Soybean	223	22	7.1	25.5	63.4	1.03	15.2
Huntington	Grass	158	12	5.2	13.8	74.5	0.62	5.50
	Tree/Grass	190	23	4.7	9.00	57.0	0.85	5.60
	Corn/Soybean	199	13	6.6	15.1	42.3	0.74	6.84
Menfro	Grass	247	20	6.2	18.0	49.3	0.98	8.73
	Tree/Grass	247	22	5.8	22.6	62.5	0.96	9.28
	Corn/Soybean	211	19	6.3	23.5	57.4	0.68	7.22

[†]CEC, cation exchange capacity.

[‡]CBD, citrate-bicarbonate-dithionite extracted element.

Experimental Design

Oxytetracycline and sulfadimethoxine (Figure 1) were two antibiotics chosen for study because they are widely used in veterinary medicine (Halling-Sorensen et al. 1998). The antibiotic OTC has three functional groups that undergo proton dissociation ($pK_{a1} = 3.33$, $pK_{a2} = 7.68$, $pK_{a3} = 9.69$ (Tolls 2001); SDT has two pK_a s which are 2.44 and 6.0 (Thiele and Aust 2004). Subsequently, these antibiotics may be cationic, zwitterionic, or anionic depending on pH, thus influencing their interaction with soil minerals and organic matter.

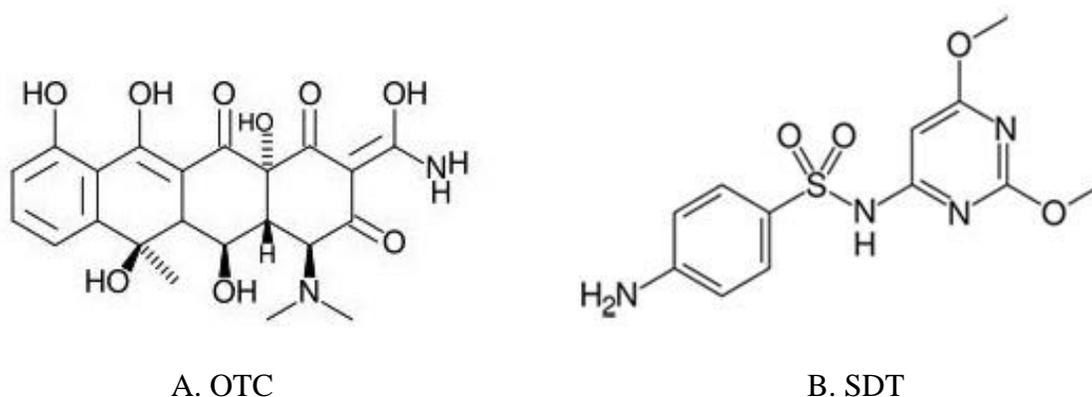


Figure 1. Chemical structures of (a) oxytetracycline (OTC) and (b) sulfadimethoxine (SDT).

Oxytetracycline sorption experiments were conducted over a range of initial aqueous phase concentrations (0.0, 0.005, 0.01, 0.025, 0.05, 0.1, 0.175, 0.25, 0.5 mmol L⁻¹), and SDT was reacted with soil at a single concentration (0.10 mmol L⁻¹). Air-dried soils (0.350 g) were added to 50 mL polypropylene co-polymer (PPCO) centrifuge tubes and suspended in CaCl₂ background electrolyte solution ($I = 0.005$ M CaCl₂). To inhibit microbial growth, samples were

spiked with concentrated NaN_3 to achieve a final concentration of 0.0015 M NaN_3 (Wolf et al., 1989); total solution volume in each reaction vessel was 35 mL. After solution addition, tubes were wrapped in aluminum foil to prevent photo-degradation and agitated for 24 h on an end-over-end shaker (7 rpm) in a constant temperature room (25°C). Reactions at each individual concentration consist of samples reacted in triplicate and blanks (no soil) reacted in duplicate. After the reaction, tubes were centrifuged at 15,000 rpm for 15 min followed by removal of the supernatant solution and filtration through 0.45 μm nominal pore size PTFE membrane filters. Samples were then analyzed to determine antibiotic concentration remaining in solution and solution pH.

Soil samples were demineralized using a modified hydrofluoric acid (HF) treatment as a pre-treatment before Fourier transformed infrared (FTIR) spectroscopy analysis to investigate differences in structural composition of soil organic matter (SOM). Using modification of the method described in Skjemstad et al (1994), 20 g of soil sample was reacted three times in 250 mL of 5% HF for 1.5 h using a rotary shaker, followed by an 18 h extraction period. Soil organic matter residue was washed five times with ultrapure water and freeze-dried. Freeze-dried SOM samples were mixed with ground KBr powder to create a powder with sample concentration of 5%. Samples were analyzed by diffuse reflectance infrared Fourier transform infrared (DRIFT) spectroscopy using a Thermo-Nicolet 4700 spectrometer with Smart DRIFT accessory. All DRIFT spectra were obtained by averaging 400 scans at 2 cm^{-1} resolution.

Aqueous Phase Analyses

Antibiotic concentrations in solution were analyzed using high performance liquid chromatography (HPLC) with an ultraviolet (UV) detector (Beckman, San Ramon, CA). Analysis of OTC was performed at a column temperature of 40°C using a reverse-phase Phenomenex Luna C₈(2) column (250 × 4.6 mm, 5 μm particle size; 100 Å pore size; Torrance, CA). The mobile phase consisted of 0.1% phosphoric acid (H_3PO_4) buffer in water (pH 2.2) and 100% acetonitrile (solvents A and B, respectively). The initial solvent mixture consists of 95% A : 5% B from 0 - 10 min. The solvent ratio changed to 75% A : 25% B between 10 and 25 min, and this ratio was kept constant from 25 to 30 min. For SDT analysis, an Agilent ZORBAX SB-CB, (150×4.6 mm, 5 μm particle size, 80 Å pore size; Santa Clara, CA) column was employed. The mobile phase for SDT analysis consisted of 20 mM KH_2PO_4 buffer and 100% acetonitrile (solvents A and B, respectively). The initial solvent mixture consists of 75% A : 25% B and this ratio is kept constant from 0 to 5 min. The solvent ratio was gradually changed to 45% A : 55% B from 5 to 15 min. At the 15 min mark, the ratio is reduced to 75% A : 25% B and held constant for final 10 min.

Mathematical Description of Sorption Data

The amount of antibiotics adsorbed to soil after reaction was calculated from,

$$q_{\text{ads}} = \frac{(C_{\text{ads,B}})(V_{\text{B}}) - (C_{\text{ads,S}})(V_{\text{S}})}{m_{\text{s}}}$$

where q_{ads} is the surface excess of antibiotic (i.e., amount adsorbed) after the reaction period (mmol kg^{-1}), $C_{\text{ads,B}}$ and $C_{\text{ads,S}}$ are the equilibrium antibiotic concentrations (mmol L^{-1}) in blank

(B) and samples (S) after reaction, V_B and V_S are the volume of solution (L) added to samples and blanks, and m_S is mass of soil (kg). The partition coefficient, K_d , was determined using the following equation,

$$K_d = \frac{q_{ads}}{C_{ads,S}}$$

Desorption experiments were initiated immediately after the adsorption step by adding a volume of methanol equivalent to the volume of supernatant removed as a means to determine total desorbable antibiotic (Thiele-Bruhn et al. 2004). Adsorbate retention was calculated from,

$$q_{des} = q_{ads} - \left\{ \frac{(C_{des,S})(V_{des}) - (C_{ads,S})(V_{ent})}{m_S} \right\}$$

where q_{des} is the surface excess remaining on the surface after the desorption period (mmol kg^{-1}), $C_{des,S}$ is the equilibrium antibiotic concentration in solution after the desorption reaction period, V_{des} is the volume of solution in the reaction vessel during desorption phase, and V_{ent} is the volume of entrained solution remaining in the adsorption pellet after removal of adsorption phase supernatant. Adsorption and desorption data were fitted by the Freundlich isotherm model to provide a concise set of parameters for comparison between the soils,

$$q_{ads\ or\ des} = K_f C_{ads\ or\ des}^N$$

where the parameters K_f and N are positive valued adjustable parameters. The parameters are obtained from a log-log plot of the adsorption isotherm data (K_f is the intercept and N the slope of the resulting line).

RESULTS AND DISCUSSION

Adsorption/desorption experiments were conducted to investigate OTC sorption and retention in different soils (Fig. 1). The isotherm data demonstrate that OTC was strongly adsorbed by all soils investigated and OTC had a relatively high affinity for the soil surface at low surface coverage. Desorption isotherms show that the antibiotic was not readily desorbed from soil in the presence of methanol as hysteresis is evident between all adsorption and desorption isotherms.

Sorption of OTC was best fitted by the Freundlich equation with correlation coefficients (R^2) ranging from 0.80 to 0.98 (Table 2). The Freundlich parameters, $\log K_f$ and N , indicate the affinity of the antibiotic for the solid and the degree of isotherm curvature, respectively. Adsorption $\log K_f$ values ranged from 3.20 to 3.51 and from 1.35 to 3.98 for desorption isotherms. The values of N varied from 0.58 to 0.98 for adsorption and from 0.12 to 0.57 for desorption. These values indicate that adsorption isotherms range from nearly linear ($N = 1$) to nonlinear, L-shaped isotherms ($N < 1$). Although mechanisms of adsorption and more detailed processes are not revealed by adsorption isotherms, a higher degree of isotherm nonlinearity suggests a greater degree of heterogeneous adsorption sites may be present in the soil and specific mechanisms of adsorption may be occurring (Essington 2004; Thiele-Bruhn et al. 2004). At higher initial aqueous antibiotic concentrations, the specific binding sites become saturated via antibiotic adsorption and reduce the affinity of OTC for the soil particle surfaces.

Figure 3 is a comparison of K_d values of OTC and SDT at an initial concentration of 0.1 mM antibiotic. The mean K_d values for OTC were 1203, 586 and 1781 $L\ kg^{-1}$ for Armstrong, Huntington and Menfro soils, respectively. The mean K_d values for SDT were 27, 130 and 157 $L\ kg^{-1}$ for Armstrong, Huntington and Menfro soils, respectively. Distribution coefficient values of OTC are an order of magnitude greater than K_d values of SDT. The K_d values for OTC are in agreement with previous studies; however, K_d values for SDT are greater than values reported by others (Tolls 2004). We attribute this difference to differences in experimental conditions used in this study relative to others.

ANOVA results demonstrate that K_d values for OTC were significantly greater ($p < 0.05$) for VBS soils relative to cropped soils. For SDT, K_d values were significantly greater ($p < 0.05$) for tree/grass buffers relative to the other vegetation types studied. Irrespective of the antibiotic studied, K_d values were always significantly different ($p < 0.05$) between the soil types. The

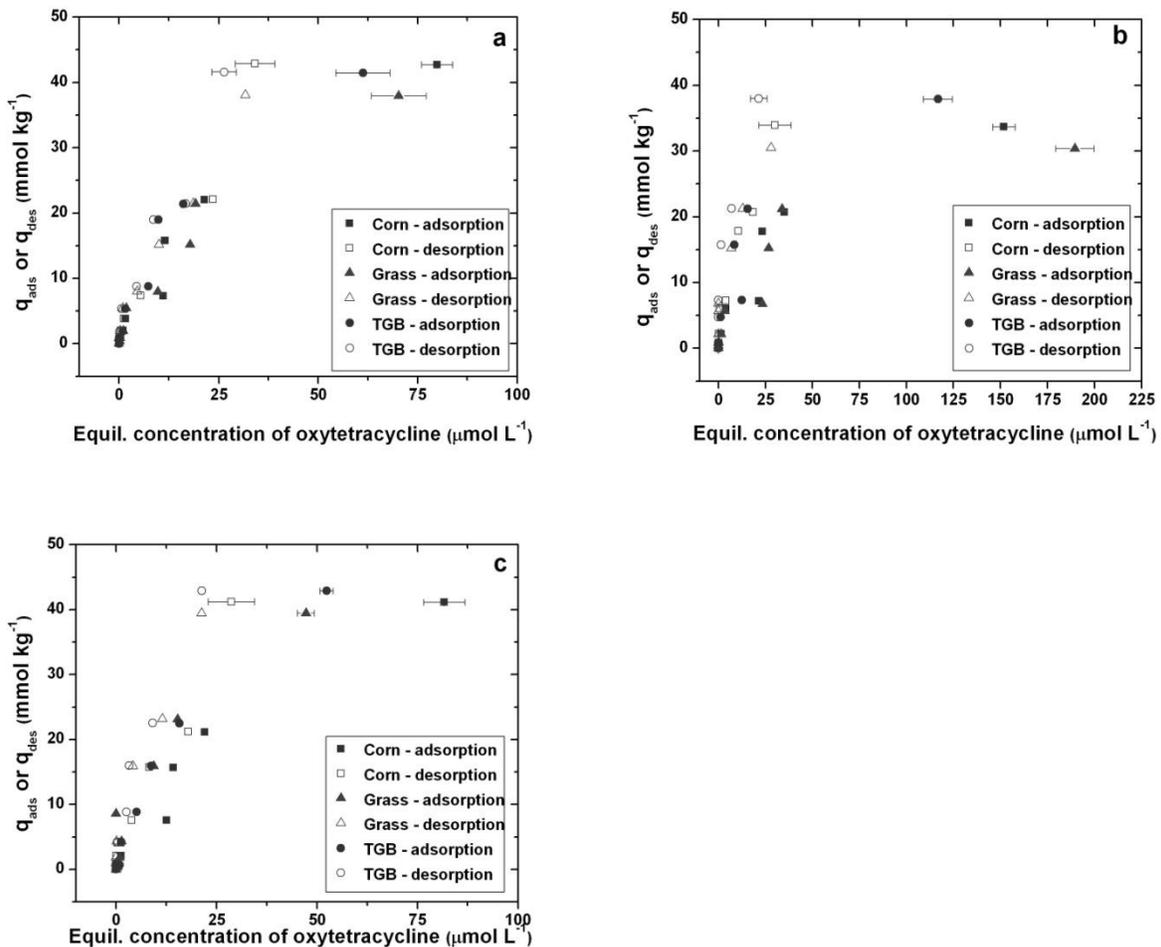


Figure 2. Oxytetracycline adsorption/desorption to the (a) Armstrong, (b) Huntington, and (c) Menfro soils. Error bars, where observed, represent the 95% confidence interval.

Table 2. Freundlich model parameters for OTC adsorption/desorption isotherms.

Soil	Phase	$\log K_f \pm 95\% \text{C.I.}$	$N \pm 95\% \text{C.I.}$	$R^2 (n)$
Menfro Corn/Soybean	Adsorption	3.51 ± 0.11	0.80 ± 0.13	0.90 (20)
	Desorption	3.81 ± 0.06	0.43 ± 0.06	0.94 (18)
Menfro Grass	Adsorption	3.20 ± 0.25	0.98 ± 0.22	0.82 (20)
	Desorption	3.98 ± 0.04	0.41 ± 0.04	0.98 (12)
Menfro Tree/Grass	Adsorption	3.36 ± 0.10	0.78 ± 0.10	0.92 (24)
	Desorption	1.35 ± 0.28	0.12 ± 0.01	0.92 (27)
Armstrong Corn/Soybean	Adsorption	3.33 ± 0.06	0.70 ± 0.05	0.97 (24)
	Desorption	3.60 ± 0.06	0.55 ± 0.06	0.95 (21)
Armstrong Grass	Adsorption	3.33 ± 0.06	0.70 ± 0.05	0.97 (24)
	Desorption	3.64 ± 0.06	0.57 ± 0.06	0.96 (18)
Armstrong Tree/Grass	Adsorption	3.42 ± 0.05	0.72 ± 0.05	0.97 (24)
	Desorption	3.74 ± 0.06	0.54 ± 0.06	0.96 (18)
Huntington Corn/Soybean	Adsorption	3.25 ± 0.07	0.63 ± 0.05	0.96 (24)
	Desorption	3.92 ± 0.10	0.35 ± 0.10	0.80 (17)
Huntington Grass	Adsorption	3.26 ± 0.07	0.58 ± 0.05	0.96 (24)
	Desorption	1.38 ± 0.36	0.12 ± 0.02	0.86 (27)
Huntington Tree/Grass	Adsorption	3.45 ± 0.08	0.61 ± 0.07	0.93 (24)
	Desorption	1.46 ± 0.37	0.12 ± 0.02	0.85 (27)

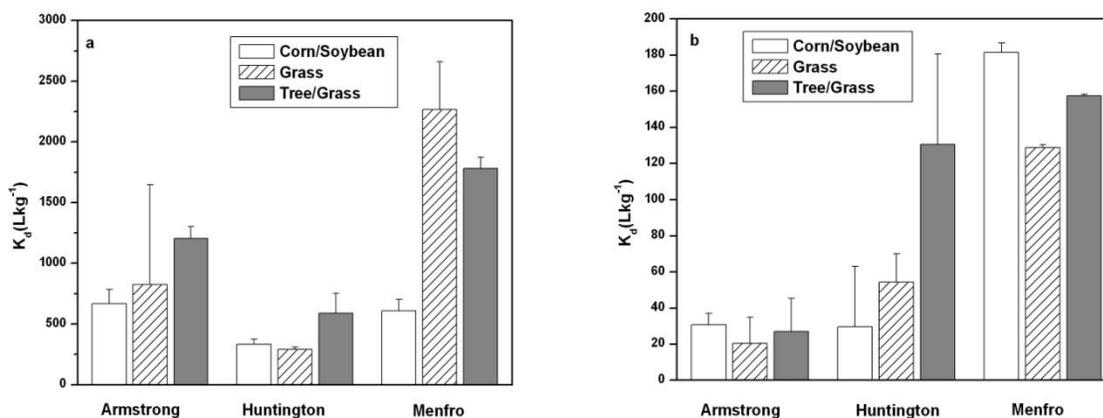


Figure 3. Solid-solution distribution coefficients (K_d) for (a) oxytetracycline and (b) sulfadimethoxine at 0.10 mM initial antibiotic concentration.

differences of the K_d between vegetation types may due to soil pH differences. Both OTC and SDT have multiple pK_a values; when pH is less than pK_{a1} , the cationic species are dominant and, at pH greater than pK_{a2} , the anionic species are dominant. Zwitterionic species are predominate within the pH range between these pK_a values. Within each site studied, soil pH is lowest in the tree/grass buffers and highest in the cropland soils, and this coincides with tree/grass buffers and grass buffers soils having greater K_d values than cropland soils. Thus, it appears that reduced pH within the buffer soils enhances antibiotic sorption via effects on antibiotic speciation. More acidic pH results in higher concentrations of cationic and zwitterionic antibiotic species that may interact to a greater extend with negatively charged sorption sites on clay minerals and soil organic matter.

Diffuse reflectance Fourier transform (DRIFT) spectroscopic analysis of HF-treated soils suggests that organic matter chemical composition is similar under the vegetative species planted on the three soil types (Fig. 4). Therefore, it does not seem likely that differences in soil organic matter (SOM) chemical composition play an important role in sorption differences observed between the vegetative buffer and cropland soils. Although, the quantity of SOM and subsequent effects on soil CEC may be important factors influencing antibiotic sorption capacity of the soils studied. Regression analyses further exploring correlations between soil properties and antibiotic sorption are in progress and will further elucidate interpretation of the data.

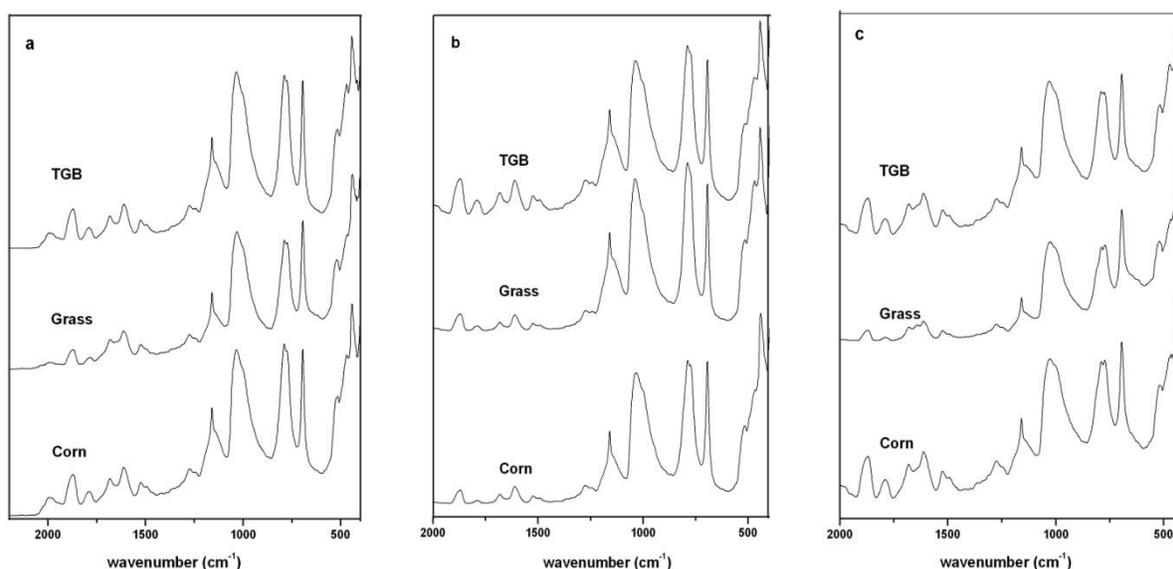


Figure 4. Diffuse reflectance Fourier transform (DRIFT) spectra of hydrofluoric acid-treated soils: (a) Armstrong soil, (b) Huntington soil, and (c) Menfro soil.

CONCLUSIONS

The OTC has high affinity to all soils studied and OTC was not readily desorbed by methanol; hysteresis was observed between all OTC adsorption and desorption isotherms. Distribution coefficient values of OTC are an order of magnitude greater than those of SDT, and K_d values were significantly different between soil types. More importantly, K_d values for OTC were significantly greater for VBS soils relative to cropped soils, and K_d values of SDT were

significantly greater for tree/grass buffers relative to the other vegetation types studied. Spectroscopic analysis of HF-treated soils suggests that organic matter chemical composition is similar under the vegetative species planted on the same soil type. Soil pH appears to have a significant influence on antibiotic adsorption due to effects on antibiotic species present in solution. Overall, the results indicate that VBS may help mitigate antibiotic loss from agroecosystems.

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UTILIZING VEGETATIVE BUFFER STRIPS TO REMOVE DISSOLVED AND SEDIMENT-BOUND HERBICIDES FROM SURFACE RUNOFF

R. N. Lerch¹, C. H. Lin², and H. E. Garrett²

¹USDA-Agricultural Research Service, Cropping Systems and Water Quality Research Unit,
Columbia, MO

²Center for Agroforestry, University of Missouri

Contact: Bob.Lerch@ars.usda.gov

Abstract: Vegetative buffer strips (VBS) have been recommended as a potential approach for mitigating herbicide transport in surface runoff derived from agronomic operations. However, the effect of buffer designs and species composition on reducing herbicide transport has not been well documented. An on-going experiment consisting of three VBS designs and one cultivated fallow control replicated in triplicate was conducted to assess effectiveness in reducing herbicide transport for claypan soils. The four VBS treatments include: (1) continuous cultivated fallow (control), (2) perennial fescue, (3) fescue with a switchgrass barrier, and (4) native vegetation (mainly eastern gamagrass). The effect of season (spring, summer, and fall) on the effectiveness of these treatments is also being assessed. Rainfall simulation was used to create uniform antecedent soil moisture content in the plots and to generate runoff. Runoff collection equipment is installed across the plots at 1 m above (upslope) of the filter strips and at 1, 4, and 8 m into the VBS treatments. Evapotranspiration and total leaf area estimates have also been measured since 2007. To date, four sets of data have been collected: summer 2004; summer 2006; fall 2007; and summer 2008. Herbicides include atrazine, metolachlor, glyphosate, isoxaflutole, mesotrione, and 2,4-D. Results from 2004 showed that all VBS treatments significantly reduced the transport of both dissolved and sediment-bound atrazine, metolachlor and glyphosate in surface runoff. VBS with native species were most consistently effective at reducing transport of these herbicides. Four meters of native VBS removed about 75-80% of the atrazine, metolachlor and glyphosate in surface runoff. The implementation of native species buffers could provide desired reductions in herbicide transport with less land taken out of production.

ASSESSMENT OF WATERSHED AND SITE-SPECIFIC CHARACTERISTICS IN RELATION TO STREAMBANK EROSION

M. Tufekcioglu¹, T.M. Isenhardt², J.L. Kovar³, J.R. Russell⁴ and R.C. Schultz⁵

¹339 Science II, Iowa State University, Natural Resource Ecology and Management
Ames, IA 50011

²215 Science II, Iowa State University, Natural Resource Ecology and Management, Ames, IA
50011

³USDA-ARS National Soil Tilth Laboratory, 2110 University Blvd. Ames, IA 50011-3120

⁴Animal Science, Iowa State University, 337 Kildee Hall, Ames, IA 50011

⁵215 Science II, Iowa State University, Natural Resource Ecology and Management, Ames, IA
50011

Contact: mtufekci@iastate.edu

Abstract: An emerging challenge in watershed-scale research is to not only quantify the amount of sediment contributed to receiving waters from various erosion processes but also to identify the extent of major source areas, and to develop management strategies to reduce sediment and nutrient inputs. In this on-going study, watershed and site-specific characteristics including basin area, drainage density, stream bed slope, length and sinuosity, land cover by stream order, eroded stream length and area, bank erosion rates and stocking rates (cow-days ha⁻¹ yr⁻¹) were calculated for the assessment of current watershed conditions and stream health. Total surveyed watershed area and stream length in the study were 163 km² and 317 km, respectively. Our long-term objective for this project is to assess the current riparian land-uses and stream characteristics of the study sites and throughout the watersheds, and identify any interactions between stream bank erosion parameters and watershed and/or site-specific characteristics. Current watershed assessment showed that within the 50 m corridor on both sides of the stream, 46 to 61 % of riparian area was devoted to agricultural use and only 6 to 11 % was in CRP and with the rest mainly in unmanaged use. Intensive agricultural use in riparian areas can be directly related to excessive amounts of sediment and nutrient load to streams and lakes and their impairment of providing insufficient ecological services.

BUFFER EFFECTS ON RUNOFF, DISSOLVED ORGANIC CARBON AND SEDIMENT LOSS IN A CORN-SOYBEAN ROTATION USING A PAIRED WATERSHED APPROACH

Kristen Veum¹, Keith Goyne¹, Peter Motavalli¹, Ranjith P. Udawatta², and Harold E. Garrett²

¹Dep. of Soil, Environmental and Atmospheric Sciences, University of Missouri, 302 ABNR Building, Columbia, MO 65211,

²Center for Agroforestry, 203 ABNR, University of Missouri, Columbia, MO 65211

Contact: goynek@missouri.edu

Abstract: Organic matter plays several important roles in the biogeochemistry of terrestrial and aquatic ecosystems including the mobilization and transport of nutrients and pollutants. Cropping, tillage practices and vegetative buffer strip installation affect runoff, sediment and dissolved organic carbon (DOC) losses. While many studies show buffers reduce pollutant export from agroecosystems, buffer strips may be a source of DOC and contribute to surface water pollution. Using a paired-watershed approach, the objectives of this study were to determine the effect of grass and agroforestry buffers on runoff, sediment and DOC loss, compare losses between growing and fallow seasons, and compare losses between crops (corn and soybean). The study design consisted of three small agricultural watersheds located in the claypan region of northeast Missouri planted to a corn (*Zea mays* L.) – soybean [*Glycine max* (L.) Merr.] rotation using no-till; one watershed was planted with grass buffer strips, one with agroforestry buffer strips, and one unaltered watershed served as the control. Runoff, sediment loss and DOC loss were measured during a six-year calibration period (1991 – 1997) prior to buffer installation and for a nine-year treatment period (1997 – 2006). The grass buffer strips significantly decreased runoff by 8.4% ($p = 0.015$) during the treatment period while the agroforestry buffer system exhibited no significant change in runoff ($p = 0.207$). Loss of DOC was not significantly affected by grass or agroforestry buffer installation ($p = 0.535$ and $p = 0.246$, respectively). Additionally, no significant difference in runoff or DOC loss was found between crops (corn and soybean) or between seasons (growing and fallow). Similar investigations on sediment loss relationships were found to be inconclusive. Overall, this study indicates that grass buffer systems are effective at reducing runoff and that DOC contamination of surface waters is not exacerbated by either type of vegetative buffer strip.

SECTION 3

Agroforestry Adoption

ECOLOGICAL GOODS AND SERVICES AND AGROFORESTRY: THE BENEFITS FOR FARMERS AND THE INTERESTS FOR SOCIETY

Jean Nolet¹, Claude Sauvé¹, Maria Olar¹, Maribel Hernandez¹, Marjolaine Mondon¹, Caroline Simard¹, Louis-Samuel Jacques¹, André Vézina², Nathan De Baets², Maud Ablain³, and Pierre Etcheverry³

¹EcoRessources Consultants, 825, rue Raoul-Jobin, Québec, QC, Canada, G1N 1S6.

²Activa Environnement Inc., 106, rue Industrielle, New Richmond (Québec), G0C 2B0.

³Centre d'expertise sur les produits agroforestiers (CEPAF), 235, route 230 ouest, La Pocatière, QC, Canada, G0R 1Z0.

Contact: jean.nolet@ecoressources.ca

Abstract: The main objective of this project is to estimate the social value of environmental goods and services (EG&S) generated by agroforestry practices and to evaluate the profitability of these practices for agricultural producers and for society. Two agroforestry practices are considered: riparian buffer zones and windbreaks. Moreover, the situations in two representative agricultural watersheds serve our analysis (Chateauguay and Fouquette watersheds). Among the numerous EG&S that are provided through agroforestry practices, nine have been chosen for this study: agriculture-related odors, aestheticism of the landscape, terrestrial biodiversity, surface water quality, carbon sequestration, road accidents, clearing snow from roads, treatment of drinking water and wild pollinating insects. Several economic valuation methods have been used, such as hedonic pricing value, benefit transfer, productivity method or experimental economics.

Key Words: benefit-cost analysis, extrapolation, windbreaks, riparian buffers, watershed, hedonic prices, benefit transfer, experimental economics, productivity method, Quebec.

INTRODUCTION

Québec's agricultural sector is facing diverse environmental problems: water quality degradation, appearance of blue algae, soil erosion from wind and water, and the presence of odors associated with certain types of animal manure management. The voluntary and deliberated introduction of trees and bushes in the agricultural environment, of agroforestry techniques such as windbreaks and of agroforestry riparian systems can contribute to mitigating these problems.

In fact, agroforestry generates a number of ecological goods and services (EG&S) of value to society, such as the protection of watercourses, biological diversity, embellishment of the landscape and carbon sequestration. The generation of EG&S by farmers is likely to ease their relations with other residents of rural areas and to improve their image vis-à-vis society. However, it remains highly questionable that the benefits of the agroforestry systems that produce EG&S outweigh the costs for the farmers.

METHODOLOGY

As we could not measure the costs and benefits of all agroforestry practices implemented throughout the entire province of Québec, we selected the two practices most likely to be implemented in the province: windbreaks¹ and riparian agroforestry systems² (De Baets et al. 2007). Our research approach also concentrated on the ecological goods and services that seemed most important. In order to estimate the private costs and public benefits of these EG&Ss, we chose two watersheds that represent two different realities - one in the proximity of urban agglomerations (Châteauguay watershed) and the second one in a remote area (Fouquette watershed). The ensuing results were then extrapolated unto the total area of Québec.

For the two watersheds studied, we conceived and developed three scenarios of agroforestry installations: a regulatory-level scenario that reflects Québec regulations on riparian buffers³; a priority-level scenario developed with members of watershed committees who, as a matter of priority, seek to implement installations to protect watercourses and problematic road segments, and to reduce odors from livestock barns⁴; and lastly, a high-level scenario⁵, which seeks to generate a maximum of EG&S. The selection and arrangement of plant species in the riparian agroforestry systems and in the windbreaks were made in function of protection objectives, climate zones and watershed soils (for more details see De Baets and Vézina 2008).

ECONOMIC RESULTS

The economic analysis began with a study of the private costs and benefits of agroforestry implementations (see Simard et al. 2009). The net costs for farmers were then compared with the social benefits evaluated for the EG&S. We carried out a cost-benefit analysis according to factor costs (thereby excluding government transfers) on a 40-year planning horizon with a real discount rate of 6%.

Private cost-benefit analysis

Comparison of agroforestry systems

The following table presents the economic results of the high-level implementation scenario for the two watersheds studied and allows us to compare to what extent the different agroforestry systems are of interest to farmers.

¹ In Québec, we distinguish between two principal types of windbreaks: windbreak structures that protect crops and soils and windbreak structures around agricultural infrastructure (buildings, roads, farms, manure pits, etc).

² De Baets et al. (2007) propose applying the term “riparian agroforestry system” to riparian buffers that were intentionally created by planting arborescent or shrubby ligneous species

³ The regulatory scenario in the two watersheds encompassed trees and shrubs every 3 meters with a width of 3 meters on all banks qualified as “weak”, “very weak” and “average”.

⁴ The priority scenario in the Fouquette river watershed encompassed trees and shrubs along 10 meters in width on very weak banks and along both banks of the fish spawning area. The priority scenario of the Esturgeon river watershed encompassed trees and shrubs along 10 meters in width on very weak banks of the Esturgeon and Noire rivers and on the main Saint-Rémi watercourse (Cinq branch).

⁵ The high-level scenario in the two watersheds encompassed riparian installations of 25 meters in width for all riparian zones in agricultural environments qualified as “very weak”, “weak” and “average”.

Table 1: Economic results from the high-level scenario in the two watersheds (in thousands of dollars)

	RB		WBb		WBc		WBr	
	Fouquette	Esturgeon	Fouquette	Esturgeon	Fouquette	Esturgeon	Fouquette	Esturgeon
Length (km)	134	296	9.43	24.81	140	219	8.15	48.48
Total costs (C)	3,293	8,007	83.12	239.72	663.92	1,093	24.92	158.86
Total benefits (B)	754.92	1,664	387.25	1,074	412.27	1,210	2.69	16.01
B-C	-2,538	-6,343	304.13	834.81	-251.65	117	-22.22	-142.85
Ratio (B/C)	0.23	0.21	4.66	4.48	0.62	1.11	0.11	0.10

Source: CEPAF Calculator (www.wbvecan.ca)

Legend: RB = Riparian buffers

WBb = Windbreaks adjacent to buildings

WBc = Windbreaks protecting crops

WBr = Windbreaks adjacent to roads

m: meter

B: benefits; C: costs

B/C: benefits/costs ratio

A comparison of the agroforestry systems in the two studied watersheds demonstrates that windbreaks along roads are less interesting for farmers because their benefit-cost ratio is below 0.12. Next come riparian buffers with a ratio of 0.2. Windbreaks that protect crops, which increase crop output, have a ratio approaching 1 while the ratio of windbreaks next to buildings is above 4. Windbreaks installed along livestock barns are therefore highly profitable and offer important benefits (avoided snow clearing and heating costs).

If installed riparian buffers also have a windbreak function that protects crops or livestock barns, one would have to calculate the additional benefits and the findings would improve. According to our hypothesis, a riparian buffer is likely to only become profitable if it also offers wind protection for buildings and roads closed to farms.

Comparison of three scenarios on two watersheds

Of the regulatory, priority and high-level scenarios in the two watersheds studied, no implementation scenario is economically profitable for farmers. In fact, all benefit-cost ratios are below 1. The following table outlines the economic results of the three implementation scenarios studied for the two watersheds that were analyzed.

TABLE 2: PRIVATE OVERVIEW OF THE THREE SCENARIOS IN THE TWO WATERSHEDS (IN THOUSANDS OF DOLLARS)

	Regulatory-level		Priority-level		High-level	
	Fouquette	Esturgeon	Fouquette	Esturgeon	Fouquette	Esturgeon
Total costs (C)	554.18	1,401	1,627	1,039	4,065	9,499
Total benefits (B)	79.40	199.07	346.10	175.86	1,557	3,965
B-C	-474.77	-1,202	-1,281	-863.59	-2,508	-5,534
Ratio (B/C)	0.14	0.14	0.21	0.17	0.38	0.42

Source: CEPAF Calculator (www.wbvecan.ca)

It is important to note that, in the Esturgeon river watershed, the length of installations in the priority-level scenario (79 km) is smaller than in the regulatory-level scenario (296 km).

The high-level scenario is most in deficit (-\$2.5 million margin for the Fouquette river watershed and -\$5.5 million for that of the Esturgeon river).

The benefit-cost (B/C) ratios of the scenarios go from 0.14 for the regulatory-level scenario of the two watersheds to 0.42 (high-level, Esturgeon river). Even though the high-level scenarios are more in deficit in absolute terms than the others, they demonstrate a more favorable B/C ratio (however, the costs remain more than two times higher than the benefits). This is due to the composition of the other two scenarios (regulatory and priority-level), which include less beneficial agroforestry systems made up of riparian buffers (for the regulatory-level scenario) and windbreaks adjacent to roads (for the priority-level scenario). For these two scenarios, the total costs are four to seven times higher than the total benefits.

Farmers' lack of enthusiasm for agroforestry practices can be explained in part by the fact that discounted private benefits rarely outweigh the costs farmers incur. Except for windbreaks that protect livestock barns and windbreaks that protect crops, the aggregate private costs of the studied agroforestry systems are 4 to 20 times higher than the private benefits they generate. On average, for all the simulations carried out in the framework of this stage, the costs are three times higher than the benefits. This conclusion holds even truer for farmers if we include the support of *Assurance stabilisation des revenus agricoles* (ASRA), which increases costs related to the loss of farmland. What remains to be determined is whether the ecological goods and services that agroforestry practices provide to society, justify a State intervention.

Social benefits

To estimate the value of the EG&S generated by the implementation of agroforestry practices in the two watersheds, four economic evaluation methods were used (see Olar et al. 2009a). The hedonic method helped to evaluate the reductions in agriculture-related odors and the aestheticism of the landscape. Experimental economics were used in the evaluation of the enrichment in terrestrial and aquatic biodiversity, as well as in the aestheticism of the landscape. The benefit transfer method was used for the monetary evaluation of the improvement of water quality, carbon sequestration and enrichment in terrestrial and aquatic biodiversity. The

productivity method was used to calculate reductions in costs for clearing snow from roads and treating potable water, and to estimate the economic value of an increase in the number of wild pollinating insects.

The results relating to the monetary value of EG&S, evaluated over a 40-year period and discounted accordingly, are presented in the following table. The EG&S are organized according to monetary order of importance.

TABLE 3: CLASSIFICATION OF EG&S AND CURRENT MONETARY VALUE (IN MILLION \$)

Order	EG&S	Scenario	Monetary value	
			Fouquette	Châteauguay
1	Carbon sequestration	Regulatory-level	0.224	7.317
		Priority-level	0.689	4.080
		High-level	2.057	56.081
2	Terrestrial biodiversity	Regulatory-level	0.540	2.422
		Priority-level	0.358	1.830
		High-level	1.351	50.308
3	Reduction in costs for clearing snow from roads	Regulatory-level	Not applicable in the case of RB	
		Priority-level	0.088	4.229
		High-level	0.142	12.147
4	Improvement in the quality of surface water	Regulatory-level	0.068	3.618
		Priority-level	0.068	2.763
		High-level	0.070	3.618
5	Improvement of the landscape	Regulatory-level	0	1.770
		Priority-level		1.145
		High-level		3.437
6	Increase in the number of wild pollinating insects	Regulatory-level	0.0001	0.533
		Priority-level	0.0005	0.590
		High-level	0.002	3.442
7	Decrease in treatment costs of potable water	Regulatory-level	Not applicable: subterranean source of potable water in this watershed	0.393
		Priority-level		0.085
		High-level		0.393
8	Reduction in agriculture-related odors	Regulatory-level	Not applicable because there are no WBb in these scenarios	
		Priority-level		
		High-level	0	0
Total		Regulatory-level	0.347	16.056
		Priority-level	1.205	14.725
		High-level	3.623	129.430

Legend: RB = Riparian buffers, WBb = Windbreaks adjacent to buildings

It is highly interesting and surprising to note that carbon sequestration is the EG&S that falls into first place in the two watersheds. That value represents between 27% and 64% of the total benefits according to the implementation scenario. As a result, carbon sequestration provides a considerable benefit. The absolute value is even more important in the Châteauguay river watershed because of the implementation surface. As this watershed is less wooded than that of the Fouquette river, more agroforestry installations are possible and, as a result, there are more possibilities to sequester carbon.

Biodiversity was attributed a high value but it remains comparable to those found in other literature reviews. We note that the aggregate value is higher in the Châteauguay river watershed than in that of the Fouquette river. This is due to the fact that the implementation surface in the Châteauguay river watershed is larger than that of its counterpart. We also note that the priority-level scenario offers fewer benefits than the two other scenarios in the case of the Châteauguay river. This is due to the decreased surface of agroforestry installations implemented in this scenario.

The impact on the reduction of snow clearing costs for public roads is significant in both watersheds in the priority and high-level scenarios. According to the results of the measurement protocol that was used, the presence of hedges along roads diminishes the number of snow clearing rounds by 29%, which affects the absolute value of avoided costs.

The most surprising result was that improvements in the quality of surface water came in fourth in terms of the value of benefits provided by agroforestry implementations. It is important to underline that the estimated value of the improvement of water quality is a low estimation as the impact of agroforestry installations on phosphorous were not measured and the impact on the established parameters (turbidity and fecal coliform bacteria) were estimated at the river mouth. This in part explains the low result. On the other hand, we note that the value is much higher in the Châteauguay river watershed than in that of the Fouquette river, primarily due to the larger number of households found there.

As for the value of landscapes, our results indicate that the implementation of agroforestry systems has no impact on the improvement of the landscape in the Fouquette river watershed, which has large forest coverage, contrary to that of the Châteauguay river. These results are interesting because they support the idea that adding trees to places where many exist already, adds no value, whereas adding them to places where there are not many trees, adds value to the landscape.

The priority-level scenario in the Châteauguay river watershed offers the least benefits because the number of properties to have improved landscapes depends directly on the length of agroforestry installations, which are the shortest in the priority-level scenario.

However, it is important to mention that the value of the landscape is only captured in part because the methodology used only targets the residents of the two watersheds. Non-residents' appreciation of the landscape is ignored by this methodology.

An increase in the number of wild pollinating insects comes in sixth position on the basis of their monetary value for both watersheds. The difference in value between the two watersheds is essentially due to the larger crop variety found in the Châteauguay river watershed as well as its larger surface area. The most important value is traced back to the high-level scenario, followed by the priority-level scenario and the regulatory-level scenario, both for the Châteauguay and Fouquette river watersheds. This classification is due to the fact that the high-level scenario encompasses the most expansive area of agroforestry implementations and that wild pollinators increase with the habitat areas available to them.

The impact of agroforestry implementation on the reduction of treatment costs of potable water is fairly weak because the latter only takes water turbidity into consideration. Savings on the annual treatment costs of potable water in the watershed can be considered negligible.

It also seems that the implementation of agroforestry systems has no impact on the reduction of agriculture-related odors in either of the watersheds. There are few pig farms in the area of the watersheds studied, which is probably why the value of a reduction in odors is not significant. However, all the values found are comparable to those in other literature reviews.

For the Châteauguay river watershed, the value of all EG&S is in the same ballpark for the regulatory and priority-level scenarios (\$16 and \$14.7 million, respectively). This is essentially due to the fact that the agroforestry implementation area, in the case of the Châteauguay river watershed, is higher in the regulatory scenario than in the priority-level scenario. The social benefits in the regulatory-level scenario are therefore higher in absolute value, and even more so as the value of carbon sequestration is significant. For the Fouquette river watershed, the value of all EG&S is, in contrast, three times higher in the priority-level scenario than in the regulatory-level scenario.

For the high-level scenario, which encompasses agroforestry implementation seeking a maximization of EG&S, the social value of EG&S is \$129.43 million for the Châteauguay river watershed and \$3.6 million for the Fouquette river watershed. This difference in scale between both watersheds for the same scenario can be explained by the larger surface area of the Châteauguay river watershed. The fact that average revenues are higher there also increases the value. In addition, the improvement of the landscape and reduction in the treatment costs of potable water were, respectively, zero and unquantifiable in the Fouquette river watershed.

The scenario that received the highest value is by far the high-level scenario, characterized by the most expansive area of agroforestry implementations. The regulatory-level scenario comes in last in the case of the Fouquette river watershed and second in the case of the Châteauguay river watershed. It is important to note that the value of the priority-level scenario, characterized by the placing of installations in the most critical locations, is probably underestimated due to the evaluation methods used. These did not allow us to capture the value-added of resolving the worst environmental problems.

Global analysis at the watershed level

The total social benefits and private net costs for both watersheds were compared in order to confirm or disprove the starting hypothesis that an intervention by the government favoring the establishment of agroforestry practices would be justified (see Olar et al. 2009b for further details).

The two following tables show the net present values (NPV) and benefit-cost ratios at the private level (table 4) as well as the benefit-cost ratios at the level of society (table 5) in the Fouquette and Châteauguay river watersheds.

TABLE 4: PRIVATE NET COSTS AND PUBLIC BENEFITS FOR THE TWO WATERSHEDS

Scenario		Private net costs		Public benefits	
		Fouquette	Châteauguay	Fouquette	Châteauguay
Regulatory-level	NPV (M\$)	-0.474	-15.658	0.347	16.056
	B/C	0.14	0.14	N/A	N/A
Priority-level	NPV (M\$)	-1.293	-1.441	1.205	14.725
	B/C	0.21	0.17	N/A	N/A
High-level	NPV (M\$)	-2.508	-73.310	3.623	129.430
	B/C	0.38	0.42	N/A	N/A

Source: CEPAF and ÉcoRessources Consultants

Legend: NPV = Net Present Value, B/C: Benefit/Cost Ratio, N/A: Not Applicable

TABLE 5: OVERVIEW OF THE COST-BENEFIT ANALYSIS FOR THE TWO WATERSHEDS

Scenario		Public benefits – Private net costs		Ratio of public benefits / private net costs	
		Fouquette	Châteauguay	Fouquette	Châteauguay
Regulatory-level	NPV (M\$)	-0.1	0.4	N/A	N/A
	B/C	N/A	N/A	0.73	1.03
Priority-level	NPV (M\$)	-0.09	3	N/A	N/A
	B/C	N/A	N/A	0.93	1.29
High-level	NPV (M\$)	1.1	56	N/A	N/A
	B/C	N/A	N/A	1.44	1.77

Legend: NPV = Net Present Value, B/C: Benefit/Cost Ratio, N/A: Not Applicable

In reading the table we note that in all the scenarios in the Châteauguay river watershed, the public benefits outweigh the costs incurred by farmers to establish and maintain agroforestry practices. However, this is not the case for the Fouquette river watershed, in which only the high-level scenario results in sufficient public benefits to more than compensate the costs incurred by farmers for establishing and maintaining agroforestry practices. In this manner, installations in Fouquette-type watersheds (extensive) are less profitable than those in Châteauguay-type watersheds (intensive).

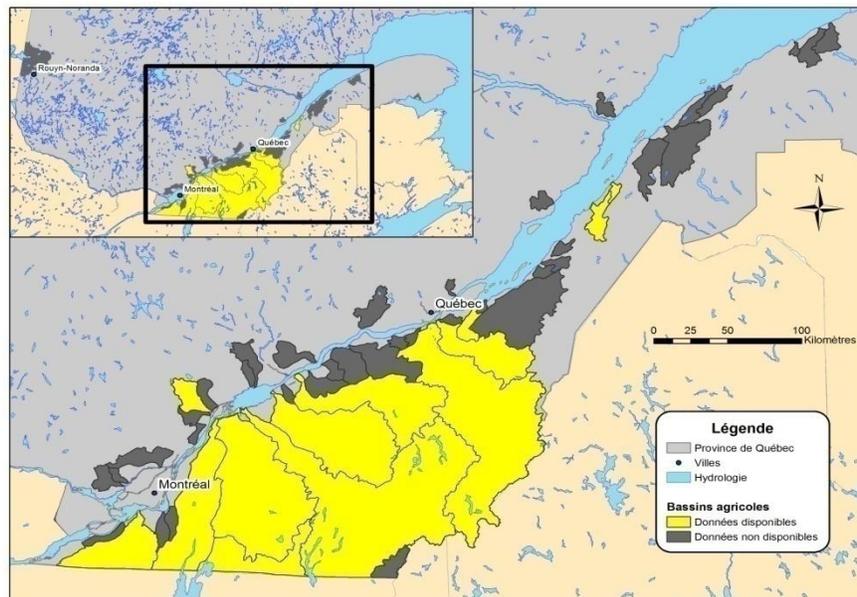
If we take into consideration the number of EG&S that were not considered in the current analysis, as well as the practical difficulties of defining some of the EG&S we analyzed, we realize that this evaluation constitutes a low estimation of the total value of EG&S. We thereby find that the value of EG&S that emanate from the establishment of agroforestry practices is significantly higher for the public than the costs they engender for farmers.

Global analysis at a Québec level

Following our analysis of two watersheds that are representative of two different realities affecting the territory of Québec, an extrapolation was carried out for the totality of Québec's agricultural land (see Olar et al. 2009b for further details). The global overview sought to integrate all the results from the two watersheds and to extrapolate them to a Québec scale by basing itself on 13 watersheds. The selection of the 13 watersheds⁶ was made according to different criteria: (1) the agricultural watersheds (of level 1) have to have a cultivated area higher than 20% of their total area, (2) the watersheds have to be amongst the 33 priority watersheds outlined by the National Water Policy and (3) the data of the River Network of the Ministry of Sustainable Development, Environment and Parks in Québec (MDDEP) must be available.

The following figure illustrates the location of the 13 watersheds on which we based our extrapolation. We note that almost all of Québec's agricultural land was covered.

FIGURE 1: LOCATION OF THE 13 EXTRAPOLATED WATERSHEDS



Source: Compilation made by Activa Environnement based on data from the Ministry of Natural Resources and Fauna (MRNF), the *Commission de protection du territoire agricole du Québec* (CPTAQ) and the *Centre d'expertise hydrique du Québec* (CEHQ).

The extrapolation was conducted per EG&S, agroforestry system and implementation scenario. The following table shows the net present values (NPV) and the private and public benefit-cost ratios of the three implementation scenarios at a Québec level.

⁶ The thirteen watersheds studied are Baie Missisquoi, Bayonne, Bécancour, Boyer, Châteauguay, Chaudière, Etchemin, Fouquette, Kamouraska, Nicolet, Richelieu, Saint-François and Yamaska.

TABLE 6: RESULTS FROM THE COST-BENEFIT ANALYSIS AT A QUÉBEC LEVEL

Scenario		Private Net Costs	Public Benefits	Public benefits – Private net costs	Ratio of public benefits / private net costs
Regulatory-level	NPV (M\$)	-209.39	244.15	35 M\$	N/A
	B/C	0.14	N/A	N/A	1.11
Priority-level	NPV (M\$)	-211.05	288.8	78 M\$	N/A
	B/C	0.16	N/A	N/A	1.37
High-level	NPV (M\$)	-1,038.54	1,902	864 M\$	N/A
	B/C	0.43	N/A	N/A	1.83

Legend: NPV = Net Present Value, B/C: Benefit/Cost Ratio, N/A: Not Applicable

At the level of the 13 watersheds, the regulatory, priority and high-level scenarios show private net deficits of, respectively, \$209, \$211 and \$1,038 million and B/C ratios of 0.14, 0.16 and 0.43. Although the high-level scenario was in greater deficit than the others, it offers a more favorable B/C ratio (0.43). This is explained by the fact that this scenario contains profitable agroforestry installations such as windbreaks that reduce heating and snow clearing costs and that enable higher crop turnout.

The public benefits of the scenarios for the entire Québec area go up to \$244, \$288 and \$1,901 million for the regulatory, priority and high-level scenarios, respectively. These social benefits are more significant than the private net costs and result in public net benefits of an order of \$35 million in the case of the regulatory-level scenarios, of \$78 million in the case of the priority-level scenario and of \$864 million in the case of the high-level scenario. In the case of the high-level scenario, EG&S-related benefits are twice as great as the private costs incurred by farmers.

At first glance, it is a bit surprising to note that the priority-level scenario leads to lower results than the high-level scenario. Indeed, one of the starting assumptions was that the public benefit/cost ratio of the priority-level scenario would be higher because it targeted what seemed to be priority installations. However, our results simply reflect the fact that, contrary to previous beliefs, the most important benefits relate to carbon sequestration and not water quality. The area of the implementation, which determines the carbon sequestration capacity, is the element that most affects the public value of agroforestry installations. The high-level scenario generates a higher ratio of public benefits / private net costs than the priority-level scenario, which wrongly assumed that the most important benefits would be derived from improvements in water quality.

As public benefits outweigh private net costs, society gains from the implementation of agroforestry systems. Although the extrapolation is based on weaker information than that used for the representative watersheds, the obtained ratios both for the regulatory scenario (low estimation) and for the high-level scenario (high estimation) should comfort us. The implementation scenarios seem to result in enough public benefits to justify a government intervention in the establishment of agroforestry practices.

DISCUSSION

The results of this study lead us to the conclusion that identified agroforestry practices do not generate sufficient and immediate revenues to prompt farmers to implement such practices. On average, for all the simulations carried out in the framework of this project, the private costs were three times higher than the private benefits. This conclusion would hold even truer from the perspective of the Québec farmer if we considered the support of ASRA, which would increase the costs related to lost farmland.

Nonetheless, the ratio of public benefits / private net costs obtained for the different implementation scenarios can comfort us. Although our extrapolation is based on weaker information than that used for the representative watersheds, the ratios seem to result in sufficient public benefits to justify providing assistance to farmers in order to help them implement and maintain agroforestry practices.

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COMMUNICATING THE ECONOMIC AND ENVIRONMENTAL IMPACTS OF AGROFORESTRY SYSTEMS

Laura Poppy¹, Janna Lutz¹, and Henry de Gooijer¹

¹Agriculture and Agri-Food Canada, Agroforestry Division, Indian Head, SK, Canada, S0G 2K0.
Contact: Laura.Poppy@agr.gc.ca

Abstract: The Agriculture and Agri-Food Canada Agroforestry Division conducts research, development and delivers technology tools, products and services including tree and shrub seedlings for the adoption and integration of agroforestry practices by producers. The Division works toward increasing the adoption of agroforestry by demonstrating that agroforestry practices can be both environmentally and economically beneficial if properly integrated as a management practice in the agricultural landscape. To do so, it is important to demonstrate the return on investment for the producer, highlighting private benefits, while also determining opportunities that recognize public benefits. Agricultural practices are constantly changing as producers adopt new technologies and adapt to changing markets, social concerns and changing physical environments. Some producers may no longer consider trees in the agricultural landscape necessary as they rely more on adopted technologies and machinery advancements to impact production and environmental issues traditionally addressed by shelterbelts and tree buffers. As farms become larger and demographics of the farm population change, there is less time and traditional labour for producers to plant and care for trees. Agroforestry specialists and development staff must be cognizant of agricultural trends and keep this in mind when developing agroforestry marketing strategies and programming that is directed at producers. Using the AAFC-PFRA Agroforestry Division's Prairie Shelterbelt Program as an example, this presentation will focus on government & producer investment in agroforestry systems and the economic and environmental impacts of agroforestry systems for the producer and on the agricultural landscape.

INTRODUCTION

The agricultural regions of the Canadian Prairie Provinces experience year-round extreme temperature variations, strong winds and snow build up, all of which can have huge impacts on quality of life. Everywhere on the continent, including the prairies, environmental issues such as water quality and quantity, habitat for preserving biodiversity and concerns about climate change have increased the focus of the roles that trees play on the landscape. Shelterbelts and other agroforestry systems have been used to address these issues and can positively impact agricultural production systems and the quality of life of rural people. Communicating these benefits, in terms of both economic and environmental impacts to agricultural producers, is the focus of the work of the Agriculture & Agri-Food Canada's (AAFC) Agroforestry Division which is based out of Indian Head, Saskatchewan.

INVESTMENT BY THE GOVERNMENT OF CANADA

Research conducted by AAFC's Agroforestry Division has identified many benefits to agroforestry, both environmental and economic. Agroforestry is a beneficial management practice (BMP) and is generally understood and recognized by most landowners on the prairies and across Canada. However, adoption by landowners has been limited and is not always at the level practitioners and program managers would like to see. In temperate areas, such as the Canadian prairies, highly mechanized, monocrop agriculture has marginalized woody plants on the landscape (Kort and Poppy 2009). As well, continuing technological and demographic changes are further challenges to the long-term, sustainable use of trees in agricultural landscapes. In western Canada, agroforestry practices are a voluntary action by the landowner. As a result, agroforestry adoption requires a certain level of buy-in from the landowner. Therefore, it is important for practitioners to stop and reflect on why adoption of agroforestry practices may not be occurring and to try to understand and address the reality producers are facing in regards to barriers.

Understanding adoption techniques and developing new ways to secure higher levels of adoption of conservation practices involving woody plants is critical to the future success of agroforestry programs (Brandle 2004). The role of woody plants, whether in shelterbelts, riparian buffers or other agroforestry plantings, continues to be the focus of the AAFC Agroforestry Division's research and information development. The Division uses several techniques to increase adoption of agroforestry practices by landowners, including targeted research & information development as well as supplying tree seedlings and technical services at no charge to rural landowners through the Prairie Shelterbelt Program.

In 1901, the Government of Canada established the AAFC Agroforestry Division tree nursery at Indian Head, Saskatchewan. The primary function of the facility was to produce and distribute hardy tree and shrub seedlings at no charge to settlers in western Canada. This service continues to this day and is accomplished through the Division's Prairie Shelterbelt Program (PSP) which is administered out of Indian Head, Saskatchewan. The PSP is one of the longest running government programs, with over 100 years of service to farmers and rural landowners in western Canada. By 2008, the AAFC Prairie Shelterbelt Program had distributed an estimated 600,000,000 tree and shrub seedlings. This is enough trees to circle the globe 27 times (at 6' spacings) and to sequester over 218 mega tonnes of CO₂ which is the equivalent to the weight of 95 million adult elephants!

In the early years, the Division's PSP provided seedlings mainly for fuelwood and farmstead shelter. However, in the dirty thirties and 1980s more emphasis was placed on planting trees for soil and crop protection. On the Canadian prairies, shelterbelts and tree buffers are now planted for a variety of reasons such as farm, field and livestock protection, increased crop yields, beautification, energy reduction, diversification and biomass production. These and other private benefits are generally understood and recognized by landowners and many are scientifically documented (Kort and Brandle 1991). However, shelterbelts and other agroforestry practices are now also recognized for their many public ecological goods and services (Kulshreshtha and Kort 2009). These goods and services, or public goods, are linked to the protection of soil, water, air and biodiversity, however, they are not easily quantified.

The government of Canada has invested in agroforestry programs and practices through AAFC's Agroforestry Division. The investment includes personnel and operations of the Division including research and development and delivery of technology tools, products and services, along with providing tree and shrub seedlings through the Prairie Shelterbelt Program. The Division works toward increasing the adoption of environmentally beneficial management practices by agricultural producers for the management of land, water, air and biodiversity, specifically through the development and integration of agroforestry systems into the agricultural landscape.

BENEFITS OF AGROFORESTRY ON THE PRAIRIES

The government's investment in agroforestry is significant. However, it should be noted that the contribution of the landowner/producer is even more so. The joint investment by the producer includes the long-term allocation of land required for tree planting and the investment to prepare, plant and maintain tree plantings over time. Studies conducted by the AAFC Agroforestry Division (Kulshreshtha and Kort 2009 (Sharpe 2001) have found that producers in western Canada invest 1.5 dollars for every dollar invested by the government in agroforestry programs and services (i.e. Prairie Shelterbelt Program). The return on investment generates between 2 and 6 times the value in private and public benefits (Figure 1).

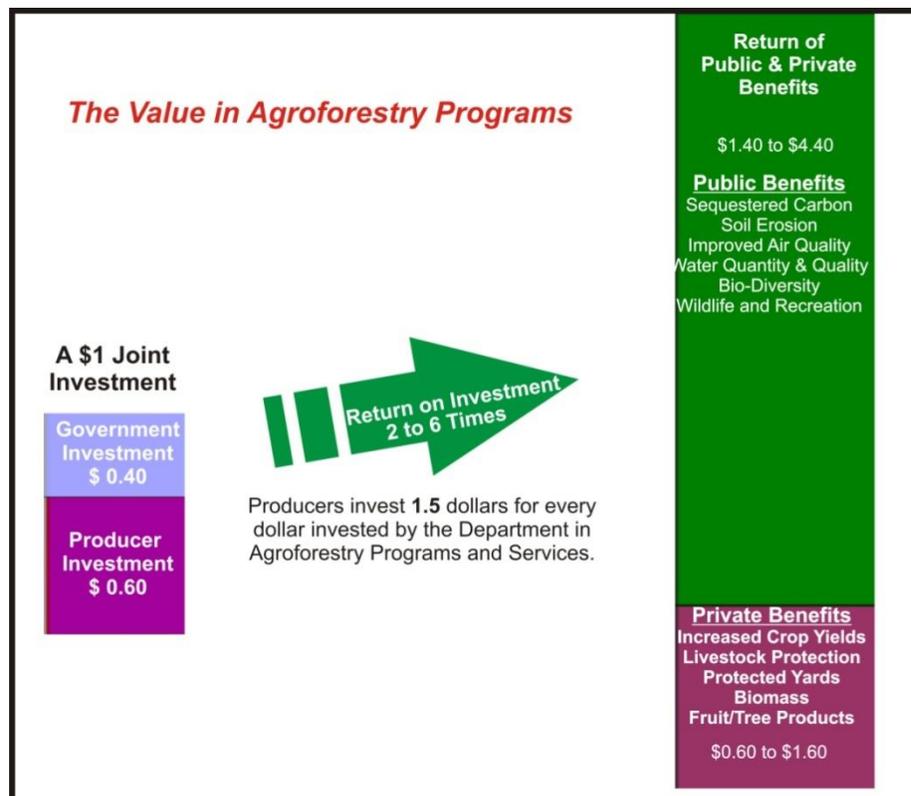


FIGURE 1 Public and Private Return on Investment

The Prairie Shelterbelt Program supplies approximately 4 million seedlings each year to over 7000 farm clients. The impacts of this service are varied (Figure 2). In 2007/2008, the following

public and private benefits and Farm Gate Impacts of 3.8 million PSP trees were found (Kulshreshtha and Kort 2009):

- Crop benefits: \$ 0.9 Million (Net Present Value),
- Livestock benefits: 28 % reduction in energy requirements for beef cows, 10 % increase in rate of gain of feeder cattle,
- Protection of 1482 farm yards: snow clearing and home heating (\$ 0.4 Million reduction in home heating costs),
- Increase crop yields and decrease soil erosion on 12610 ha of crop land: \$11.35 Million in the value of topsoil conserved,
- Bio-energy and bio-fuels from woody biomass,
- \$8.8 Million in annual harvestable biomass in shelterbelts,
- Provide 198 ha of wildlife habitat and protect 270 km of riparian areas: \$2.1 million in enhanced water resource protection through riparian plantings, and
- Sequester 1.4 mega tonnes of CO₂ by 2057.

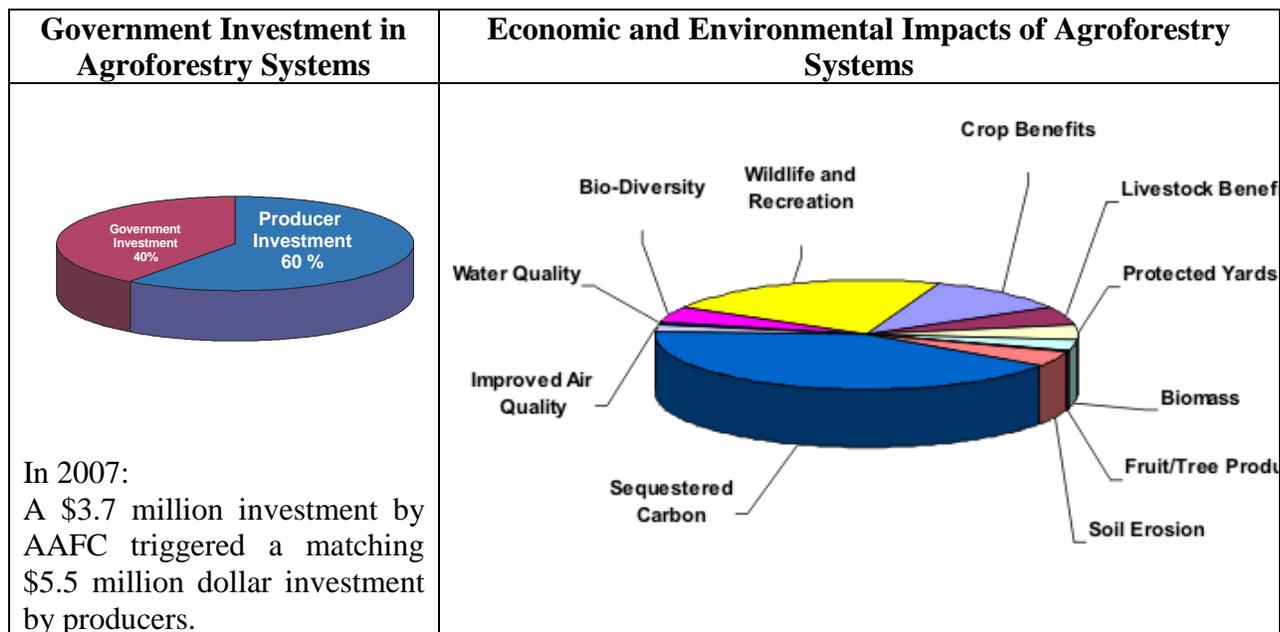


Figure 2 Economic and Environmental Impacts of Agroforestry Systems

ADOPTION BARRIERS

Private and public benefits of agroforestry are scientifically documented (Kort and Brandle 1991) and many are recognized and acknowledged by landowners, researchers and practitioners. There is value in incorporating agroforestry into agricultural production systems. However, adoption continues to be at a lower than expected rate. Having discussed the benefits of agroforestry to producers, we have to stop and reflect on why adoption doesn't automatically occur. We need to have an understanding of the reality producers are facing and what the barriers to adoption of agroforestry practices are in order to determine how to target our communication efforts.

Producers at this time face many pressures and realities. Agricultural production is a business where productivity must be maximized, markets are volatile, input costs are increasing, time and labour are in short supply, and societal scrutiny regarding environmental practices is increasing. Adopting any new practice on the landscape that may impact production and the economic bottom line involves risk and uncertainties.

A ground-truthing survey to determine diversification and adaptation was carried out by AAFC's Prairie Farm Rehabilitation Administration (PFRA) in East Central Saskatchewan in 2000. Producers noted in the survey that a lack of finances was the highest ranked reason that they were not making changes to their current operation. When asked what they would need in order to make changes to their current operation, the responses included need for a program, other (labour pool, commodity prices, initiatives, and time), technical support and education and training.

Barriers to adoption of agroforestry beneficial management practices (BMP's) include economics, demographics, land tenure, policy, research & information, skills and training, compatibility and delivery barriers.

Economics – In many cases there is not a direct correlation to the economic returns on agroforestry activities. As well, there is a lack of market information. Many, if not most, agricultural innovations that have occurred, have been based on economics and profitability with a clear understanding of the consequences which decreases the risk factor. In many cases, establishing any form of agroforestry practice does have a high initial establishment and maintenance cost and a long term commitment before any economic gains are apparent. During difficult financial times, the adoption of environmentally based practices is lower than adoption of economically based ones.

Demographics – StatsCanada has recorded that the average age of a Canadian farmer is 52 years (StatsCanada Census of Agriculture, 2006). This may have an impact on agroforestry adoption. With many producers nearing retirement, this long-term horizon may not be attractive. Besides the aging farm population, the current state of farming has seen many producers take on off-farm jobs as they look for stable and profitable income which reduces their time available to pursue other on-farm innovations and activities. There is also a real labour pool shortage, especially for seasonal work, to assist producers and allow for them to expand their operations.

Land Tenure – A change has been noted in land ownership trends with a slight drop in owned land and a 9.9% increase in rented or leased lands (StatsCanada Census of Agriculture, 2006). StatsCanada results indicate that of Canada's agricultural land, 61-66% is farmed by the private owner. The remainder is under some form of rental agreement. In some cases, farmers who are retiring or wanting to downsize see renting as a way of retaining ownership of their land. In other cases, investor groups or others not actively farming are buying land as they consider it to be a relatively safe investment. Some farmers may not have the means to invest in land and they see land rental as a way to increase the size of their operation without large capital investments. When farmers are working and maintaining the land for others, there may not be the same desire to improve the land with agroforestry practices, especially since the benefits may take years to be appreciated and the land tenure agreement may well be expired before these benefits are realized.

Policy – The message coming from the policy makers must be very consistent and has to be delivered at the grass roots level. There is a lack of or insufficient programs, policy support and incentives for agroforestry practices. Programs appear and disappear, but it is the good practices that we must promote and that will be effective and enduring on the landscape. In a study of graziers (Greiner et al., 2009), BMP's were adopted by those who were intrinsically motivated to do so by their lifestyle and conservation goals while others that were motivated by economic and social goals, required external incentives.

Research & Information – Research as well as extension activities, education and demonstrations are very important in promoting adoption of agroforestry practices. Producers need decision support to make changes on their land. Regional demonstrations, technical support and improved information and understanding are integral to adoption of innovative practices. A Center for Subtropical Agroforestry (CSTAF) survey of professionals stated one of the main reasons for the lack of adoption of practices in some areas was due to a lack of familiarity with the practice and a lack of demos (Workman, Allen, 2004).

Skills and Training - Agroforestry practices are not widely recognized as there is a lack of knowledge including lack of management skills, lack of access to technical information or lack of its existence, lack of decision making tools and sustainability of different systems.

Compatibility – Whether this is a real or perceived barrier, compatibility or conflict between BMP practices may challenge landowners. Timing of the highest labour requirements may overlap with other farming practices. There may be a perceived incompatibility between the various outputs of a system such as competition between crops, livestock and trees. Agroforestry is not always viewed as a practical, profitable or low cost option for producers. In some cases, agroforestry is not even viewed as a land management tool.

Delivery Barriers – Program/project success is often based on economic results, however quantifying environmental performance is far more difficult. There is a definite need for involvement by extension professionals, policy makers and stakeholders to spread the word to landowners. In many cases the research conducted is not regional and site specific, which can reduce the uptake and reliability of the research and initiates the need for local demonstrations. In the CSTAF study, a major limitation to adoption in some areas was due to a lack of well documented local agroforestry experiments and positive experiences. In many of the programs we have worked within, delivery is enhanced by the positive experiences that are communicated amongst producers giving the practices credibility at the local level.

Recent research suggests that we must first understand the motivations and risk attitudes of the producer in order understand their willingness to adopt various BMP's on their land (Greiner et al., 2009). Obviously motivations and risk attitudes vary by individual and are related to their personal beliefs, attitudes, circumstances and personal goals. This would lead us to believe that communication and the extension work we do cannot be a “one size fits all” solution, but must rather involve a variety of choices and methods so that we can tailor to suit individual personalities. Simple signage to communicate the producer's commitment or simply letting them know they have done something positive for the next generation is enough of a motivator, however others require more for adoption to occur.

ADOPTION OF AGROFORESTRY

There are a number of techniques and tools the AAFC Agroforestry Division is using to address barriers, increase adoption of agroforestry by landowners and to advance agroforestry on the Canadian Agriculture landscape.

Agroforestry Technical Service Delivery, Support and Development of Products

The AAFC Agroforestry Division is focused on increasing the overall awareness of the benefits of agroforestry practices and systems. This is done through the development and delivery of information and technology tools and products for producers, partners and the general public.

The Division also focuses on producing high quality, prairie hardy tree and shrub seedlings for distribution through the Prairie Shelterbelt Program (PSP) to eligible landowners. In partnership with research, PSP is continually evaluated and refined and processes are monitored to improve stock, increase survival and advance nursery function.

The following are examples of the Agroforestry Division's service delivery, support and development of products:

- Development and maintenance of the PSP, TREES database, tree delivery system and partner network. Accomplished through associations with staff and partners and routinely adapted to meet client and partner needs,
- Availability of a toll free number, and walk-in technical support with direct one-on-one access to technicians, researchers and program developers who can provide information and answer technical questions relating to the PSP, agroforestry practices, research and tree planning, planting and care,
- Maintenance and support one of AAFC's most widely accessed and utilized web pages,
- Development of agroforestry related information for clients, partners and staff. Distribution and provision of agroforestry and Program information for the web, agricultural offices, trade shows, producer meetings, partner workshops, tours, newspaper and magazines,
- Development and support of agroforestry demonstration sites to apply new research and technical information on a practical landscape level,
- Conduct ground-truthing surveys on existing tree planting sites to monitor survival, site management and fate and function of PSP trees, and
- Specialized programs, such as the Shelterbelt Enhancement Program (SEP), were initiated to overcome maintenance issues, increase the adoption of agroforestry practices, and meet environmental targets.

Agroforestry Research

The AAFC agroforestry research unit focuses on the development of agroforestry science, technology and genetic material for the improvement of the agroecosystem and support of agroforestry practices in Canada and abroad. The following are the main AAFC agroforestry research goals and outcomes:

- Improving technology for enhanced tree performance and health through a long-term, viable tree breeding and tree improvement program,
- Evaluating tree culture and understanding tree biology,
- Improving knowledge and understanding of agroforestry practices and their impact, function and integration on the landscape,
- Tree adaptation work to address current and future environmental and biological stresses,
- Developing agroforestry tools to assist in planning agroforestry systems and predicting impacts, and
- Developing and maintaining National and International research projects and partnerships.

CONCLUSION

Agroforestry continues to be high on Agriculture & Agri-Food Canada's national agenda. Agroforestry continues to play an integral role in improving the competitive position of the agricultural sector in Canada and contributing to the future sustainability of the agricultural land resource base. The success of agroforestry adoption will lie in the ability of practitioners and researchers to address adoption barriers and continue to support and promote agroforestry research, development and programs and services for the benefit of all Canadians.

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AROUND THE GLOBE AND ACROSS CANADA THE AGRICULTURE AND AGRI-FOOD CANADA AGROFORESTRY DIVISION

Tricia Pollock¹ and Henry de Gooijer¹

¹Agriculture and Agri-Food Canada, Agroforestry Division, Indian Head, SK, Canada, S0G 2K0.
Contact: tricia.pollock@agr.gc.ca

INTRODUCTION

The Agroforestry Division of the new Agri-Environment Services Branch of Agriculture and Agri-Food Canada is in transition from a predominantly regional focus to a national role in providing leadership and expertise in agroforestry research, development and delivery across Canada. In its expanded role, the Agroforestry Division seeks to enhance agroforestry practices through the development of partnerships with regional and local agroforestry interests. National coordination will assist to identify and prioritize research needs, develop and publish technical materials, and to establish demonstration sites to promote agroforestry as an economically viable and sustainable agricultural practice. However, many challenges exist in the expansion to a national role. This document will provide a history of the existing Division, its structure and the issues of functioning as a national organization.

Agricultural land is one of the key foundations in defining agricultural production. Agricultural production, while being environmentally and economically sustainable, must continually adapt to meet the challenges and opportunities provided by changing markets, environment and societal expectations. By integrating trees into agriculturally productive landscapes, agroforestry provides a science-based means of achieving key objectives in agricultural sustainability and natural resource management. Agriculture and Agri-Food Canada's Agroforestry Division has the knowledge, experience and mandate to bring agroforestry solutions and opportunities to Canadian agriculture.

Agroforestry practices have been identified as agricultural activities that can assist Agriculture and Agri-Food Canada's priority areas of Climate Change and Water Quality under the current Growing Forward initiative of the Government of Canada. Shelterbelts and other agroforestry practices are recognized as Beneficial Management Practices (BMPs) and are being applied across the country as part of Environmental Farm Plans (EFPs) which will use trees to achieve measurable and meaningful environmental goals.

By increasing the number of trees and shrubs established in Canada and enhancing agricultural production systems, agroforestry contributes to the environmental priorities for the sustainable use of and reduced impact on water, soil, and climate change by agricultural production. The roots of trees act as nutrient filters and as such are able to reduce pesticides and other harmful contaminants found within farm run-off from reaching water reserves, either above or below ground. In regards to water conservation, trees provide shade which can reduce water consumption and groups of trees (such as it has been shown for field shelterbelts) can retain

snow and therefore increase ground moisture levels. Field shelterbelts are widely recognized as an effective tool in the management of soil organic matter and soil erosion. As well, trees can contribute to improving the organic content of soil through the natural composting of shed leaves and roots. Trees and other plant materials remove air pollutants from the air and are essential tools in any response to global warming as they are able to sequester carbon and other greenhouse gases. AAFC, and others, have conducted recent research into the extent to which the management of trees and shrubs in agroforestry systems sequester carbon and reduce emissions.

Agroforestry contributes to the strategic outcomes for agriculture outlined by the Canadian Government and contributes to the profitability of the agricultural sector. The competitiveness and innovation within the sector is enhanced by agroforestry practices that provide new commercial opportunities in the bio-economy. Agroforestry contributes to society's priorities through research and development that provides insight into agricultural practices that can improve environmental performance implemented as best management practices. Agroforestry practices also provide resilience in the landscape helping to mitigate productivity losses and manage production risks.

HISTORY OF THE AGROFORESTRY DIVISION

In the late 1800's, the Department of Agriculture began testing tree species in Brandon, Manitoba and Indian Head, Saskatchewan. In 1902 the Department of the Interior established the Forest Nursery Station at Indian Head, Saskatchewan. The nursery provided hardy tree seedlings to settlers of the Prairie region as a means of making the area more habitable and to help them meet building and fuel needs. Seedlings were provided free of charge in order to promote tree planting on public and private land.

In 1930, the Federal Forest Nursery Stations were transferred to the Dominion Experimental Farms Branch of the Department of Agriculture. At this time, there was an increase in seedling-production capacity and in efforts towards designing and promoting effective shelterbelts. The promotion of shelterbelts became the Nursery's primary focus during the 1930's and onwards as they were found to be a highly effective tool in reducing levels of soil erosion. While not transferred to the Prairie Farm Rehabilitation Administration (PFRA) until the 1960s, the nursery assisted rehabilitation of the Prairies through its promotion of shelterbelt plantings and provision of tree seedlings.

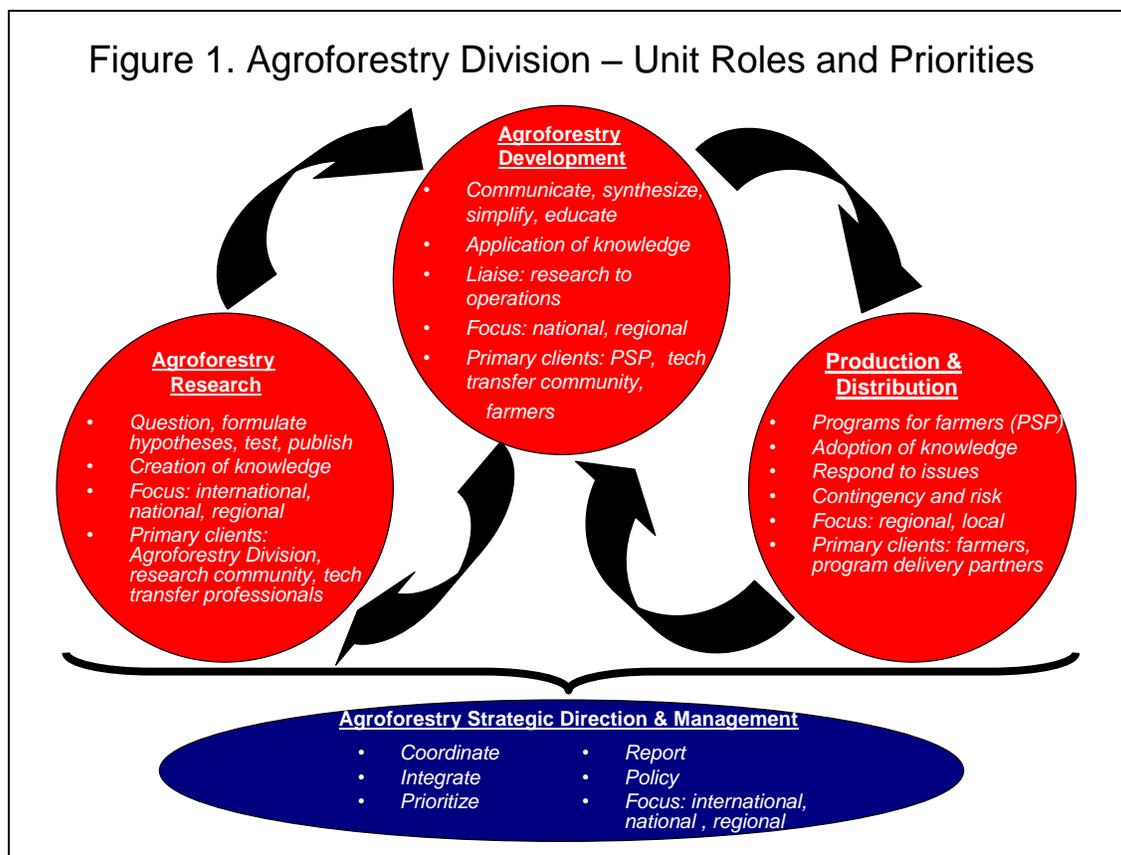
With the official transfer of the nursery to PFRA in 1963, the practice of shelterbelt planting was further supported by an increase in applied research capacity at the facility and expansion into new areas of tree breeding, insect and weed control, tree seedling viability, seedling processing and storage and soil related problems. The applied research had the dual role of assisting in increasing the quantity and quality of the nursery's seedlings as well as acquiring knowledge as to how best establish healthy tree and shrubs within the Prairie climate.

In 1987, the nursery was re-named the Shelterbelt Centre to more accurately recognize the broader and more comprehensive scope of applied research and technology transfer performed at the facility beyond the growing and distribution of seedlings. The Centre, however, maintained the original operational objectives of the Forest Nursery Station (produce seedlings, conduct

research, collect statistics and information) under PFRA’s mandate to “...secure the rehabilitation of drought and soil drifting areas in the Provinces of Manitoba, Saskatchewan and Alberta and to promote within those areas systems of farm practice, tree culture, water supply, land utilization and land settlement that will afford greater economic security.”

DESIGN AND FUNCTION OF THE DIVISION

The Agroforestry Division is comprised of four separate units. Each of the units within the Agroforestry Division has roles and priorities particular to the scope of their activities (Figure 1). The Research Unit, the Agroforestry Development Unit, and the Tree Production and Distribution Unit work closely together to create knowledge, technology transfer tools and products, and high-quality plant material. Similarly, the Agroforestry Division operates in an integrated manner with the Directorate, Branch and Department to ensure agroforestry practices have a role in the sustainable management of Canada’s agricultural land base.



Agroforestry Strategic Direction and Management

The Agroforestry Strategic Direction and Management unit coordinates the Division activities, including financial and human resources. This unit, lead by the Agroforestry Division Manager, provides support and direction for the management of AAFC Agroforestry Division programs, inputs into the development and management of other branch and departmental agroforestry initiatives, and leads the development and implementation of management instruments for

Division programs. The Strategic Direction and Management Unit are responsible for determining the direction and overall mandate for the Division's activities.

Production and Distribution Unit

The Production and Distribution Unit's primary function is the physical production and distribution of the seedlings required to meet the demands of the Prairie Shelterbelt Program (PSP) and related programs supported by AAFC, focusing on high quality plants, client satisfaction and environmentally sustainable production. The Prairie Shelterbelt Program is an on-going program which provides technical services and tree and shrub seedlings at no charge for planting shelterbelts and for agricultural conservation and land reclamation projects in Manitoba, Saskatchewan, Alberta and northeastern British Columbia.

The Production and Distribution Unit builds on the genetic selections and assessments of the Agroforestry Research Unit to produce hardy tree and shrub seedlings suitable for desired agroforestry uses on prairie planting sites. The Unit is also responsible for the allocation and distribution of seedlings to clients of the PSP on an annual basis. This requires partnerships with other departments, agencies, and non-government organizations to deliver seedlings to clients.

Agroforestry Development Unit

The Agroforestry Development Unit's primary functions are to support and promote the adoption of agroforestry practices by Canadian farmers and to increase the visibility and understanding of agroforestry science. It also has direct responsibilities in support of both the Agroforestry Research Unit and the Production and Distribution Unit in the delivery of Prairie Shelterbelt Program (PSP).

The Agroforestry Development Unit develops and maintains current and factual information for the development and implementation of agroforestry practices. The information is regionally and locally relevant. It is targeted towards landowners, practitioners and decision makers. The Unit's work is designed to support sustainable agroforestry expansion.

The goals of the Development Unit are to increase the overall awareness of benefits of Agroforestry, develop information products based on research results and expert knowledge in conjunction with the Agroforestry Research unit, develop technology and information transfer tools and methods to assist in the adoption of agroforestry practices, provide technical support to AAFC programs related to Agroforestry, provide guidance to the Agroforestry Research unit and the Production and Distribution units based on interaction and feedback from knowledge and information transfer programs and technical support functions, and develop collaborative delivery mechanisms to promote agroforestry.

Agroforestry Research Unit

The Agroforestry Division's Research Unit concentrates on advancing agroforestry science, technology and development of genetic materials. The goal of the unit is to address identified knowledge gaps in agroforestry science and increase the understanding of agroforestry practices

in a way that contributes to the scientific knowledge on tree health, growth and function; agroforestry design; and the environmental, social and economic effects of agroforestry.

The unit conducts a mixture of applied and basic research which involves systematic investigation and discovery to develop, verify and scientifically test the validity of a hypothesis, or theory related to Agroforestry. The Research unit includes researchers at the Shelterbelt Centre. The unit has built research relationships with AAFC Research Branch which also extends to Universities and other institutions. The unit is also internationally recognized and actively involved in cooperative international research projects.

The Agroforestry Division Research Unit has been performing tree improvement breeding for over 60 years and has one of the longest running tree research programs in North America. When the Tree Improvement Program began, emphasis was placed on screening different species for hardiness and adaptability. Today, the program's focus is on developing genetically improved trees and the research has a national scope which is advancing through partnerships.

The goal of the Agroforestry Research Unit is to develop agroforestry science, technology and genetic materials for the improvement of agro-ecosystems. The Unit's activities are managed through two research streams: Improved Tree Performance and Health, and Improved Knowledge of Agroforestry Practices.

Research in the Improved Tree Performance and Health stream includes research in three main areas:

- *Tree Genetics*: Develop improved trees and shrubs that are adaptable to current and future environmental and biological stresses to ensure long term viability and function of agroforestry systems. Improvement strategies concentrate on developing genetically diverse seed strains that are well adapted to local ecosystems.
- *Tree Biology*: Create a better understanding of how trees grow and respond to the environment and identify and improve key characteristics such as cold hardiness, nutrient uptake, drought tolerance and water use efficiency that allow trees to resist environmental and biological stresses.
- *Tree Culture*: Develop innovative, environmentally sound management strategies and practices for healthy agroforestry systems by researching cultural factors that impact health, growth and function of trees and shrubs. This includes nursery management, nutrition, pests and diseases and weed competition.

Research in the Improved Knowledge of Agroforestry Practices area includes:

- *Impact and Function*: Studies to increase understanding of how agroforestry practices protect water and soil, sequester carbon, affect biodiversity and crop productivity.
- *Agroforestry Design*: Development of optimal designs and management systems so that agroforestry practices provide desired environmental, social and production benefits and are efficiently integrated into agricultural production systems.
- *Landscape Integration*: Development of knowledge and tools to improve decision making and better predict and quantify the benefits of agroforestry within agro-ecosystems, to determine where agroforestry practices are most effective and will have the greatest impact.

A NATIONAL ROLE IN AGROFORESTRY

Agroforestry is not new to Canadian agriculture. Agroforestry has uniquely evolved with a significant amount of research, development and extension occurring in all agricultural regions. Certain practices, such as shelterbelts, are well known and have been supported by AAFC. Other agroforestry practices, such as silvopasture, alley cropping and riparian buffer systems are less common in Canada but have potential to improve agriculture's economic and environmental sustainability.

The Agroforestry Division set its roots in Indian Head, Saskatchewan as the Shelterbelt Centre for regional tree production and distribution. Over the past century, it has grown and is now, as a Division, branching out across Canada focusing on providing service and expertise nationally. The transition is from a predominantly regional focus to a national role in providing leadership and expertise in agroforestry research, development and delivery across Canada. This transition brings with it many challenges including the need to build and enhance partnerships across the country, an expansion of the current knowledge base around Agroforestry design and practices, national coordination and leadership, research coordination, fiscal and human resources, integrating with existing regional activities, and policy development.

It should be noted that the Agroforestry Division is not currently devoid of national roles in agroforestry, and in fact, units such as the Strategic Management and Research Units already play a significant role in shaping and promoting Agroforestry across Canada. The Research Unit conducts research projects and has built partnerships, not only nationally but internationally as well. National research programs managed by the Agroforestry Division Research Unit have impacted agroforestry practice in all provinces by involving universities and Research Branch. Research projects on riparian buffers, tree genetics, livestock operations, and biomass production are examples of some of the current activities in collaboration at the national level. The integration of tree related best management practices into farm level environmental farm programs is also supported for all regions of the country.

Agroforestry practices are particular to farming systems, the physical and ecological environment, and the regional and social cultures. Agroforestry in the prairie region has evolved from the need for shelterbelts to provide protection to prairie farms and fields. Ecologically, much of this area is considered arid to semi-arid grasslands, mixed grassland and Aspen parkland environments. The species of trees introduced into the landscape, and the growth and function of those trees are very much limited by the grassland environment. In contrast, many of the agricultural regions in eastern Canada are based in boreal, mixedwood plains and Atlantic Maritime ecological regions where trees and tree culture are very much part of the landscape and local knowledge. The need for riparian buffers is much more prominent in agricultural landscapes dissected by numerous streams, rivers and riparian zones. Interest in Silvopasture systems in many areas of British Columbia is being driven by the need to develop economic and environmentally sound agricultural practices on forested lands affected by the Mountain Pine Beetle. Downturns in the forest industry and the need to create new economic products have also increased interest in integrated uses of once strictly forested lands. In its expanded national role, the Agroforestry Division must not only recognize this diversity in practice, but also the diversity in client and partner in its effort to promote sustainable practices.

The evolution of the Agroforestry Division from a regionally based Division to a fully national entity requires an increased level of knowledge and understanding of the potential benefits that agroforestry represents to Canadian farmers and the environment in all agricultural regions of the country. Agricultural production systems and land unit values vary across agricultural regions and are continually evolving. Agroforestry practices conducted and Agroforestry designs implemented in one region of the country may be unsuitable in other regions due to high land costs, machinery size or current production systems. As an example, many traditional prairie shelterbelts are being removed as machinery size increases and minimum till production systems replace conventional tillage systems. The challenge is to design Agroforestry systems that not only integrate well with current production systems, but also integrate well with evolving production systems while enhancing economic and environmental sustainability. Agriculture is also a shared jurisdiction between provincial governments and the federal government; therefore activities within each province may have to be adapted to federal-provincial agreements.

The Agroforestry Division can provide many functions in a national agroforestry role. Fundamentally, the Division can provide national ownership, leadership and direction to an area of science and land management practice that is often caught between agricultural practice and forestry. The Division can provide a broader and more inclusive environment for research and extension programs that support the development and implementation of regionally unique agroforestry practices and systems.

Continued leadership and coordination in research by the Agroforestry Research Unit into agroforestry systems, design, tree genetics, products and impacts will have a significant role in guiding agroforestry practice and implementation at the national level. Working with regional partners, coordinated research programs can reduce regional duplication while still providing answers to fundamental questions of design, impact and function. A national body can also provide scientific and limited financial support for specific regional research programs.

The development of innovative information resources that are current, factual and local relevant and the coordinated delivery of those resources are additional roles the National Agroforestry Division. Again, working with regional partners, national and regional workshops, field days and tours can be delivered to landowners and land use decision makers. A national agroforestry website, national and regional newsletters, the development of agroforestry planning materials, and economic evaluations of agroforestry practices are examples of some of the functions of the national centre.

Constructive and innovative Agroforestry policy development is also required at the national level. While agriculture is a shared jurisdiction between the federal government and the provinces, it is useful to develop and define acceptable Agroforestry practice and design, backed by science, before regulations that may constrict Agroforestry practice and benefits are imposed based on other standards. The National Division will work to develop science based policy and practice for adoption by producers in all provinces of the country.

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AFFORESTING FORMER AGRICULTURAL LANDS WITH HIGH VALUE HARDWOODS IN SOUTHERN ONTARIO

Patrick J. Howe¹, Jian Wang¹ and Reino Pulkki¹

¹Faculty of Forestry and the Forest Environment, Lakehead University,
Thunder Bay, On, Canada, P7B 5E1.
Contact: pjhowe@lakeheadu.ca

Abstract: With the onset of another environmental revolution, interest in establishing afforested plantations on marginal farmland in southern Ontario has been renewed. To supply private landowners with the tools needed to afforest their land in a successful, cost effective manner, we must first address the technical knowledge gap that exists in a regional context.

This study was a side by side comparison between traditional afforestation practices and alternative techniques that we feel may address some of the common obstacles to modern afforestation. The study investigated the influence of two planting types (planted and seeded) and three vegetation management regimes (plastic mulch, herbicide and control) on the growth and development of black cherry (*Prunus serotina* Ehrh.), bur oak (*Quercus macrocarpa* Michx.) and red oak (*Quercus rubra* L.) plantations in the London Ontario region. The analysis of the three year results found plastic mulch to be an effective alternative to herbicide use, without the annual application commitment. Red oak was identified as an appropriate tree species for afforestation. However, the success of bur oak was limited by site quality and hydrology. Planted black cherry was identified as an appropriate candidate for afforestation because it can quickly occupy and persist in an open field environment. Although the seeded oak species did produce a high proportion of successful germination, a clear conclusion on the success of direct seeding was unable to be formed due to the age of our plantations.

Keywords: black cherry, bur oak, direct seeding, herbicide, planting, plastic mulch, red oak.

INTRODUCTION

Afforestation, as defined by the Kyoto protocol, is the direct, human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and /or the human-induced promotion of natural seed sources (UNFCCC 2002). Afforestation has not been widely adopted in southern Ontario. The elimination of tree planting subsidies in the early 1990s made afforestation a risky and expensive practice for Ontario farmers. As a result, afforestation began a consistent decline (White and Kruz 2005) and research and development into improved and more cost effective methods were also abandoned.

With the onset of another environmental revolution, a renewed interest in establishing afforested plantations has surfaced. Recent government incentives, such as the \$20 million dollar Forest 2020 initiative and the 50 million tree program, are encouraging Ontario landowners to afforest their land for carbon sequestration (Newmaster *et al.* 2006). Such incentives have farmers and private land owners across Canada actively afforesting their land.

In southern and eastern Ontario alone there are over 900,000ha of abandoned marginal farmland eligible for afforestation. Creating a program that can successfully afforest these lands begins with addressing the considerable knowledge gap that exists in the field of afforestation. Efficient and cost effective methods for afforesting farmland with high value hardwoods must be investigated in a regional context. This study aimed to address some of the financial and social obstacles of afforestation by comparing traditional practices with proposed alternatives. The study investigated the influence of two planting types (planted and seeded) and three vegetation management regimes (plastic mulch, herbicide and control) on the growth and development of black cherry (*Prunus serotina* Ehrh.), bur oak (*Quercus macrocarpa* Michx.) and red oak (*Quercus rubra* L.) plantations in the London Ontario region. Our objectives are to 1) assess direct seeding as a successful alternative to planting nursery stock; 2) assess plastic mulch as an effective vegetation management alternative to herbicide use; 3) assess the suitability of black cherry, bur oak and red oak to afforestation of former agricultural fields.

MATERIALS AND METHODS

Study Site and Experimental Design

Three study sites of approximately 1 ha were established at the Pittock Conservation Area, Fingal Wildlife Management Area and Littlejohn Farm outside of London Ontario in the spring of 2006. The soil texture class was silty sand at the Pittock site and silty loam at the Fingal and Littlejohn sites. To provide a receptive seed bed each site was disked and ploughed the fall prior to planting. An electric fence surrounded each site to discourage deer browsing. Within each site, fifty-four completely randomized 100m² square plots were arranged in a 2x3x3x3 factorial design. Factors consisted of:

- Planting method (direct seeding, planting)
- Tree species (red oak, bur oak, black cherry)
- Vegetation control type (no control, simazine/round up, plastic mulching)
- Replications (3)

The 10m x 10m plot contained three rows of five planting locations with a between row spacing of 3m to facilitate mowing. Mowing is a common means of controlling competing vegetation in an afforested plantation. All outer planting locations were situated 1m from the plot's edge and the perimeter of each plot was treated with simazine to reduce edge effects. Seeds were collected in the fall of 2005, sealed in plastic bags and refrigerated overwinter. Planting occurred the following spring from April 30th to May 6th. The oak seeds were planted at a depth of 2cm at a density of 3-5 seeds per planting location. The smaller black cherry seeds were planted at a density of 10-15 seeds per location. The bare root 2+0 red oak, 1+0 bur oak and 1+0 black cherry seedlings were carefully planted to ensure natural root system development. Simazine treatments occurred in May of 2006 at a rate of 5.68kg/ha at the Pittock site and 7.8kg/ha for the other two sites. A second application occurred in November of 2006 for the Fingal and Littlejohn sites and in April 2007 at the Pittock site.

Measurements and Analysis

Germination, survival and seedling height were collected for all planting locations in the spring and fall of each year from 2006 to 2008. Root collar diameters (RCD) were collected for a

randomly selected plot for each treatment at each site in the fall of 2008. For analysis, height growth was converted to an increment to provide a standard platform for comparison between planted and seeded treatments. To avoid confounding the results by including the random termination of cases, negative growth increments exceeding -10cm between time steps were removed from the analysis. To eliminate errors in the transformation as a result of zeros and negative numbers a constant of 11cm was added to each case. The data was then Log10 transformed to fit a normal distribution. A repeated measures ANOVA with three time steps was conducted on the incremental height growth accompanied by a Scheffe post hoc test. Survival and germination proportions were calculated separately at the plot level. The square root transformed survival and germination data were analysed using a repeated measure ANOVA procedure with six time steps. Root collar diameter measurements were analysed using a univariate ANOVA procedure. All analysis was performed in SPSS version 16.0.

RESULTS

Germination

Germination was highly varied between sites (Figure 1a). The final measurement at the Pittcock site had the greatest proportion germinated (0.69) and was statistically similar ($\alpha=0.05$) to the Fingal results (Table 1). The Littlejohn site yielded the poorest results with a peak germination proportion of 0.43 in fall 2008. Over time, the vegetation management regime proved to have a significant impact on germination capacity (Table 1), although by fall 2008 those differences seem to be resolved (Figure 1b). Due to the poor results in the first three time steps, the plastic mulch treatment produced significantly lower results than the other two treatments. The black cherry data was removed from analysis because it was generally unsuccessful. The seeded red oak had a higher germination success than bur oak (Figure 1c).

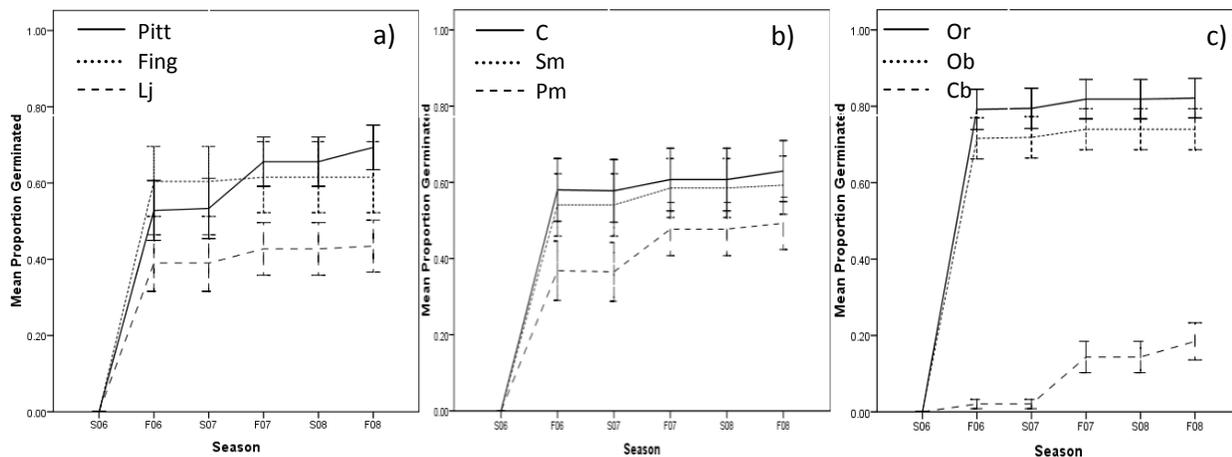


Figure 1: Average germination proportions plotted over a three year time horizon with standard error bars. a) Site b) Vegetation management regimes c) Species.

Table 1: Main effects repeated measures ANOVA results ($\alpha=0.05$) for average germination proportions of seeded plots.

Source of variation	df	MS	F	P
Site	2	0.873	13.136	≤ 0.000
Species	1	0.137	2.063	0.161
Management	2	0.529	7.957	0.002
Site*Species	2	0.153	2.301	0.117
Site* Management	4	0.133	2.004	0.118
Species* Management	2	0.053	0.800	0.458
Site*Species* Management	4	0.070	1.050	0.397
Error	32	0.066	.	.

Survival

Survival of planted seedlings proved to be a very sensitive response variable (Table 2). By fall 2008 all three sites and all three species were producing significantly different survival results (Figure 2a, c). Average survival proportions varied from 0.44 to 0.87 depending on the treatment. The vegetation management post hoc test revealed that the herbicide treatment was similar to the other two treatments but the plastic mulch treatment yields were significantly higher than the control (Figure 2b).

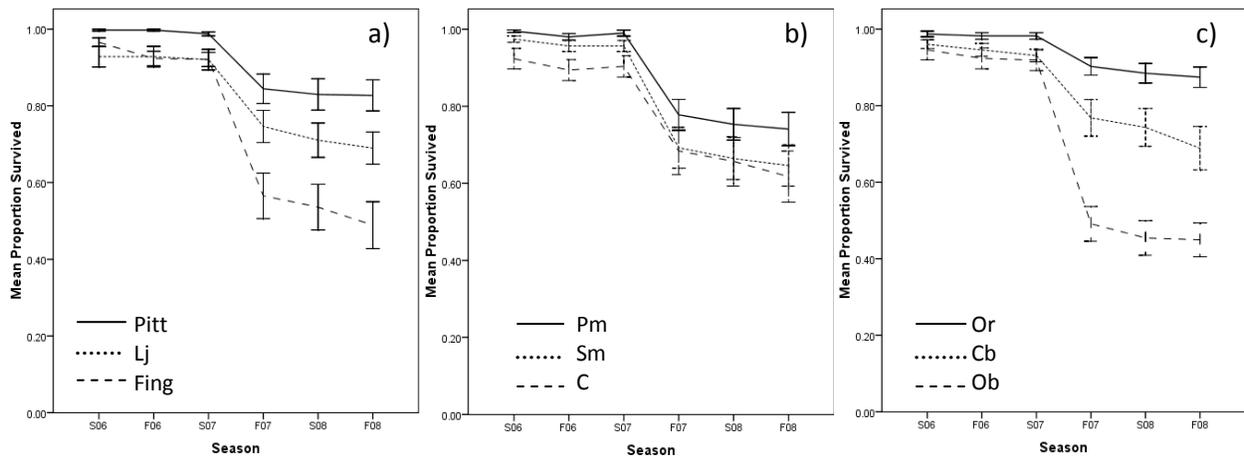


Figure 2: Average survival proportions plotted over a three year time horizon with standard error bars. a) Site b) Vegetation management regimes c) Species.

Table 2: Main effects repeated measures ANOVA results ($\alpha=0.05$) for average survival proportions of planted plots.

Source of variation	df	MS	F	P
Site	2	0.658	17.879	≤ 0.000
Species	2	0.999	27.163	≤ 0.000
Management	2	0.203	5.507	0.007
Site*Species	4	0.114	3.102	0.023
Site*Management	4	0.052	1.412	0.243
Species*Management	4	0.066	1.785	0.146
Site*Species*Management	8	0.015	0.397	0.918
Error	53	0.037	.	.

Height Increment

The height increment results (Table 3) indicate site (Figure 3b) was highly significant, influencing not only the results of the main effects but the interaction terms as well. While the Littlejohn and Fingal sites saw a consistent decline, incremental height growth increased dramatically at the Pittock site. A difference is also seen between planting types (Figure 3a). Planted trees had significant advantage over seeded trees after three seasons. The incremental growth increased for planted trees while it decreased for seeded trees. Due to the slow growth of the tolerant hardwood species such a result is expected. The species term (Figure 3d) identified black cherry as the species that produced the greatest height increment as of fall 2008. Red oak had an incremental growth significantly less than black cherry but greater than bur oak. Through time the vegetation management term produced an insignificant variation in average incremental height growth. By the third season the mulching and herbicide treatments are began to separate themselves as superior treatments to the control.

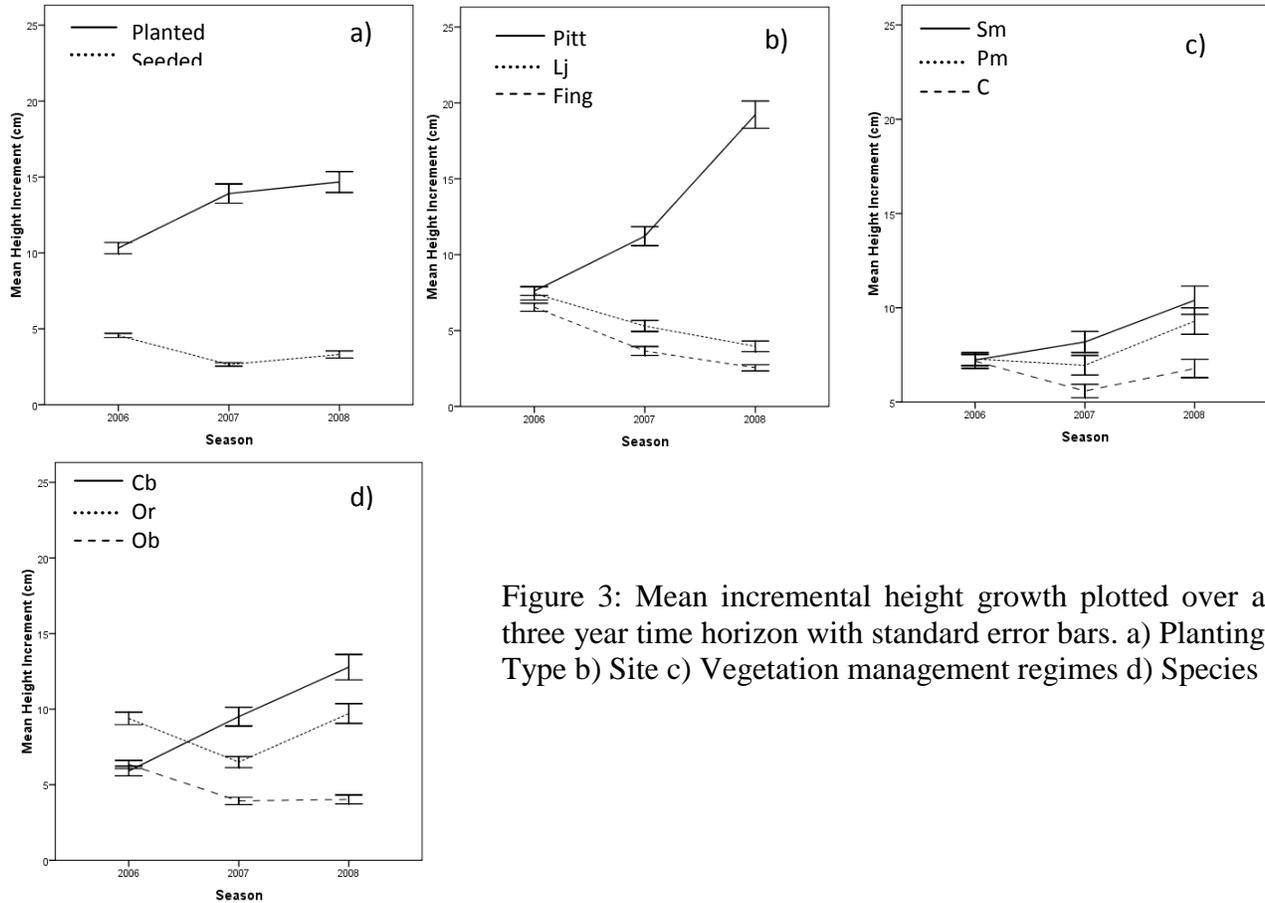


Figure 3: Mean incremental height growth plotted over a three year time horizon with standard error bars. a) Planting Type b) Site c) Vegetation management regimes d) Species

Table 3: Main effects repeated measures ANOVA results ($\alpha=0.05$) for average incremental height growth.

Source of variation	df	MS	F	P
Site	2	6.295	140.915	≤ 0.000
Plant	1	5.730	128.284	≤ 0.000
Species	2	0.645	14.428	≤ 0.000
Management	2	0.070	1.570	0.209
Site * Plant	2	0.835	18.683	≤ 0.000
Site * Species	4	0.724	16.213	≤ 0.000
Site * Management	4	0.342	7.646	≤ 0.000
Plant * Species	2	2.061	46.145	≤ 0.000
Plant * Management	2	0.011	0.246	0.782
Species * Management	4	0.063	1.418	0.226
Site * Plant * Species	3	0.195	4.359	0.005
Site * Plant * Management	4	0.064	1.439	0.219
Site * Species * Management	8	0.105	2.361	0.016
Plant * Species * Management	4	0.089	1.985	0.094
Site * Plant * Species * Management	5	0.093	2.088	0.064
Error	1261	0.045	.	.

Root Collar Diameter

In the planted model for RCD all terms were significant (Table 4). Profile plots (Figure 4) of the site, species and management terms show the Pittock site consistently producing higher RCD. Bur oak remained the species that is less productive while the vegetation management treatments produce comparable results. Post hoc tests for planted and seeded trees were consistent with the discoveries of the height increment tests. However, contrary to the aforementioned tests, the simazine application separated out as producing a significant improvement on RCD growth.

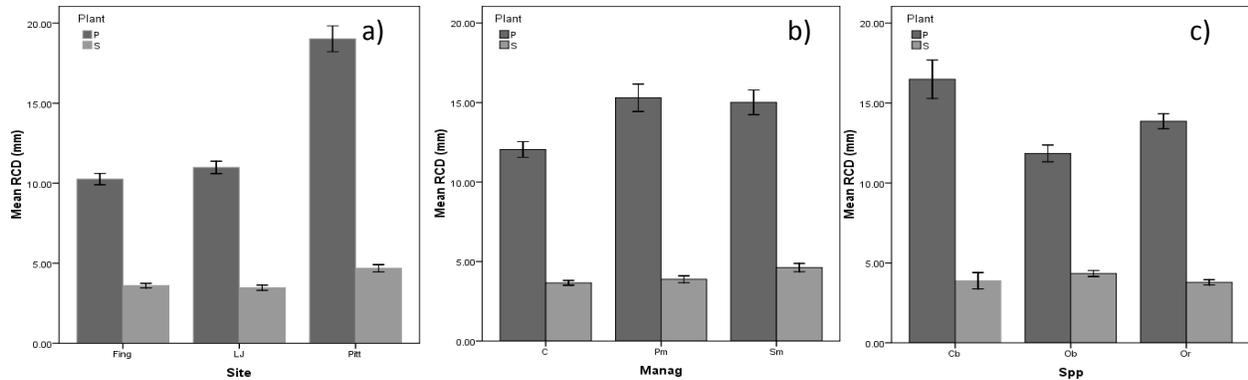


Figure 4: Average root collar diameter growth in fall 2008 for planted and seeded plots separated by a) Site b) Species c) Management regime.

Table 4: Univariate ANOVA results ($\alpha=0.05$) of root collar diameter measurements for planted and seeded trees

Planted					Seeded				
Source of variation	df	MS	F	P	Source of variation	df	MS	F	P
Site	2	1.654	76.132	≤ 0.000	Site	2	0.176	6.995	0.001
Species	2	0.101	4.668	0.001	Species	2	0.134	5.325	0.006
Management	2	0.262	12.064	≤ 0.000	Management	2	0.110	4.370	0.014
Site * Species	4	0.527	24.253	≤ 0.000	Site * Species	3	0.031	1.224	0.302
Site *	4	0.098	4.527	0.001	Site * Management	4	0.213	8.442	≤ 0.000
Management *	4	0.082	3.759	0.005	Species *	4	0.050	1.997	0.096
Management *	4	0.082	3.759	0.005	Management *	4	0.050	1.997	0.096
Site * Species *	7	0.063	2.912	0.006	Site * Species *	3	0.029	1.152	0.329
Management *	7	0.063	2.912	0.006	Management *	3	0.029	1.152	0.329
Error	286	0.022	.	.	Error	224	0.025	.	.

DISCUSSION

The site treatment heavily impacted all the analyses. Seed germination, seedling survival, incremental height growth and root collar diameter growth were all significantly greater for the Pittock site. Soil texture class is the logical explanation for this phenomenon. The sandier soil at the Pittock site provided an ideal growing environment for the oak species while providing adequate drainage to support consistent improvement for the black cherry seedlings. Also black

cherry prefers sites with higher coarse fragment content (Marquis 1991), which was the case at the Pittock site. The Fingal and Littlejohn sites had a higher content of silt and clay in the soil which when saturated provided poor growing conditions for the moisture intolerant black cherry, and inferior growing conditions for the oak species when compared to a sandier soil. This discovery supports most work in the afforestation field which suggests that matching the tree species to site type is the best way to ensure a successful plantation (von Althen 1991, Groninger 2005).

The planting method factor indicates that three years of data collection for seeded plots is not enough time to produce comparable results to planted stock even if the data was standardized. The large initial root mass common to planted stock does not develop naturally in such a short period. With the stressful environment that abandoned fields present, the rapid development of a root system becomes especially challenging. However, the potential for directly seeded trees to catch up to planted stock is not lost. With the slow growing nature of these hardwood species it may be difficult to detect comparable results within the first 10 years after planting (Sander 1991).

The vegetation management results suggest that plastic mulch can match or even exceed the performance of herbicide use in terms of average height increment growth, RCD growth and seedling survival. The plastic mulch treatment did not perform well for the seeded plots but this does not suggest that the practice is inappropriate for direct seeding. Variable germination success is common for directly seeded plantations (von Althen 1991). With proper site preparation, directly seeded plantations could be left until the fall or spring after planting before applying the mulch. This would improve germination success and reduce the likelihood of investing money in a vegetation management practice where no trees are present. Plastic mulch is an expensive vegetation management option thus postponing its application may be a wise management practice.

Although the oak species are from the same genus they performed quite differently in the field trial. The silvics of bur oak indicate that it is very sensitive to flooding (Johnson 1991, Cogliastro *et al.* 2003). With the high silt and clay content of the Fingal and Littlejohn sites bur oak is likely to perform poorly. The black cherry results indicate that this species is suitable for afforestation only when planted. The germination requirements for black cherry are strict and because it can seed bank for up to three years after sowing, a homogenous and successful plantation is unlikely. The planted results show that black cherry seedlings consistently produce good growth regardless of the response variable especially at the Pittock site. Black cherry's traits as a generalist species enable it to grow and occupy a site rapidly and its survival rates suggest that it is able to withstand a competitive environment.

CONCLUSION

As interest in afforestation in southern Ontario increases, more landowners will be faced with critical decisions pertaining to the success of their plantations. There are a number of services available to the public who wish to afforest their land in Ontario but there is very little published research on proven techniques for the do-it-yourself landowner. In this paper we confronted three typical decisions made when undertaking afforestation. We have demonstrated the potential for

plastic mulch as an effective alternative to herbicide use without the annual application commitment. We identified red oak as an appropriate tree species for afforestation and bur oak as a species whose success in afforested plantations seems limited by site quality and hydrology. We also demonstrated the potential that planted black cherry has for quickly occupying and persisting on an afforested site. A clear conclusion on the success of direct seeding was unable to be formed due to the age of our plantations. However, when comparing the germination percentages and the survival percentages in our study, the possibility for the directly seeded trees to persist and become mature still exists.

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SECTION 4

Economics and Marketing

TRANSITIONING FROM WILD COLLECTION TO FOREST CULTIVATION OF INDIGENOUS MEDICINAL FOREST PLANTS IN EASTERN NORTH AMERICA

Eric P. Burkhart¹ and Michael G. Jacobson²

¹Shaver's Creek Environmental Center, the Pennsylvania State University, Petersburg, PA 16669, USA

²School of Forest Resources, the Pennsylvania State University, University Park, PA 16802, USA

Abstract: The forest flora of eastern North America includes many herbaceous plant species traded in domestic and international medicinal markets. Conservation concerns surrounding wild-collection exist and transitioning to cultivation in agroforestry systems has potential economic and ecological benefits. Costs and revenues associated with adopting forest cultivation were modeled for eight North American medicinal forest plants. Sensitivity analysis examined profit potential in relation to (1) discount rates; (2) propagation methods; (3) prices; (4) growing period; (5) production costs; and (6) yields. Results indicate that intensive husbandry of six of eight species would be unprofitable at recent (1990-2005) price levels. Exceptions are American ginseng (*Panax quinquefolius* L.), and under certain circumstances (e.g., maximum historic prices, low production costs) goldenseal (*Hydrastis canadensis* L.). Direct marketing to consumers and retailers might improve grower profits, but is undermined by the availability of cheaper, wild-collected product. We suggest that the North American medicinal plant industry could play a key role in facilitating any transition from wild to cultivated product, perhaps through development of a certification and labeling program that brands "forest cultivated" products. This could generate price premiums, to be passed along to growers, but must be accompanied by aggressive consumer education. A "forest cultivated" certification and labeling program has potential to benefit industry and consumers if assurances regarding product identity and quality are a central feature. Plant species that are not viable candidates for commercial cultivation due to limited consumer demand (i.e., species with "shallow," erratic markets) are best addressed through proactive government and industry initiatives involving targeted harvester education programs.

Keywords: financial analysis, forest farming, medicinal plant conservation, non-timber forest products, plant husbandry, specialty forest products.

INTRODUCTION

As many as fifty plant species indigenous to eastern North American forestlands annually find their way into domestic and international medicinal trade networks (Robbins 1999; Strategic Sourcing 2008). Some of the most prominent North American trade species are gathered from forestlands (Bailey 1999; Emery *et al.* 2003; McClain and Jones 2005) and represent important non-timber forest products (NTFPs). Among these, collection pressure is widely acknowledged for American ginseng (*Panax quinquefolius* L.) and goldenseal (*Hydrastis canadensis* L.); however, there is also significant commerce in other species including black cohosh (*Actaea*

racemosa L.), blue cohosh (*Caulophyllum thalictroides* L.), bloodroot (*Sanguinaria canadensis* L.), false unicorn root (*Chamaelirium luteum* L.) and wild yam (*Dioscorea villosa* L.)

Collection from wild populations is a concern since many species are slow-growing perennials with low fecundity and/or juvenile recruitment rates. Presently, two North American medicinal forest plants---American ginseng and goldenseal---are included in Appendix 2 of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) due to concerns over sustainability of wild harvests, and additional species have been suggested as suitable candidates for listing.

Rather than collect from wild populations, cultivation of indigenous North American medicinal forest plants is an alternative (United Plant Savers (UPS) 2008). *In situ* cultivation using agroforestry practices such as forest cultivation are especially attractive (Rao, Palada, and Becker 2004), as there are potential advantages or benefits compared with field-based cultivation. Advantage include production cost savings, final product characteristics or qualities, and offers multiple economic and ecological benefits to landowner and society, since the practice has the potential to increase income while maintaining forest integrity (Hill and Buck 2000). Income derived from forest cultivation is received at shorter intervals than timber, giving private forest landowners more revenue options, enabling them to pay annual taxes and other carrying costs. Facilitating private landowner interest in adopting forest cultivation can therefore drive interest in forest stewardship, raise awareness about indigenous forest plants, and positively influence silvicultural decisions.

Transitioning from wild-collection to forest cultivation of indigenous North American medicinal forest plants is an economic opportunity with concomitant conservation and ecological merits. However, there has been limited financial evaluation of agroforestry crop candidates in relation to recent market price trends. This paper presents financial analyses (i.e., cost and revenue models) for agroforestry cultivation of eight North American medicinal forest plants, using sensitivity analysis to examine profit potential relative to costs, revenues, discount rates, production length, propagation methods, and yields. Market price data were compiled for the period 1990-2005 and were adjusted for inflation. Results identify market and production factors requiring careful consideration by those interested in agroforestry cultivation of indigenous North American medicinal forest plants, and highlight constraints to transitioning from wild collection to forest cultivation.

METHODS

All analyses were conducted utilizing a spreadsheet template (= basic model) which was modified (= adjusted model) for sensitivity analyses (e.g., discount rate, time to harvest, no stock costs, no annual costs). The term “basic model” as used in this paper refers to the original template whereas “adjusted model” indicates modified templates where key variables were altered. Basic model parameters use the woods-cultivated approach to forest cultivation premised upon the idea that more intensive methods would tend to increase yields by increasing survival, growth, and root weight. However, adjusted models in which annual costs are removed are included and could be considered similar to the less intensive wild-simulated cultivation approach. Price data for developing this analysis came from contacts with “local buyers/country

dealers” and “regional consolidators” and covers the period 1990-2005. Before conducting any analyses, all prices were adjusted for inflation. The basic model includes two propagation methods: seed and juvenile rootstock transplants sourced from a commercial nursery¹.

The basic model incorporated a four percent discount rate. Two slightly higher rates, six and eight percent, were used in adjusted models to examine net present value (NPV) sensitivity. Because both basic and adjusted models utilized real prices, future revenues were treated the same by removing inflation from discount rates (Klemperer 1996). Break even prices were calculated by dividing production costs by the projected yields. Break even yields were calculated by dividing production costs by minimum, maximum, and mean prices. In both calculations, only variable costs were used, in keeping with the variable versus fixed cost assumptions presented under “labor and material costs.”

RESULTS

Net Present Value (NPV) results for both basic and adjusted models are given in Table 1. Only the most favorable production method (most profitable/least unprofitable) results are given for each selected discount rate. As expected, as discount rate increased, profitability decreased for all species. However, there were no changes from profitable to unprofitable with any species in response to increasing discount rates. In general, the NPV results for all models suggest adoption of forest cultivation for all species except American ginseng would be unprofitable at even the lowest discount rate. This is true regardless of propagation method, although for most species propagation from seed is apparently less costly despite the generally longer cropping period. The results did not differ with price level.

¹ See Burkhart and Jacobson 2008 for details about the 8 species, stocking requirements and estimated costs, crop production parameters and yield estimates, plant spacing and numbers, years to harvest, yield estimates, labor and material costs.

Table 1. Net present value (NPV, US\$, 1/10 Ha) of North American medicinal forest crop candidates at three discount rates and three price levels (mean, minimum, maximum prices, 1990-2005). NPV given is for the most profitable propagation method. [@]

	NPV (4% discount rate, US\$)			NPV (6% discount rate, US\$)			NPV (8% discount rate, US\$)		
	Mean price	Min price	Max price	Mean price	Min price	Max price	Mean price	Min price	Max price
ACRA [#]	-12,731 ^T	-12,888 ^T	-12,485 ^T	-12,312 ^S	-12,441 ^S	-12,092 ^T	-11,654 ^S	-11,770 ^S	-11,472 ^S
CATH	-15,609 ^T	-15,662 ^T	-15,495 ^T	-14,851 ^T	-14,899 ^T	-14,750 ^T	-14,171 ^T	-14,214 ^T	-14,081 ^T
CHLU	-14,137 ^S	-15,454 ^S	-12,720 ^S	-13,272 ^S	-14,403 ^S	-12,056 ^S	-12,505 ^S	-13,479 ^S	-11,458 ^S
DIVI	-12,971 ^T	-13,044 ^T	-12,810 ^T	-12,543 ^T	-12,610 ^T	-12,394 ^T	-12,148 ^T	-12,210 ^T	-12,010 ^T
HYCA	-10,518 ^S	-12,084 ^S	-8,423 ^S	-10,257 ^S	-12,084 ^S	-8,388 ^S	-10,011 ^S	-11,259 ^S	-8,340 ^S
PAQU	15,261 ^T	4,610 ^S	32,030 ^T	12,414 ^T	2,879 ^S	27,372 ^T	9,937 ^T	1,455 ^S	23,307 ^T
PHAM	-7,782 ^S	-7,816 ^S	-7,707 ^S	-7,611 ^S	-7,643 ^S	-7,538 ^S	-7,448 ^S	-7,480 ^S	-7,379 ^S
SACA	-13,441 ^S	-14,234 ^S	-12,632 ^S	-12,783 ^S	-13,490 ^S	-12,061 ^S	-12,190 ^S	-12,822 ^S	-11,545 ^S

[@] Method of propagation: ^S = seed, ^T = transplant.

[#] Abbreviations: ACRA= *Actaea racemosa*; CATH= *Caulophyllum thalictroides*; CHLU= *Chamaelirium luteum*; DIVI= *Dioscorea villosa*; HYCA= *Hydrastis canadensis*; PAQU= *Panax quinquefolius*; PHAM= *Phytolacca americana*; SACA= *Sanguinaria canadensis*.

To examine whether recent industry pricing will support forest cultivation, break even prices (i.e., the cost of production divided by the yield) were calculated for each species and compared with 1990-2005 prices². With only one exception, American ginseng, both basic and adjusted model break-even price results were much higher than historic prices. This suggests that, barring significant future price increases, forest cultivation would not be profitable for seven of eight species included in this analysis. The exception, American ginseng, had break-even prices well below historic price levels in all model scenarios.

These findings did not change even when parsimonious adjusted models were created (i.e., early harvest + no stock costs + no annual costs), and did not differ with propagation method. Only goldenseal showed profit earning potential in adjusted models, if cropping period (early harvest) and production costs were reduced (no stock + no annual costs) and mean or maximum prices were obtained. When break-even prices were examined by propagation method, the calculated break-even price from seed was lower than transplants for more than half of the plant species (i.e., CHLU, HYCA, PAQU, PHAM, SACA), despite the fact that a shorter cropping period is

² See Burkhart and Jacobson 2008 for details of this model

generally required using transplants (in turn reducing labor and material costs). This resulted from the fact that seed is usually less expensive than rootstock in the nursery trade. Scenarios in which cultivation using transplants had a lower break-even price (i.e., ACRA, CATH, DIVI) resulted from relatively higher seed costs, coupled with added labor and material costs necessitated by the longer cropping period when grown from seed.

Even when all stock costs were removed from models (no stock costs), calculated break-even prices for all species except American ginseng remained well above recent historic prices. Moreover, removing stock costs from models affected break-even prices to a lesser extent than shortening the cropping period (early harvest) or eliminating annual production costs (no annual costs). These results suggest that while planting stock costs are an important determinant of profit potential, they are less important than other production costs such as cropping period, annual labor, and materials.

The influence of crop period on profitability was examined using an adjusted model to consider the shortest possible rotation (early harvest)³. The break-even prices calculated from these results indicate that hastening harvests can improve the economics of forest cultivation, but this alone is not enough to change the general findings that recent historic prices are well below break-even. Shortening the cropping period did have more influence on determining break-even prices than did eliminating planting stock costs.

Adjusted models in which annual production costs such as labor and materials were excluded (no annual costs) had the most significant impact on break-even prices. In all cases, the exclusion of annual costs produced break-even prices that were at most half those calculated in basic models.

Calculated break-even yield values indicate that yields for all species except American ginseng would need to greatly increase to recover investment costs. Half of the species (ACRA, CATH, DIVI, PHAM) would require unrealistic yield increases for cost recovery and profit potential. Of the remaining, three (CHLU, HYCA, SACA) would require modest yield increases and favorable market prices (e.g., mean, maximum prices). Only American ginseng would require no yield increases to recover production costs and provide profit; according to model results, yields for this species could be reduced and cost recovery and profit potential would likely remain.

DISCUSSION

Individuals may choose to adopt forest cultivation for other than purely financial reasons such as personal interest, household consumption, and/or conservation intentions; however, any broad transition from wild collection to forest cultivation of the plants considered in this study is likely to require financial justification or rewards for adopters. This is especially true since many species require multiple years before harvesting, and the investment tied-up in each forest crop can be significant during intervening years. Net present value (NPV) results revealed that, with one exception (e.g., American ginseng), adopting forest cultivation for the plants considered in these models would be unprofitable, assuming wholesale product prices continue at recent historic levels.

³ see Burkhart and Jacobson 2008 for details of this model

Adjusted models (i.e., sensitivity analyses) were used to examine the relative influence of key variables in determining break-even prices and yields. Of the variables examined, annual production costs (i.e., labor and supply costs) most affected break-even prices, because the majority of the species considered require multiple years until harvest, and annual production costs accrue during this period. From a practical standpoint, this suggests that husbandry approaches using minimal husbandry practices, i.e., “wild-simulated” approach, may best reduce production costs and thereby improve revenue potential. However, there are likely trade-offs to adopting a minimal husbandry approach, including reduced plant survival and yields. It must be emphasized that even when annual production costs (i.e., all costs except planting and harvesting costs) were removed from adjusted models, calculated break-even prices were still much greater than recent prices. Thus, reducing production costs is likely to be only part of any solution to improving the economics of forest cultivation.

Shortening the time between planting and harvest (i.e., cropping period) was the second most influential factor in determining break-even prices. Accordingly, propagation methods and production practices that reduce the cropping period are likely to benefit producers. Such practices might include using transplants rather than seed as planting stock. While transplant costs are generally greater than seed costs, annual production costs represented the greatest single investment expense in these models; thus, careful deliberation must be given to potential cost savings accrued by using transplants. The time to harvest is perhaps best shortened by selecting cropping sites most favorable to optimal growth for each species. Manipulation of soil conditions, via tillage or amendments, may encourage rapid growth and higher yields, but these will also increase production costs.

The economics associated with forest cultivation might also be improved by responsible gathering of local planting stock, since stock from nursery suppliers is presently very expensive for most species. One potentially less expensive alternative to buying nursery stock (although there will still be time and labor costs) is to use local germplasm through seed, seedling, or rootstock collection and replanting, which can concomitantly help to retain genetic diversity in the species.

Manipulating production practices through fertilization, irrigation, and/or increasing sunlight levels to improve yields may favorably alter forest cultivation economics. However, modeled break-even yield estimates indicate that significant yield increases would need to occur for nearly all species to recover costs, much less earn profits. Even where field cultivation appears to hold promise, artificial shade is a significant production cost to include in economic projections.

One solution for increasing grower profits, and thus forest cultivation, might be the development of industry certification and labeling programs for forest cultivated product. Such programs could be used to generate economic “premiums” and raise wholesale market prices to levels that support cultivation. Without price “premiums” generated through certification and labeling programs, transitioning from wild to forest cultivated sources for many plants is not likely to be profitable unless there are significant, demand driven increases in wholesale prices (in which case collection pressure would also increase) or unless alternative market opportunities develop. Educational efforts and promotional campaigns must therefore be a component of any efforts to

develop product certification and labeling programs, and encourage consumer attention to product origins. Such efforts must articulate the benefits to consumer and society from purchasing certified forest cultivated materials, and should include assurances regarding identity, source, sanitation, and quality (i.e., appearance, chemical or otherwise).

The willingness of some individuals to collect indigenous forest plants despite low prices facilitates low prices in the wholesale market. Collectors may engage in collection regardless of pricing because wild plant products serve as a secondary or tertiary income source, or a “safety net” during difficult financial times (Bailey 1999; Cozzo 1999; Emery *et al.* 2003). Accordingly, there may be little desire or ability to adopt intensive husbandry practices requiring significant investment and costs. Many collectors choose to collect wild plant products for enjoyment (Bailey 1999; Emery *et al.* 2003). Additionally, markets for many plants are easily satiated and annual consumer demand unpredictable. Although the outlook at the time of establishment can be favorable, one cannot predict future market conditions, and “bust” cycles can erode any projected profits. Buyers frequently require contractual agreements before purchasing larger quantities (e.g., 100 lbs or more), and growers may consequently have a difficult time selling product even if market conditions are “good” at the time of planting. In this context, wild-collection is considered by many in the North American industry as perhaps the only practical means for obtaining plant materials when consumer demand for a particular botanical suddenly increases.

Because of these constraints, wild collection is likely to continue for many indigenous forest plants. Concern for trade species that do not garner a high enough price to support cultivation must be addressed through alternative programs including wild management and collector education programming, rather than through initiatives encouraging cultivation. In such efforts, the development of certification programs for non-timber forest products or harvesters may provide a mechanism for addressing stewardship concerns for wild-collected species (Shanley, Pierce, and Laird 2005). While these could be state or federal government programs, programs would likely be more effective and self-sustaining if industry initiated, in consultation with botanists, horticulturalists, collectors and others who can provide guidance and grounded perspective. Basic guidelines and standards for North American species could be regionally tailored, using published international standards for wild collection (e.g., WHO 2003) as a foundation. Product certification and labeling accompanied by consumer education could provide assurances to consumers, and generate price “premiums” to support harvester outreach and other program components.

CONCLUSION

The model results obtained suggest that forest farming of many native medicinal plants in eastern North America would not be profitable at recent historic prices. Wholesale market prices are far below production costs for many species, and pricing is not equitable among species with similar production requirements. Significant price differences exist between species with approximately the same production requirements and yield potentials (e.g., American ginseng versus blue cohosh). While this difference can be attributed to market factors (e.g., differences in consumer demand, scarcity of supplies), there is nevertheless little incentive for adoption of intensive husbandry given such realities. Even the most parsimonious crop production models (e.g., early

harvest + no stock costs + no annual costs) failed to generate break-even prices commensurate with recent historic wholesale prices; rather, with all species except American ginseng and goldenseal, calculated break-even prices far exceeded recent industry prices. Yield increases alone are not likely to resolve financial shortcomings since many species would need dramatic, and largely unrealistic, yield gains to even recover production costs, much less earn a profit.

Although this analysis only included eight plant species, these conclusions are equally applicable to other indigenous forest plants including bethroot (*Trillium erectum* L.), cranesbill (*Geranium maculatum* L.), mayapple (*Podophyllum peltatum* L.), stoneroot (*Collinsonia canadensis* L.), and Virginia snakeroot (*Aristolochia serpentaria* L.). For all of these species, the wholesale prices paid during 1990-2005 for raw materials was well below agroforestry production costs (data and model results not included in this paper). Wild collection is likely to continue for these species because investment in cultivation is simply not profitable, and because collection is amenable to the industry's need to respond to intermittent demand in an often highly volatile marketplace (i.e., "boom and bust" cycles). Accordingly, there is need for both technical support for agroforestry production of species with profit potential and significant demand (e.g., American ginseng and goldenseal) as well as for collector guidance for species that are likely to continue to be collected because prices do not support intensive husbandry and/or demand is sporadic. While there may be conservation benefits associated with forest cultivation of indigenous plant species, guidance provided to those interested in transitioning from lesser to more intensive forms of forest plant husbandry must include consideration of inflation, discount rates, and other time-related economic factors that will inevitably impact the profitability of crops requiring multiple years to attain harvestable maturity. Species that are not economically feasible for cultivation, particularly due to limited market demand, are best served through development of proactive government and industry initiatives involving targeted harvester education and possibly NTFP certification programs.

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ASSESSING THE GROWTH POTENTIAL AND FUTURE OUTLOOK FOR THE US MAPLE SYRUP INDUSTRY

Michael Farrell

Cornell University's Uihlein Forest, 157 Bear Cub Lane, Lake Placid, NY 12946
Contact: mlf36@cornell.edu

Abstract: There is currently a tremendous opportunity to increase the amount of maple syrup produced in the US. This paper addresses the number of potentially tappable maple trees, the factors that affect their utilization for syrup production, and the overall future outlook for the maple industry. The latest USFS FIA data for 19 states was analyzed in order to estimate the number of potential taps while the utilization rate was based on the 2008 NASS data. The US currently only taps .4% of all potentially tappable maple trees, with the highest percentage of trees tapped in Vermont, at 2.1%. If all states were to tap the same percentage of maples that sugarmakers in Vermont do, the resulting economic impact would be over \$300 million annually. During the current economic recession, there is increasing attention given to strategies aimed at growing the US maple industry. Demand is still strong, prices are at record levels, and many sugarmakers are expanding their operations while others are just getting started. Although the current outlook is bright, long-term concerns for the US maple industry include climate change, the exchange rate and production levels in Canada, invasive species such as Asian longhorn beetle, and the overall global economic outlook.

Keywords: maple syrup, economics, FIA, sugar maple, red maple, sustainability

INTRODUCTION

Worldwide consumption of pure maple products has been steadily rising with demand far outpacing supply in recent years. The US currently imports four times as much syrup from Canada as it produces, so there is tremendous room for expansion just to fill domestic markets (Agriculture Canada 2006). Maple syrup was once a much larger component of the rural economy, as the US produced a record equivalent of 6,613,000 gallons of maple syrup in 1860, with most of the syrup actually boiled down further to produce granulated maple sugar (US Census 1860). Maple production has fallen dramatically over the years, with only 1,635,000 gallons produced in 2008 (NASS 2008).

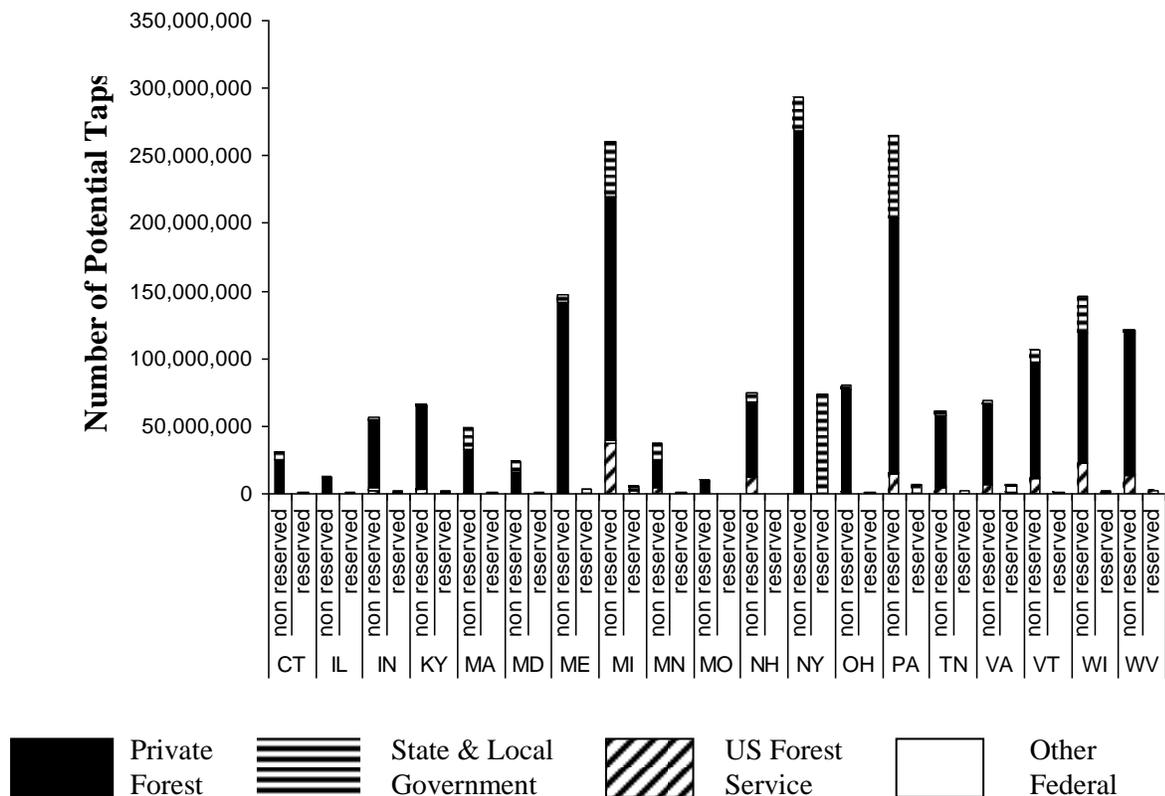
The situation today is improving. Demand is up and prices are at an all time high, so many sugarmakers are in the process of expansion and new producers are entering the market (Dravis 2009). The interest in increasing production is so great that Senator Charles Schumer (D-NY) introduced legislation in April 2008 that was reintroduced in March 2009 by Schumer and Rep. John McHugh (R-NY) that would provide grants and incentives to states in order to increase the number of trees being tapped on private lands (Churchill 2008, Schwaner-Albright, 2009). In order to determine the growth potential and economic impact of the maple industry, this paper assesses the number of tappable maple trees in US forests, current and potential economic

impacts of the maple industry, strategies for increasing production, and the long-term outlook for maintaining a vibrant maple industry.

ASSESSING THE TAPPING POTENTIAL

In order to determine the tapping potential in the US, analyses were performed using the latest US Forest Service Forest Inventory & Analysis (FIA) data from 19 states that contain a significant number of sugar (*Acer saccharum*) and red maples (*Acer rubrum*). For an overview of the history, background, and methodology used in the FIA program, please refer to <http://fia.fs.fed.us/> The number of potential taps were estimated by summing all of the sugar and red maples greater than 10" dbh and applying conservative tapping guidelines- 1 tap for a 10-17" tree and 2 taps for trees 18" and greater. The data are classified by ownership category- private, US Forest Service, other federal land, and state & local government. They are also divided between the tappable (non-reserved) and non-tappable (reserved) trees, as many forestlands that are legally prohibited from timber production are also likely to be restricted from tapping.

Figure 1. Number of potential taps by state and ownership category. Analysis based on latest FIA data for each state analysis using conservative tapping guidelines.



The figures presented in this paper overestimate the actual tapping potential for several reasons. In order to economically tap maples, the trees must be located close enough to a road and the

density must be high enough to justify collecting the sap. Research is currently in progress to refine the data based on these factors. The first step is to recalculate the number of potential taps by only counting the maple trees that occur in plots containing a minimum of 20 taps/acre in order to meet minimum density requirements. Once these plots have been identified, further spatial analysis with GIS will determine the distance of the plots to a road. Maple trees that are located ≥ 1 mile from the nearest access road will be eliminated, as it would be considered too difficult to economically tap and gather sap from these trees. Conducting these two basic analyses will provide a much more refined estimate of the number of potential taps, but it is far from perfect and is limited by the nature of the FIA data.

There are a number of other factors that impact the actual tapping potential. Topographic features certainly affect how easy and practical it is to gather sap. For instance, areas that are too flat, particularly those found along floodplains, are very difficult to access during sugaring season, and setting up tubing systems (even with vacuum) is difficult without sufficient grade. Conversely, very steep hillsides are nearly impossible to collect with buckets and require significant athleticism to set up tubing systems and tap the trees. Furthermore, analyzing individual FIA plot data fails to account for the total number of forested acres surrounding the plots, which has a direct influence on the commercial potential for tapping. In order to justify setting up a vacuum tubing system, there should be enough trees at put out at least 1,000 taps, which usually requires at least 15 acres. While small tracts of ≤ 15 acres are adequate for hobbyists and small-scale producers, much larger acreage is required to justify tapping for commercial syrup production.

Finally, it is important to note that the FIA data do not account for a significant percentage of the trees that are actually tapped. Maples growing in yards, parks, and along roads are favored by producers who collect with buckets due to the easy access and large volumes of sweet sap they generate. In order to quantify these potential taps, much more detailed inventory data must be collected by urban forestry research methods.

POTENTIAL ECONOMIC IMPACT OF THE US MAPLE INDUSTRY

Significant differences exist in the extent of maple syrup production throughout the United States. Vermont clearly dominates the industry due to its relatively high utilization rate while states such as Michigan, New York and Pennsylvania have tremendous potential for expansion. USDA's National Agricultural Statistics Service only tracks maple syrup production for 10 states and Indiana's data were provided by the Indiana Division of Forestry. Therefore, 8 of the states listed in Table 1 are lacking current information on the number of taps and the corresponding utilization rate. It is assumed that syrup production levels are so low that it is not worth the trouble to track production in these states. For some of the states, such as Kentucky and Tennessee, even though maples grow abundantly, the climate may not be suitable for commercial syrup production. More research is needed to determine the potential for sap flow and the economic feasibility of producing maple syrup in the winter months along the southern range of sugar maple.

Table 1. Current and Potential Economic Impact of the US Maple Industry. Analysis based on 2002-05 FIA Data and 2008 NASS Maple Syrup Statistics.

State	Number of Potential Taps	Number of Taps in 2008	2008 Utilization Rate	Number of taps based on Vermont's utilization rate	Possible Annual Production using Vermont's utilization rate	2008 value of syrup production	Possible average value of syrup production based on Vermont's utilization rate
Connecticut	30,097,870	62,000	0.21%	634,667	126,933	\$600,000	\$5,077,335
Illinois	12,187,490	-	-	256,995	51,399	-	\$2,055,958
Indiana	56,388,249	28,837	0.05%	1,189,046	237,809	\$391,320	\$9,512,368
Kentucky	66,236,188	-	-	1,396,707	279,341	-	\$11,173,657
Massachusetts	48,514,211	220,000	0.45%	1,023,008	204,602	\$2,200,000	\$8,184,064
Maryland	23,593,069	-	-	497,502	99,500	-	\$3,980,013
Maine	147,702,680	1,270,000	0.86%	3,114,572	622,914	\$8,600,000	\$24,916,578
Michigan	260,206,740	405,000	0.16%	5,486,919	1,097,384	\$4,000,000	\$43,895,355
Minnesota	37,244,260	-	-	785,361	157,072	-	\$6,282,889
Missouri	9,968,335	-	-	210,200	42,040	-	\$1,681,600
New Hampshire	74,866,853	360,000	0.48%	1,578,700	315,740	\$3,400,000	\$12,629,600
New York	293,247,888	1,480,000	0.50%	6,183,650	1,236,730	\$12,880,000	\$49,469,203
Ohio	79,938,332	395,000	0.49%	1,685,641	337,128	\$4,720,000	\$13,485,129
Pennsylvania	265,209,912	475,000	0.18%	5,592,420	1,118,484	\$3,800,000	\$44,739,361
Tennessee	60,768,756	-	-	1,281,417	256,283	-	\$10,251,334
Virginia	68,737,448	-	-	1,449,451	289,890	-	\$11,595,605
Vermont	106,701,981	2,250,000	2.11%	2,250,000	450,000	\$20,000,000	\$18,000,000
Wisconsin	146,121,771	540,000	0.37%	3,081,236	616,247	\$5,200,000	\$24,649,888
West Virginia	120,793,900	-	-	2,547,153	509,431	-	\$20,377,224
Total	1,908,525,926	7,485,837	0.39%	40,244,645	8,048,929	\$65,791,320	\$321,957,161

To estimate the potential for increasing production, calculations were performed to determine the number of taps that could be put out on an annual basis if 2.1% of the total number of potential taps were used. This is the percentage of trees that are tapped in Vermont, which represents the current upper limit for what is realistic in other states. Annual syrup production was estimated based on an average yield of .2 gallons/tap/year. It is worth noting that new vacuum tubing can result in yields as high as .5 gallons/tap whereas traditional bucket systems may only yield .1 gallons/tap. Values were estimated by multiplying possible production figures by a very conservative price of \$40/gallon. If one was to account for the additional value of selling syrup in retail containers, producing value-added maple confections, and the associated revenues generated through agri-tourism events such as Maple Weekend, the economic impact would be significantly greater than the \$321 million figure displayed in Table 1.

STRATEGIES FOR INCREASING PRODUCTION

Public policies can have a significant impact on syrup production levels. This is evidenced in Quebec, where roughly 75% of the world's syrup is now produced. Although they have far fewer maples than the US, government support for the maple industry in Quebec has led to a surge in production over the past 30 years. The government has implemented cost-sharing programs for producers to purchase the necessary equipment to develop cost-effective sugaring operations. Crown land has also been made readily available for tapping under very favorable lease rates. In fact, recent studies concluded that the net benefits of using public forests in Quebec for syrup production are greater than using them solely for timber management (MRN-

MAPAQ 2000). For comparison purposes, approximately 25% of the total potential taps in the US occur on government owned land, yet hardly any of these trees are made available for tapping.

It is clear that more favorable government policies and support could greatly benefit the US maple industry. In April 2008 and again in March 2009, Senator Charles Schumer (D-NY) introduced the Maple Tapping Access Program Act. This would provide competitive grants to states to increase the number of trees being tapped on private lands. Until now, only limited federal resources have been devoted towards maple production, the vast majority of which have been directed towards Vermont. Additional resources are expected to benefit the maple industry through the latest Farm Bill, as the Specialty Crops legislation and Beginner Farmer & Rancher Development Program both serve as potential funding sources to help grow the industry.

Socioeconomic and cultural factors also play a crucial role in determining where and to what extent syrup production occurs (Hinrichs 1998). In order to transform sap flowing in trees into maple syrup, there must be a willing and able workforce that has the knowledge, desire and ability to do so. To this end, additional extension efforts could be focused on educating landowners about the opportunities and methods of getting into maple production. In a country that has been losing manufacturing jobs at an alarming rate, it is important to recognize that each sugarhouse is a small factory converting an abundant natural resource unique to North America into a valuable with increasing worldwide demand. Rural development programs in the northeast could provide incentives, low-interest loans and training opportunities to attract more landowners into syrup production.

If the US devotes additional resources towards increasing production of pure maple syrup, it is also essential to devote sufficient resources towards marketing and promotion. The Canadians increased production drastically in the 1990s but did not invest enough in selling their product. A large surplus developed and prices plummeted, so they instituted a quota system in 2003 to limit supply and drive prices back up. Producers also organized a marketing board and started devoting substantial resources towards international marketing and promotion (Gagne 2008). Their efforts have paid off, as prices are at an all time high, the surplus has been exhausted, and there is now a worldwide shortage of pure maple syrup (Dravis 2008a). In order to maintain syrup production as a profitable enterprise, it is important to remember this lesson and keep sales on pace with increased production.

FUTURE OUTLOOK AND CONCERNS FOR THE US MAPLE INDUSTRY

There is significant concern about the sustainability of the maple syrup industry in North America (Whitney and Upmeyer 2004). While the current outlook is bright, there are important variables that could have drastic impacts on US maple production. These include climate change, the exchange rate and production levels in Canada, invasive species such as Asian longhorn beetle, and the fate of the global economy.

Many scientists are rightfully concerned about the impact of climate change on the North American maple syrup industry (MacIver et al. 2006, Rock & Spencer 2001). The rise in global temperatures has already influenced the timing of sap flow and will continue to do so in the

future (Chabot and Childs 2007). Long term climate projections are not favorable for sugar maple throughout much of its range in the eastern US (Iverson et al. 2006). However, despite these gloomy projections, the current climate is still favorable for sap flow and producers can adjust the timing of tapping to take advantage of earlier sap flows (Wilmot 2008, Dunn 2008). Furthermore, FIA data seem to suggest that shade-tolerant maples are increasing in abundance underneath the oak-hickory dominated forest on southern edge of sugar maple's range. Further research and monitoring is needed to determine the effect of climate change and other variables on long term distribution trends. In fact, how we manage our forests, deer populations, acid rain, and invasive species could have a larger effect on sugar maple distribution than climate change.

Even if sugar maples decline in northeastern forests, red maples are likely to continue to increase in abundance. Although red maples typically contain lower sap sugar content and bud out earlier in the spring, they are an acceptable and widely used species for syrup production (Chapeskie et al. 2006). With increased use of reverse osmosis technology to remove most of the water in sap before boiling, sap sugar content is not as important as it used to be and red maples will continue to gain wider acceptance among sugarmakers.

The Canadian exchange rate has a direct influence on the profitability and production levels of US maple syrup. When the US dollar is strong, it is cheaper for US bottlers and distributors to buy Canadian syrup. In the past, American sugarmakers have reduced production when they could not compete with cheaper Canadian syrup. This phenomenon could resurface if the US dollar remains strong compared to the Canadian dollar. Canadian production has also been low in recent years due use of a quota system coupled with poor weather. However, if Quebec continues to relax the quota system and they have a couple years of favorable weather, there could be a large spike in Canadian production. This could temporarily drive global prices down, threatening the profitability and desire to expand among US producers.

The Asian longhorn beetle (ALB) has been found in several port cities over the past decade and eradication efforts so far have been mildly successful. This pest was recently found in Worcester, MA very close to abundant hardwood forests (Dravis 2008b). If the ALB is able to escape into the wild, it could have devastating effects on not only the maple syrup industry, but many other industries that rely on healthy northern hardwood forests. It is imperative to eradicate ALB from the Worcester area and continue to make sure that ALB stays out of the northeastern forests.

Finally, the fate of the global economy could have a strong influence on demand for maple syrup. Pure maple products are a luxury item that some economists consider to be recession proof (Thomas and Schumann 1994). However, if the global economy continues to slump, sales should be affected to a certain degree. Maple producers will have to be more aggressive in their marketing and promotion efforts in order to keep the local and international markets thriving. Per capita consumption of pure maple syrup in the US is currently very low, so there is tremendous room for growth, especially in the niche markets focused on local and healthy foods.

CONCLUSION

The US has a tremendous resource of untapped maple trees that could be utilized to fill the growing worldwide markets for pure maple syrup. Although there are concerns about long-term

sustainability, the current climate is very favorable to increasing production. In fact, getting more landowners involved in maple production and more Americans consuming pure maple syrup is an effective mechanism to ensure the sustainability of sugar maples in the US. We only devote time and resources to the things we care about- if maple syrup was more integral to our entire nation's identity, as it is in Quebec and Vermont, we would likely do more to ensure that maples persist in our future forests.

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PROVIDING PRODUCTS AND RESOURCES: THE FORESTFIRST APPROACH TO AGROFORESTRY KNOWLEDGE

Joanne Kowalski, BSA, MSc, PAg

ForestFirst

101 – 106 Central Avenue, Prince Albert Saskatchewan, Canada S6V 4V4

Contact: jkowalski@forestfirst.ca

Abstract: ForestFirst (formerly the Saskatchewan Forest Centre) has been the primary knowledge provider for the forest and agroforest sectors in western Canada since 2001. Initially set up for technology transfer, ForestFirst has a new direction focused on business development and on creating a viable agroforestry industry in Saskatchewan. Interest in agroforestry has increased along with demand for services, impelling ForestFirst to expand its knowledge base and research program. Always working within a partnership philosophy, the agroforestry division has evolved its mandate to include research and outreach. ForestFirst has maintained a two-way communication approach in its extension work and a participatory model is used in research. Incorporation is not only from research results but practical on-the-ground knowledge becomes invaluable. It is working together with scientists, growers and businesses that drive much of the research undertaken by the ForestFirst agroforestry division. The agroforestry knowledge base established at ForestFirst is recognized as the lead source in the province. As a result, ForestFirst now offers several products that are client centred and provides information on a variety of topics in a variety of media. These media include: a web based hybrid poplar crop production manual, “how to” videos, research and popular publications. These products are accessible online through our web site and feedback indicates are accessible and used as a resource. Further extension activities and resources include a library, one-on-one consultation, field days, a management course and conferences. ForestFirst generated knowledge is used globally; for example, our Hybrid Poplar Crop Manual is used as a resource for establishing and managing hybrid poplar crops by many companies worldwide.

SCREENING AND TESTING PHYTOCHEMICALS IN EASTERN REDCEDAR (*JUNIPERUS VIRGINIANA*) FOR DEVELOPMENT OF POTENTIAL ENTREPRENEURIAL OPPORTUNITIES

Chung-Ho Lin¹, Brian. M. Thompson², Hsieh Y. Hsieh², Robert N. Lerch³, Robert J. Kremer³, Mihaela M. Cernusca¹, and Michael A. Gold¹

¹ Center for Agroforestry, University of Missouri, Columbia, MO 65211

²Department Veterinary Pathobiology, MU Life Science Center

³ U.S. Department of Agriculture-Agricultural Research Service, Cropping Systems and Water Quality Research Unit, Columbia, Missouri 65211

Contact: Linchu@missouri.edu

Abstract: Eastern redcedar (*Juniperus virginiana*) is often considered a “trash or nuisance” tree. In some states, this species has been declared invasive and management strategies have been adopted to destroy it. However, value-added phytochemical products from eastern redcedar have the potential to create new industries in regions such as Missouri with an abundant redcedar resource. As a first step toward the development of such industries, it is essential to characterize, and quantify the composition of the individual phytochemicals within various redcedar tissues with modern chromatographic, spectroscopic and bioassay technologies, followed by an evaluation of their commercial applications in agricultural, pharmaceutical, and cosmetic industries. In this study, the distilled cedar oil, cedar sawdust and various tissues including roots, leaves, fruits, branches, sapwoods, and heartwood were collected and intensively extracted with solvents. Separation and fractionation of the phytochemicals with a range of polarity were performed by liquid/liquid extractions followed by a reverse-phase liquid chromatography. Bioassays were performed to evaluate the potent biological activities (herbicidal, antifungal, antibacterial, antitermitic, pesticidal, antitumoral activities, etc.) in each fraction. The potent compounds in the extracts showing high bioactivities will be isolated and further purified for chemical characterization and structure elucidation purpose.

INTRODUCTION

A recent study of the Missouri hardwood industry found that much of the industry is over 50 years behind in both its industrial practices and its marketing model. It went on to state that for the majority of businesses that are locked into an outmoded attitude toward hardwood products, there is no enabling mechanism for capturing modern value adding processes as a means for entering new market areas. They concluded that too many small and medium sized producers are generating predominately low value products, even from high grade raw materials, because of their failure to understand how to compete in the higher value market areas (Hackman and Thompson, 2003). The same can be said about many producers in the Missouri red cedar industry.

Eastern redcedar (*Juniperus virginiana*) is often considered a “trash or nuisance” tree. In some states, this species has been declared invasive and management strategies have been adopted to destroy it. However, another more positive side to redcedar has been revealed through a market

research study indicating a profitable expanding marketplace generating \$60 million dollars in annual sales. The eastern redcedar market ranges from large firms with gross annual sales over \$16 million to small operations with less than \$10,000 per year gross annual sales. Critical resources needed to compete in the eastern redcedar marketplace include access to raw material and labor, market knowledge, financial resources, and the cultivation of personal relationships among players in the value chain. (Gold et al., 2005).

Eastern redcedar is an important source of volatile oils. Cedarwood oil has a significant commercial value in a broad range of applications from cold-remedy salves to room sprays and insecticides. Its extensive utilization in a broad range of products is attributable to its unique properties, such as its odor, repellency or toxicity to many pests, antibacterial, antifungal and antitermitic activities. The aromatic oils found in eastern redcedar heartwood repel clothing moths and are widely used in perfumes (Alemayehu et al., 1998; Lawson, 1990). Aromatic oils are toxic to some ant species (Argentine ant and odorous house ant), and eastern redcedar mulch is effective in discouraging ant colonization (Meissner and Silverman, 2001). Eastern redcedar oils are also effective in repelling Formosan subterranean termites (Zhu et al., 2001). Heartwood extractives may inhibit growth of fungi and bacteria (Lee et al., 1999). Eastern redcedar heartwood has approximately 10 times the oil extractives of sapwood. Due to a higher proportion of heartwood to sapwood in closed-canopy stands of eastern redcedar, trees grown under closed stand conditions may contain 4 to 5 times as much oil in the bolewood as open-grown trees of the same diameter (Wittwer et al., 1999).

Value-added oil based products from eastern redcedar have the potential to create new industries in regions such as Missouri with an abundant redcedar resources. As a first step toward the development of such industries it is essential to verify and quantify the composition of the individual phytochemicals within redcedar oil followed by an evaluation of recovery methods, processing and yield (Semen and Hiziroglu, 2005).

MATERIAL AND METHODS

Basically, the distilled cedar oil, cedar sawdust and various tissues including roots, leaves, fruits, branches, sapwood, and heartwood were collected and intensively extracted with solvents. Separation and fractionation of the phytochemicals with a range of polarity were performed by liquid/liquid extractions and reverse-phase liquid chromatography. The isolation and identification of the potential biologically active phytochemicals will be carried out by various modern chromatographic separation techniques, mass spectrometry, and nuclear magnetic resonance (NMR) spectroscopy. Bioassays were performed to evaluate the potent biological activities (herbicidal, antifungal, antibacterial, antitermitic, pesticidal, antitumoral activities, etc.) in each fraction. The potent compounds in the extract that show high bioactivities were isolated and further purified for structure characterization and elucidation purpose.

RESULTS AND DISCUSSION

During 2007-2008, several biologically active compounds extracted from ERC leaves have been successfully purified and characterized. The concentrations and chemical structure were confirmed with high performance tandem mass spectrometry (HPLC-MS/MS), gas

chromatography ion-trap tandem mass spectrometry (GC-MS/MS), ³H- nuclear magnetic resonance (NMR), ¹³C-NMR and 2D-NMR. Many of the active phytochemicals demonstrated strong anti-microbial activities against a wide range of human bacterial pathogens, including *Staphylococcus aureus* and MRSA (Methicillin-resistant *Staphylococcus aureus*), *Bacillus anthracis*, *Bacillus cereus*, *Vibrio* sp., *Listeria monocytogenes*, and *Streptococcus* spp. (Table1). Several isolated compounds have shown a promising potential for various cosmetic and pharmaceutical applications due to its anti-bacterial, anti-inflammatory, anti-fungal, anti-malarial, antioxidant, and anti-tumoral effects. At least one of the identified compounds has been successfully incorporated into the formulation of cosmetic skincare products for acne treatment in the existing market. A recent US patent describing new cosmetic application of this compound for reducing skin inflammation or treating inflammatory disorders, pain or purities was reported by Johnson & Johnson (2005).

	Minimum Inhibitory Concentrations (MIC)	
	($\mu\text{g mL}^{-1}$)	(μM)
<i>Clostridium</i> sp.	21.4	75
<i>Streptococcus pyogenes</i> (Group A Strep)	85.7	300
<i>Streptococcus agalactiae</i> (Group B Strep)	85.7	300
<i>Listeria monocytogenes</i>	85.7	300
<i>Pseudomonas</i> sp.	85.7	300
<i>Vibrio</i> sp.	142.8	500
<i>Salmonella</i> sp.	No effects	No effects
<i>Staphylococcus aureus</i> (MRSA)	21.4	75
<i>Bacillus anthracis</i>	42.9	150
<i>Bacillus subtilis</i>	85.7	300

Table 1. Minimum inhibitory concentrations of the purified compounds

The results of our bioassay have shown strong activities of the purified compounds not only against melanin development (skin pigmentation), but act against the mouse melanoma cell line B16F10luc, a cell line genetically engineered with green fluorescent protein for bioassay purpose (Figure 1 and Figure 2). The isolated phytochemicals possessed a abitetane diterpene moiety which has shown excellent inhibitory effects on melanin development and tyrosinase activity. They have been recognized by their great potential for skin care application for preventing and ameliorating the pigmentation after sun-burn/spots/freckles/liver spots. (e.g., skin-whitening). This class of diterpenoid has been proven to be highly safe for external skin application.

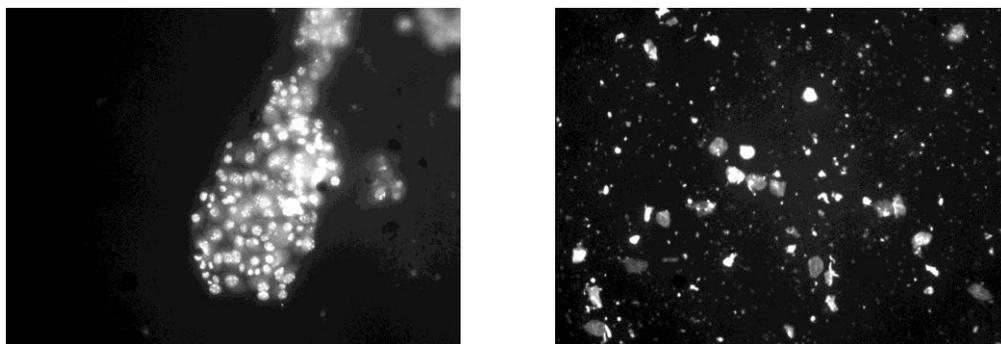


Figure 1. Effects of isolated diterpenoids on survival of mouse melanoma cell line B16F10luc. Melanoma cells in control (left) and cells treated with isolated diterpenoids (right) at concentrations of 200 ppm (0.7 μ mole/ml). The cell line was genetically engineered with fluorescent protein for bioassay purpose.

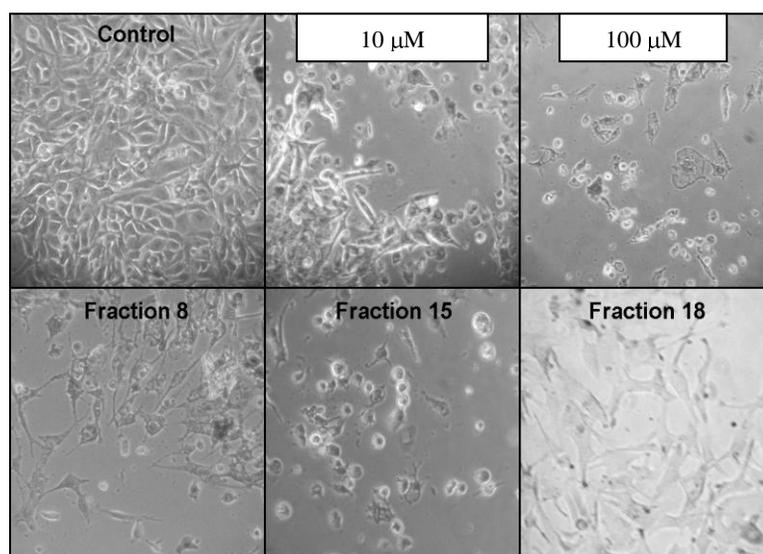


Figure 2. Effects of isolated diterpenoids on survival of the mouse melanoma cell line B16F10luc. Melanoma cells prepared in control and cells treated with purified compound or ECR leaf fractions containing novel isolated diterpenoids at concentrations of 200 ppm (0.7 μ mole/mL)

Other isolated potent isomeric diterpenoids or abietane diterpene analogs have also demonstrated strong anti-microbial activities against a wide range of human pathogens in our preliminary screening process. However, their applications have not yet been characterized and their potential for commercialization has not been assessed. Figure 3 illustrates the antibacterial (against *Staphylococcus* MRSA and *Bacillus* sp.) and antifungal activities (against yeast) of the isolated fractions containing highly bioactive diterpenoids.

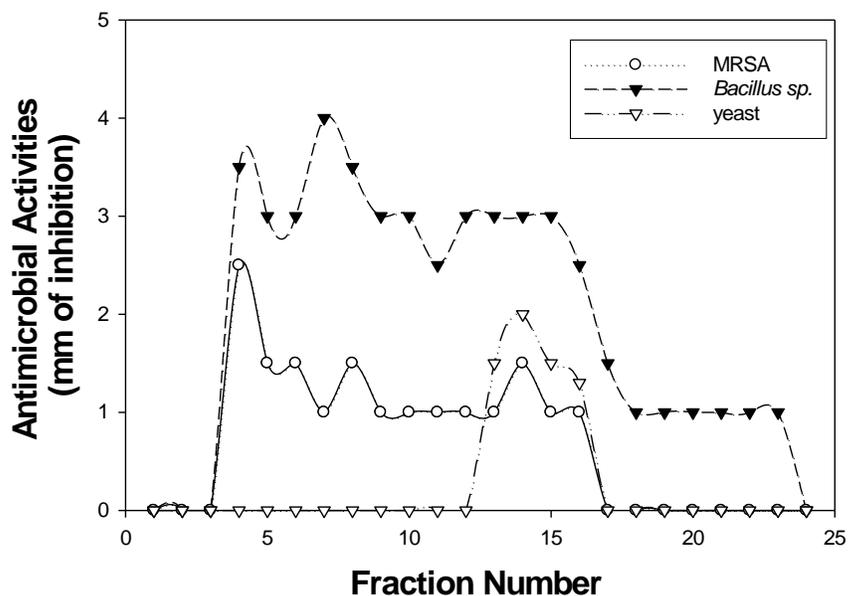


Figure 3. Antimicrobial activities of isolated fractions containing highly bioactive diterpenoids.

CONCLUSIONS

Many classes of isolated biologically active phytochemicals in eastern redcedar have shown promising health benefits. Our current efforts are to continue the screening and isolation processes for potent compounds in the extracts. The compounds in the extracts showing high bioactivities will be isolated and further purified for chemical characterization and structure elucidation purpose.

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SECTION 5

Bioenergy

AGROFORESTRY – LINKING ENERGY/FOOD PRODUCTION/ NATURAL RESOURCE OBJECTIVES ON AGRICULTURAL LANDS

Michele Schoeneberger

U.S. Forest Service, USDA National Agroforestry Center - USFS Southern Research Station,
N. 38th Street and East Campus Loop, Lincoln, NE 68583-0822, 402-437-5178 ext. 4021
Contact: mschoeneberger@fs.fed.us

Abstract: Today, agriculture is being called upon to help reduce the United State's dependence on foreign oil through production of bioenergy crops. This demand is currently being met through grain-based ethanol production systems, with the future foundation being built on cellulosic feedstock. The economic benefit to participating farmers has been significant, however, there are now growing concerns as to the longer-term economic and ecological implications of such systems. Because the sustainability and health of our nation's lands will ultimately be determined in how bioenergy along with other demands are handled, we need to be find new ways to better connect energy, food production and natural resource objectives on agricultural lands.

Agroforestry can support energy, water quality, wildlife habitat, carbon sequestration and, even income diversification goals, while leaving the bulk of the land in agricultural production. Agroforestry practices can provide the conservation functions necessary for 1) water, soil and air quality protection, 2) wildlife habitat ranging from game species with recreational value to pollinators essential for food security, 3) greenhouse mitigation through carbon sequestration, and other ecosystem services impacted by biofuel feedstock production. Potential energy benefits of agroforestry are also numerous such as reduction of fertilizer and fuel use resulting from putting marginal lands into agroforestry and out of annual crop production. Incorporating a range of perennial herbaceous and woody short rotation crops in creative agroforestry arrangements provides an additional source of cellulosic feedstock as well as high value bioproducts to augment commercial sources. As small generator technologies continue to come on line, these agroforestry systems could – through strategic arrangement and species selection – provide many of the services listed above simultaneously, while also providing the feedstock for improving on-site energy independence – a big step in achieving bio-economic sustainability on our agricultural lands.

RIPARIAN FOREST BUFFERS: BUILDING A SUSTAINABLE BIOENERGY FUTURE

Gary Bentrup¹, Michele Schoeneberger¹, and Bruce Wight²

¹USDA National Agroforestry Center - USFS Southern Research Station

²USDA National Agroforestry Center – Natural Resources Conservation Service
N. 38th Street and East Campus Loop, Lincoln, NE 68583-0822

Contact: gbentrup@fs.fed.us

Abstract: As society transitions to bioenergy production on agricultural lands, this future must be formulated in a way that the other services from agricultural lands are not compromised. Agroforestry, and in particular riparian forest buffers (RFBs), can contribute to a sustainable, multi-functional bioenergy future. RFBs can mitigate adverse impacts from bioenergy production systems such as polluted runoff from grain-based ethanol operations as well as potentially augment feedstocks for bioenergy production. Properly designed, located and managed, RFBs can do this while providing other services the landowner and society demand from these lands, including air and water quality, wildlife habitat, carbon sequestration and alternative income opportunities.

Current research is contributing to our technological understanding of whether and how bioenergy objectives can be met within RFB practice design and management. Our greatest challenge, however, is building the socio-economic and political frameworks that will ultimately determine its acceptance and adoption by landowners and resource professionals. Education will be imperative, not only of potential landowners but also those involved in policy and program formulation and delivery, to develop mutually beneficial connections between bioenergy production and other ecosystem services. Shifts in farm policy, programs and markets will be necessary to make adoption of RFBs more attractive to landowners. Programs like the newly created Biomass Crop Assistance Program (BCAP) will be invaluable to help landowners transition to a diversified bioenergy system.

Tools for designing and locating RFBs to optimize multiple services, including bioenergy, are needed to facilitate discussion and formulation of shared agendas among landowners, resource professionals and the energy industry. Strategies for current and future use of RFBs within bioenergy production systems requires going beyond our current business-as-usual approach. We must shift from a single issue focus to creating RFB designs, programs, and policies that satisfy multiple objectives.

Keywords: riparian forest buffers, bioenergy, biofuels, ecosystem services, planning

INTRODUCTION

In an effort to reduce America's dependence on foreign oil, combat volatile petroleum markets and provide cleaner and more climate change-friendly energy sources, the U.S. has mandated that 36 billion gallons per year (GPY) of ethanol be blended into conventional petroleum-based

gasoline in America by 2022. Current production of biofuels, primarily corn-based ethanol, has grown to more than 9 GPY during 2008. While this rapid increase in biofuel production has had some economic benefits, new information is suggesting that the impacts on soil, water and wildlife resources will exceed any short-term benefits (Marshall 2007, NRC 2007). One study suggests that the increase in corn cultivation required to meet the goal of 15-36 GPY of renewable fuels by the year 2022 would increase the annual average flux of dissolved inorganic nitrogen (DIN) export in to the Gulf of Mexico by 10–34% (Donner and Kucharik 2008). Generating just 15 GPY of corn-based ethanol by the year 2022 will increase the odds that annual DIN export exceeds the target set for reducing hypoxia in the Gulf of Mexico to >95% (Donner and Kucharik 2008). Clearly, we have policies in direct conflict with each other.

Economic fallout of biofuel production on food, feed and fuel markets, as well as determining the real environmental footprint of its production cycle, are also areas of much concern and discussion. Doornbosch and Steenblik (2007) have concluded that the “potential of the current technology of choice – ethanol and biodiesel – to deliver a major contribution to the energy demands of the transport sector without compromising food prices and the environment is very limited.” Even cellulosic-based bioenergy systems, while possibly more sustainable, have related concerns and are now being scrutinized in terms of environmental greenness and broader issues of sustainability.

To compound these problems, ecosystem services provided by lands enrolled in conservation programs, such as Conservation Reserve Program (CRP), will be greatly minimized or lost as lands are pulled out of enrollment and converted back into crop production – either for biofuel crops or as a replacement for displaced food crop production. In Nebraska, there is currently 1.12 million acres enrolled in CRP but there is an expected reduction in acres by 84% in the next five years (Pheasants Forever 2009).

Despite these substantial problems, agriculture will still need to be a part of the energy solution. It is clear that bioenergy production from agricultural lands can not be implemented as a 1-dimensional program without having serious repercussions on other ecosystem services, these programs must be formulated in a way that these other services from agricultural lands are not compromised. Through innovation, we can proactively create management practices and systems that connect energy, food production and ecosystem services on agricultural lands. Riparian forest buffers (RFBs) by their very location, composition and impacts on the landscape provide a beginning step in this direction – an opportunity to augment services on agricultural lands that will be required for sustainable bioenergy production (Schoeneberger et al. 2008).

Riparian Buffers – Connecting Energy/Food Production/Ecosystem Services Objectives

Riparian forest buffers (RFBs) can provide numerous services, including water quality protection, wildlife habitat, carbon sequestration and recreational and income-generating opportunities (Fig. 1).

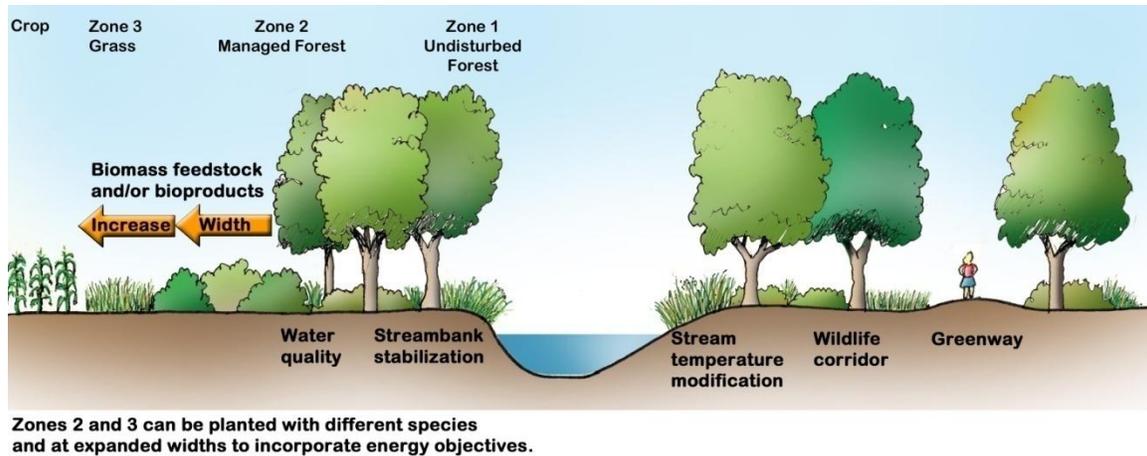


Fig. 1. Riparian forest buffers can be managed for multiple purposes, including those in support of energy objectives. More innovative designs, species selection, and management guidelines will be needed for these energy objectives to be met, along with others landowners and society already demand from them. (Source: Schoeneberger et al. 2008)

With proper design, placement and management, they may provide many of these services *while* also contributing to energy objectives in a number of important ways (see Box 1).

Box 1. Roles Riparian Forest Buffers Can Play in Support of Energy Objectives.

- **CONSERVATION SERVICES:** RFBs may mitigate adverse ecological impacts created by bioenergy production, especially in regards to water quality.
- **COMBINED HEAT & POWER (CHP) for ETHANOL PLANTS:** Plant materials in RFBs may be a source of feedstock to generate electricity and steam reliably on-site; reducing GHG emissions and operating costs.
- **BIOENERGY PRODUCTS:** Many plants suitable for use in RFBs, especially in Zone 2, produce fruits and nuts that have high yields and bio-oil properties (e.g., hazelnut, Osage orange, Chinese tallow, Jatropa)
- **BIOMASS FEEDSTOCK:** The biomass components of RFBs may serve as sources of feedstock to augment commercial ethanol production.
- **ON-SITE/LOCAL HEATING POWER PRODUCTION:** As the technology for small (5-50kW) generators that can utilize a variety of forest & agricultural residues becomes more available, RFBs can provide sources of residue for meeting on-site heating and power needs.

RFBs need to be an integral component of any bioenergy crop production strategy in order to provide critical water, soil and wildlife conservation services, especially in systems involving monocultures and/or annual crops. Advantages of using RFBs in bioenergy production are listed

in Box 2. By modifying RFB design (while not compromising its primary purposes for water quality, streambank stabilization, or wildlife habitat); these buffers can ‘assume additional duties’ in support of energy objectives. These RFBs can be part of a “combined food and energy” (CFE) system on the farm (Kuemmel et al. 1997). This more multipurpose approach is gaining interest and support, especially in Europe where they are dealing not only with bioenergy, greenhouse gases and sustainable agricultural issues, but also the significant reduction in European Union (EU) crop subsidies to the agricultural sector.

Potential management options being examined include integrating annual crops with mixed perennial plantings, such as willow and Miscanthus, as a means to generate biofuel materials, ecosystem services, and a livable income for the farmers. The riparian environment is ideal for realizing the good growth of short rotation woody crop species (SRWC) and is also an area where we are trying to maximize the phytoremediation potential with these fast growing trees. By providing these multiple services, which include those that support energy - *while* leaving the bulk of the land still open for agricultural production, RFBs could be both a viable and an appealing piece to begin linking the energy, food production and ecosystem services on these lands.

Box 2. Advantages of Using Riparian Forest Buffers in Support of Energy Objectives

- RFBs are located on lands that are marginal/sensitive to most agricultural operations but which are suitable for many perennial herbaceous and woody crops.
- The use of perennial herbaceous and woody plants in multi-species RFBs does not require the high level of inputs of annual crops and can harvest the excess nutrients; resulting in water protection and production of biomass.
- Reduction in annual soil disturbance, along with year-around plant cover provides greater soil and water quality protection and wildlife habitat.
- Herbaceous and woody species that can and have been utilized in Zones 2 & 3 have more favorable net energy conversion ratios than corn, with many of the woodies (e.g. willow, hybrid poplar and cottonwood) having ratios of ~1:11, co-firing with coal, and ~1:16 through gasification.
- The woody component in a bioenergy-modified RFB offers greater flexibility in harvest times, easier storage (e.g. ‘on-the-stump’) and greater flexibility in end-use, all which contribute to reducing farmer risk.
- The multipurpose, diversified nature of a bioenergy-RFB provides added resilience against climate change variability and extremes.

Riparian Buffer Planning and Design for Bioenergy

Incorporating energy objectives into RFB designs will require new RFB guidelines, standards, and designs. Establishment, management and harvesting protocols that include a bioenergy component will be of the utmost importance so that production and harvesting do not compromise RFB functions for other services. Further, the RFB must be integrated into a whole-farm management plan as well as the larger landscape context. As with all RFB planning and design efforts, including that for bioenergy, the main questions that need to be addressed are:

1. *What do we want the RFB to accomplish?*
2. *Are the location and/or conditions appropriate for these purposes?*
3. *What plant species and combination of species should be used in the RFB?*
4. *What management will be required to attain these objectives from the RFB?*

To effectively answer these questions, a multi-scale planning and design process should be used (Ndubisi 2002, Bentrup et al. 2003). Multi-scale planning is necessary because riparian functions vary at regional, landscape, and site scales and not all objectives can or should be achieved with riparian buffers at every location (NRC 2002). Landscape and individual site constraints and opportunities will dictate what goals are feasible, which in turn will be modified by community and landowner desires and needs. Landowner goals, like minimizing soil erosion and producing feedstock for bioenergy production, can often be accomplished by just focusing on the site conditions while a larger scale perspective is often required for community-driven goals, like water quality and wildlife habitat.

A key element in the planning process is the use of GIS-based spatial assessments to determine where objectives can be realistically accomplished. Several assessments already exist that can identify locations to grow agroforestry specialty products, improve riparian connectivity for wildlife, and enhance water quality (e.g., Bentrup and Leininger 2002, Bentrup and Kellerman 2004, Dosskey et al. 2006). Other types of assessments that could be conducted for bioenergy buffers include proximity to a biofuel refinery and flood-prone lands suitable for SRWC. By combining these types of assessments, locations can be identified where multiple objectives can be simultaneously achieved.

In regards to plant selection, current species combinations/systems have been designed primarily for the purposes of improving water quality and enhancing wildlife values. New planting designs will need to be created to take advantage of emerging carbon markets and other ecosystem service markets. Other considerations include stress and pest resilience by the RFB plants themselves and may also include species/combination selections that can provide pollinator habitat and biocontrol of pests in adjacent crops.

While there is significant information on the bioenergy properties of many herbaceous species, more work needs to be conducted on the yield and sustainability of short rotation woody species production under different site conditions and management practices. Performance of SRWCs (e.g., poplar, willow and black locust) will need to be evaluated not only in regards to growth on marginal lands and in creating positive interactions with nearby crops, but also in terms of cellulosic qualities for biofuel use. We already have a pretty solid foundation for using willows

for applications ranging from bioenergy, living snowfences, phytoremediation, and riparian buffers, while others are adding to our understanding on the potential of poplars to harvest nutrients from runoff, providing both phytoremediation and biomass.

Many of these woody species may have the potential to produce high value bio-oil and other bioproducts. Hazelnut, a shrub-like tree already used in many conservation practices, has been found to have higher yields of bio-oils and with better thermal qualities than soybean (Xu et al. 2007)). Studies with Osage orange, a species once extensively planted in hedgerows are revealing that this plant can yield significantly large amounts of latex and other potentially high value compounds important for energy, chemotherapy, insecticidal and other uses (Alan Gravett, personal communication).

Using new species and species combinations, however, brings another whole set of potential problems. A big consideration will be the potential for ‘weediness’ or invasiveness. In RFB plantings, the emphasis has been to use native plant materials where at all possible, recognizing that ecosystems can generally keep native plants in check. Unfortunately, many of the high value bioenergy species have the potential to become invasive, especially some of the nonnative grasses, such as Miscanthus, and species being genetically bred for attributes such as greater water use efficiency, like switchgrass). Similarly, these plantings could also then harbor and promote populations of pests. Through planning and careful assessment, we need to consider all potential impacts to better design for multiple functions and to prevent creating new, unforeseen problems.

Getting Them into the Ground

While we are developing the technological basis of how bioenergy objectives can be achieved within RFBs we need a similar investment to build our understanding of the socio-economic and political factors that will determine getting bioenergy buffers in the ground. Some of the questions that need to be answered include:

- 1. How do we build the infrastructure needed to transition to a cellulosic-based biofuel future?*
- 2. Can multipurpose RFBs serve as a transitioning tool towards a mixed, diversified biofuel production landscape?*
- 3. What incentives are needed to get RFBs in place?*
- 4. What tools are needed to promote acceptance and adoption of the practice?*

Market uncertainty for cellulosic feedstocks is a big barrier right now. Investments for commercial production using cellulose are based on having a secured base of feedstock availability. With corn-based ethanol production, this was simply a matter of switching end-use of a crop already in place. With cellulosic feedstock crops, we are faced with the challenge of getting feedstock in the ground years before a refinery plant is feasible. Farmers are reluctant to lose control of their land by putting it under perennial operations, especially as it requires a longer-term investment before they would realize a return.

Shifts in farm policy, programs and markets will be necessary to make adoption of RFBs more attractive to landowners. First, conservation programs in the Farm Bill need to have incentives and flexibility to promote CFE-like operations and not just piece-meal actions. Incentives should provide farmers with a reasonable level of support for offsetting upfront establishment costs and reducing their investment risks. The newly created Biomass Crop Assistance Program (BCAP) moves in that direction by providing payments to farmers while they establish and grow biomass crops in areas around biomass facilities. Switching crop subsidies to conservation payments for more carbon-neutral biofuels may be another alternative; one already occurring in the EU. Another way may be to develop ecosystem service markets which pay farmers for services provided from conservation practices. Unfortunately, ecological benefits of perennial crops, especially derived from diversified plantings, are hard to quantify, and, even then, may be less real to the farmer than the price per bushel of biofuel crop.

Education will also be imperative, not only to landowners but also those people involved in policy and programs formulation and delivery. A survey of farmers in Tennessee showed that few were aware of the potential of growing switchgrass for bioenergy, and an even smaller proportion of that group was willing to consider it (Jensen et al. 2007). What reaction should we expect if we try to promote more innovative, diversified systems for the farms? Growing biofuel crops, beyond that of corn, will require a major paradigm shift for farmers. Developing and managing combined food and energy farms will be an even bigger step. Again, RFBs that address landowner objectives in addition to societal objectives may be a way to ease into this transition.

To facilitate this transition, we will need tools to foster the discussion and formulation of shared agendas among landowners, resource professionals and the energy industry. The recently published *Conservation Buffers: Design Guidelines for Buffers, Corridors, and Greenways* provides science-based rules-of-thumb for designing multifunctional buffers, giving resource professionals the information they need to communicate complex concepts to landowners <http://www.bufferguidelines.net> (Fig. 2).

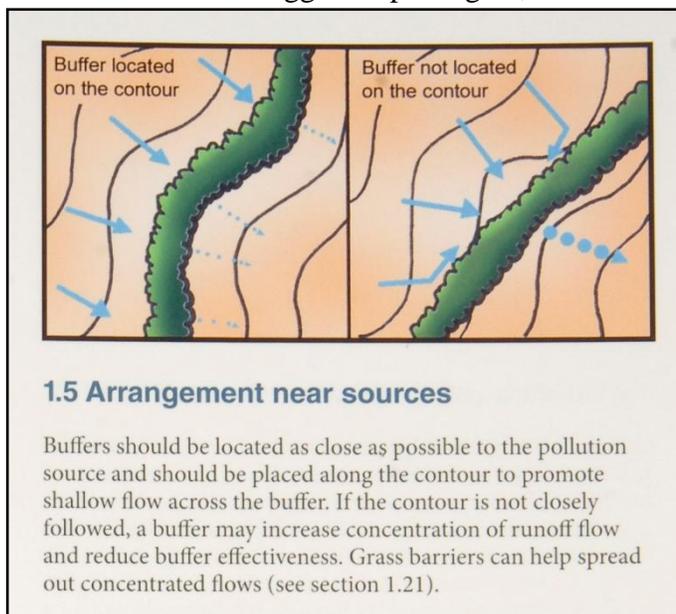


Fig. 2. An illustrated, easy-to-understand guideline from the publication *Conservation Buffers: Design Guidelines for Buffers, Corridors, and Greenways*

One survey has shown that landowners are often less inclined to adopt wide riparian buffers and yet buffers for bioenergy will probably need to be wide to accommodate all of the necessary objectives (Sullivan et al. 2004). In many cases, this barrier can be overcome when landowners see an image of what is being proposed. Visualization software, such as *CanVis* developed by the National Agroforestry Center, can help the landowners see these perennial systems as they

would appear in different arrangements and over time on their lands. Visual simulations promote acceptance and adoption by communicating ideas clearly, by inviting feedback on the alternatives, and by instilling a sense of shared ownership in the practice so that it is supported and maintained for long run <http://www.unl.edu/nac/simulation/products.htm> (Fig. 3).



Fig. 3. Visual simulations depicting two different riparian buffer alternatives.

Riparian buffers can play an important role in the transition to a sustainable bioenergy future. The key will be to link it to the many other issues surrounding our agricultural lands. The potential for designing “bigger, better *and* bioenergy riparian buffers” is there but this potential will need to be better conceptualized and developed, better communicated to those responsible for developing program and policies, and better communicated to landowners, and most importantly, to the resource professionals that will be delivering this technology.

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WOOD ASH FROM BIOENERGY SYSTEMS AS A SOIL AMENDMENT FOR CROP PRODUCTION

Mark J. Kopecky¹ and N. Larry Meyers²

¹Department of Agriculture and Agribusiness, University of Wisconsin-Extension, Price County UW-Extension, 104 South Eyder Avenue, Phillips WI (USA) 54555

²Professor Emeritus, Department of Plant and Earth Science, University of Wisconsin-River Falls, River Falls WI (USA) 54022

Contact: mark.kopecky@ces.uwex.edu

Abstract: Wood is a renewable energy source that can be practical for many applications. Wood ash produced as a byproduct of commercial, industrial, and institutional bioenergy operations can be an economical, effective, and environmentally friendly soil amendment for crop production. Wood ash provides liming benefits along with potassium, phosphorus, calcium, magnesium, and micronutrients. Research in Wisconsin has demonstrated that wood ash benefits a variety of agronomic crops and can be practical for farmers to use.

We conducted greenhouse and field studies to evaluate the effects of landspreading industrial wood ash on the yield and elemental composition of forage crops and on soil nutrient levels. Biomass yields generally increased with ash application up to 20 tons/acre and decreased at applications exceeding this level (Meyers and Kopecky, 1998). Wood ash application usually produced yields greater than those obtained with the limed and fertilized control treatment. No undesirable elements accumulated in forage tissue at ash application rates up to 20 tons/acre.

Clean wood ash (produced from only wood and bark without synthetic substances in the fuel stream) is permitted for organic crop production systems in the United States. It is especially valuable in areas with acidic soils, and can be landspread with equipment that is commonly used in cropping systems. Wood ash is already being used as a soil amendment in some areas of North America, but in other cases it is disposed of in landfills. Using wood ash for crop production can save money for farmers and bioenergy users and is a more sustainable stewardship practice.

Key Words: organic, liming, byproduct, landspreading, landfills, sustainability, stewardship

USE OF WOOD AS A BIOENERGY SOURCE

Industrial, commercial, and institutional bioenergy applications

Wood has traditionally been used as a fuel source throughout ages. In areas with cold climates, it is a common home heating energy source. In recent decades, many industrial, commercial, and institutional applications of wood-based bioenergy have been used. In Wisconsin alone, there are over 200 industries, businesses, and schools that burn wood (Wisconsin Department of Natural Resources, 2009). Well-designed and –operated systems are relatively efficient and non-polluting, with the added benefit of having no net effect on atmospheric carbon dioxide. The

resulting ash from these operations may be used as a beneficial soil amendment, but is sometimes landfilled as a waste product.

AGRONOMIC USE OF WOOD ASH

General characteristics, historical use, and current potential

Wood ash has historically been known as a valuable soil amendment (the term “potash” originated from the potassium carbonate produced by leaching wood ash). In general, wood ash can substitute as a lime source for use on acidic soils and contains a number of plant nutrients that may be beneficial for crop production. Wood ash produced from burning “clean” wood and bark with no foreign materials included in the waste stream is approved as a soil amendment for organic crop production under the U.S. Department of Agriculture’s National Organic Program standards.

Wisconsin research: Agronomic effects of ash application

We analyzed sixteen ash samples from northern Wisconsin sources, including bottom ash and fly ash, to determine the range of elemental concentrations of 15 elements (Table 1). From 1990 to 1994, we conducted greenhouse and field research to ascertain the agronomic value of ash from several wood burning industries in northern Wisconsin. Ash was added to the soil at rates equivalent to 0, 5, 10, 20, and 40 tons per acre and the effect on crop yield, soil pH, and nutrient levels were measured.

Greenhouse studies showed alfalfa and barley yield response from wood ash applications of five to twenty tons per acre to be significantly greater than those from commercial lime and fertilizer applied at rates recommended by soil test. The field research trials also showed favorable crop responses from wood ash application. Alfalfa plots in Price County, Wisconsin treated with ash at rates from 2.5 to 20 tons per acre, exhibited yields comparable to plots treated with commercial lime and fertilizer applied at rates recommended by soil test. No harmful effects on crops were observed when ash was applied at rates up to 20 tons per acre.

Table 1. Elemental content of sixteen ash samples from northern Wisconsin.¹

Element	Range of Concentrations	Pounds Applied in 10 Ton/Acre Ash Application
Calcium (Ca)	22-45%	4,400-9,200
Magnesium (Mg)	1.2-2.2%	240-440
Phosphorus (P ₂ O ₅ equivalent)	1.1-2.3%	230-460
Potassium (K ₂ O equivalent)	1.3-4.6%	260-910
Aluminum (Al)	0.2-1.1%	42-230
Iron (Fe)	0.1-1.1%	26-210
Manganese (Mn)	0.06-0.3%	12-56
Zinc (Zn)	0.01-0.5%	3-100
Boron (B)	0-210 ppm ²	0-4
Chromium (Cr)	0-14 ppm	0-0.3
Copper (Cu)	0-54 ppm	0-1.1
Nickel (Ni)	0-7 ppm	0-0.1
Cadmium (Cd)	0-22 ppm	0.4
Cobalt (Co)	0-6 ppm	0-0.1
Lead (Pb)	0-17 pm	0-0.3
Sulfur (S)	See Footnote 3	See Footnote 3

¹From Kopecky et al., 1995²ppm = parts per million³Sulfur concentration was not determined in the Wisconsin research. Other research reports sulfur concentrations of 0.38% to 2.0% in wood ash, which would yield 76 to 400 lb in a 10 T/A application.

Lime and Fertilizer Value of Wood Ash

The monetary value of wood ash is highest in areas where agricultural limestone prices are high and where ash sources are located nearby, but the plant nutrient content of ash is also substantial. The potential dollar value of wood ash is shown in Table 2. In addition to the value of lime and macronutrients, ash can also supply significant amounts of sulfur, boron, and other micro-nutrients.

Table 2. Economic value of wood ash at various nutrient levels and limestone costs.¹

Constituent	Range in Content	Economic Value (Dollars Per Ton)² at Different Limestone Costs³
Lime Value (NI)	40-49 to 80-89	\$9-30
Potash (K ₂ O)	26 to 92 lb/ton	\$17.70-62.70
Phosphate (P ₂ O ₅)	22 to 46 lb/ton	\$11.00-23.10
Total Range in Value:		\$37.70-115.80

¹ From Kopecky et al., 1995² Assumes cost of potash (from 0-0-60) equals \$0.68/lb of K₂O; cost of phosphate (from diammonium phosphate) equals \$0.50/lb P₂O₅.³ Based on NI 80-89 limestone, ranging from \$20-30/ton.

Heavy Metal Content

The concentration of heavy metals in wood ash is very low. The element that is present in the highest amounts relative to cumulative loading limit restrictions in Wisconsin is Zn. Based on average concentration in the ash samples we tested, it would require eighty-one 10 T/A application to reach the legal loading limit for this element.

PRACTICAL CONSIDERATIONS

Using Wood Ash: Transportation and Storage

Wood ash is a caustic material (strongly alkaline) and quite dusty when first taken out of the combustion facility. Ash that is stockpiled in the open tends to hydrate after several months and becomes less dusty. Some facilities add water to ash directly to reduce its dustiness. Dry ash must always be covered during transport. Ash can be stockpiled adjacent to fields where it will be used until it is spread. If the ash is very fluid, storage areas can be banked with low earthen berms to contain the pile. Once ash is stockpiled it crusts quickly, so loss to wind is not usually a problem.

Spreading Wood Ash

Fresh ash can be difficult to spread because of its fluidity and dustiness, and therefore should be hydrated by adding water before spreading. Wood ash that has been hydrated can be spread with manure spreaders, lime trucks, or fertilizer wagons, depending on the equipment available. For many farmers, manure spreaders will be the most practical means. Ash can be loaded from the stockpile with a skid steer or a tractor with a front end loader.

Safety Considerations

When working around ash, wear personal protection equipment (goggles, dust mask and protective clothing). Ash can be harmful if it comes in contact with eyes or skin or is inhaled. Fresh ash can be very hot - be careful to keep flammables away from fresh ash.

CONCLUSIONS

Industrial wood ash can be used as a safe, effective, and economical soil amendment. It is especially useful where lime is required, but is useful for other situations where potassium needs are high or where forage legumes are to be grown. Ash is approved as a soil amendment for organic crop production in the United States.

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PRODUCTIVITY AND ENERGY CONTENT OF HYBRID POPLAR CLONES IN WEST-CENTRAL MINNESOTA

Diomy Zamora¹, Gary Wyatt¹, Ulrike Tschiner², and Dean Current³

¹University of Minnesota Extension

²Bioproducts and Biosystems Engineering, University of Minnesota

³Center for Integrated and Natural Resources and Agricultural Management, University of Minnesota

Contact: zamor015@umn.edu

Abstract: Agroforestry systems and practices are getting recognition as approaches in producing feedstocks for energy while mitigating environmental problems such as deteriorating water quality. Hybrid poplar is a common agroforestry species in Minnesota that is used primarily in wellhead protection areas. The interest and use of *Populus* feedstocks for biofuel, bioenergy, and bioproducts is increasing because of the growing demand of alternative energy source due to rising fuel cost. Hybrid poplars are ideal feedstocks for energy because such species could generate significant biomass and provide a plethora of ecological services. Much research has been conducted regarding clonal production of hybrid poplars, however, there is insufficient information available on the biomass production and energy conversion potential of some hybrid poplar clones. To effectively develop plans for the power and heat production systems of the biorefinery, information on these parameters from such species is necessary. Several gasification systems in Minnesota often fail because of species compatibility with the gasifier system. In response to this problem, we conducted a study involving energy value and productivity assessment of common hybrid poplars clones in Central Minnesota using the 1995 and 1997 hybrid poplar plantations in Westport, MN. Therefore this presentation will present the biomass production and energy values of common hybrid poplar clones harvested from these plantations. Harvesting of clones was conducted on a replicated manner. Each tree representing each clone was divided into three sections (base, middle and top). Chemical content of each of this section was analyzed at the Forest Products Laboratory of the University of Minnesota. Chemical content analyzed include btu, glucose, xylose, galactose, arabinose, mannose, lignin, and ash. Nutrient content of ash was also analyzed. Knowing this information would enable us to recommend appropriate species from agroforestry system that would provide greater benefits to biorefinery industries. Also, we would be able to recommend to landowners appropriate agroforestry species for such purpose.

POPLAR CLONAL TRIAL IN SASKATCHEWAN

Shannon Poppy

Saskatchewan Forest Centre, 101-1061 Central Avenue, Prince Albert, Saskatchewan, Canada
S6V 4V4, 306-765-2856

Contact: spoppy@forestfirst.ca

Abstract: The prairie provinces of Canada are in desperate need of new poplar clones. At this time there are only a limited number of clones available which leaves the agroforestry industry with little diversity to choose from. In the spring of 2008 The Saskatchewan Forest Centre embarked on a project with Agriculture and Agrifood Canada PFRA Shelterbelt Center to address this problem. The project involves Balsam poplar progeny and hybrid poplar clones. The Balsam material was collected from all over Canada and placed in a 5 acre trial. This is a sister trail to a site at the PFRA Shelterbelt Centre in Indian Head Saskatchewan. Balsam poplar could prove to be a new fast growing crop for prairie producers. Also, 150 new Hybrid poplar clones were bred and grown in containers. These clones will be planted out in a 10 acre site in 2009. The hope that from these 150 hybrid poplar clones we will find trees that are faster growing than the trees we have available now, trees that are better for lumber production and insect and disease resistant.

ESTABLISHMENT OF COTTONWOOD/SWITCHGRASS BIOENERGY AGROFORESTS IN THE LOWER MISSISSIPPI ALLUVIAL VALLEY

Hal O. Liechty¹, Chris Stuhlinger¹, Michael Blazier², Matthew Pelkki¹, Philip Tappe¹, and Charles West³

¹Arkansas Forest Resource Center, University of Arkansas;

²Louisiana State University AgCenter;

³Crop, Soils, and Environmental Science, University of Arkansas

Contact: liechty@uamont.edu

Abstract: Switchgrass (*Panicum virgatum* L.) and cottonwood trees (*Populus deltoides* L.) are among the most promising species for cellulosic feedstock production in the Lower Mississippi Alluvial Valley (LMAV). These species are commonly cropped individually in monocultures, but growing these species in allies as an agroforest could be an attractive alternative. Agroforest systems such as this would be an especially appealing management option for landowners with small or moderate size land holdings. This type of cropping system provides an assortment of management alternatives, a range of economical and social benefits, and important ecosystem services that can be implemented on a variety of field and farm scales. Growing cottonwood, which is periodically harvested (every 4-8 years), and switchgrass, which is harvested annually, allows landowners to take advantage of changing markets by adjusting the year that cottonwood trees are harvested while receiving an annual return from switchgrass. We are establishing four different switchgrass-cottonwood agroforest configurations at three sites in the LMAV to evaluate the ability of these systems to provide cellulosic feedstocks as well as ecosystem services. Information concerning design of the study as well as initial establishment activities will be presented.

Keywords: cottonwood, switchgrass, cellulosic feedstock

SECTION 6

Upland Buffer Processes

EMISSION OF THE GREENHOUSE GAS NITROUS OXIDE FROM RIPARIAN FOREST BUFFERS, WARM-SEASON AND COOL-SEASON GRASS FILTERS AND CROP FIELDS

Thomas M. Isenhardt¹, Dong-Gill Kim², and Richard C. Schultz¹

¹Natural Resource Ecology and Management, Iowa State University, Ames, IA, 50011

²Department of Civil & Environmental Engineering, University College Cork, Cork, Ireland

Contact: isenhardt@iastate.edu

Abstract: Denitrification is recognized as the major mechanism for reducing nitrate in riparian buffers and thus diminishing non-point source pollution (NPS) of surface water bodies subject to high nitrogen loads. However, increasing denitrification rates in riparian buffers may be trading the problem of NPS pollution of surface waters for atmospheric deterioration and increased global warming potential because denitrification produces nitrous oxide (N₂O), a greenhouse gas also involved in stratospheric ozone depletion. It is therefore important to quantify the emissions of N₂O from different kinds of vegetated riparian buffer systems, and identify ways to minimize emissions while simultaneously maximizing denitrification. We measured N₂O emissions from soils; nitrate (NO₃⁻-N) and dissolved N₂O in groundwater; and soil properties in riparian forest buffers, warm-season and cool-season grass filters, and a crop field located in the Bear Creek watershed in central Iowa. Results suggest that N₂O emissions from soils in all riparian buffers were significantly less than in the crop field, but no differences among types of riparian buffers were observed. Nitrate in outflow groundwater of riparian buffers was significantly lower than in inflow groundwater of riparian buffers. However, dissolved N₂O in inflow and outflow groundwater of riparian buffers were not significantly different from one another. These results are useful in developing management protocols for riparian forest and other perennial vegetation practices for NPS pollution attenuation and additional multiple benefits.

Key Words: riparian forest buffer, filter strip, water quality, nitrate, greenhouse gas, nitrous oxide, groundwater.

INTRODUCTION

Important functions of riparian buffers related to NPS pollution control are filtering and retaining sediment, and immobilizing, storing, and transforming chemical inputs from uplands (Schultz et al., 2004). Many studies have shown that riparian buffers can reduce sediment erosion to surface waters by 70 to 95% (Lee et al. 2003), N fluxes by 5 to more than 90% (Dukes et al. 2002) and P losses by 27 to 97% (Kuusemets et al. 2001). Denitrification is recognized as the major mechanism for reducing nitrate (NO₃⁻-N) within riparian systems, with removal generally ranging from 2–7 g N m⁻² y⁻¹ (Watts and Seitzinger 2000).

It recently has been hypothesized that increased denitrification within riparian areas may trade a water quality concern for an atmospheric resulting from the greenhouse effect of N₂O produced during nitrification and denitrification and its contribution to ozone depletion concern (Groffman et al. 1998). The global warming potential of N₂O is 298 times that of carbon dioxide (CO₂) and

25 times that of methane (CH₄) in a 100-year time horizon (Forster et al. 2007). Some studies (Groffman et al. 1998, 2000, Hefting et al. 2003, 2006) have concluded that N transformation within riparian buffers with high NO₃⁻-N loads results in a significant increase of greenhouse gas emission. In contrast, because riparian buffers efficiently decrease NO₃⁻-N, a source of N₂O emissions, riparian buffers could provide an opportunity to decrease dissolved N₂O emissions if we can develop reliable strategies for decreasing N₂O production during denitrification (Groffman 2000). Studies supporting this proposition include Blicher-Mathiesen and Hoffman (1999), who reported that denitrification in a riparian soil can act as a sink for dissolved N₂O in the inflowing groundwater as well as for N₂O produced internally. However, very few studies have addressed these issues and the data that can be utilized to evaluate these possibilities are extremely limited. Clearly, there is a need to evaluate processes influencing production, consumption, and transport of N₂O in different riparian buffers and to assess the potential to decrease emissions.

An objective of this study was to compare N₂O emission from riparian buffer systems established for water quality improvement comprised of forest, warm-season grasses, and cool-season grasses and an adjacent crop field. A second objective was to quantify transport and fate of NO₃⁻-N and dissolved N₂O in groundwater under crop fields and riparian buffers, and assess whether groundwater exported from crop fields and riparian buffers is a significant source of dissolved N₂O.

MATERIALS AND METHODS

The study area consisted of three forest buffers, three warm-season grass filters, one cool-season grass filter, and a crop field, all located within the riparian zone within the Bear Creek watershed, Story County and Hamilton County, Iowa, United States of America. Bear Creek is a third order stream with typical discharges of 0.3 to 1.4 m³ sec⁻¹. The watershed drains 6,810 ha of farmland, with nearly 90% of the area in a corn-soybean rotation. An ongoing objective of the Bear Creek watershed project has been to establish riparian buffers along the upper portions of the watershed as willing landowners and cost-share are identified. This has provided a variety of sites of different streamside vegetation and buffer age to utilize in assessing the spatial and temporal variability of riparian buffers in reducing NPS pollution. Forest buffers and warm-season grass filters were previously under row-crop cultivation and the cool-season grass filter was previously under livestock grazing. Details of the riparian buffer design, placement, and plant species are given in Schultz et al. (2004). The crop field was planted to a corn (*Zea mays* L.) and soybean (*Glycine max* L. Merr.) rotation, with corn in 2006 and soybeans in 2005 and 2007. The areas used in this study are all located on the same soil mapping unit (Coland) and have similar topography.

Nitrous oxide flux from soils under riparian forest buffers, warm-season and cool-season grass filters, and the crop field were measured weekly from October 2005 through December 2007 (no measurement in mid April to mid May, August, and September to October 2006 in the crop field). Nitrous oxide flux samples were collected at mid-morning using static vented chambers and nitrous oxide concentrations were determined with a gas chromatograph. Nitrous oxide flux was calculated from the linear slope of N₂O concentration change over time (Holland et al. 1999). Soil temperature and soil moisture at 5-cm soil depths were measured simultaneously

with N₂O gas collection at one site per vegetation type. Daily rainfall and snow data were provided by the nearest meteorology station (Colo, IA). Cumulative N₂O fluxes were calculated by linear interpolation and numerical integration of soil-temperature-corrected daily flux measurements between sampling times. Six intact soil cores (5.3 cm diameter) were collected to a depth of 15 cm in each of the vegetation types in Oct. 2006 and Sept. 2007. Soils were analyzed for soil pH, gravimetric moisture content, total C (TC) and total N (TN), and soil inorganic N [NO₃⁻-N and ammonium (NH₄⁺-N)].

At each site, 12 monitoring wells were installed in three transects from the crop field edge to the creek along proposed groundwater flow paths, and a stilling well was installed to record the surface water elevation of the creek (Simpkins et al. 2002). Groundwater sampling and monitoring was conducted monthly in monitoring wells and stilling wells from Nov. 2005 to Apr. 2008 and samples were analyzed for NO₃⁻-N, Cl⁻, pH, dissolved organic carbon, and dissolved N₂O. Hydraulic head was measured with an electronic water level tape. Additional data for this study included monthly groundwater samples collected from 1997 to 1999 in the same monitoring and stilling wells at each site (Spear 2003). Cumulative annual flux of NO₃⁻-N and dissolved N₂O-N in groundwater at the crop field edge of the buffers was estimated using measured concentrations, average linear velocity, effective porosity, and cross sectional area of the aquifer adjacent to Bear Creek.

Normality of the distribution of the data was analyzed using the Shapiro-Wilk normality test. One-way analysis of variance (ANOVA) was used to evaluate the differences in soil properties, and diel and seasonal N₂O flux by site. When the standard assumptions of normality were violated, non-parametric Kruskal-Wallis one-way ANOVA on ranks was used. Differences were considered significant at the $P < 0.05$ level. To determine the relationship between soil properties and N₂O flux, correlation analysis using the GLM procedure was applied and NONLIN procedure was utilized for deriving the best fit of N₂O flux models developed by the relationship between soil temperature and N₂O flux. These statistical analyses were conducted in SAS version 8.1 (SAS institute, 1999).

RESULTS

Soil properties

Soils within the forest buffer and warm and cool-season grass filters had significantly lower bulk density, higher pH, TC, TN, and NH₄⁺ than crop fields, while soil NO₃⁻-N was not significantly different. Soils had longer dry (soil moisture < 15%) and frozen (soil temperature < 0°C) periods in 2007 than in 2006. From 15 June to 15 Aug. 2006 (93 d), soils were extremely dry within crop fields for 12 days, within forest buffers 0 days, and within grass filters 51 days. In comparison, from 15 June to 15 Aug. 2007 (93 d), soils were extremely dry within crop fields for 78 days, within forest buffers for 32 days, and within grass filters for 24 days. From January to March 2006 (90 days), soils were frozen within the crop field for 47 days, within forest buffers for 17 days, and within grass filters for 49 days. In comparison, from January to March 2007 (90 days), soils were frozen within the crop field for 82 days, within forest buffers for 46 days, and within grass filters for 62 days.

Soil N₂O flux

When assessed seasonally, N₂O flux in the crop field was significantly correlated with air temperature, soil temperature, and soil moisture. In all riparian buffers, N₂O flux was significantly correlated with air temperature and soil temperature during this same period. The average of observed N₂O fluxes in the crop field (39.4 ± 7.1 g N₂O-N ha⁻¹ d⁻¹, $n = 76$) was significantly higher than in riparian buffers (2.8-11.0 g N₂O-N ha⁻¹ d⁻¹, $n = 72-93$), but there were no differences among riparian buffer vegetation types (Fig. 1). In both 2006 and 2007, annual cumulative N₂O emission was significantly greater in the crop field (7.2 kg N₂O-N ha⁻¹ in 2006 and 16.8 kg N₂O-N ha⁻¹ in 2007) than in forest buffers (1.8 kg N₂O-N ha⁻¹ in 2006 and 4.5 kg N₂O-N ha⁻¹ in 2007) and grass filters (1.8 kg N₂O-N ha⁻¹ in 2006 and 3.4 kg N₂O-N ha⁻¹ in 2007). The annual cumulative N₂O emission in the crop field, forest buffers, and grass filters in 2007 were 2 to 2.5-fold larger than 2006.

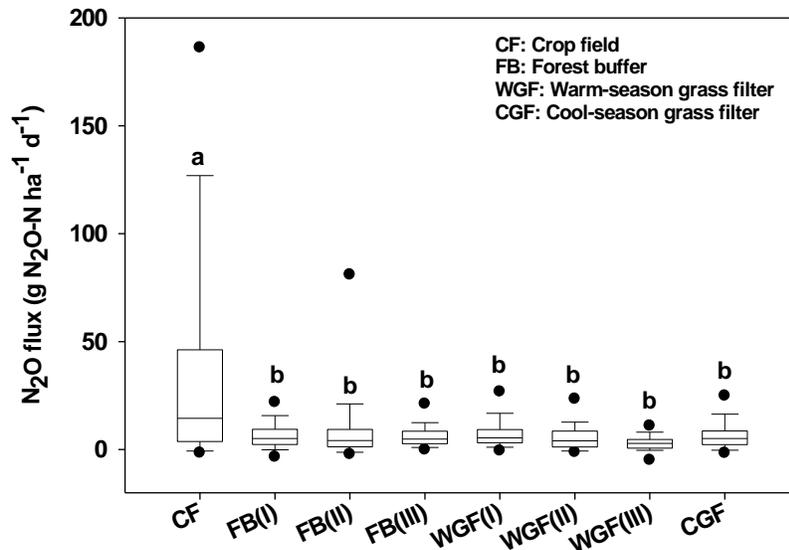


Figure 1. Daily N₂O flux from soils within the crop field and riparian buffers in 2006 and 2007 ($n = 72-93$). I, II, and III indicate replicates. The lower boundary of the box indicates the 25th percentile, the line within the box marks the median, and the upper boundary of the box indicates the 75th percentile. Error bars indicate the 90th and 10th percentiles. Solid circles indicate outliers.

Several periods of peak N₂O emission contributed significantly to annual N₂O emission in both the crop field and riparian buffers (Fig. 2 (A) and (B)). Across all vegetation types, N₂O peak emissions were 3 to 10-fold greater than base-line levels after the thawing of frozen soil or rewetting of dry soil and the peaks returned to lower levels within a week. Soils within the crop field showed higher peak rates of N₂O emission than riparian buffers in both 2006 and 2007. As a result, the contribution of peak emissions to annual N₂O emission was larger in the crop field than in riparian buffers during both years, with the contribution higher in 2007 than 2006.

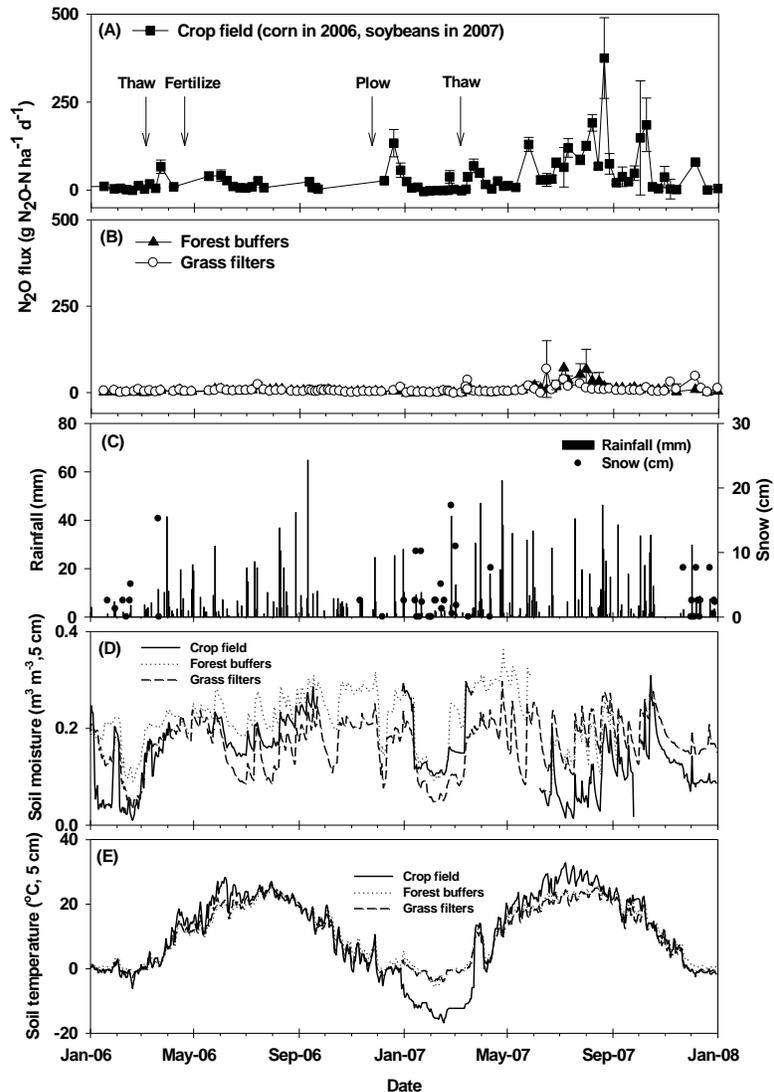


Figure 2. Nitrous oxide emissions (A, B), precipitation (C), and daily average of soil moisture (D) and soil temperature (E) in forest buffers (n = 3), grass filters (n = 4), and adjacent crop field (n = 1) during 2006 and 2007. Observations are mean values with standard errors of the mean in (A) and (B).

Groundwater N₂O flux

Within the cool-season grass filter sites, average NO₃⁻-N concentration was 9.5 mg L⁻¹ in groundwater wells adjacent to crop fields and 4.9 mg L⁻¹ in wells adjacent to creek, during 1997-1999 (Fig. 3), and 9 and 3.3 mg L⁻¹, respectively, during 2005-2008 (Fig. 4), representing a decrease of 48% in 1997-1999 and 59% in 2005-2008. In Jan. 2006-Dec. 2007, NO₃⁻-N flux in groundwater from the crop field to the cool-season grass filter was 14.2 kg N and NO₃⁻-N flux from the cool-season grass filter to the creek was 5.1 kg N (Fig. 3). This indicates that 9.1 kg N

was removed from the groundwater as it flowed from the crop field through the cool-season grass filter.

	Crop field	Multi-species riparian buffer	Bear Creek	Cool-season grass filter	Crop field	
Groundwater flow direction	→ →	→ →		← ←	← ←	Groundwater flow direction
Cl ⁻	20.6 (1.2)	20.9 (1.0)		13.4 (1.0)	13.2 (0.9)	Cl ⁻
NO ₃ ⁻ -N	4.9 (0.5)	5 (0.4)		4.9 (2.4)*	9.5(0.7)*	NO ₃ ⁻ -N
NO ₃ ⁻ /Cl ⁻	0.3 (0.1)	0.2 (0.0)		0.4(0.0)*	0.8(0.1)*	NO ₃ ⁻ /Cl ⁻
Dissolved N ₂ O-N	6.1(1.0)	6 (0.7)		6.8(0.8)	7.8(1.2)	Dissolved N ₂ O-N
DOC	1.1(0.1)	0.6 (0.4)		0.7(0.4)	0.9(0.4)	DOC
DO	3.4(0.5)	2.8(0.2)		2.6(0.3)	5(0.3)	DO
pH	7.5(0.0)	7.5(0.0)		7.3(0.0)	7.5(0.0)	pH

Figure 3. Groundwater characteristics adjacent to crop fields and Bear Creek in a multi-species riparian buffer and a cool-season grass filter in 1997-1999 (data from Spear 2003). Unit for Cl⁻, NO₃⁻-N, DOC, and DO is mg L⁻¹ and unit of dissolved N₂O-N is µg L⁻¹. The value inside parenthesis is standard error of the mean and an asterisk (*) indicates P < 0.05. The number of measurements: Cl⁻ (n = 21-23), NO₃⁻-N (n = 26-29), NO₃⁻/Cl⁻ (n = 17-22), dissolved N₂O-N (n = 26-27), DOC (n = 3), DO (n = 19-21), and pH (n = 3).

Within the riparian forest buffer, average NO₃⁻-N concentrations were 4.9 mg L⁻¹ in groundwater wells adjacent to the crop field and 5.0 mg L⁻¹ in wells adjacent to the creek, respectively, during 1997-1999 (Fig. 3), and 4.0 and 2.0 mg L⁻¹, respectively, during 2005-2008 (Fig. 4). The differences in concentrations during 1997-1999 were not significant (Fig. 3) but, within this same buffer, average NO₃⁻-N concentration in groundwater decreased by 49.5% in 2005-2008 (Fig. 4). In Jan. 2006-Dec. 2007, NO₃⁻-N flux in groundwater from the crop field to the multi-species riparian buffer was 4.4 kg N and groundwater NO₃⁻-N flux from the multi-species riparian buffer to the creek was 2.1 kg N (Fig. 4). This indicates the NO₃⁻-N flux was 2.3 kg N (52.2%) lower in groundwater nearest the creek compared to near the crop field edge.

In the cool-season grass filter, the average NO₃⁻/Cl⁻ ratio within groundwater adjacent to crop fields was significantly higher than adjacent to the creek in both 1997-1999 and 2005-2008 (Fig. 3, 4). Within groundwater under the multi-species riparian buffer, there was no significant difference in the average NO₃⁻/Cl⁻ ratio of groundwater adjacent to crop fields and adjacent to the creek in 1997-1999 (Fig. 3). However, within this same system, the average NO₃⁻/Cl⁻ ratio within groundwater adjacent to crop fields was significantly higher than that adjacent to the creek in 2005-2008 (Fig. 4).

	Crop field	Multi-species riparian buffer	Bear Creek	Cool-season grass filter	Crop field	
Groundwater flow direction	→ →	→ →		← ←	← ←	Groundwater flow direction
Cl ⁻	20.8 (1.2)	18.2 (0.6)		18.2 (0.6)	20.6 (1.2)	Cl ⁻
NO ₃ ⁻ -N	4.0 (0.3)*	2.0 (0.2)*		3.3 (0.3)*	7.9 (0.5)*	NO ₃ ⁻ -N
NO ₃ ⁻ -N flux	4.4	2.1		5.1	14.2	NO ₃ ⁻ -N flux
NO ₃ ⁻ /Cl ⁻	0.2 (0.1)*	0.1 (0.0)*		0.2 (0.0)*	0.4 (0.0)*	NO ₃ ⁻ /Cl ⁻
Dissolved N ₂ O-N	9.0 (1.1)	9.1 (1.3)		14.4 (2.2)	11.6 (1.5)	Dissolved N ₂ O-N
Dissolved N ₂ O-N flux	8.3	7.7		20.0	19.7	Dissolved N ₂ O-N flux
DOC	1.2 (0.1)	1.0 (0.1)		1.1 (0.1)	1.9 (0.1)	DOC
DO	3.3 (0.3)	2.7 (0.3)		2.7 (0.3)	3.3 (0.5)	DO
pH	7.4 (0.1)	7.4 (0.0)		7.4 (0.1)	7.5 (0.1)	pH

Figure 4. Groundwater characteristics (in 2005 - 2008) and NO₃⁻-N and dissolved N₂O-N fluxes (in Jan. 2006 - Dec. 2007) adjacent to crop fields and Bear Creek in a multi-species riparian buffer and a cool-season grass filter in 2005-2008. Unit for Cl⁻, NO₃⁻-N, DOC, and DO is mg L⁻¹, dissolved N₂O-N is µg L⁻¹, NO₃⁻-N flux is kg N (2006 and 2007 years) ⁻¹, and dissolved N₂O-N flux is g N (2006 and 2007 years) ⁻¹. The value inside parenthesis is standard error of the mean and an asterisk (*) indicates P < 0.05. The number of measurements: Cl⁻ (n = 29), NO₃⁻-N (n = 29), NO₃⁻/Cl⁻ (n = 29), dissolved N₂O-N (n = 25-26), DOC (n = 8), DO (n = 26-27), and pH (n = 21).

Within groundwater under the cool-season grass filter, there was no significant difference in dissolved N₂O-N concentration in wells adjacent to the crop fields and adjacent to the creek during both 1997-1999 and 2005-2008. In Jan. 2006-Dec. 2007, dissolved N₂O-N flux was 19.7 g N in groundwater adjacent to the crop field and 20.0 g N in the cool-season grass filter near the creek (Fig. 3). This pattern was repeated in groundwater under the multi-species riparian buffer, with no significant difference in dissolved N₂O-N concentrations in groundwater adjacent to crop fields and the creek during either 1997-1999 or 2005-2008. There was a significant negative relationship between water temperature and dissolved N₂O concentration in groundwater adjacent to both crop fields and the creek within the grass filter and the multi-species riparian buffer. There was also a significant relationship between DO and dissolved N₂O concentration in groundwater adjacent to the creek within the multi-species riparian buffer.

DISCUSSION

In our studies, measured N₂O emissions from soils within all riparian buffers were significantly lower than within the crop field and there were no observed differences in N₂O emissions among the different riparian buffer vegetation types (Fig. 1). Observed emissions in our studies were similar to N₂O emission from soils in unfertilized grass lands and forest in temperate regions (Groffman et al. 1998, Stehfest and Bouwman 2006). In contrast, some studies (Walker et al. 2002, Hefting et al. 2003) have shown much higher N₂O emission from soils within riparian areas. They suggested that the higher rates of N₂O emissions within the forested buffer zone were associated with higher NO₃⁻-N concentration in the groundwater, and that N transformation by buffer zones with high NO₃⁻-N loading resulted in a significant increase of N₂O emission. This is consistent with the work of Ullah and Zinati (2006) who reported that prolonged N loading resulted in higher N₂O emissions in riparian forest soils compared to emission rates from non-exposed forest soils. Hefting et al. (2006) reported that locations with high NO₃⁻-N removal efficiency also contribute significantly to increased N₂O emission from riparian zones. Considering all of these results, it is likely that N₂O emission from riparian buffers is highly site specific and may vary with site characteristics such as soil type, magnitude and speciation of N input, and hydrologic characteristics (Walker et al. 2002).

The magnitude and frequency of the episodic N₂O emissions observed in our studies indicate the importance of frequent measurements to reduce the uncertainty of longer-term N₂O flux measurements and may partially explain the differences in results from previous studies. Many future climate change scenarios predict more severe droughts associated with summer drying and intense precipitation in a future warmer climate (Sillmann and Roeckner 2008) and an increase in freeze and thaw frequency (Gu et al. 2008). The observed peak N₂O emissions during the thawing of frozen soils and rewetting of dry soils in the crop field 2007 have important implications for greenhouse gas emission in a changing climate which predicts a greater frequency of such conditions.

Nitrate concentration in groundwater was significantly decreased under the cool-season grass filter in both 1997-1999 and 2005-2008 and under the multi-species riparian buffer in 2005-2008. Our data showed a decrease in the NO₃⁻/Cl⁻ ratio in both sites, with a significant decrease in NO₃⁻-N concentration and an insignificant change in the Cl⁻ concentration. These results suggest that dilution from a converging or diverging flow path was not a major factor contributing to the decrease in groundwater NO₃⁻-N concentration (e.g. Vidon and Hill 2004, Davis et al. 2007). Uptake of NO₃⁻-N by vegetation was not investigated in this study but is known to occur in riparian buffers (Hefting et al. 2005).

In our studies, there was no significant NO₃⁻-N decrease observed during 1997-1999 under the multi-species riparian buffer. However, there was a significant decrease in NO₃⁻-N during Jan. 2006-Dec. 2007. While not directly studied, the age of the buffer could be a potential contributing factor for the difference in N removal efficiency. Our results regarding NO₃⁻-N decrease without increasing dissolved N₂O in the cool-season grass filter or the multi-species riparian buffer can be explained three different ways. First, it may be that denitrification completed the reduction of NO₃⁻-N to N₂ without producing N₂O (Blicher-Mathiesen and Hoffman 1999). In the groundwater, very low concentrations of DO (< 2 ppm) were often

observed and the anaerobic microsites might support completion of denitrification. This possibility is supported by the significant relationship found between DO and dissolved N₂O. Second, N₂O produced in groundwater can be released into unsaturated soil above the groundwater table. However, since the N₂O emission measured on the soil surface includes the N₂O produced in the unsaturated soil layer, the results suggest that release of N₂O produced in groundwater into unsaturated soil above the groundwater table to be an insignificant pathway of NO₃⁻-N losses. Third, vegetation and microbial communities within the riparian buffers can assimilate and immobilize NO₃⁻-N resulting in NO₃⁻-N decrease without increasing dissolved N₂O in the groundwater. Since this study did not investigate NO₃⁻-N losses by these pathways, we cannot exclude the possibility. Overall, it is suggested that the cool-season grass filter or the multi-species riparian buffer should be considered insignificant sources of dissolved N₂O flux.

CONCLUSIONS

Annual N₂O emissions from soils within all riparian buffers were significantly lower than within the cropped fields and no differences were observed among the different kinds of riparian buffers. While N₂O peak emissions following the rewetting of dry soils and thawing of frozen soils contributed significantly to annual N₂O emission in the crop field, soils in riparian buffers were less sensitive to the events. Monitoring of groundwater under a cool-season grass filter, a multi-species riparian buffer, and adjacent crop fields during 1997-1999 and 2005-2008 indicated that the concentration of dissolved N₂O was not significantly changed, even when the concentration of groundwater NO₃⁻-N were decreased by 49.5% under the multi-species riparian buffers and 58.8% under the cool-season grass filter, over the same time periods. The decrease in the NO₃⁻/Cl⁻ ratio in groundwater under riparian buffers with significant NO₃⁻-N concentration decrease provides evidence that dilution from a converging or diverging flow path was not a major factor contributing to the decreased NO₃⁻-N concentration in groundwater. Based on these results, we suggest that the riparian buffers established adjacent to crop fields to decrease NO₃⁻-N did not increase dissolved N₂O in groundwater and dissolved N₂O flux from the crop fields was negligible in comparison to soil N₂O emission.

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NITRATE AND FECAL COLIFORM CONCENTRATIONS IN SILVOPASTURE AND PASTURE LEACHATES

Douglas G. Boyer¹ and James P. S. Neel¹

¹Appalachian Farming Systems Research Center, USDA-ARS, 1224 Airport Rd., Beaver, WV 25813

Contact: doug.boyer@ars.usda.gov

Abstract: A major limitation to efficient forage-based livestock production in Appalachia is asynchrony of forage availability and quality with nutritional requirements of the grazer. Silvopasture is being studied to improve the seasonal distribution and persistence of high quality herbage, sustainability and environmental integrity of the agricultural landscape. Fundamental knowledge of the impacts of agricultural practices on water quality is needed to address producer goals and societal concerns. Water quality was monitored at the soil/bedrock interface under conventional pasture (CP), silvopasture (SP), and hardwood forest (HF) on a central Appalachian landscape. The pasture and silvopasture were rotationally grazed by sheep during the spring to fall grazing season (2004-2008). Geometric mean fecal coliform bacteria concentrations were greatest in SP (18.0 cfu 100 ml⁻¹) with no difference between CP (7.5 cfu 100 ml⁻¹) and HF (5.6 cfu 100 ml⁻¹). Mean NO₃-N concentration was lowest in SP (2.2 mg L⁻¹) and greatest in CP (4.4 mg L⁻¹) and HW (4.1 mg L⁻¹). Mean NH₄-N concentrations showed different trends with the lowest mean concentration in CP (0.7 mg L⁻¹) and the greatest in SP and HW (2.6 mg L⁻¹). The observations will be important information for the development of decision support tools for maximizing forage and livestock productivity, through silvopastoral management on sloping land of central Appalachia, while protecting surface and groundwater quality.

Key Words: percolation, macropores, water quality, groundwater, Appalachian hardwoods

INTRODUCTION

Efficient forage-based livestock production in Appalachia is limited by asynchrony of forage availability and quality with nutritional requirements of the grazer. Producers require dependable plant resources and management practices that improve the seasonal distribution and persistence of high quality herbage, sustainability, and environmental integrity of agricultural landscapes. Silvopastoral agroforestry systems are being investigated for potential production and environmental benefits on complicated landscapes common to the Appalachian region (Feldhake and Schumann 2005).

High infiltration rates, macropores (Holden 2009), thin soils and fractured bedrock (Levison and Novakowski 2009) are common on central Appalachian landscapes and contribute to rapid recharge of shallow groundwater (Kipp and Dinger 1987). Deciduous forest sites of the region are characterized by thick surface organic layers and extensive systems of macropores (Carmean 1957). Staley et al. (2008) found that conversion of deciduous forest to silvopasture resulted in soil chemistry changes indicative of rapid transition to improved pasture. Boyer and Neel (2007) found that surface litter changes and remnant macropores in silvopasture recently established

from deciduous forest resulted in changes organic carbon transport to the soil/bedrock interface. Grazing land management system effects on nutrient cycling and the fate and transport of pathogens require careful study in order to develop environmentally effective systems that protect public health.

Numerous field and model studies have shown the intimate linkage between hillslope hydrology and N-cycling and fecal coliform bacteria (FC) transport (e.g., Cirimo and McDonnell 1997; Dorner et al. 2006). The purpose of this study was to determine if the delivery of inorganic nitrogen ($\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, and $\text{NH}_4\text{-N}$) and fecal coliform bacteria with water leaching to the soil/bedrock interface differs between pasture (CP), forest (HF), and silvopasture (SP) systems.

MATERIALS AND METHODS

The study site is located in southern West Virginia at $37^\circ 47' 39''$ N, $80^\circ 58' 22''$ W (Fig. 1). The conventional pasture is composed primarily of orchard grass (*Dactylis glomerata* L.), Kentucky bluegrass (*Poa pratensis*), and white clover (*Trifolium alba*) and has been maintained as pasture for many years. The conventional pasture is surrounded by mixed hardwood forest, part of which was converted to silvopasture by thinning the primarily red oaks (*Quercus sp.*) and planting orchard grass, rye grass (*Lolium perenne* L.), and white clover. Four 1.9 cm diameter piezometers (Solinst, Georgetown, Ontario, Canada) were installed to the soil/bedrock interface in each land use category (pasture, silvopasture, and forest). The lowest 30 cm of each piezometer was stainless steel and screened. The pasture and silvopasture areas were rotationally grazed by sheep during the growing season.

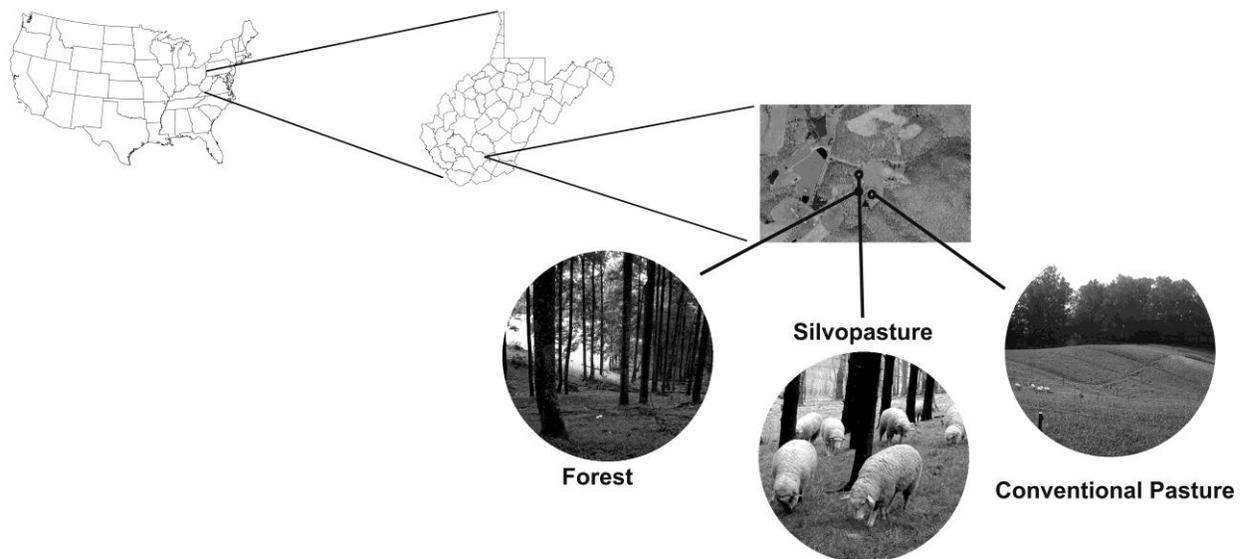


Figure 1. Study location.

Shortly after storms water samples were retrieved from the piezometers with a peristaltic pump (Geotech Environmental Equipment, Inc., Denver, CO) and 4.8 mm diameter silicone tubing. Water samples were transported back to the laboratory in sterile plastic bottles on ice. The water samples were quickly filtered through 0.45 μm filters which were placed on mFC nutrient agar media in Petri plates. FC were counted on the filter media following incubation at 44.5° C for 22 to 24 hours and recorded as colony forming units (CFU) per 100 ml. The sample water that passed through the filters was analyzed by suppressed ion chromatography (Dionex Corp., Sunnyvale, CA) for major anions and cations and recorded as mg L^{-1} .

The period of record is September 2004 through December 2008. In seasonal analyses spring is March – May, summer is June – August, fall is September – November, and winter is December – February. Sheep usually grazed the SP and CP sites April – October. FC counts were normalized by adding one to all FC counts and transforming to logarithms (base 10) for all statistical analyses. Statistical tests were done with the Statistical Analysis System (SAS Institute, Inc., Cary, NC). All statistical tests are significant at the $P \geq 95$ percent level unless stated otherwise.

RESULTS

Water appeared at the soil/bedrock interface more frequently in silvopasture site than the pasture or forest sites. The total number of storm samples collected at the silvopasture, pasture, and forest sites was 296, 179, and 71, respectively. Table 1 shows the summary statistics for inorganic N and FC concentrations in each of the land use treatments.

Table 1. Summary statistics for inorganic N and fecal coliform concentrations in silvopasture (SP), pasture (CP), and hardwood forest (HF). Means with the same letter are not significantly different within rows.

	SP		CP		HF	
	mean ¹	s.e. ²	mean	s.e.	mean	s.e.
Number of samples	296		179		71	
Inorganic N (mg L^{-1})	4.9 ^a	0.62	5.0 ^a	0.38	6.3 ^a	1.52
NO ₂ + NO ₃ -N	2.2 ^a	0.26	4.4 ^b	0.34	4.1 ^b	0.78
NH ₄ -N	2.6 ^a	0.49	0.7 ^b	0.10	2.6 ^a	1.36
Fecal coliforms (CFU 100 ml ⁻¹)	18.0 ^a	1.21	7.5 ^b	1.28	5.6 ^b	1.45

¹Geometric mean (mean of the logarithms transformed back to a real number) for fecal coliforms.

²Standard error for fecal coliforms is the anti-log of the standard error of log concentration.

Seasonal means of NO₃-N concentrations are shown in Figure 2. NO₃-N concentrations in the SP leachates are lower than the concentrations in CP or HW leachates in all seasons, but spring. NO₃-N concentrations were greatest in fall with CP and HW NO₃-N concentrations averaging

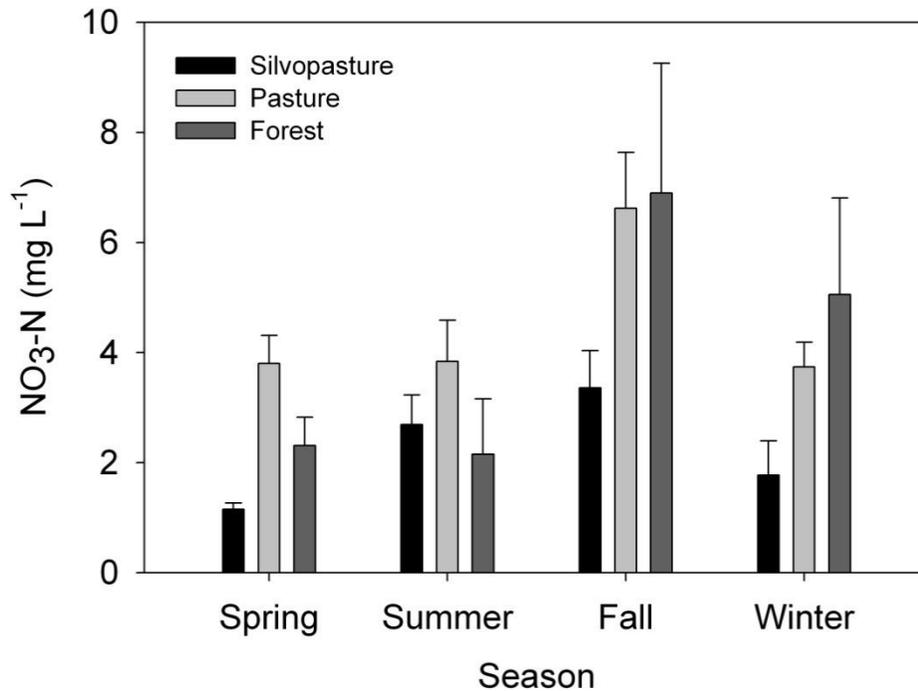


Figure 2. Mean seasonal NO₃-N concentrations at the soil/bedrock interface in silvopasture, pasture, and hardwood forest land uses. Spring = Mar – May, Summer = June – Aug., Fall = Sept. – Nov., Winter = Dec. – Feb.

6.6 and 6.9 mg L⁻¹, respectively. The fall NO₃-N concentration in SP averaged 3.4 mg L⁻¹. Linear regression analysis of NO₃-N concentration versus days since start of study failed to indicate any significant trend during the study. Linear regression trend analysis of NH₄-N concentrations did indicate significantly decreasing concentrations. NH₄-N concentrations decreased about 2 mg L⁻¹ yr⁻¹ in SP and HW land uses and about 0.15 mg L⁻¹ yr⁻¹ in CP.

Geometric mean FC concentrations at the soil/bedrock interface were highest in summer in all three land use treatments (Fig. 3) and FC concentrations were next highest in fall and gradually decreased through winter to their lowest concentrations in spring. The highest geometric mean FC concentrations during the growing season occurred in the forest site, which was not grazed by sheep. Trend analysis using linear regression failed to show any significant trend in log FC concentrations in the CP or HW land uses, but a highly significant ($P \geq 99.9$) decreasing trend (0.23 log CFU 100 ml⁻¹ yr⁻¹) in the SP land use.

Cumulative frequency analyses of the occurrence of NO₃-N concentrations show similar results up to about 30 percent of the samples (see Fig. 4). At the 30 percent level nitrate concentrations increase more rapidly in CP and least rapidly in SP. The CP and HW cumulative frequency curves converge at about 80 percent of the samples and the SP samples remain lower until about 95 percent of the samples where all three curves are similar. Higher FC concentrations are shown

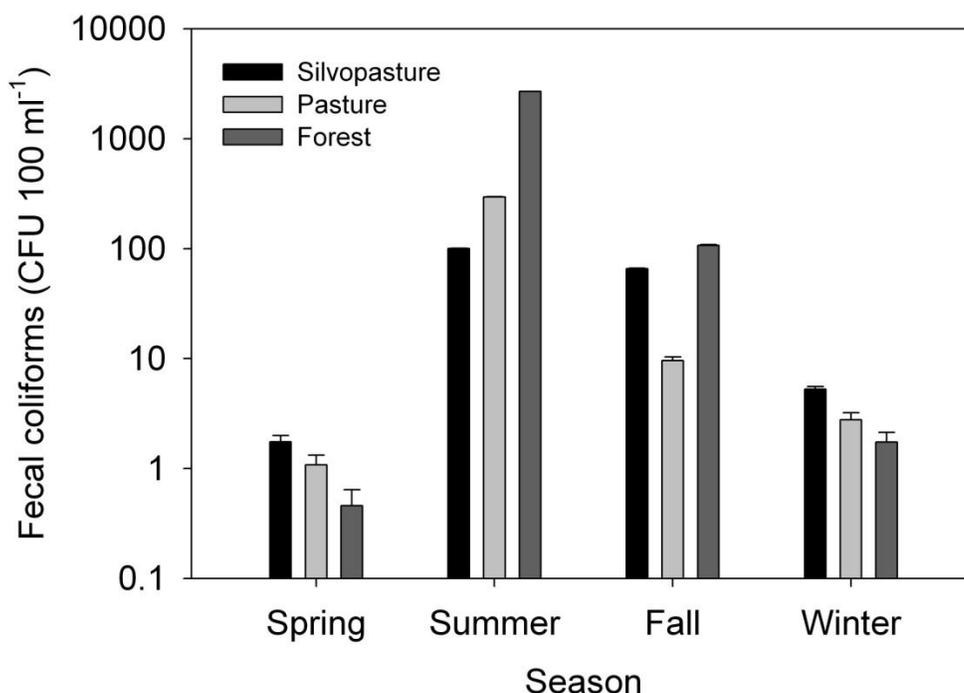


Figure 3. Geometric mean seasonal FC concentrations at the soil/bedrock interface in silvopasture, pasture, and hardwood forest land uses. Spring = Mar – May, Summer = June – Aug., Fall = Sept. – Nov., Winter = Dec. – Feb.

for SP in Figure 5. Forty percent of the samples from SP had FC concentrations ≤ 1 CFU 100 ml⁻¹. More than sixty percent of the CP and HW samples had FC concentrations ≤ 1 CFU 100 ml⁻¹.

DISCUSSION

The low NO₃-N concentrations at the soil/bedrock interface in SP relative to those in CP and HF are encouraging from a water quality standpoint. NO₃-N concentration in SP might have been expected to be similar to those in HF, but the forage plants in SP were probably using much of the NO₃-N that might have been expected to leach. Staley et al. (2008) found that soil chemical characteristics of these same silvopasture sites were rapidly approaching pasture-like conditions, but they did not look at NO₃-N. Over time, SP NO₃-N might be expected to approach the concentrations found in CP, but the trend analysis failed to show any movement in that direction. The high NO₃-N concentrations in fall in CP and HW might be related to leaf fall in HF and senescing of white clover in CP. There was much less leaf fall and little white clover in the SP plots and the C3 grasses in the SP plots were likely able to use much of the NO₃-N that did result from those sources.

There is a constant shift in soil systems between NH₄-N and NO₃-N as oxidizing and reducing conditions occur. The lack of differences in total inorganic N concentrations between the three land uses, but shifted emphasis of NH₄-N and NO₃-N between the systems indicates that the land uses were having differential effects on the oxidizing and reducing conditions.

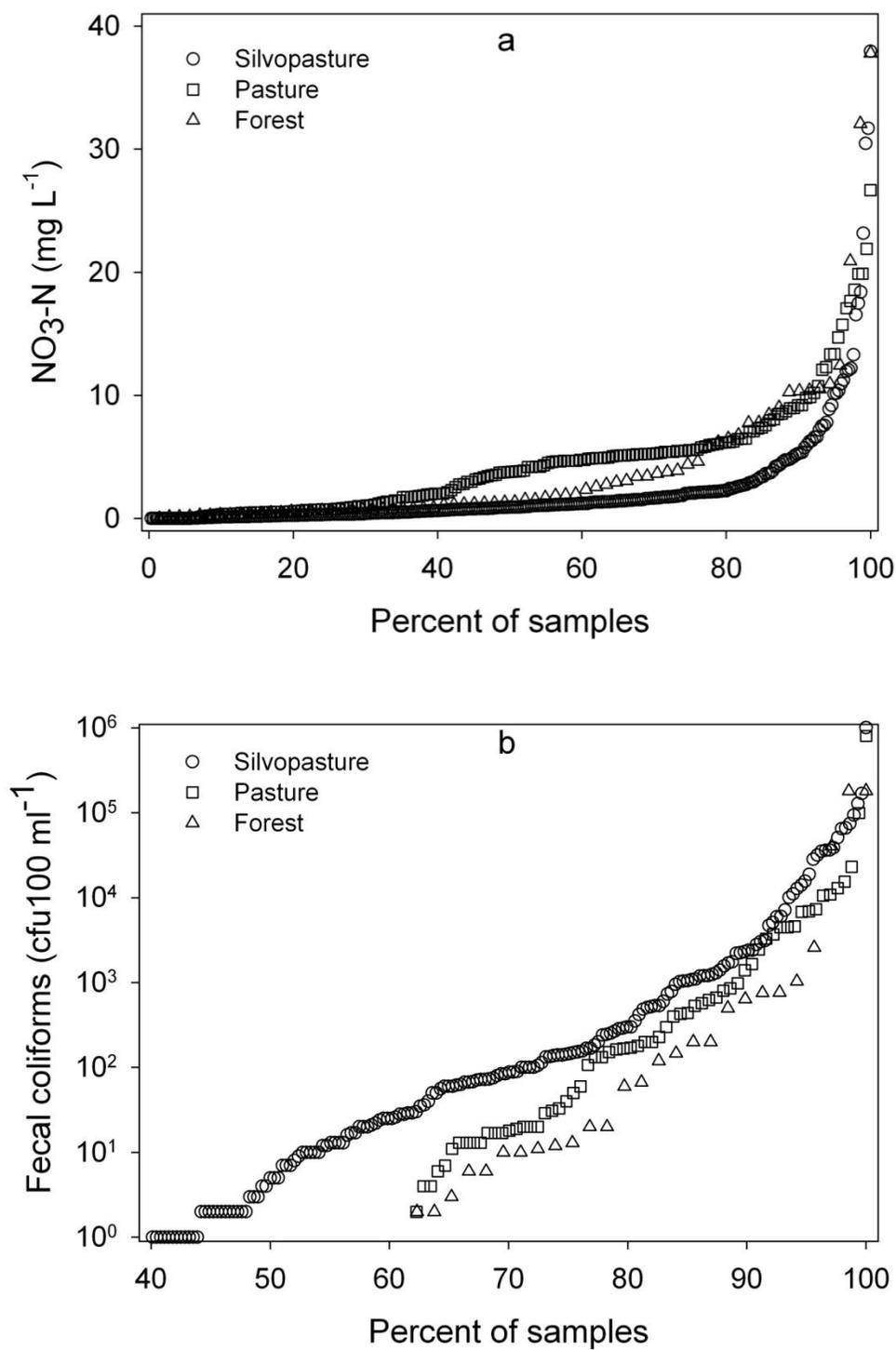


Figure 4. Cumulative distributions of a.) $\text{NO}_3\text{-N}$ and b.) FC concentrations at the soil/bedrock interface in silvopasture, pasture, and hardwood forest.

The high geometric mean FC concentrations in SP are troubling and might have resulted from a well-organized system of macropores and disturbance of the surface litter layer. Removal of some of the organic litter layer diminishes the sites ability to intercept water before it reaches mineral soil and the macropores provide a fairly direct route to deeper soil layers bypassing much of the filtration provided by the soil matrix. Boyer et al. (2009) found that macropores readily transmitted *Cryptosporidium* oocysts, which are two to four times greater in size than FC, through soil. The high FC concentrations at the soil/bedrock interface in HW were a surprise since livestock were not grazed in the vicinity of the piezometers. Results shown in Figure 4b indicate that FC were not transported to the soil/bedrock interface on a regular basis (more than 60 percent of the HW samples did not test positive for FC). The intermittent high FC counts in HW water samples were probably a result of FC transported from wild animal burrows through intersecting macropores. Wild animals cannot be excluded as sources of FC in the SP samples, but a much higher percentage of samples in SP tested positive for FC indicating that sheep manure was a source of bacteria.

Geometric mean FC concentrations in SP would be expected to equal the geometric mean concentration in CP after five to six years if the current trend continues. However, the SP sites should retain some of the macropore features and FC concentrations might still be somewhat greater than those in pasture at the soil/bedrock interface. FC bacteria reaching the soil/bedrock interface are expected to experience a tortuous route through bedrock fractures, often in-filled with sediment, and never reach surface water. A higher portion of flow in CP might be overland flow providing fecal coliform bacteria a more direct route to surface water.

Results from this study show that NO₃-N contributions to shallow groundwater are less under silvopasture than conventional pasture. Macropores in silvopasture systems seem to lend easier transport of fecal organisms to shallow groundwater, but the tortuous route flow route through fractured bedrock to surface water should minimize impacts on surface water quality. Ungrazed buffers along surface streams might provide effective barriers to fecal bacterial contamination from silvopasture areas where overland flow is minimized. The observations from this study will be important information for the development of decision support tools for maximizing forage and livestock productivity, through silvopastoral management on sloping land of central Appalachia, while protecting surface and groundwater quality.

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CT-MEASURED MACROPORES AS AFFECTED BY AGROFORESTRY AND GRASS BUFFERS FOR GRAZED PASTURE SYSTEMS

Sandeep Kumar¹, Stephen H. Anderson¹, and Ranjith P. Udawatta^{1,2}

¹Department of Soil, Environmental and Atmospheric Sciences, University of Missouri-Columbia

²Center for Agroforestry, University of Missouri-Columbia, Columbia, MO 65211, USA.

Contact: sk9fd@mizzou.edu

Abstract: Agroforestry and grass buffers have been proposed for improving water quality in watersheds. Buffer vegetation influences soil porosity, essential for water, gas and nutrient transport in soils. The objective of the study was to compare differences in CT-measured macropore (>1000- μm diam.) and coarse mesopore (200- to 1000- μm diam.) parameters within agroforestry (AgB) and grass buffer (GB) systems associated with rotationally grazed (RG) and continuously grazed (CG) pasture systems, and to examine relationships between CT-measured pore parameters and saturated hydraulic conductivity (K_{sat}). Soils at the site were Menfro silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalf). Six replicate intact soil cores, 76.2 mm diam. by 76.2 mm long, were collected using a core sampler from the four treatments at five soil depths (0-50 cm at 10-cm intervals). *Image-J* software was used to analyze the five equally spaced images from each core. CT-measured soil macroporosity (>1000 μm diam.) was 13 times higher (0.053 m^3m^{-3}) for the buffer treatments compared to the pasture treatments (0.004 m^3m^{-3}) for the surface 0-10 cm soil depth. Buffer treatments had greater macroporosity (0.020 m^3m^{-3}) compared to pasture (0.0045 m^3m^{-3}) treatments. The K_{sat} values for buffer treatments were five times higher and bulk density was 5.6% lower compared to pasture treatments. CT-measured pore parameters (except macropore circularity) were positively correlated with K_{sat} . This study illustrates the benefits of agroforestry and grass buffers for maintaining soil pore parameters critical for soil water and nutrient transport.

Abbreviations: AgB, agroforestry buffer; CG, continuously grazed pasture; CT, computed tomography; GB, grass buffer; K_{sat} , saturated hydraulic conductivity; NPSP, nonpoint source pollution; RG, rotationally grazed pasture

INTRODUCTION

Agroforestry buffers have been recently introduced to improve environmental quality and diversify farm income. Agroforestry and grass buffers help in reducing nonpoint source pollution (NPSP) from row crop areas by improving soil hydraulic properties and reducing surface runoff (Udawatta et al., 2002; Seobi et al., 2005). These buffers increase the soil porosity relative to row crop land management under tilled or no-till practices (Seobi et al., 2005). Establishment of buffers in pasture areas has been shown to decrease soil bulk density and increase soil porosity (Kumar et al., 2008).

Soil porosity is an important parameter related to transport and storage of water and nutrients in the soil. Water transmission and storage depend on the geometry and size distribution of soil

pores (Eynard et al., 2004). Pore size distribution and connectivity of pores, is believed to control soil hydraulic properties (Pierret et al., 2002).

X-ray CT scanning has been shown by various researchers to be useful for measuring soil microstructure (Phillips and Lannutti, 1997; Alshibli et al., 2000). X-ray CT scanning has given promising results for measuring the shape, distribution, and arrangement of soil pores within the soil (Udawatta et al., 2008b). This technique also has been applied to characterize pore continuity and tortuosity (Udawatta et al., 2008b). According to Tollner et al. (1994), X-ray CT scanning can provide aggregate size data consistent with traditional testing.

CT procedures have advantages compared to traditional methods since these procedures provide a finer resolution on a mm- to micrometer-scale (Gantzer and Anderson, 2002). The non-destructive nature of CT scanning allows the same soil sample to be scanned at different times. Carlson et al. (2003) reported that the best advantage of CT is its ability to quickly and nondestructively image the interior of a three-dimensional object. CT techniques can give the three dimensional structure of soil pores. Another advantage of X-ray CT scanning is its ability to quantitatively measure soil bulk density and water content distributions in undisturbed soil samples (Heijs et al., 1995).

The objective of the study was to compare effects of agroforestry buffer (AgB) and grass buffer (GB) systems associated with rotationally grazed pasture (RG) and continuously grazed pasture (CG) systems on CT-measured macropore (>1000- μm diam.) and coarse mesopore (200- to 1000- μm diam.) parameters and to examine relationships between CT-measured pore parameters and saturated hydraulic conductivity (K_{sat}).

MATERIALS AND METHODS

Study Area and Management

The experimental site is located at the Horticulture and Agroforestry Research Center (HARC) in New Franklin, MO, USA (39°02'N, 92°46'W, 195 m above mean sea level). The study site was established in 2000 to compare the effects of grass and agroforestry buffers on runoff water quality (Kumar et al., 2008). The pasture areas and buffers were re-seeded with tall fescue (*Festuca arundinacea* Schreb) in 2000. The pastures were also seeded with red clover (*Trifolium pretense* L.) and lespedeza (*Kummerowia stipulacea* Maxim.) into the fescue in 2003. Four rows of eastern cottonwood trees (*Populus deltoids* Bortr. ex Marsh.) were planted into the fescue to create the agroforestry buffers in 2001. Trees were planted at 3 m intervals within and between rows. Additional information about the study site can be found in Kumar et al. (2008).

Soils at the site are Menfro silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalf). The annual precipitation of the experimental site for the last 50 years (1956-2006 year) is 967 mm; mean temperature in July is 25.6°C and mean temperature in January is -2.1°C. The treatments included agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG), and continuously grazed pasture (CG) systems. The GB and AgB buffer treatments were fenced from the pasture areas preventing access by the cattle. The RG treatment was rotationally

grazed with six fenced areas (paddocks) within the small watershed. The CG pasture treatment was continuously grazed by cattle with no rest.

Grazing was initiated at the site in late March or early April and discontinued in late October or early November each year. During late July or early August, cattle were removed for about one month due to poor grass growth. The pasture treatment sites had been grazed for three years prior to sampling. Each year, beef cows were introduced in the pasture area with average weight of 520 kg. The number of cattle for the small watershed (0.8 ha) was three. Eighty-five percent of the grazing area (0.64 ha) of the watershed was divided into six smaller rotationally grazed paddocks with a single wire electric fences for cattle management. The other 15% of the grazing area was continuously grazed. The cows were moved between paddocks on each Monday and Thursday with each paddock being grazed for 3.5 days and rested for 17.5 days.

Sample Collection

Intact soil cores were collected from the four treatments and five soil depths (0 to 50 cm in 10 cm increments) with six replications per treatment on 6 and 7 June, 2007. The Plexiglas rings were 76.2 mm long and 76.2 mm diam. The CG treatment samples were taken from six replicate continuously grazed areas and RG samples were taken from six replicate rotationally grazed areas. The AgB samples were taken from soil under six replicate trees, three each from two tree rows in the agroforestry buffer area. These samples were taken at a distance of 20 cm from the base of tree trunks in the agroforestry buffer. The GB samples were taken from six replicate grass buffer areas. Soil cores were labeled, trimmed, and sealed in plastic bags and transported to the laboratory and stored at 4°C until measurements were taken.

Scanning and Image Analysis

Soil cores were saturated with a dilute salt solution (CaCl_2 ; 6.24 g L⁻¹ and MgCl_2 ; 1.49 g L⁻¹) to retain soil structure. After 24 h, weights were recorded and samples were then drained at 35 cm tension for 24 h using a glass-bead tension table, which removed water from pores > 85 μm equivalent cylindrical diameter to enhance image contrast between air-filled pores and soil solids. These cores were scanned using a Siemens Somatom Plus 4 Volume Zoom X-ray CT scanner to acquire CT scan images. Five images were acquired from each core at the following scan depths from the core surface: 1.7, 2.8, 3.9, 5.0, and 6.1 cm. The pixel resolution was 0.19 by 0.19 mm. The width or “slice” thickness was 0.5 mm producing a volume element (voxel) size of 0.018 mm³.

Images were analyzed using the *Image-J* ver. 1.27 software (Rasband, 2002) to examine the treatment effects on pore size distributions and pore characteristics.

The macropore and mesopore characteristics analyzed included porosity (macroporosity plus coarse mesoporosity), macroporosity (>1000-μm diam.), and coarse mesoporosity (200- to 1000-μm diam.). In addition, fractal dimension of macropores was analyzed. Macroporosity and mesoporosity at each scan depth were calculated from the total area of all macropores and mesopores isolated in the image at a given depth divided by the cross sectional area (2500 mm²) of the selected region on the soil core image.

The threshold value selected to analyze all images was 40 (range is 0 to 255). The values lower than the threshold values were identified as the air-filled pores and the values greater than threshold value were identified as non-pore. The fractal dimension of macropores was determined with zero to 100 threshold values to better populate the low porosity samples with pores (Gantzer and Anderson, 2002).

Saturated Hydraulic Conductivity and Bulk Density

After scanning, saturated hydraulic conductivity and dry bulk density were determined on all 120 soil cores. Saturated hydraulic conductivity was measured using the constant head method (Klute and Dirksen, 1986). The same soil cores were used for determining bulk density as described by Blake and Hartge (1986).

Statistical Analysis

A test for homogeneity of variance was conducted to evaluate the variability within the different treatments due to the systematic arrangement of treatments. Single degree-of-freedom contrasts were also determined and were conducted as follows: *buffers vs. pastures*, *grass buffer vs. agroforestry buffer*, and *rotationally grazed pasture vs. continuously grazed pasture*. The differences in pore characteristics among scans along the soil core were statistically compared to evaluate depth and management influences using PROC MIXED (SAS Inst., 1999). Statistical differences were declared significant at the $\alpha = 0.05$ level.

RESULTS AND DISCUSSION

CT-Measured Porosity, Macroporosity and Coarse Mesoporosity

CT-measured porosity (macroporosity plus coarse mesoporosity), macroporosity and coarse mesoporosity were significantly influenced by the AgB, GB, RG, and CG treatments ($P < 0.01$, Table 1, Fig. 1). Significant differences were found for two contrasts: 'buffers vs. pastures' and 'grass buffer vs. agroforestry buffer' ($P < 0.01$; Table 1). Buffers had higher porosity (271%), macroporosity (322%), and coarse mesoporosity (140%) as compared to pasture treatments. All three parameters were found to be the highest for the GB treatment.

Soil depth zones (10 cm increment depths) also influenced porosity, macroporosity and coarse macroporosity (Table 1). Porosity decreased linearly with soil depth ($r = -0.82$). Similar trends were found with macroporosity ($r = -0.82$) and coarse mesoporosity ($r = -0.83$). The greatest differences among depth zones for porosity, macroporosity and coarse mesoporosity were observed between the 0-10 and 10-20 cm depth zone.

Porosity, macroporosity, and coarse mesoporosity values decreased from the first to second depth zones for the AgB (77, 79, 82%, respectively) and GB (57, 63, 25%, respectively) treatments; whereas, an increase in the values of these parameters was observed in the RG (86, 150, 50%) and CG (100, 75, and 200%) treatments for similar depth zones (Fig. 1). This was probably caused by cattle grazing on the pasture treatments. Interactions between treatment and soil depth zone were also found ($P < 0.010$; Table 1; Fig. 1).

Previous studies in Iowa and Missouri showed that grass, tree and native prairie improved CT-measured porosity and macroporosity (Rachman et al., 2005; Udawatta et al., 2006, 2008a). The data from the current study showed that the CG treatment had the lowest porosity and macroporosity which will probably contribute to more surface runoff

Table 1. Average CT-measured porosity (porosity, macroporosity, and coarse mesoporosity) and fractal dimension of macropores as influenced by agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG), and continuously grazed pasture (CG) treatments and soil depth along with the analysis of variance.

	Porosity	Macro-porosity	Coarse Mesoporosity	Fractal Dimension
Treatment means	m ³ m ⁻³	m ³ m ⁻³	m ³ m ⁻³	
Agroforestry buffer (AgB)	0.018 ^b	0.013 ^b	0.004 ^b	1.21 ^b
Grass buffer (GB)	0.034 ^a	0.026 ^a	0.008 ^a	1.41 ^a
Rotationally grazed (RG)	0.008 ^c	0.005 ^c	0.003 ^c	1.14 ^b
Continuously grazed (CG)	0.006 ^c	0.004 ^c	0.002 ^c	1.08 ^b
Depth means				
0- to 10-cm	0.035 ^a	0.035 ^a	0.029 ^a	1.33 ^a
10- to 20-cm	0.017 ^b	0.017 ^b	0.013 ^b	1.21 ^b
20- to 30-cm	0.010 ^c	0.010 ^{bc}	0.007 ^{bc}	1.15 ^c
30- to 40-cm	0.009 ^c	0.009 ^c	0.005 ^c	1.14 ^c
40- to 50-cm	0.011 ^c	0.011 ^{bc}	0.007 ^{bc}	1.13 ^c
	Analysis of Variance, P > F			
Treatment	<0.01	<0.01	<0.01	<0.01
Buffers vs. Pastures	<0.01	<0.01	<0.01	<0.01
GB vs. AgB	<0.01	<0.01	<0.01	<0.01
RG vs. CG	0.63	0.78	0.10	0.10
Depth	<0.01	<0.01	<0.01	<0.01
Treatment by Depth	<0.01	<0.01	<0.01	<0.01

The ANOVA table represents significance levels among treatments and depths for the measured parameters.

from this area. In contrast, the buffer treatments had higher porosity and macroporosity values which will allow better infiltration of water and hence less runoff.

CT-Measured Fractal Dimension of Macropores

Fractal dimension of macropores was significantly affected among the four treatments (P<0.01; Table 1). The fractal dimension of macropores ranged from 1.08 (CG treatment) to 1.41 (GB treatment). Significant differences were found for two contrasts: ‘buffers vs. pastures’ and ‘grass buffer vs. agroforestry buffer’ (Table 1). The higher fractal dimension values for the surface 0-10 cm depth observed in the AgB (1.53) and GB (1.62) treatments may suggest more macroporosity and hence a higher probability of preferential water flow due to large and more elongated pores compared to the RG and CG treatments. The fractal dimension of macropores increased from the first to second depth zone (1.08 to 1.21; 1.06 to 1.08, respectively, for RG and CG treatments); with further depths, the values decreased.

The continuous grazing treatment lowered the fractal dimension for the first depth zone; hence values for this treatment increased from the first to second depth. Soil depth zone also influenced the fractal dimension of macropores ($P < 0.01$). Fractal dimension decreased with soil depth (Table 1) as did macroporosity.

Correlation of Pore Parameters and Saturated Hydraulic Conductivity

An evaluation of soil bulk density and saturated hydraulic conductivity is presented prior to correlation analysis of properties. Soil bulk density was different among the treatments ($P < 0.01$; Fig. 2). Buffer treatments (1.35 g cm^{-3}) had 5.6% lower soil bulk density than pasture treatments (1.43 g cm^{-3}). Soil bulk density changed with soil depth zone ($P < 0.01$). Bulk density generally increased with soil depth for the buffer treatments whereas for the CG treatment bulk density was unaffected after the second soil depth zone (Fig. 2). Interactions between treatment and soil depth were also found ($P < 0.01$; Fig. 2). The current study supports findings reported in previous research (Kumar et al., 2008).

The K_{sat} values were found to be different among the treatments. The buffer treatments had the highest (75.8 mm h^{-1}) K_{sat} , averaged across depths while the two grazed pasture treatments had the lowest K_{sat} (15 mm h^{-1}). The K_{sat} was about 31 times higher in the buffers as compared to grazed pasture systems for 0-10 cm soil depth zone. The K_{sat} values significantly decreased with increasing soil depth zone (Fig. 2).

For correlation analysis, averages of the five scan depths per core were used as core parameters for each property. Nine CT-measured pore parameters (number of pores, number of macropores, number of coarse mesopores, porosity, macroporosity, coarse mesoporosity, area of largest pore, circularity of macroporosity, and fractal dimension of macropores) along with bulk density were regressed with saturated hydraulic conductivity (Table 2).

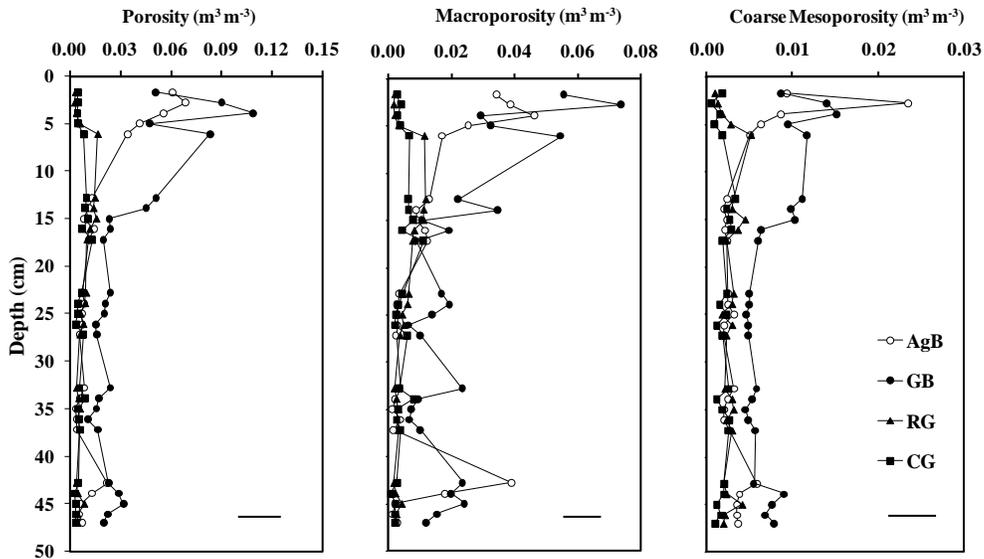


Figure 1. CT-measured porosity, macroporosity, and coarse mesoporosity for the agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG) and continuously grazed pasture (CG) treatments influenced by soil depth. The bar indicates the LSD (0.05) values.

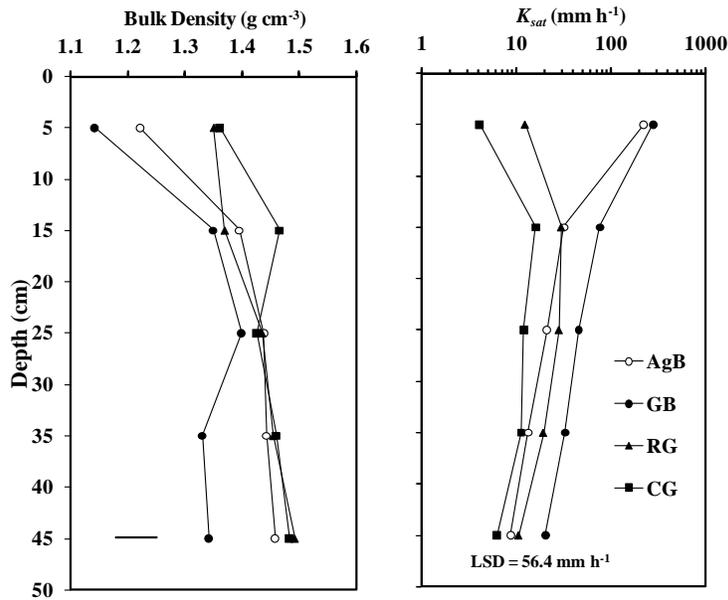


Figure 2. Mean soil bulk density and saturated hydraulic conductivity (K_{sat}) for the agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG) and continuously grazed pasture (CG) treatments influenced by soil depth. The bar indicates the LSD (0.05) value for bulk density. The LSD (0.05) value for K_{sat} is listed on the graph due to log scale.

All CT-measured pore parameters except circularity were positively correlated with K_{sat} . Circularity was negatively correlated due to more circular pores being present among the pasture

treatments which had lower K_{sat} . Among the nine CT-measured pore parameters, macroporosity explained 58% of the variation in saturated hydraulic conductivity (Table 2).

Number of macropores with porosity was the best two parameter combination and accounted for 63% of the variation in K_{sat} . The number of macropores with macroporosity was the second best two parameter combination (Table 2). Regression analysis showed that macroporosity and porosity ranked the best when evaluating single parameters. Dosskey et al. (2007) reported that increased macroporosity should increase infiltration and reduce sediment transport capacity of the runoff water. Our findings imply that the buffers which had higher porosity and macroporosity will infiltrate more water and allow less runoff.

Table 2. Relationships between CT-measured pore parameters with saturated hydraulic conductivity.

Relationship	Coefficient of Determination	Significance Level
<i>Single parameter</i>		
$K_{sat} = -0.36 + 3743.88*\text{macroporosity}$	0.580	0.001
$K_{sat} = -6.51 + 3166.25*\text{porosity}$	0.579	0.001
$K_{sat} = -30.84 + 1.58*\text{pores}^\dagger$	0.517	0.001
<i>Two parameters</i>		
$K_{sat} = 4.59 - 5.93*\text{macropores}^\dagger + 6825.76*\text{porosity}$	0.635	0.001
$K_{sat} = 10.9 - 3.54*\text{macropores} + 6292.15*\text{macroporosity}$	0.607	0.001

[†]Pores = number of pores, macropores = number of macropores.

CONCLUSIONS

This study evaluated the hypothesis that buffers would influence CT-measured soil pore parameters in pasture systems. Agroforestry and grass buffer treatments had higher porosity, macroporosity, coarse mesoporosity, and fractal dimension of macropores compared to grazed pasture treatments. Buffer treatments also had lower soil bulk density (5.6 %) and higher saturated hydraulic conductivity (5 times higher) compared to pasture treatments. The K_{sat} for the buffer treatments was 31 times higher compared to pasture treatments within the upper 0-10 cm depth.

Most CT-measured pore parameters within buffer treatments usually decreased significantly between the first and second depth zones (0-10 and 10-20 cm) while values in these depth zones either increased slightly or stayed the same for the pasture treatments. All CT-measured pore parameters except circularity were positively correlated with K_{sat} . Increased macroporosity in buffer areas will probably increase soil water infiltration, increase gas exchange, and reduce runoff and nonpoint source pollution. Differences in pore parameters were attributed in part to differences in root growth and development among the treatments. For improved infiltration, buffer zones should be managed to prevent cattle traffic for better maintenance of soil pore characteristics.

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AGROFORESTRY AND GRASS BUFFER EFFECTS ON WATER QUALITY ON GRAZED PASTURE WATERSHEDS

Ranjith P. Udawatta^{1,2}, Harold E. Garrett², and Robert L. Kallenbach³

¹Department of Soil, Environmental and Atmospheric Sciences, ²Center for Agroforestry, and ³Department of Plant Sciences, University of Missouri, Columbia, MO 65211.

Contact: UdawattaR@missouri.edu

Abbreviations: AB, Agroforestry Buffers; GB, Grass Buffers, NPSP, non point source pollutants; TN, total nitrogen; TP, total phosphorus.

Abstract: Conservation practices including agroforestry and grass buffers are believed to reduce non point source pollution (NPSP) from grazed pasture watersheds. Agroforestry, a land management practice that intersperses agricultural crops with trees, recently received increased attention in the temperate zone due to its environmental and economic benefits. However, studies are limited that examined buffer effects on water quality on grazed pasture watersheds. Six small watersheds, two with agroforestry buffers, two with grass buffers, and two control watersheds were used to test the hypothesis that agroforestry and grass buffers reduce NPSP from grazed pasture watersheds. Vegetation in grass buffer and pasture areas include red clover (*Trifolium pretense* L.) and lespedeza (*Kummerowia stipulacea* Maxim.) planted into fescue (*Festuca arundinacea* Schreb.). Eastern cottonwood trees (*Populus deltoids* Bortr. ex Marsh.) were planted into fescue in agroforestry buffers. Soils at the site are mostly Menfro silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalfs). Watersheds were instrumented with two-foot H flumes, water samplers, and flow measuring devices in 2001. Composite water samples were analyzed for sediment, and total nitrogen after each runoff event to compare treatment differences. Watersheds with agroforestry and grass buffers had significantly lower runoff volumes as compared to the control watersheds. The loss of sediment, and total nitrogen were smaller for the buffer watersheds. The results of the study suggest that establishment of agroforestry and grass buffers help reduce NPSP pollution from grazed pasture watersheds. It is anticipated as trees grow and roots occupy more soil volume, the reduction in N in runoff should increase on the agroforestry watershed.

Key Words: HARC, Menfro soil, nitrogen, phosphorus, runoff, sediment

INTRODUCTION

Agricultural management practices including grazing management are often blamed having adverse effects on the quality of surface and ground waters. The U.S. Environmental Protection Agency (2000) noted that most common pollutants to rivers and streams from livestock grazing include pathogens, siltation, organic enrichment, and nutrients. A 500-kg dairy cow produces 43 kg manure d⁻¹ (Hubbard et al. 2004). Each ton of manure produced by a cow contains approximately 4.5 kg N, 2.3 kg P₂O₅, and 3.6 kg of K₂O. A grazing cow returns 79% of the N, 66% of the P, and 92% of the K consumed back to the soil. In some regions, watersheds under poor grazing management discharge 5 to 10 times more nutrients than those under cropland and

forest production (Hubbard et al. 2004). Poor grazing management practices not only increase contamination of surface and ground waters but reduce farm income. These pollutants enter the water bodies through surface flow and or subsurface flow.

Although surface and subsurface losses from grazed pastures are related to rainfall amounts (Campbell and Allen-Diaz 1997), these losses vary with soil type. For example, in the unglaciated plains of Ohio, 20-75% of the loss occurs in base flow (Owens et al. 1991) while on highly permeable soils in the mid-Atlantic coastal Plains, 43-75% of the loss occurs in underflow (Volk et al. 2006). Therefore, highly permeable soils as found in areas similar to the current study site in particular need conservation measures that reduce water contamination from grazing management.

Control of NPSP from grazing is important to improve water quality (Agouridis et al. 2005). Grazing management practices can be improved to protect water quality while maintaining farm profitability and grass production. According to a review by Dahlin et al. (2005), nutrient loss can be reduced and production can be improved through proper management of grazing animals and pastures. A recent study in New York showed that management can help reduce soil-phosphorus build-up and losses at field and watershed scale (Ghebremichael et al. 2008). Adoption of alternative practices that improve soil and water quality and farm income are essential for sustainability of small, family livestock operations.

Implementation of water quality protection may include establishing vegetative buffers, protecting stream and streambanks, and managing grazing. Russell (2006) showed that vegetative buffers reduce significant quantities of nutrients in runoff. Studies conducted on grazed pasture watersheds have shown that establishment of buffers at the field edge improves soil physical properties (Wood et al. 1989; Kumar et al. 2008). Faster growing trees with deeper root systems function as an efficient safety net to capture nutrients that were lost from the crop or pasture root zone. On the soil surface, tree roots, fallen branches, and litter material reduce flow velocity and thereby enhance sedimentation. Moreover, they help reduce loss of sediment bound nutrients. Establishment of buffers may also help reverse adverse effects such as increased bulk density and reduced porosity (Daniel et al. 2002; Wheeler et al. 2002).

States are now required to implement water quality criteria, based on USEPA guidelines or by using other scientifically defensible methods (Ice and Binkley 2003). Land owners, state agencies and other regulatory authorities need scientifically proven, practically realistic, and biologically acceptable buffer development guidelines for the protection of water resources. Use of agroforestry buffers and riparian buffers to reduce NPSP from grazed pasture watersheds seems advantageous from economic and practical perspectives. Unfortunately, experimental studies comparing effectiveness of these buffers by ecoregions or landuses are largely missing from the literature. There is a need for more information on the effects of buffers on water quality, to enable farmers to adopt the most suitable practice for their farm. This paper examines (1) the effects of agroforestry and grass buffers on discharge of water, sediment, and nutrients, and (2) the effects of precipitation distribution on runoff, sediment and nutrient loss on grazed pasture watersheds. The results reported here are part of a long-term study to evaluate soil and water quality as influenced by agroforestry and grass buffers on grazed pasture watersheds.

MATERIALS AND METHODS

Study watershed and management

Six mini watersheds located at Horticulture Agroforestry Research Center, New Franklin, Missouri, USA (39° 02' N and 92°46' W, 195 m above mean sea level), were studied during 2000-2008 period (Fig. 1). The watersheds represent two conservation management practices and a control treatment. Two watersheds have agroforestry buffers and two watersheds have grass buffers. The remaining two watersheds have no buffers. The vegetation in the buffer and grazing areas consist of tall fescue (*Festuca arundinacea* Schreb), red clover (*Trifolium pretense* L.), and lespedeza (*Kummerowia stipulacea* Maxim.). Four rows of eastern cottonwood trees (*Populus deltoides* Bortr. ex Marsh.) were planted in 2001 at 3m between and within row spacings to create the agroforestry buffers. The grazing area is 107 m long and 60 m wide. The buffer area at the lower landscape position is 107 m long and 15 m wide. The average tree diameter at the end of the 2008 growing season was 13 cm at breast height (1.4 m above ground).

Soils in the watersheds are Menfro silt loam (fine-silty, mixed superactive, mesic Typic Hapludalfs) with 30% slope. The long-term mean precipitation (1956-2007) for the study area is 970 mm (<http://mrcc.isws.illinois.edu>). Of this precipitation, about 64% falls in April through September. The mean temperature in July is 31.7°C and mean temperature in January is -7.6°C.

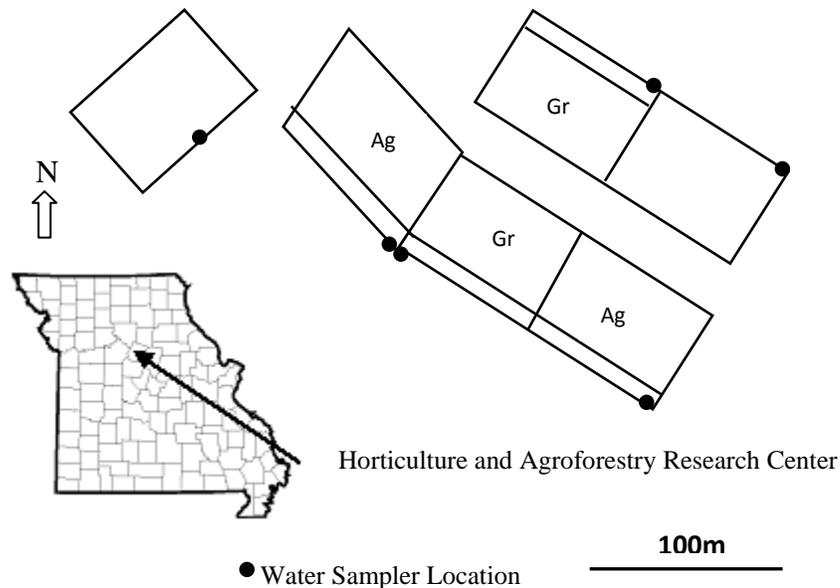


Figure 1. The six studied watersheds at Horticulture and Agroforestry Research Center (HARC), New Franklin, Howard County, Missouri. The inset map shows approximate location of the HARC Center. Narrow strips on four watersheds represent agroforestry (Ag) and grass (Gr) buffers.

Watersheds were established and managed with no cattle for four years and cattle were introduced in 2005. Each year since grazing begun, 450-490 kg beef cows have been placed in the pasture area for approximately 215 days between March and November. In brief, a four-wire

fence was installed around the watershed area and between the grazing and buffer areas. The grazing area within each watershed was divided into six paddocks with electric fences and the cattle were rotated to the adjoining paddock after 3.5 days of grazing. Thus each paddock is rested for 17.5 days. Additional information about cattle management and the study site can be found in Kumar et al. (2008).

Sample collection and analysis

Each watershed is instrumented with a 2-foot H flume, ISCO water sampler (Lincoln, NE, USA), and a ISCO bubbler flow measuring device to record flow rate, water level, sampling time and to collect water samples. These units are removed from the watersheds during the third week of December when the water in the stilling well is frozen. Thus the sample collection period extends from February/March to late-December each year.

Flow measuring devices control the sampler to collect water samples. A 125-mL sample was collected after each 5 m³ flow, and samples were composited. Water samples were transferred from the field to the laboratory and analyzed for sediment and total nitrogen (TN). Unprocessed samples were refrigerated at 4°C until analysis. After a runoff event, flow, level, and sample intake time data were downloaded to a laptop computer.

A known volume of a well mixed sample was filtered through a pre-weighed glass microfiber filter (934-AH) using a vacuum pump (maximum vacuum 7 lbs in⁻² above ambient) to estimate sediment weight. These filters were dried at 105°C to a constant weight. Differences between the tare weights and sample volume were used to estimate the weight of suspended sediment.

A Lachat Quick-Chem 8000 Analyzer was used to determine TN concentrations. Total nitrogen was determined using cadmium reduction on unfiltered samples following potassium persulfate digestion. The detection limits for the TN method is 0.002 mg L⁻¹.

Statistical analysis of data will be performed using SAS (SAS Inst. 1999). Random variables, runoff, sediment loss, and nutrient loss will be analyzed as a split-plot in time. The main plot will consist of management and the subplots will consist of year and interaction of management*year. The fixed effects are management, year, and the interaction of management*year. Mean differences will be determined using Fisher Least Significance (LSD) and will be calculated using a LSMeans statement within the Proc Mixed procedure. The variance-covariance matrix will be investigated using AIC coefficient to determine the most suitable mean separation procedure.

RESULTS AND DISCUSSION

Precipitation

The study area received 15 and 48% more precipitation than the long-term mean (970 mm) in 2004 and 2008, respectively (Fig. 2). The precipitation amounts were 5, 17, and 10%

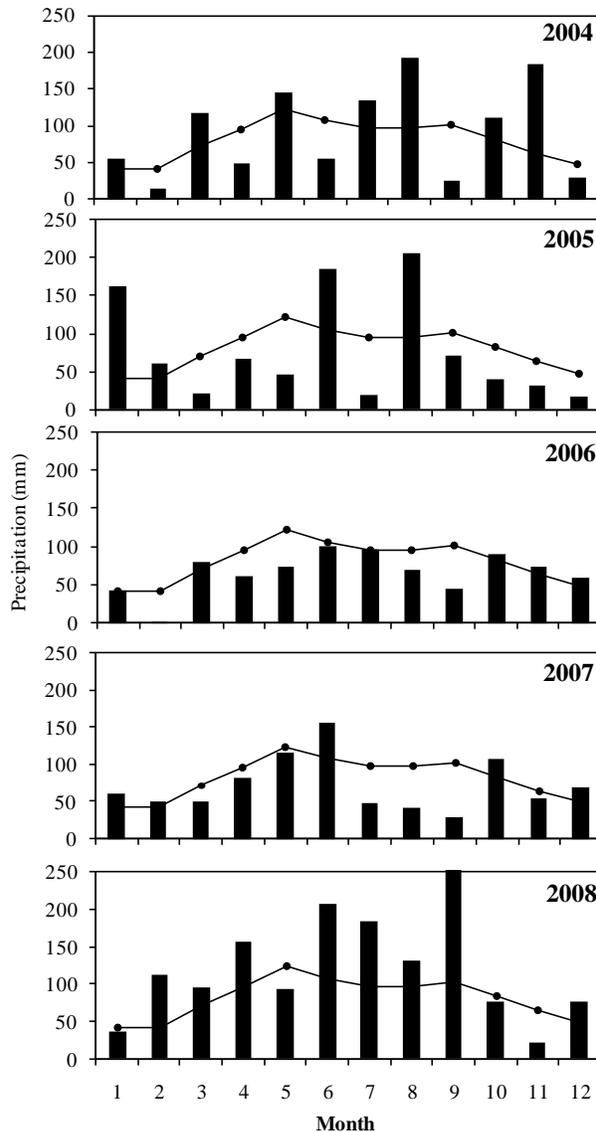


Figure 2. Monthly precipitation (bars) and long-term mean (line) for the study site from 2004 to 2008.

differed greatly among treatments and years, ranging from 0 m³ ha⁻¹ yr⁻¹ (2006) to 2548 m³ ha⁻¹ yr⁻¹ (2004 on the control). During the study period, agroforestry, grass buffer, and control treatments produced 2655, 3067, and 5598 m³ ha⁻¹ runoff, respectively, between 2004 and 2008. On average the two buffer treatments produced only 30 and 59% of runoff of the control treatment in 2004 and 2008 (Fig. 3). In years with very small number of runoff events, the difference between the buffer and control treatments was small and differences were not significant. The total runoff on agroforestry and grass buffer treatments was not significant on 2004, 2005, and 2007. The total runoff was significantly different in 2008 between the two buffer treatments. The control treatment produced significantly more runoff event during years (2004) with 115% of the normal rainfall.

below the long-term mean in 2005, 2006, and 2007. There was no runoff in 2006 during the driest year of the study. Measurable runoff events produced by the various watersheds generally followed precipitation (Fig. 2 and 3). The highest number of runoff events was reported in 2008. Watersheds produced 7, 2, 2, and 13 runoff events in 2004, 2005, 2007, and 2008, respectively. All six watersheds produced same number of runoff events each year although the volumes were different.

In a 10-yr study with three adjacent corn-soybean rotational watersheds in northeast Missouri and another study with riparian and Conservation Reserve Program in northern Missouri, Udawatta et al. (2002: 2006) observed more runoff events when precipitation was greater than normal and fewer events when precipitation was normal or below normal. The current study site is different from the latter two sites, it has deep and well drained soils and produce little runoff as compared to soils with restrictive horizons as found in Northern Missouri. Furthermore, yearly, seasonal and within growing season variation in the frequency and intensity of precipitation also influence the number of runoff events.

Runoff

The annual discharge of water per area differed greatly among treatments and years, ranging from 0 m³ ha⁻¹ yr⁻¹ (2006) to 2548 m³ ha⁻¹ yr⁻¹ (2004 on the control). During the study period, agroforestry, grass buffer, and control treatments produced 2655, 3067, and 5598 m³ ha⁻¹ runoff, respectively, between 2004 and 2008. On average the two buffer treatments produced only 30 and 59% of runoff of the control treatment in 2004 and 2008 (Fig. 3). In years with very small number of runoff events, the difference between the buffer and control treatments was small and differences were not significant. The total runoff on agroforestry and grass buffer treatments was not significant on 2004, 2005, and 2007. The total runoff was significantly different in 2008 between the two buffer treatments. The control treatment produced significantly more runoff event during years (2004) with 115% of the normal rainfall.

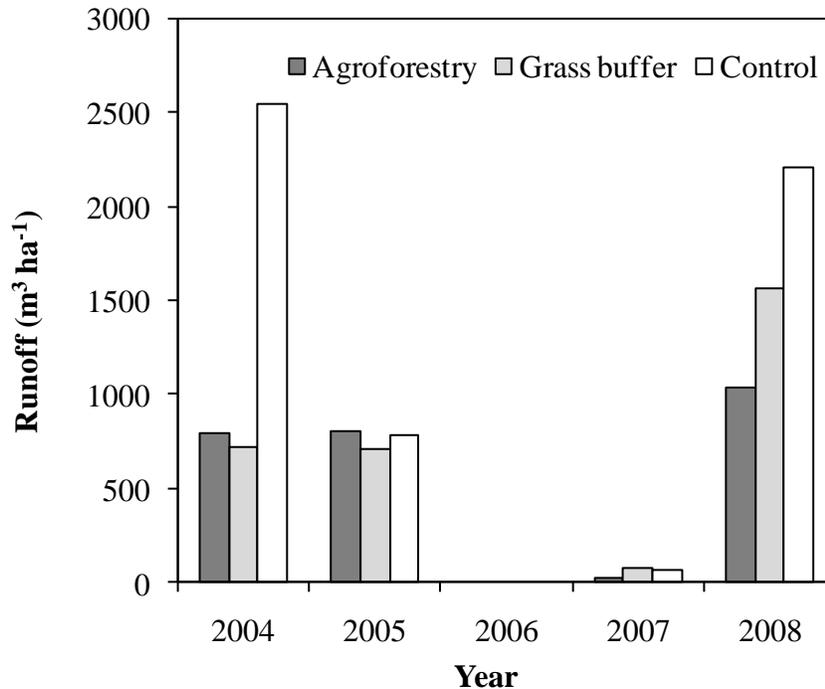


Figure 3. Annual runoff volumes by agroforestry buffer, grass buffer, and control treatments from 2004 to 2008

Trees and undisturbed grass buffer vegetation improve infiltration and water holding capacity of soils. Studying soil physical properties, Kumar et al. (2008) showed that saturated hydraulic conductivity was 16.7 times greater in the buffer areas as compared to the grazed areas. Trees reduce runoff, soil erosion and nutrient loss from watersheds and improve infiltration (Gilliam 1994). In France, 5.7 and 11.1 m wide grassed filter strips reduced runoff by 8 to 89% and 37 to 91% respectively (Patty et al. 1997). In this study, 15-m wide buffers effectively controlled runoff during years with above normal precipitation. Although large runoff events remove significant amounts of NPSP from watersheds (Morgan et al. 1986; Robinson et al. 1996; Udawatta et al. 2004) smaller events that occur more frequently account for a greater proportion of total nutrient loss than infrequent large events (Quinton et al. 2001; Udawatta et al. 2004). Therefore, a well established buffer designs including upland buffers are imperative to control NPSP in runoff from more frequent small events and infrequent large events.

Sediment loss

Soil loss on watersheds was significantly affected by treatments. Soil loss in runoff water generally paralleled rainfall amounts. It varied between 47 and 91 kg ha⁻¹ during the 5-year study period (Fig. 4). Grazing watersheds with agroforestry buffers lost only 51% as compared to the loss on the control. The control watersheds without buffers lost 36% more soil than the watersheds with buffers.

Permanent vegetation, including the trees and undisturbed grass in the buffer areas of watersheds may have utilized more water, thus runoff and erosion losses were less than that in a watershed with no buffers. Research also shows that most of the sediment and nutrients are retained within

the first 4 to 7.5 m of the strip and thereafter increasing the width results in marginal retention of pollutants (Robinson et al. 1996; Schmitt et al. 1999). Results of this study show that buffers with trees seem to be more effective than grass alone in this study, probably due to improved soil properties and greater resistance to the surface flow.

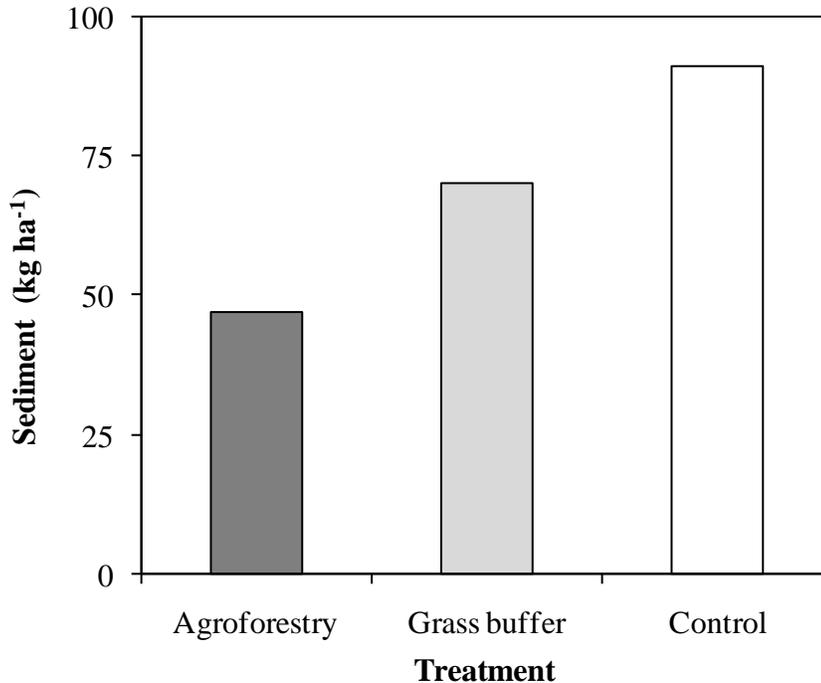


Figure 4. Total soil loss on agroforestry buffer, grass buffer, and control treatment watersheds from 2004 to 2008.

Nitrogen loss

Total nitrogen (TN) loss was significantly affected by treatments (Fig. 5). It ranged from 1.85 kg ha⁻¹ in the agroforestry treatment to 7.47 kg ha⁻¹ in the control treatment. The difference was significant among the three treatments. The control treatment lost 4 and 3.2 times more TN than agroforestry and grass buffer treatments.

Total nitrogen losses reported in this study show that agroforestry and grass buffers significantly reduce losses in runoff from grazed pasture. Cattle are allowed to graze near the sample collection unit and flume approach area as compared to watersheds with buffers. As cattle walk near the flume during wet periods, more soil and nutrient loss cannot be reduced. This implies the importance of no-access buffer strips along streams on grazed pasture watersheds.

CONCLUSIONS

This study was designed to examine agroforestry and grass buffer effects on NPSP reduction from grazed pasture watersheds. Results indicate that watersheds with buffers significantly reduce runoff volume and loss of sediment and nutrients in runoff. However, the difference in

runoff volume among the three treatments was not significant during years with below normal precipitation. During years with above normal precipitation buffers were extremely effective in reducing NPSP and protecting water quality. Results of the study suggest that more emphasis should be placed on management strategies that minimize runoff and NPSP losses. Upland buffers as a protective measure may help reduce soil erosion and nutrient losses from grazed pasture watersheds to naturally occurring levels and protect water quality.

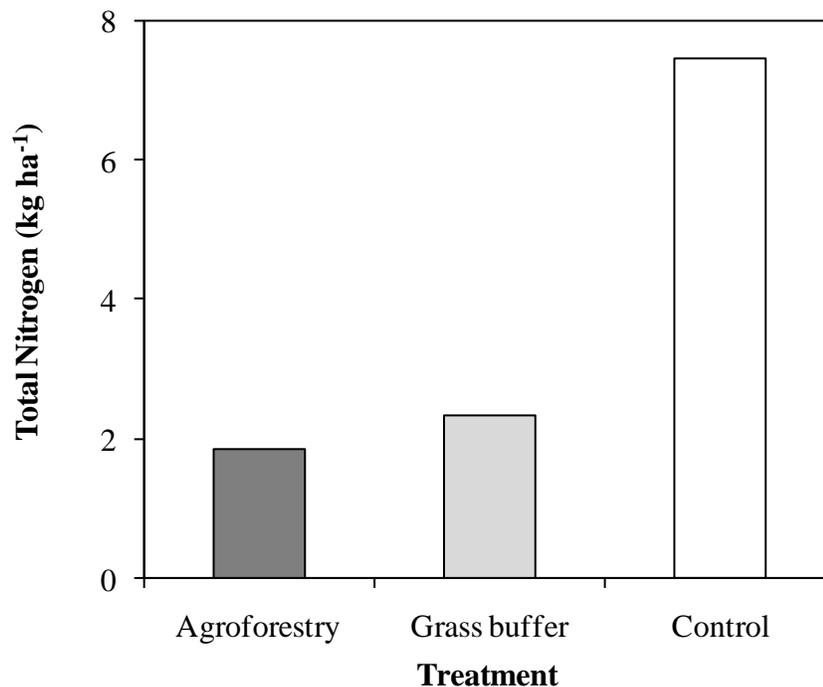


Figure 5. Total nitrogen loss on agroforestry buffer, grass buffer, and control treatment watersheds from 2004 to 2008.

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INTRODUCTION OF ATRAZINE-DEGRADING *PSEUDOMONAS* SP. STRAIN ADP TO ENHANCE RHIZODEGRADATION OF ATRAZINE

C.H. Lin^{1*}, B.M. Thompson², H.Y. Hsieh², R.N. Lerch³, R.J. Kremer³ and H.E. Garrett¹

¹Center for Agroforestry, University of Missouri

²Department Veterinary Pathobiology, MU Life Science Center

³USDA-ARS, Cropping Systems and Water Quality Research Unit,

Contact: Linchu@missouri.edu

Abstract: The herbicide atrazine (ATR) has been widely applied to fields in the US and Mid Western states. Recently, public health and ecological concerns have been raised about contamination of surface and ground water by the persistent ATR and its chlorinated metabolites due to their toxicity and potential carcinogenic or endocrinologic effects. Phytoremediation has been proven to be one of the most cost-effective mitigation practices for removal of ATR from surface runoff derived from agronomic operations. Current ongoing research has identified several plant species showing a promising capacity to degrade most of the soil ATR to less toxic or less mobile metabolites in the rhizosphere. However, the mineralization of ATR and its chlorinated metabolites or complete cleavage of the triazine ring in the rhizosphere was limited to less than 2-10% under both laboratory and field conditions. Despite the persistence of ATR and its degradates in the environment, a few bacteria strains including *Pseudomonas* sp. ADP have been isolated in the past decade from heavily contaminated ATR spill sites. These bacteria contain a series of genes encoded on the self-transmissible plasmid pADP-1 responsible for various processes of ATR degradation resulting in completed ring cleavage resulting in the rapid mineralization of ATR into carbon dioxide. We investigated the synergistic effect of introducing these biological agents to enhance the rhizodegradation of ATR. The developed knowledge may lead to future field application to reduce the local concentration of ATR and its metabolites in rhizospheres, and minimize the overall concentrations that leach into nearby water sources.

INTRODUCTION

Atrazine (ATR) has been one of the leading herbicides widely applied in the US and Mid Western states. Recently, public health and ecological concerns have been raised about contamination of surface and ground water by the persistent ATR and its chlorinated metabolites, due to their toxicity and potential carcinogenic or endocrinology effects. Phytoremediation has been proven to be one of the most cost-effective mitigation practices to remove ATR from surface runoff derived from agronomic operations. Current ongoing research has identified several plant species showing promising capacities to degrade most of the soil ATR to less toxic or less mobile metabolites in the rhizosphere (Lin et al., 2008; Lin et al., 2007). However, completed mineralization of ATR and its chlorinated metabolites or cleavage of the triazine ring in the rhizosphere was limited to less than 2-10% under both laboratory and field conditions (Krutz et al., 2004; Lin et al., 2007; Lin et al., 2005). Despite the persistence of ATR and its degradates in the environment, a few bacteria strains including *Pseudomonas* sp. ADP have been isolated in the past decade from spill sites heavily contaminated with ATR. These bacteria

contained a series of genes encoded on a self-transmissible plasmid pADP-1 responsible for various processes of ATR degradation resulting in completed ring cleavage that rapidly mineralize the ATR into carbon dioxide (**Figure 1**). We investigated the synergistic effects of introducing these biological agents to enhance the rhizodegradation of ATR. The developed knowledge will hopefully lead to future field application to reduce the movement of ATR and its metabolites to water sources. The objectives of this work are to: 1) monitor mineralization and degradation activities by ATR degraders in the rhizosphere environment; 2) develop DNA-based molecular techniques to quantify the gene expression and population of these ATR degraders in the rhizospheres and 3) screen for species that sustain the ATR-mineralization and degradation activities.

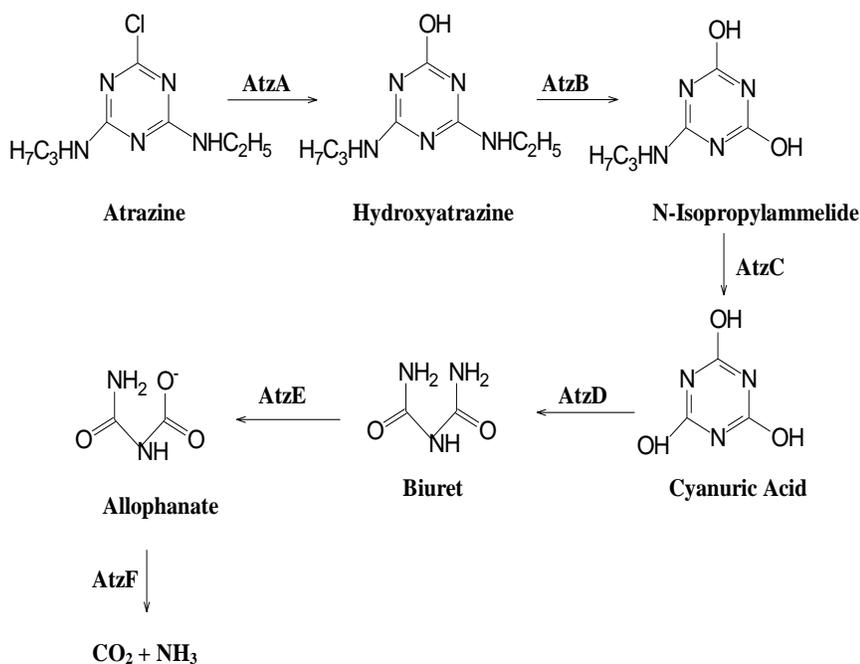


Figure 1. Catabolic degradation of atrazine by *P. ADP* (Martinez et al., 2001).

MATERIAL AND METHODS

The experiment was conducted in a walk-in growth chamber with three species treatments: 1) hybrid poplar clones (*Populus deltoides* X *Populus nigra*, clones 80X01038 **POP**); 2) switchgrass (*Panicum virgatum* L., **SW**) and 3) eastern gammagrass (*Tripsacum dactyloides*, **EG**). A control treatment with no plants was also included. Plants were allowed to grow in a mixture of 60% sand and 40% Mexico Silt Loam soil for 12 months. The rhizosphere soil was separated from the plants, and 1 μCi ^{14}C -ATR was then added to the soil. Prior to ^{14}C -ATR application, 2 mL *P. ADP* cell suspension (4×10^6 cells g^{-1} dry soil) were added to the rhizosphere soils. An experiment unit without *P. ADP* was setup as a control for each species treatment. The herbicide treated soil was then incubated in sealed jars for 11 days at 25°C in the dark. ATR mineralization was measured using alkali traps (2 M NaOH) placed in the jars, and the traps were periodically replaced throughout the incubation period.

At the end of the 11-day incubation period, ^{14}C -ATR and its degradation products were sequentially extracted with 250 mL of 90% MeOH. The final extracts were concentrated to 200 μL and ATR and its degradation products were analyzed using high performance liquid chromatography with detection by UV and an in-line flow scintillation analyzer (HPLC–UV-FSA).

Quantification of *atzA* gene copies

To evaluate the persistence of *P. ADP* and the copy number of the degradation genes in the rhizospheres, quantification of this ATR degrading bacterium was determined by the number of the *atzA* gene copies using quantitative polymerase chain reaction (*qPCR*) techniques, including competitive polymerase chain reaction analysis (*qcPCR*) and real-time PCR. The *atzA* gene encodes ATR chlorohydrolase which catalyzes the first step of ATR mineralization by this strain of *Pseudomonas*. The copy number was correlated with the ^{14}C -ATR degradation profile of each experiment unit.

RESULTS AND DISCUSSIONS

The introduction of the *Pseudomonas ADP* into rhizospheres rapidly enhanced the rates of ATR degradation. The majority of ATR was transformed into harmless carbon dioxide within 72 hours of inoculation (**Figures 2 and 3**).

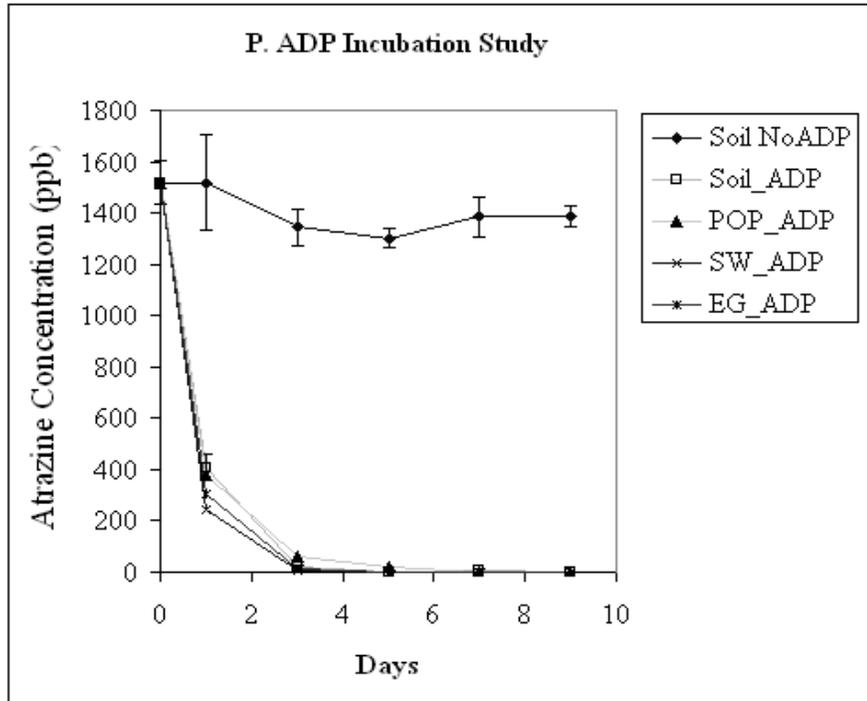
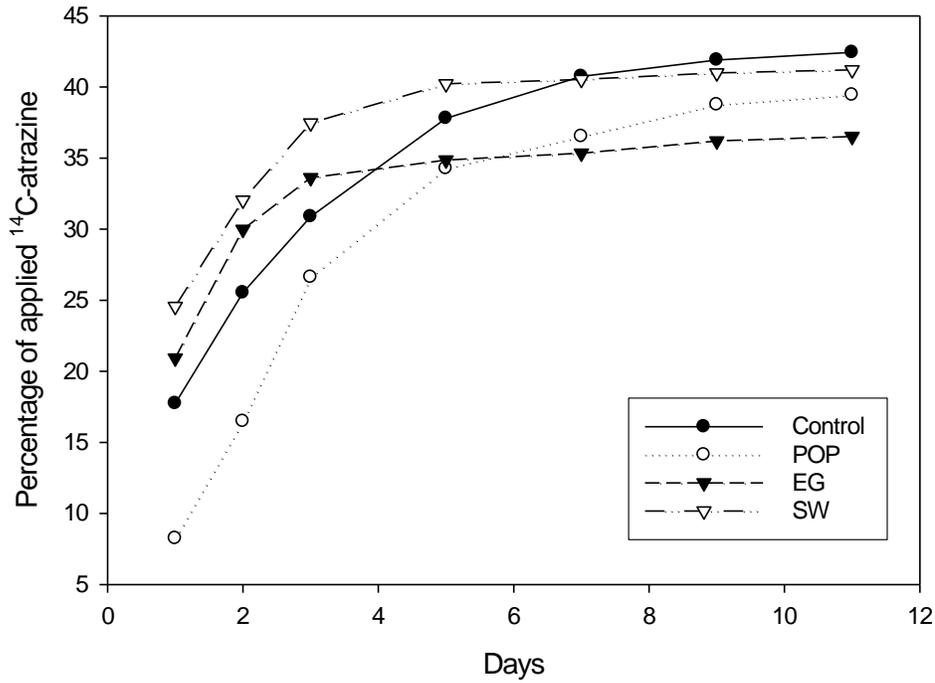


Figure 2. Degradation of atrazine with vs. without inoculation of an atrazine – degrading bacterium *P. ADP* in rhizospheres of selected species. **Soil No ADP-** (soils without inoculation); **Soil_ADAP-**(soils with *P. ADP* inoculation); **POP_ADAP-** (poplar inoculated with *P. ADP*); **SW_ADAP** (switchgrass inoculated with *P. ADP*); **EG_ADAP** (eastern gammagrass inoculated with *P. ADP*)

Percentage of ^{14}C -atrazine Mineralized with *P. ADP* Inoculation



Percentage of ^{14}C -atrazine Mineralized without *P. ADP* Inoculation

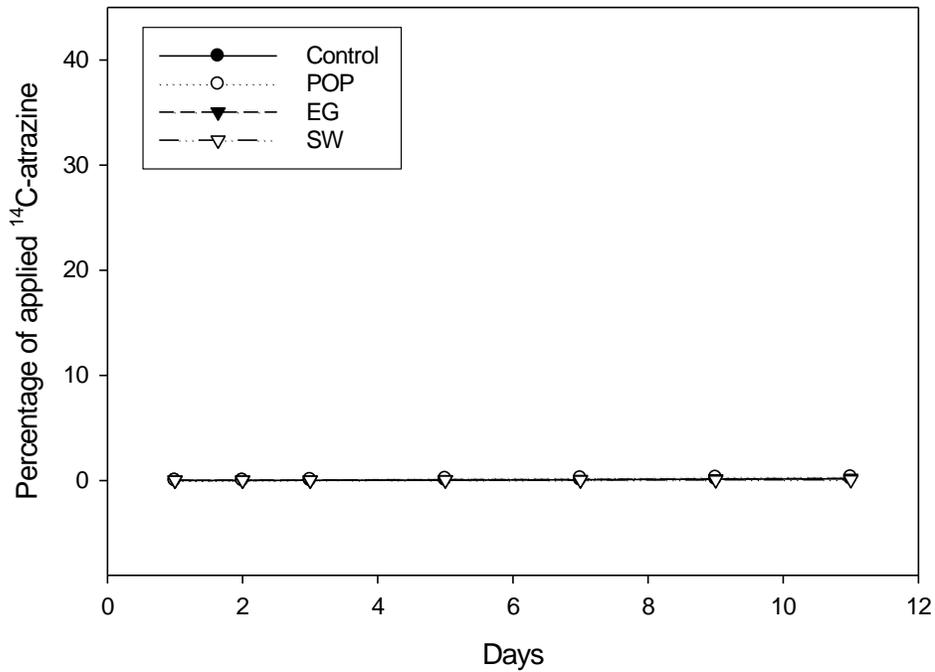


Figure 3. Percentage of ^{14}C -atrazine mineralized with (A) vs. without (B) inoculation of *P. ADP*

To quantify *P. ADP* in the rhizospheres, both quantitative competitive polymerase chain reaction analysis (*qcPCR*) and real-time PCR were successfully developed (**Figure 4**). Quantification of this ATR degrading bacterium was determined by the number of the *atzA* gene copies. The *atzA* gene encodes ATR chlorohydrolase which catalyzes the first step of ATR mineralization by this strain of *P. ADP*.

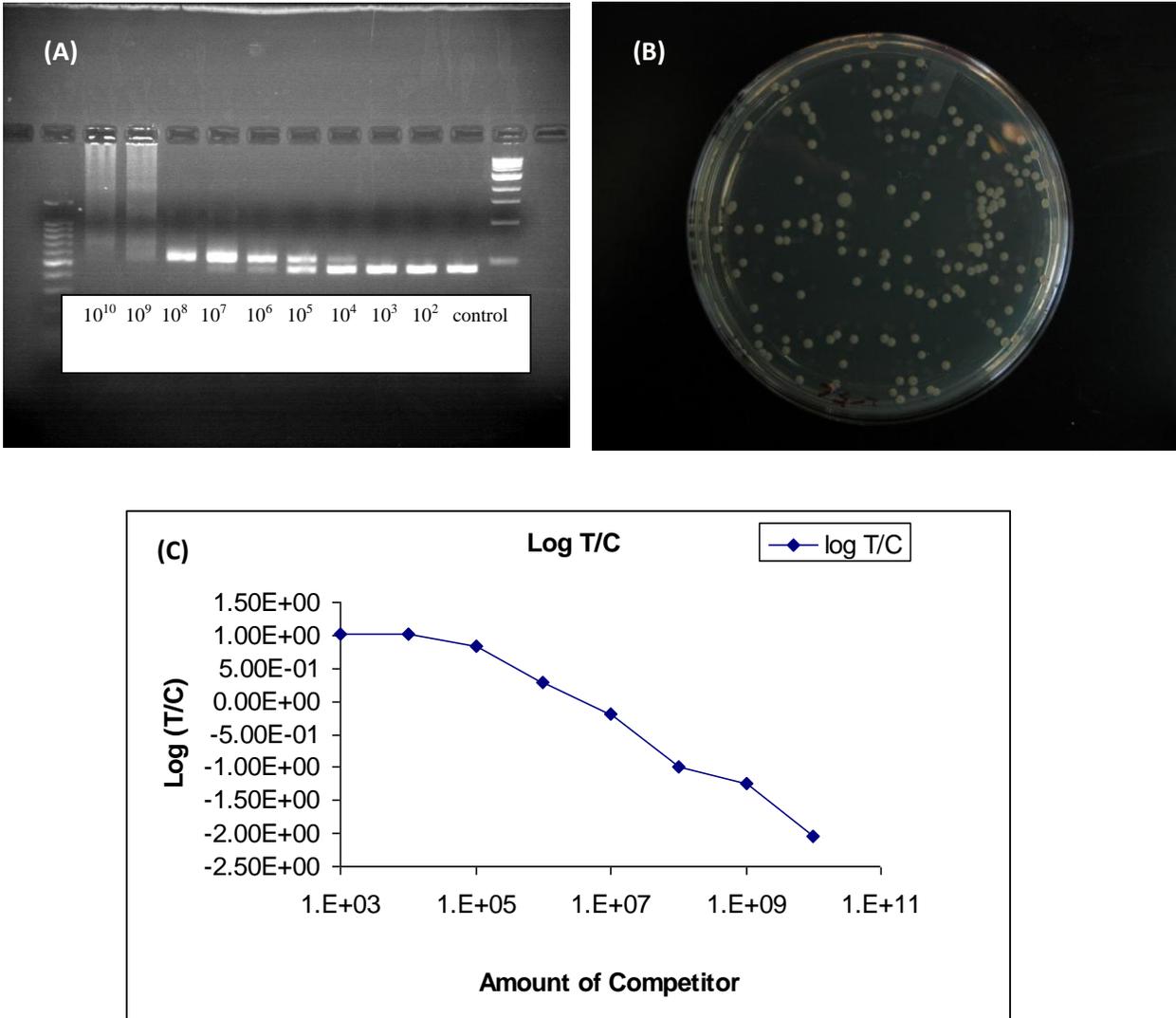


Figure 4. Quantification of *atzA* by quantitative competitive PCR. The ratios of target *atzA* (T: 440bp) to competitive DNA (C: 540bp) were calculated by quantifying their relative intensities using gel electrophoresis (A). Determine the applied *P. ADP* by plate counting (B). The number of *atzA* copies was determined by the corresponding number of competitors where $\text{Log}(T/C) = 0$, ($T = C$) (C).

A highly sensitive quantitative real-time PCR technique using *TaqMan* probe was also successfully developed (**Figure 5**). The accuracy and sensitivity of the real-time PCR technique were compared against the *qcPCR* method and traditional plate counting. The change in copy number of *atzA* in the rhizospheres was monitored with this new developed quantitative molecular technique (**Figure 6**).

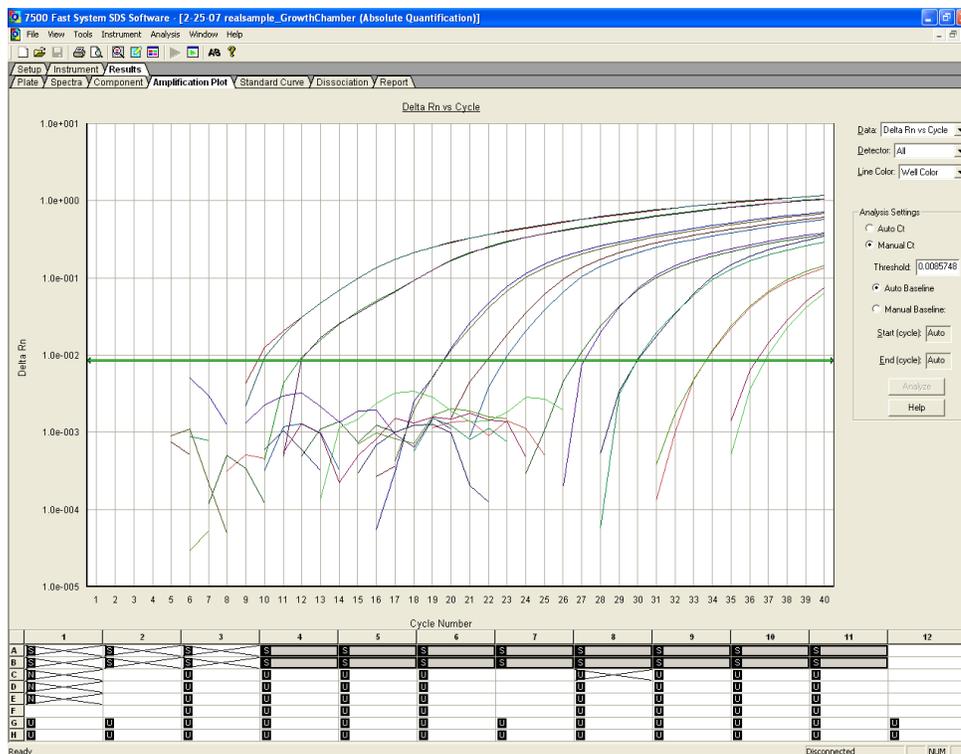


Figure 5. Quantification of *atzA* by quantitative real-time PCR using *TaqMan* probe.

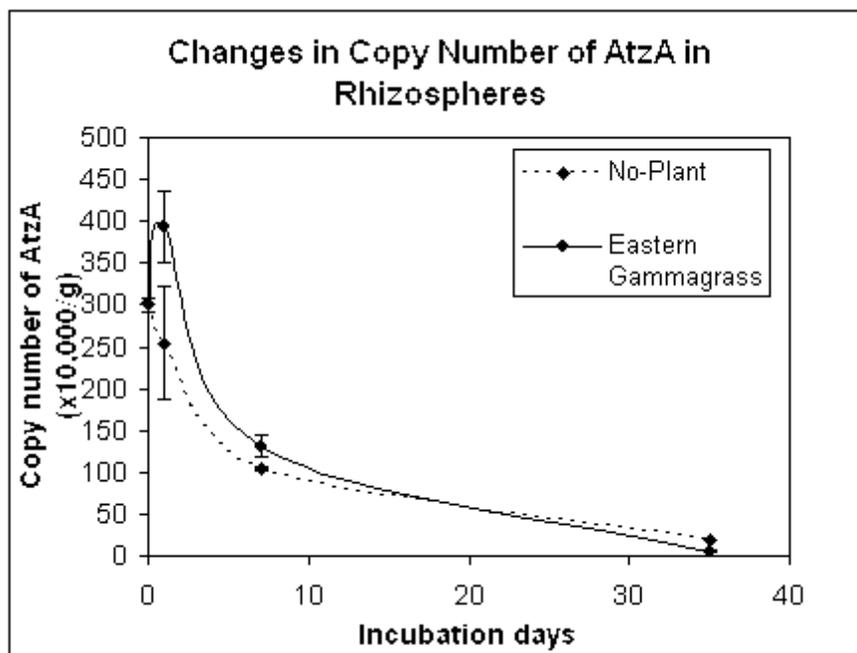


Figure 6. Change in number of *atzA* copies in the rhizospheres of eastern gammagrass and no-plant control.

Our results suggest that the copy number of *atzA* gene in eastern gammagrass was stimulated by about 60% during the first 24 hours of incubation period as compared to control (**Figure 6**). The copy number of *atzA* gene decreased over the incubation period in both treatments. We speculate that it might be the result of the complete consumption of ATR and other nitrogen substrate sources in the medium and loss of the plasmid or loss of viability of the *P. ADP* bacteria. The preliminary results from our scale-up greenhouse studies showed that eastern gammagrass was able to sustain high levels of degradation genes. Therefore, the introduction of this biological agent into warm-season grass buffers of eastern gammagrass may have great potential to rapidly transform the deposited ATR into less toxic and less mobile degradation products.

CONCLUSIONS

Introduction of *P. ADP* and other ATR degraders into vegetative buffer systems provides a promising cost-effective alternative approach to mitigate environmental contamination by ATR. The novel molecular method developed from this work will be further applied to quantify the population of ATR degraders and the number of functional degradation genes for future field and laboratory studies.

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AGROFORESTRY AND GRASS BUFFER INFLUENCES ON WATER INFILTRATION FOR A GRAZED PASTURE SYSTEM

Sandeep Kumar¹, Stephen H. Anderson¹, Ranjith P. Udawatta^{1,2}, and
Robert L. Kallenbach³

¹Soil, Environmental and Atmospheric Sciences, University of Missouri-Columbia.

²Center for Agroforestry, University of Missouri-Columbia.

³Division of Plant Sciences, University of Missouri-Columbia Columbia, MO 65211, USA.

Contact: sk9fd@mizzou.edu

Abstract: Agroforestry and grass buffers are often adopted as an alternative resource management system in agriculture for environmental and economic benefits. The objective of the study was to compare agroforestry (AgB) and grass buffer (GB) systems under rotationally grazed (RG) and continuously grazed (CG) pasture systems on water infiltration measured using ponded infiltration and tension infiltration methods. Buffer areas were fenced which prevented cattle grazing in buffer areas. Soils at the site are Menfro silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalfs). Infiltration rates were measured using ponded ring infiltration units in 2007 and 2008 for the four treatments with six replicates. Infiltration rate as a function of tension (at 50-, 100-, and 150-mm) was also measured using a tension infiltrometer in 2007. Water infiltration parameters were estimated using Green-Ampt and Parlange infiltration equations. Quasi-steady state infiltration rates (q_s) and field-saturated hydraulic conductivity (K_{fs}) for the buffers were about 30 and 40 times higher compared to pasture treatments, respectively. Green-Ampt and Parlange models appeared to fit measured data with r^2 values ranging between 0.91 to 0.98. The infiltration rate in 2007 for the GB treatment was the highest (221.4 mm h⁻¹) and for the CG treatment was the lowest (3.73 mm h⁻¹). Estimated sorptivity (S) and saturated hydraulic conductivity (K_s) parameters were higher for buffers compared to the pasture treatments. Grazing reduced infiltration rates for the pasture (CG and RG) treatments. Results show that the buffer areas have higher infiltration rates which imply lower runoff compared to pasture areas.

Keywords: Agroforestry buffer, grass buffer, Green-Ampt equation, Parlange equation, sorptivity, saturated hydraulic conductivity, water infiltration.

INTRODUCTION

Water infiltration is affected by various factors such as soil texture and structure, landscape position, management system, soil organic carbon, vegetative cover and antecedent water content. Vegetative covers have been found to increase soil organic carbon content which improves soil properties and to increase the infiltration rate. Meek et al. (1992) reported that channels formed by perennial roots are the major cause of increasing the infiltration rate. Management practices which increase soil macropores usually increase the infiltration rate.

Reduced infiltration leads to less water stored in the soil for later use by crops and often reduces crop yields (Connolly et al., 1997). Runoff associated with low infiltration is also the driving

force for soil erosion, a serious problem for sloping lands (Freebairn et al., 1986; Radford et al., 1992). Hoof trampling by grazing cattle damages the vegetation and soils of pasture areas with high stock densities (Betteridge et al., 1999; Sheath and Boom, 1997) which affects infiltration.

Agroforestry and grass buffers establish deep root systems which increase the proportion of macropores and improve the soil hydraulic properties as compared to row crop systems (Cadisch et al., 2004). Agroforestry and grass buffers are sometimes used in combination with pastures with fencing for the buffers to prevent disturbance by grazing animals. In these buffer systems where the tree and grass buffer areas are left undisturbed by grazing animals, soil properties are different compared to pasture areas which are disturbed by grazing (Kumar et al. 2008). Frequent and uneven grazing in pasture areas has been found to lower infiltration due to compaction from continuous animal traffic (Daniel et al., 2002). However, rotational grazing where cattle are allowed to graze in sequence has been shown to improve productivity of cattle compared to conventional grazing (Warren et al., 1986).

Very few studies have been conducted to evaluate the impact of buffers on water infiltration compared to grazed pasture systems. The purpose of the current study was to compare the effects of agroforestry and grass buffers on water infiltration relative to rotationally grazed and continuously grazed pasture systems. The objective of the study was to measure and compare water infiltration parameters among agroforestry buffer, grass buffer, rotationally grazed pasture and continuously grazed pasture treatments.

MATERIALS AND METHODS

Experimental site and management

The experimental site is located at the Horticulture and Agroforestry Research Center (HARC) in New Franklin, Missouri (39°02'N, 92°46'W, 195 m above mean sea level). The study site was established in 2000 to compare the influence of grass and agroforestry buffers on runoff water quality. The pasture areas and grass buffers were re-seeded with tall fescue (*Festuca arundinacea* Schreb; Kentucky 31) in 2000. Red clover (*Trifolium pretense* L.) and lespedeza (*Kummerowia stipulacea* Maxim.) were seeded into the fescue in 2003 (Kumar et al., 2008). Eastern cottonwood trees (*Populus deltoids* Bortr. ex Marsh.) were planted in 2001 into the fescue for areas designated to be agroforestry buffers. Additional information about the experimental site can be found in Kumar et al. (2008).

Soils at the site are Menfro silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalfs). The grass and agroforestry buffer areas were fenced from pasture areas preventing access by cattle. The rotationally grazed pasture treatment area was rotationally grazed with six fenced areas (paddocks) within the small watershed. The continuously grazed pasture treatment was continuously grazed by cattle with no rest. Treatments included agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG), and continuously grazed pasture (CG).

Beef cows were introduced each year in the pasture area with weights between 450 kg to 590 kg. The number of cattle for the small watershed (0.8 ha) was three. Eighty-five percent of the grazing area (0.64 ha) of the watershed was divided into six smaller rotationally grazed paddocks

with single wire electric fences for cattle management. The other 15% of the grazing area was continuously grazed. The cows were moved between paddocks on each Monday and Thursday with each paddock being grazed for 3.5 days and rested for 17.5 days (Kumar et al., 2008).

Ponded infiltration measurements

Water infiltration was measured using ponded ring infiltration units for four treatments with six replicates. The AgB measurements were taken from soil under six replicate trees, three each from two tree rows in the agroforestry buffer area. These infiltration measurements were taken at a distance of 20 cm from the base of tree trunks in the agroforestry buffer. The GB treatment measurements were taken from six replicate grass buffer areas. The RG samples were taken from six replicate rotationally grazed areas and the CG treatment measurements were taken from six replicate continuously grazed areas.

Infiltration rates were measured in late May 2007 and June 2008 using a single-ring infiltrometer with 25-cm inner diameter and 30-cm length. The ring was driven 15-cm into the soil. A positive head of 50 mm was maintained inside the ring using a Mariotte system. Infiltration measurements were conducted for about 90 to 120 minutes. Two infiltration models were used to fit infiltration data which include the Green-Ampt model (1911), and the Parlange et al. (1982) model. Throughout this paper, the Parlange et al. (1982) model will be used to referred to the Parlange model.

The Green-Ampt (1911) infiltration equation was modified by Philip (1957) for time (t) vs. cumulative infiltration (I), as follows:

$$t = \frac{I}{K_s} - \frac{\left[S^2 \ln\left(1 + \frac{2IK_s}{S^2}\right) \right]}{2K_s^2} \quad [1]$$

The physically based Parlange equation for t vs. I is

$$t = \frac{I}{K_s} - \frac{S^2 \left[1 - \exp(-2IK_s / S^2) \right]}{2K_s^2} \quad [2]$$

where t (T) is time (h), I (L) is the cumulative infiltration (mm), S ($L T^{-0.5}$) is the sorptivity ($mm h^{-0.5}$), and K_s ($L T^{-1}$) is the saturated hydraulic conductivity ($mm h^{-1}$). For estimating the S and K_s parameters, the method proposed by Clothier et al. (2002) was used.

The method to estimate field saturated hydraulic conductivity (K_{fs}) suggested by Reynolds et al. (2002) was used for estimating this parameter. It assumes one-dimensional water flow in the infiltration ring, and uses the following equation:

$$K_{fs} = \frac{q_s}{\left(\frac{H}{C_1d + C_2a} \right) + \left\{ \frac{1}{\chi^* (C_1d + C_2a)} \right\} + 1} \quad [3]$$

where K_{fs} is the field-saturated hydraulic conductivity (mm h^{-1}), q_s is the quasi-steady infiltration rate (mm hr^{-1}), a is the radius of the infiltration ring (mm), H is the hydraulic head of ponded water in the ring (mm), d is the depth of ring insertion into the soil (mm), C_1 and C_2 are dimensionless quasi-empirical constants ($C_1=0.993$ and $C_2=0.578$ for this infiltrometer), and α^* is the soil macroscopic capillary length, assumed to be equal to 0.036 mm^{-1} for the agroforestry buffer and grass buffer treatments, 0.012 mm^{-1} for the rotationally grazed pasture treatment, and 0.004 mm^{-1} for the continuously grazed pasture treatment (Reynolds et al., 2002).

Tension infiltration measurements

After completion of the measurements for ponded infiltration, without removing the ring infiltrometer, infiltration was measured with a tension infiltrometer at 50-, 100-, and 150-mm tensions. The ring was filled with a 0.5 cm deep sand layer. Infiltration was measured for 20 minutes at 1-minute intervals. After infiltration data at 50-mm tension were recorded; the tension was increased by removing the bubbling tube from the disc and then setting the tension to 100 mm. This procedure was repeated for the 150-mm tension setting. Tension infiltration measurements were only conducted during 2007.

Statistical Analysis

A test for homogeneity of variance was conducted to evaluate the variability in the infiltration measurements within the different treatments due to the systematic arrangement of treatments. Analysis of variance (ANOVA) was further conducted with SAS using the GLM procedure when variances within treatments were homogeneous (SAS Institute, 1999). Different contrasts were also determined and were conducted for the following contrasts: *buffers vs. pastures*, *grass buffer vs. agroforestry buffer*, and *rotationally grazed pasture vs. continuously grazed pasture*. Statistical differences were declared significant at the $\alpha = 0.05$ level.

RESULTS AND DISCUSSION

Ponded infiltration measurements

Two infiltration models were fit to infiltration data as a function of time for typical replicates for the agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG) and continuously grazed pasture (CG) treatments for 2007 (Fig. 1). The Green-Ampt and Parlange models fit the measured infiltration data reasonably well with the average coefficients of determination (r^2) ranging from 0.91 to 0.98.

The K_s and S parameters estimated with the Green-Ampt model were significantly higher for the AgB and GB treatments as compared to pasture treatments for both years (Table 1). Both parameters were also significantly higher for the GB treatment compared to AgB (except the Green-Ampt estimated K_s parameter for 2008; Table 1). These parameters were not significantly different between the RG and CG pasture treatments for both years. The continuously grazed pasture (CG) treatment had the lowest numerical values for K_s and S parameters estimated by the Green-Ampt and Parlange models for 2007 but not in 2008 (Table 1). In 2007, the Green-Ampt estimated K_s and S parameters were about 15.6 and 13.7 times higher in the buffer treatments

compared to pasture treatments, while values were about 8 and 15.8 times higher for buffers in 2008 as compared to pasture treatments. The values for these parameters estimated with the Parlange model were 22.7 and 12 times higher for the buffer treatments in 2007 compared to pasture treatments, while buffer treatments were 8.7 and 12.4 times higher in 2008 relative to pasture treatments.

Coefficients of variation for the fitted parameters (Green-Ampt and Parlange models) ranged from 14.0 to 106.6 for the four treatments in 2007 and 2008 (Table 1). One possible reason for the higher values for the S parameter may be due to slightly lower antecedent water content; the volumetric water content for the 0-30 cm soil profile for the buffers was 7.7 and 13.5% lower as compared to pastures in 2007 and 2008, respectively.

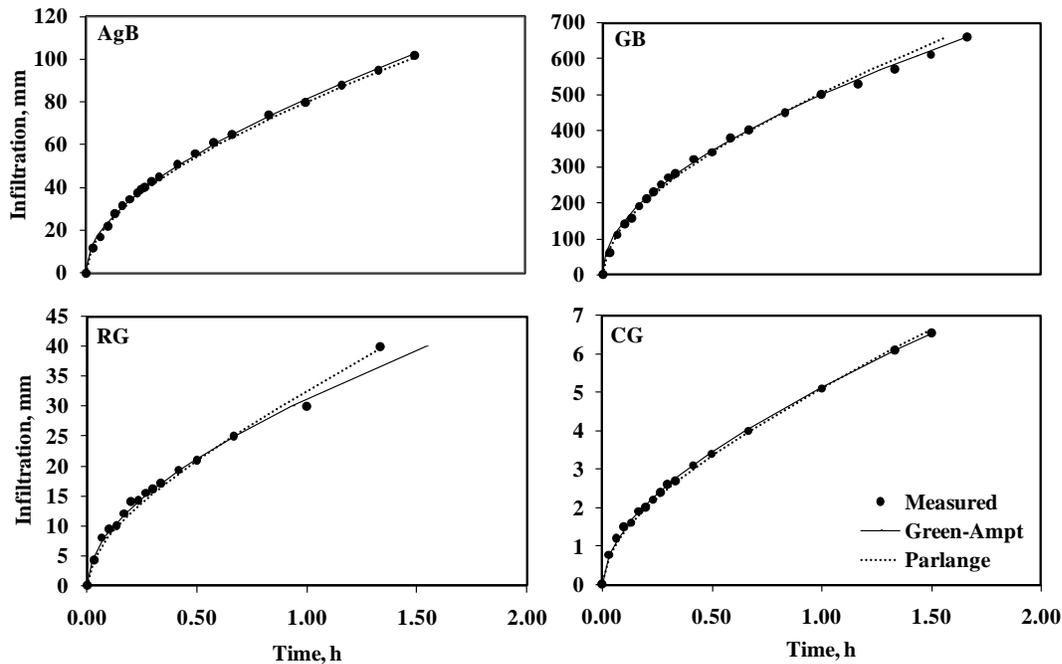


Figure 1. The Green-Ampt and Parlange models fitted to measured ponded infiltration data for typical replicates under agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG), and continuously grazed pasture (CG) treatments for 2007. Please note that y-axis scale is different for the treatments.

The quasi-steady state infiltration rate (q_s) and field saturated hydraulic conductivity (K_{fs}) were significantly different ($P < 0.01$) among the treatments. The q_s and K_{fs} values were significantly higher for GB treatment compared to other treatments in 2007 but significant differences were not observed among the other three treatments (Table 2). In 2008, both these parameters for the AgB and GB treatments were significantly higher as compared to pasture treatments (Table 2). The q_s and K_{fs} parameters were not significantly different between the RG and CG treatments for both years. The q_s and K_{fs} parameters for the buffers were about 14 and 19 times higher, respectively, as compared to pasture treatments in 2008 (Table 2).

The coefficients of variation (CV) for the CG treatment were found to be higher for these parameters in 2007 (81 %) and 2008 (66 %) compared to the other treatments. Similar CV values were found for the GB and RG treatments with average CV values of 63 and 55% for these years. The lowest CV values were found for the AgB treatment. The higher values of CV for the RB and CG treatments were probably due to lower mean values of q_s and K_{fs} parameters.

The buffers, which are prevented from cattle grazing by fences, had better plant root and shoot growth which improved the soil properties compared to grazed pasture areas. Kumar et al. (2008) reported 16.7 times higher saturated hydraulic conductivity and 11.2% lower bulk density for buffers compared to grazed pasture areas at the same site. Thus, higher infiltration is expected due to the higher saturated hydraulic

Table 1. Geometric means and coefficients of variation (CV) for saturated hydraulic conductivity (K_s) and sorptivity (S) parameters estimated by the Green-Ampt and Parlange models in the agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG), and continuously grazed pasture (CG) treatments in 2007 and 2008 (n=6).

Year	2007				2008			
	K_s		S		K_s		S	
Treatments	Mean mm h ⁻¹	CV %	Mean mm h ^{-0.5}	CV %	Mean mm h ⁻¹	CV %	Mean mm h ^{-0.5}	CV %
Green-Ampt model								
AgB	46.2 ^{b†}	53.0	94.6 ^b	38.4	71.6 ^a	49.1	133.0 ^b	57.9
GB	120.3 ^a	44.2	258.1 ^a	46.6	81.7 ^a	66.4	325.8 ^a	28.8
RG	8.59 ^c	73.3	19.5 ^b	42.8	7.90 ^b	92.2	10.8 ^c	59.2
CG	2.07 ^c	58.3	6.32 ^c	46.0	11.3 ^b	47.9	18.1 ^c	42.9
Parlange model								
AgB	40.0 ^b	23.5	80.8 ^b	14.0	83.2 ^b	64.6	110.6 ^b	43.1
GB	158.7 ^a	35.5	239.9 ^a	50.7	159.8 ^a	39.9	257.8 ^a	45.7
RG	6.75 ^{bc}	105.6	21.3 ^b	48.4	14.2 ^c	106.6	12.5 ^c	73.4
CG	2.00 ^c	50.9	5.17 ^b	56.2	13.8 ^c	58.4	17.1 ^c	41.0

[†]Means with different letters are significantly different at the 0.05 probability level.

Table 2. Geometric means and coefficients of variation (CV) of quasi-steady state infiltration rate (q_s) and field-saturated hydraulic conductivity (K_{fs}) for the agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG), and continuously grazed pasture (CG) treatments in 2007 and 2008 (n=6).

Treatments	Year							
	2007				2008			
	q_s		K_{fs}		q_s		K_{fs}	
Mean	CV	Mean	CV	Mean	CV	Mean	CV	
	mm h ⁻¹	%						
AgB	80.4 ^{b†}	14.7	59.5 ^b	14.7	105.8 ^b	16.6	78.2 ^b	16.6
GB	221.4 ^a	61.1	163.8 ^a	61.1	245.0 ^a	51.7	181.2 ^a	51.7
RG	6.15 ^b	65.6	3.84 ^b	65.6	14.8 ^c	58.4	9.23 ^c	58.4
CG	3.73 ^b	81.0	1.58 ^b	81.0	9.93 ^c	65.7	4.22 ^c	65.7

†Means with different letters are significantly different at the 0.05 probability level.

conductivity in the buffers. Hence, buffers were shown to improve water infiltration into the soil which would indicate less runoff from these areas compared to grazed pastures areas (RG and CG treatments).

Tension infiltration measurements

Measured infiltration rates at 50-, 100-, and 150-mm tensions for the AgB, GB, RG and CG treatments are shown in Table 3. Infiltration rates at 50 and 100 mm tension were significantly affected by the treatments (P<0.05; Table 3). The infiltration rate values measured at 50 and 100 mm were significantly higher for the GB treatment as compared to the other three treatments,

Table 3. Means of infiltration rate (q_s) as a function of tension for the agroforestry buffer (AgB), grass buffer (GB), rotationally grazed pasture (RG), and continuously grazed pasture (CG) treatments in 2007 year (n=6).

Treatments	Tension, mm water		
	50	100	150
	q_s (mm h ⁻¹)		
AgB	1.04 ^{b†}	0.32 ^b	0.21 ^{ab}
GB	2.77 ^a	1.45 ^a	0.40 ^a
RG	0.37 ^b	0.21 ^b	0.12 ^{ab}
CG	0.21 ^b	0.14 ^b	0.06 ^b
Analysis of variance P > F			
Treatment	<0.01	0.02	0.08
Buffers vs. Pastures	<0.01	0.03	0.02
GB vs. AgB	0.02	<0.01	0.20
RG vs. CG	0.80	0.88	0.66

†Means with different letters within a column are significantly different at the 0.05 probability level.

while the infiltration rate at 150 mm tension was significant only between GB and CG treatments (Table 3). The infiltration rate at 50 mm tension for the GB treatment was about 2.7, 7.5, and 13 times higher compared to AgB, RG and CG treatments, respectively. Single degree of freedom contrasts *buffers vs. pastures* and *GB vs. AgB* were found to be significant at 50- and 100-mm tensions ($P < 0.05$). At 150 mm tension, the infiltration rate was significant only for *buffers vs. pastures*. Infiltration rate decreased with increased applied tension with the highest decrease occurring between the 0- to the 50-mm tension values. The decrease for AgB, GB, RG and CG treatments was about 99, 99, 94 and 94% between 0- to 50-mm tension.

Correlation between K_{fs} and K_{sat} .

Laboratory data for saturated hydraulic conductivity (K_{sat}) measured in 2007 for the 0-10 cm soil depth were correlated with K_{fs} values estimated from 2007 (Fig. 2). The coefficient of determination for this regression was found to be 0.56 between K_{fs} and K_{sat} . The slope of the regression was estimated as 0.39. Bouwer (1986) and Rachman et al. (2004) proposed that K_{fs} could be estimated as $0.5 \times K_{sat}$ and $0.65 \times K_{sat}$, respectively. In the current study, this coefficient was estimated as $0.4 \times K_{sat}$, which is slightly lower than the other two studies. Rachman et al. (2004) reported that K_{fs} and K_{sat} can be related when K_{sat} is measured in small cores of 76 by 76 mm dimensions (cores of similar dimensions used in the current study) if the potential rapid-pipe flow conduits are eliminated. This was also followed in the current study.

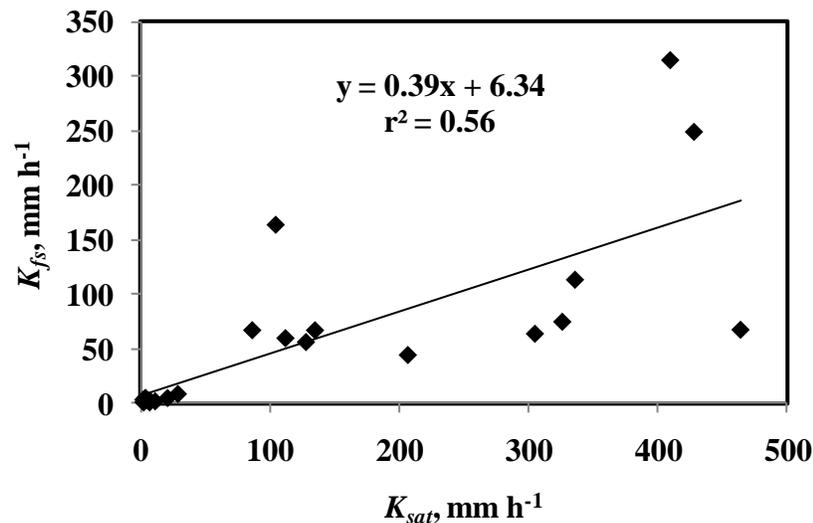


Figure 2. Field saturated hydraulic conductivity (K_{fs} , 2007 data) vs. laboratory measured saturated hydraulic conductivity (K_{sat} , 2007 data; $n=24$).

SUMMARY/CONCLUSIONS

Infiltration measurements were taken to evaluate the effects of buffers on water infiltration under grazed pasture systems. Agroforestry and grass buffers were compared to rotationally grazed and continuously grazed pasture areas. Buffers had 30 and 14 times higher quasi-steady state infiltration (q_s) in 2007 and 2008, respectively, as compared to pasture treatments. The q_s for the GB treatment (233.2 mm h^{-1}) was highest and for the CG treatment (6.83 mm h^{-1}) was lowest for the two year study. The Green-Ampt and Parlange models appeared to adequately fit the

measured infiltration data for the treatments as estimated using coefficients of determination. Fitted S and K_s parameters were highest for the GB treatment and lowest for the CG treatment. The infiltration rate decreased more between 0 and 150 mm tension for the buffer treatments compared to the pasture treatments. This was attributed to more macropores present in the buffer treatments.

Grazing reduced infiltration rates for pasture areas compared to buffer areas. Results show that the buffer areas had higher infiltration rates which imply lower runoff compared to pasture areas. Buffer areas were fenced which prevented cattle grazing in these areas which probably benefitted infiltration.

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IMPLEMENTATION OF CONTOUR VEGETATIVE BUFFERS FOR MITIGATING ATRAZINE IN GROUND WATER

C.H. Lin¹, R.N. Lerch², H.E. Garrett¹ and R.P. Udawatta¹

¹ Center for Agroforestry, University of Missouri, Columbia, MO 65211

² U.S. Department of Agriculture-Agricultural Research Service, Cropping Systems and Water Quality Research Unit, Columbia, Missouri 65211

Contact: Linchu@missouri.edu

Abstract: The efficacy of vegetative buffer strips (VBS) in intercepting herbicides from surface runoff is well established. However, effect of VBS on fate of the atrazine in ground water has not been widely studied. An established, well calibrated paired watershed consisting of 1) a corn-soybean/tree-grass buffer, 2) a corn-soybean/contour grass buffer, and 3) a control treatment with a corn-soybean rotation only was utilized to evaluate the effect of vegetation buffers and topographic factors on degradation of atrazine in groundwater. The grass buffer strips are 4.5 m wide consisting of the following forages: redtop (*Agrostis gigante* Roth), brome grass (*Bromus spp.*), and birdfoot trefoil (*Lotus corniculatus* L.). Corn-soybean width is 36.5 m. This pattern is repeated five times over the landscape. Tree-grass buffer treatments include pin oak (*Quercus palustris* Muenchh.), swamp white oak (*Q. bicolor* Willd) and bur oak (*Q. macrocarpa* Michx.) mixed with the same grass species. Buffer width is 4.5 m. Sixty 5 cm diameter x 100 cm long PVC lysimeters were implemented at depths 30 cm cross landscape positions (summit, shoulder slope and foot slope) to monitor the water quality in subsurface flow before, between and after passing through the buffer strip. A similar implementation was applied at the same topographic elevation for the control. The groundwater samples were collected from lysimeters over time after major rainfall events. Samples were filtered, refrigerated and analyzed for atrazine and its metabolites. Our result suggested that the ratios of metabolite-to-parent atrazine in ground water were significantly increased by vegetative buffers practices. Therefore, the implementation of VBS would help to promote the biodegradation of atrazine and improve the ground water quality.

AGROFORESTRY INTERACTIONS AND SOIL WATER USE IN WATERSHEDS UNDER CORN-SOYBEAN MANAGEMENT

Ranjith P. Udawatta^{1,2}, Stephen H. Anderson¹, Peter P. Motavalli¹, and Harold E. Garrett²

¹Department of Soil, Environmental and Atmospheric Sciences,

²Center for Agroforestry, and University of Missouri, Columbia, MO 65211.

Contact: UdawattaR@missouri.edu

Abstract: Agroforestry and grass buffer practices reduce non point source pollution from corn-soybean watersheds, yet little is known about the processes and mechanisms involved. The objective of this study was to compare the soil water dynamics in crop, grass, and agroforestry areas throughout the growing season to understand soil water use and recharge differences among the treatments. The study was conducted on two corn (*Zea mays* L.)-soybean (*Glycine max* (L.) Merr.) rotational watersheds with grass and agroforestry buffers at the Greenley Research Center, Knox County, MO. Campbell soil moisture sensors were installed in crop, grass, and agroforestry areas with six replications at 5, 10, 20, and 40 cm depths to record volumetric soil water content at 10 minute intervals for 2004 through 2007. Initial soil moisture was lower in tree and grass buffer areas than crop areas probably due to water use by the permanent vegetation before crops were established. The differences were larger for shallower depths as compared to the 40 cm depth. The trend continued throughout the growing season. Weekly soil moisture content was significantly higher in the crop treatment as compared to the buffer treatments. During rain events water content increased in all depths and treatments and the differences in water content among treatments diminished. At the end of the growing season, soil water content increased when water use was low and as the profile recharged by rain events. The results of the study suggest that establishment of grass and agroforestry buffers help reduce non point source pollution from row crop agriculture by using additional water that would have otherwise have been lost in runoff carrying sediments, nutrients, and pesticides.

Key Words: Water content sensors, grass buffer, Greenley Center, Putnam soil,

INTRODUCTION

Establishment of agroforestry and grass buffers on agricultural watersheds is a soil conservation practice that will result in environmental and economic benefits. Agroforestry is also considered as a sustainable land management practice for maximum benefits (Nair, 1998). Within these management systems, trees, grass, shrubs, and crops occupy the same land either in a spatial or temporal progression. The fundamental understanding of agroforestry is that the roots of plants occupy various soil layers leading to complementarity of soil use (Schroth, 1999). In contrast, competition for the water and resources could result in reduced crop yields (Ong et al. 1991). According to Cannell et al. (1996) biophysical advantages of agroforestry can be only achieved if the companion vegetation utilizes resources that were not utilized by the major crop.

The study system evaluated in this paper consists of agroforestry and grass buffers on contours on watersheds managed under corn-soybean rotation in northeast Missouri. Average rainfall is 920 mm and approximately 72% falls between April and October. Therefore, soil water is not a limiting factor for crop production in many years. However, rain events that occur during the fallow period (no crop period) cause significant sediment and nutrient loss from the watersheds (Udawatta et al. 2004; 2006). Furthermore, infrequent larger events as well as closely spaced smaller events that occur during the cropping period also cause significant sediment and nutrient losses.

The area is underlain by an impervious claypan with very low saturated hydraulic conductivity (Blanco-Canqui et al., 2002). Soil horizons above the claypan have greater K_{sat} values. Therefore, the region is vulnerable to significant sediment, nutrient, pesticide losses from row-crop watersheds during fallow periods and cropping seasons. Hence, these farming systems face significant challenges in meeting water quality standards.

Conservation practices that use excess water during the fallow and cropping periods are required to reduce sediment and nutrient losses, to maintain water quality and to reduce fertilizer costs. It has been shown that buffers improve water quality by using nutrients and water, increasing infiltration rates, and improving soil hydraulic conductivity and other associated properties. A better understanding of below-ground interactions within agroforestry buffers is needed to assist in selecting appropriate species to improve economic and environmental benefits of these systems. There is a need to understand soil water dynamics to explain differences in runoff among treatments and to develop guidelines for use of these practices. We hypothesize that permanent vegetation with deep roots and a longer active transpiration and growing season will reduce non-point source pollution (NPSP) from row crop agriculture by removing excess water and nutrients. This paper (1) examines changes in soil water content in crop, grass buffer, and agroforestry buffer areas, (2) compares differences in soil moisture dynamics as influenced by treatments, and (3) estimates differences in water use and recharge by treatment.

MATERIALS AND METHODS

Experimental Site

Agroforestry and contour grass buffer watersheds located at the University of Missouri Greenley Memorial Research Center in Knox County, Missouri, USA were studied for four consecutive years (40° 01' N, 92° 11' W; Fig.1). Details on watershed characteristics, soils, and weather and management practices can be found elsewhere (Udawatta et al., 2004; 2006). The 4.44 ha agroforestry and 3.16 ha grass buffer strip watersheds were under a corn-soybean rotation with no-till management since 1991. The contour strips for both watersheds were 4.5 m wide and 36.5 m apart (22.8 m at lower slope positions) and were planted in redbud (*Agrostis gigantea* Roth), brome grass (*Bromus* spp.), and birdsfoot trefoil (*Lotus corniculatus* L.) in June 1997. Pin oak (*Quercus palustris* Muenchh.), swamp white oak (*Q. bicolor* Willd.), and bur oak (*Q. macrocarpa* Michx.) were planted 3-m apart in the center of the buffers for the agroforestry watershed in November 1997.

The soils in the study area were mapped as Putnam silt loam (fine, smectitic, mesic Vertic Albaqualfs) and Kilwinning silt loam (fine, smectitic, mesic Vertic Epiqualfs). The watershed has a drainage restrictive B horizon with a claypan at a variable depth. The restrictive claypan produces surface runoff during high rainfall periods in combination with periods of low evapotranspiration during winter, spring, and early summer. The area chosen for installation of water sensors was a Putnam silt loam soil and had on average 1 - 2 % slope, 219 g kg⁻¹ clay, 729 g kg⁻¹ silt, 21g kg⁻¹ organic C and 6.8 pH_w in the surface horizon; while the argillic horizon started at about the 38 cm depth, and had 531g kg⁻¹ clay, 439 g kg⁻¹ silt, 0.9 g kg⁻¹ organic C and 5.5 pH_w (Seobi et al., 2005).

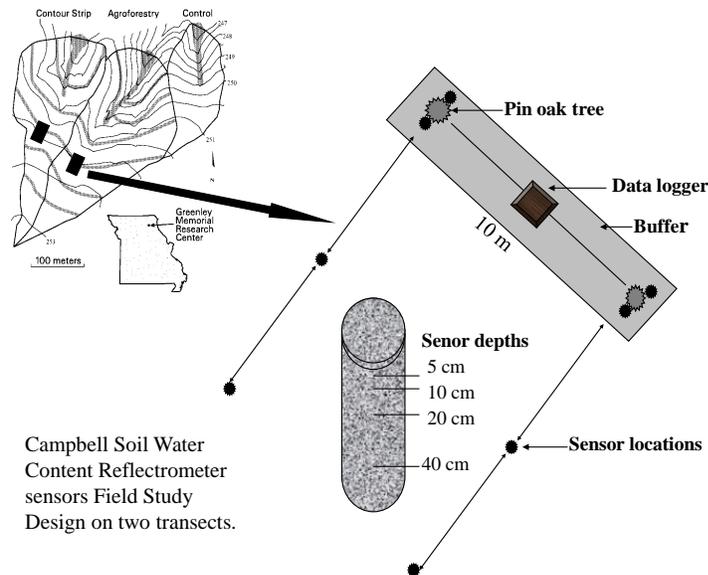


Figure 1. Study location in the State of Missouri, USA and a topographical map with 0.5-m interval contour lines on watersheds. Gray bands indicate grass-legume contour buffers (Contour Strip) and tree-grass-legume buffers (Agroforestry) on watersheds. Black bands indicate location of grass waterways. Campbell CS 616 sensor design with a data logger in the crop and buffer areas is shown on the colored diagram. Soil cylinder indicates sensor depths at each location.

Daily and hourly rainfall data were obtained from a University of Missouri webpage (<http://agebb.missouri.edu/weather/stations/knox/>). Weather data were accessed for daily and hourly time frequencies for Knox County.

Water content monitoring

Campbell CS-616 (Campbell Scientific Inc, Logan, UT) reflectometer water content sensors (Or and Wraith, 1999) were horizontally installed at 5-, 10-, 20- and 40-cm depths in four replicate locations for the agroforestry and grass (3rd buffer; counting from south) buffers and row crop treatments (between the 2nd and 3rd buffers). For the agroforestry treatment, two sets of sensors were placed under two different pin oak trees (48 cm from tree trunk) for a total of four replicates. The selected pair of trees was about 10 m apart. For the grass buffer treatment, sensors were placed at four locations with all four depths. Sensors were placed at four locations

within the crop areas. These locations were 10 and 20 m from the south edge of the buffer. All sensors were connected to a CR23X data logger through a multiplexer and powered by a deep cycle marine battery. Sensors readings in period and volumetric moisture content data were collected at 10-minute intervals. Data were extracted from the data logger each week from 14 June 2004 through 19 November 2007. Weekly water content values were obtained using data measured at 12:00 noon each Tuesday.

Data were downloaded to a laptop computer and analyzed for differences among treatments and depths. No differences were found between the positions around the trees and therefore these two positions were used as replicates. No differences were found between the two locations within the row crop treatment and therefore the two locations were used as replicates.

Statistical Analysis

Homogeneity of variance tests were conducted to check for variability within treatments for measured infiltration and water content due to the systematic arrangement of treatments. Analysis of variance (ANOVA) was further conducted with SAS using the GLM procedure when variances within treatments were homogeneous (SAS Institute, 1999). Data for all properties had homogeneous variances. Least significant differences (Duncan's LSD) were calculated to find significant differences between treatments at each soil depth. LSD values were calculated using the Proc Mixed procedure from SAS with the appropriate error terms. Volumetric water content values for treatments were analyzed by date.

RESULTS AND DISCUSSION

Precipitation

In 2004, the area received 2% more rain than the long-term mean of 920 mm. During this year August rainfall was 233% of the normal (205 mm). The rainfall amounts were lower than the long-term mean during the next three years which varied between 774 and 892 mm (Fig. 2). In 2005, 2006, and 2007 rainfall values were 16, 14, and 3% lower than the long-term mean. However, total rainfall amounts were almost the same between April and October and similar to the long-term amounts, except for 2004. These amounts ranged from 68% to 80% of the annual rainfall.

In 2004 the crop was corn. Soil water content values were similar among the treatments at the beginning of the measurement period irrespective of the treatment (Fig. 3). In general water content was close to 40% for all four measured depths except for the 5-cm depth of the agroforestry treatment (Fig. 3). During 2004, data collection began in June and trees may have used surface soil water thus reducing the soil water content at the 5-cm depth. As the growing season continued, vegetation began to use more water from all four depths. The greatest depletion occurred in the surface 5- and 10-cm depths. As less water was depleted from the 40-cm depth, differences between treatments were smaller. Compared to the crop treatment, grass and agroforestry buffer treatments maintained lower soil water content during the growing season.

Precipitation events during this period increased the water content in all four depths. Some small rain events increased water content only in the surface soil. The rain amount of 143 mm between August 17 and 27 improved soil water content in four depths. Soil water depletion decreased towards the end of growing season. And small rainfall events recharged the profile. Although the deeper horizons were recharged early in the fall, the surface two horizons took a little longer to replenish.

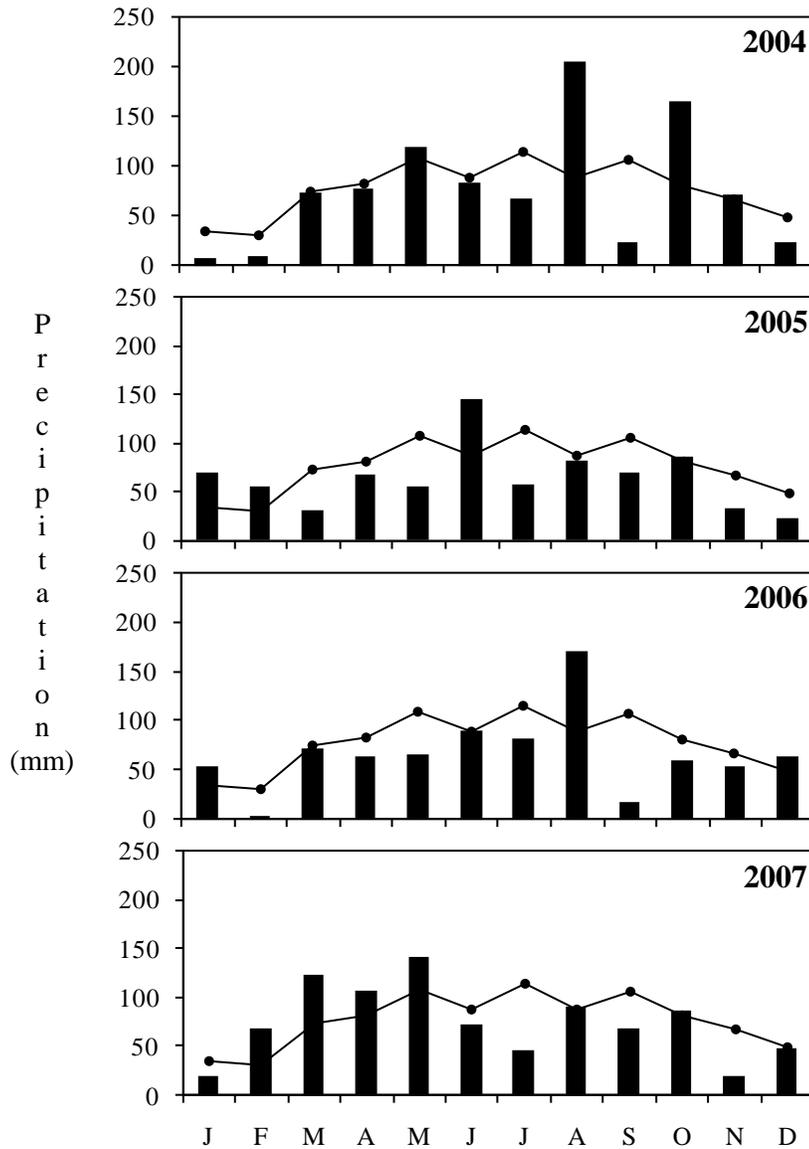


Figure 2. Monthly rainfall in mm (bars) for 2004, 2005, 2006, and 2007 at the Greenley Research Center, Novelty, MO. The line represents the long-term mean for the study location.

In 2007, the crop was soybean and soil water data are presented from March 12 to November 23 (Fig. 4). Soil water content was lower than 40% for the three surface depths at the beginning of the measurement period. This could be due to below normal rainfall amounts in 2005 and 2006. There was no difference in soil water content between the soybean and agroforestry treatments

for all four depths until June 4 (Julian 155). Soil water content was lower in the agroforestry areas as compared to crop areas for all four depths until October 8 (Julian 281). Similar to the corn year, rain events recharge the soil profile and differences in water content were not significant after the growing season. Since there were only a few large events, only the surface soil was recharged during the growing season.

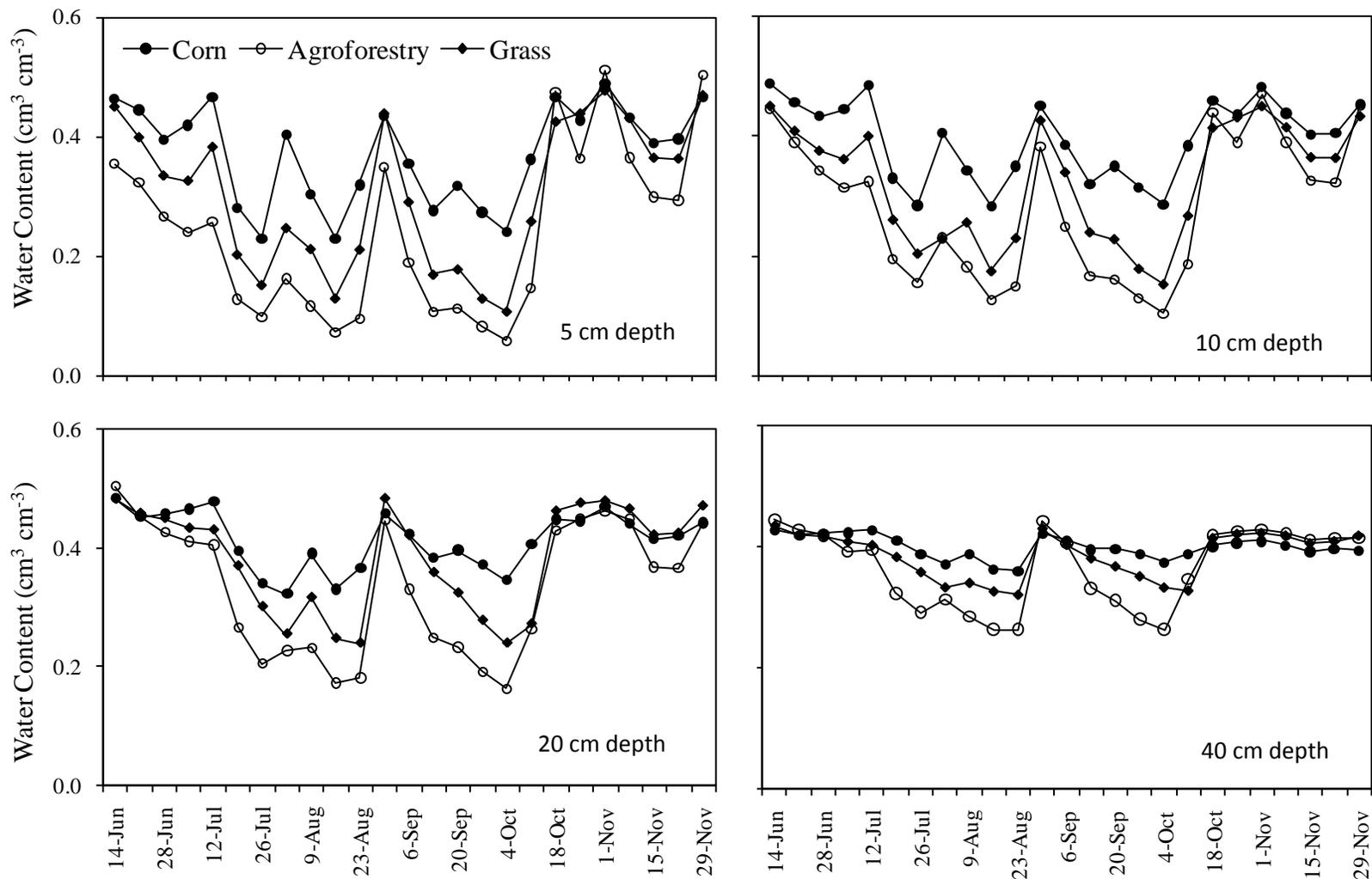


Figure 3. Volumetric soil water content estimated with the linear calibration at 12:00 noon ($n=4$) for crop, agroforestry, and grass treatments at the paired watershed study for 5, 10, 20, and 40 cm depth during 2004. Bars on the 40-cm depth graph indicate LSD values for significant differences in water content between crop and agroforestry treatments at the $\alpha=0.05$ level.

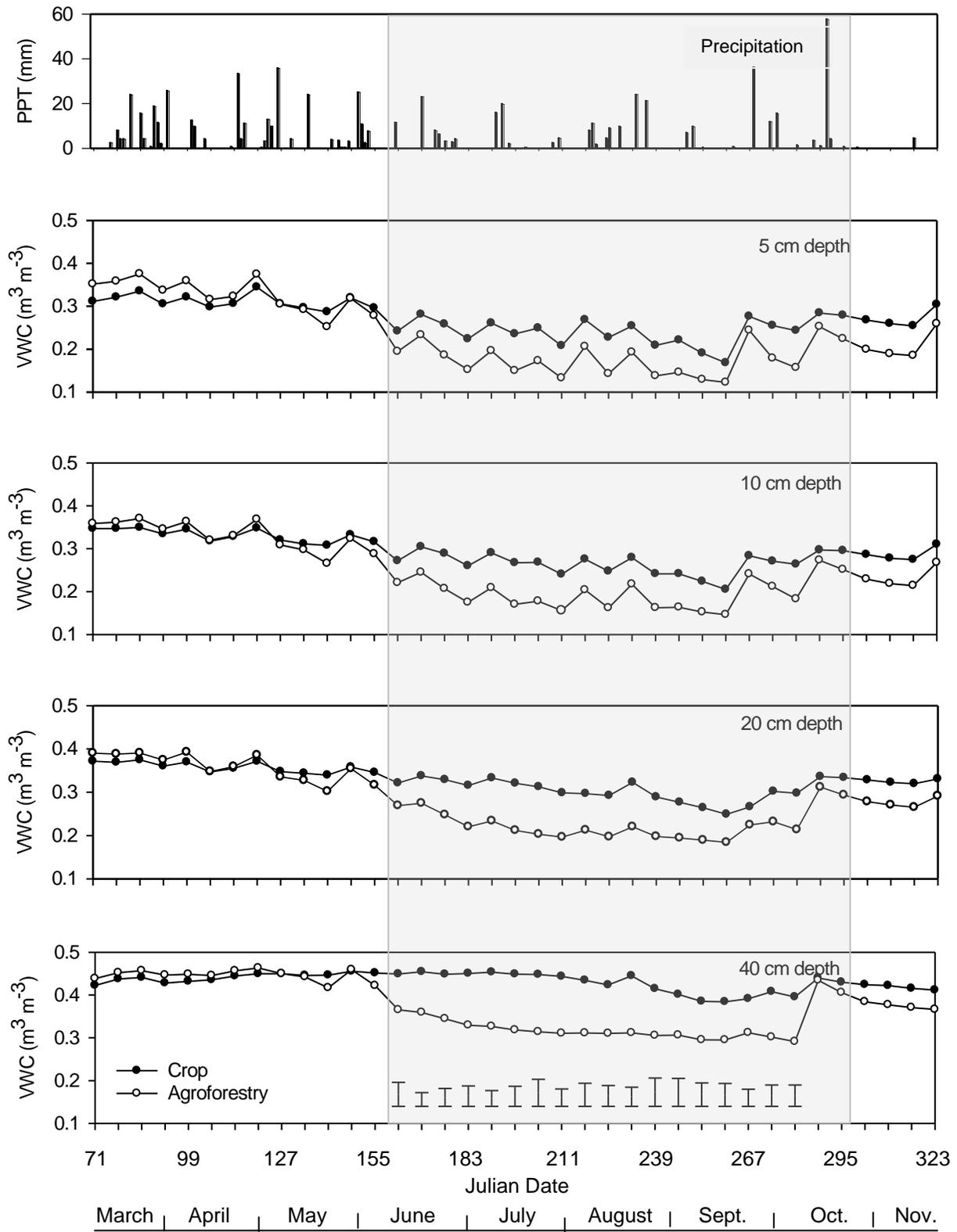


Figure 4. Daily precipitation and volumetric soil water content estimated with the linear calibration at 12:00 noon (n=4) for crop and agroforestry treatments at the paired watershed study for 5, 10, 20, and 40 cm depth during 2007. The gray area shows the crop period for soybeans. Bars on the 40-cm depth graph indicate LSD values for significant differences in water content between crop and agroforestry treatments at the $\alpha=0.05$ level.

The lower water content in the agroforestry and grass treatments compared to the row crop treatment was probably due to more water depletion by the trees compared to the row crop areas. This was attributed to the greater transpiration from the trees in the agroforestry and grass buffer treatments compared to the corn and soybeans in the row crop treatment. In addition, trees and grass begin transpiration before the crop is established thus reducing initial soil water content. They continue to transpire after the crop is harvested. It is assumed that incorporation of agroforestry and/or other permanent vegetation with longer growing seasons might reduce runoff and NPSP from watersheds under row crop management.

CONCLUSIONS

This study was conducted to examine influences of agroforestry and grass buffers on changes in water content throughout the growing season. Agroforestry and grass buffer treatments had lower water content compared to the row crop treatment irrespective of the crop. The results of the study indicate that agroforestry and grass buffer strips had more water use/transpiration during the growing season that allowed more water to be stored in the profile through increased water infiltration thus reducing runoff and soil loss for watersheds under this management system. Incorporation of agroforestry practices may help reduce non-point source pollution from row crop agriculture.

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SECTION 7

Forest Farming

FARMING THE FORESTS OF APPALACHIA: OPPORTUNITIES AND CHALLENGES

James Chamberlain

National Agroforestry Center, Southern Research Station, USDA Forest Service
1650 Ramble Road, Blacksburg, VA 24060
Contact: jchamberlain@fs.fed.us

Abstract: People have been informally farming their forests for generations, although only in recent years has attention been directed at formalizing this land-use practice through research and development. Forest farming is becoming popular for landowners to diversify income, improve resource management, and increase biological diversity. The social, ecological and economic implications of forest farming may be significant to private landowners. Forest farming focuses on producing herbaceous plants that traditionally have been wild-harvested for food, medicine, and other income generating opportunities. Many opportunities and challenges face landowners interested in forest farming. Many markets for forest farmed products are developing rapidly. Under-utilized species may present specialty opportunities for creative entrepreneurs. Shifting from wild-harvest to cultivation may present significant challenges to rural people who are economically marginalized. These new forest ventures may require additional skills and expertise. There may be additional capital or labor requirements that could put undue burden on interested landowners. Market demand and economies of scale may reduce the attractiveness of alternative forest enterprises. Technical challenges of cultivating native herbaceous plants under forest canopies may be daunting, as well. Opportunities and challenges abound for developing forest farming into a viable land-use practice for landowners in the Appalachian hardwood region.

Key Words: Appalachia, Forest Farming, Medicinal Plants, Non-Timber Forest Products

INTRODUCTION

Forest farming has been promoted as an alternative practice that can lead to better and more sustainable management of resources. The practices have been documented, formalized, but in many situations the science behind forest farming is not well developed. The potential to diversify and stabilize income sources, increase forest health, and promote alternative ‘green’ enterprises through forest farming is relatively untapped.

Early settlers to the Appalachian Mountains who wanted to make sure that they had a ready supply of products would replant seeds and treat their patches of forest herbs as if they were gardens. These informal “forest farmers” understood the need to conserve natural resources and realized the importance of taking actions to sustain those resources. Today, forest farming has become more formal with the incorporation of readily accepted farming practices. People interested in farming their forests have many opportunities and constraints that they must consider.

Sholto and Hart (1985) first promoted forest farming to increase and diversify the productive capacity of forestlands. They wanted to promote the production of a range of food and other essential products with the growing of trees for timber. These pioneers of forest farming integrated forestry, animal husbandry and horticulture to achieve maximum output and optimum conservation. They envisioned that a forest farm would integrate three main components – trees, livestock and forage. To these visionaries each piece was an essential element of a whole ecosystem. Over time, the concept of forest farming has evolved to exclude livestock and forage.

Today, forest farming involves the cultivation or management of understory crops within an established or developing forest (University of Missouri Center for Agroforestry, 2006; Agroforestry Research Trust, 2007; Center for Sub-tropical Agroforestry, 2007; Cornell Cooperative Extension, 2007; NAC, 1997). Forest farming can be done in a natural forest or a plantation, and is a sustainable production system that helps keep a forest healthy by diversifying the landscape. Forest farming requires co-management of resources for timber and non-timber products. Management may include intensive cultivation of understory species that are introduced to a stand of trees, or activities to nurture existing plants to improve their production and marketability.

There are advantages and disadvantages to forest farming (University of Missouri Center for Agroforestry, 2006). Forest health can be improved by increasing biological diversity, removing damaged and infected vegetation. It can give people additional and diversified forest income opportunities by producing for more and different markets. Forest farming can increase the amount of productive land available to the landowner. But, forest farming requires more intensive management which demands greater skills and increased time. The markets for many of the products are not well defined nor readily understood by landowners increasing the need for more research and assistance. Learning about and entering new markets may be daunting to many forest landowners. Integrating forestry and farming requires broader knowledge to understand how to grow and manage trees and understory crops, simultaneously.

Forest farmers can realize economic, ecological and social benefits. Diversifying crops, products, production cycles and land management systems, forest farmers may reduce financial risk, decrease environmental impacts and improve cultural and recreational benefits. Economic benefits include increased income from new crops that have shorter rotations and provide revenues streams while longer-term crops mature. Lands that are marginal for traditional agricultural production can be used to generate revenue. Labor may be diversified as new crops can have different production schedules. Water and other resources may be better conserved in a forest farming system. Overall, forest farming provides economic and conservation incentives that boost stewardship and community development.

LOOKING FOR OPPORTUNITIES

Potential forest farmers need to analyze internal and external factors that could influence their success. New practices may require additional skills and expertise. More capital or labor investments may be needed. Potential profit margins in new ventures, such as edible mushrooms, Christmas trees and bees, may be such that investing in these alternatives is not feasible. Landowners need to examine the markets and fully understand the potentials and pitfalls of each

possible venture. Though there are many challenges of developing forest farming, a diversified land use and management strategy can be economically rewarding to landowners willing to invest time and energy.

Growth and emerging markets

Two NTFP markets – herbal medicines and forest foods -- exhibit great growth potential for forest farming. Farming woodlots with plants that are native, have economic value and are traditionally harvested from natural forests can reduce pressures on natural populations and meet the demands of global markets. Farming the forests can provide consistent quality and quantity of products that are wanted by the herbal products industry, worldwide. Interest in and demand for forest foods, such as berries, ferns, greens, onions, mushrooms and nuts provide opportunities in other markets that may be as lucrative. Specialty and niche markets for other product categories (e.g., floral decorative, landscaping, etc.) may provide opportunities, as well.

Herbal Medicines: There are hundreds of native forest plants that are used for their therapeutic value, and marketed either as herbal medicines or dietary supplements. Farnsworth and Morris reported in 1976, that 25 percent of all prescriptions dispensed in the United States contained active ingredients extracted from plants. The number of plant species in Appalachian forests with medicinal value exceeds 125 (Krochmal and others 1969, World Wildlife Fund 1999), yet less than a dozen are commonly harvested for commerce. This region is the principal source of many of these, including black cohosh (*Actaea racemosa*), American ginseng (*Panax quinquefolius*), and bloodroot (*Sanguinaria canadensis*). The potential for expanding the medicinal plant industry is limited only by the tremendous biodiversity of the forests.

The most forest farmed native medicinal plant in Appalachia is American ginseng. Everyone knows about this species, and lots of people are promoting its production in forest farming. Over 3 decades (1978-2006), approximately 2.7 million pounds of ginseng were harvested from the hardwood forests of Kentucky, West Virginia, Tennessee, Virginia, and Indiana. Much of this was farmed in the forests by wild-simulated methods. Kentucky was the largest producer during that period, with a total harvest of 489,000 pounds of dried root. In 2006, twenty-five percent of total ginseng harvest came from Kentucky forests, and 70 percent of the total came from the combined states of Indiana, Kentucky, North Carolina, Tennessee, and West Virginia. Although, ginseng gets most of the attention, many medicinal plants grow under the same forests.

Of the 22 medicinal plants studied by the American Herbal Products Association in 2004-2005, seventeen were harvested from natural forests (AHPA 2007). Table 1 presents the estimated volumes of medicinal herbs harvested from Appalachian forests. All, except one, are herbaceous understory plants. Only one species, Lady Slipper (*Cypripedium* spp.) is reportedly predominantly cultivated. According to the AHPA survey, 100 percent of Bethroot (*Trillium erectum*) used in commerce is harvested from natural forests. An average of 190 thousand pounds of slippery elm (*Ulmus rubra*) bark was harvested annually from 1997 through 2005. Star root (*Alertris farinosa*), is a slow-growing forest plant that is harvested for its root. Other native medicinal plants, such as Black cohosh (*Actaea racemosa*) offer more opportunities.

Table 1. Estimated production volumes of Appalachian medicinal herbs, 2004 - 2005

Year	Plant Part	Scientific	Alertris	Trillium	Actaea	Sanguinaria	Caulophyllum	Chamaelirium	Hydrastis	Hydrastis	Cypripedu	Ulmus	Aristolochia	Dioscorea
		Binomial	farinosa	erectum	racemosa	canadensis	thalictroides	luteum	canadensis	canadensis	m.spp.	rubra	serpentaria	villosa
		Common Name	Alertris	Bethroot	Black cohosh	Bloodroot	Blue cohosh	False Unicorn	Goldenseal	Goldenseal	Lady's slipper	Slippery Elm	Virginia snake-root	Wild yam
		root	root & rhizome	root	root	root	root & rhizome	leaf	whole plant	bark	root	tuber		
2005	Cultivated		2	0	6930	0	126	1043	33756	7092	15	1731	0	363
	Wild		51	1038	136370	5328	8039	4945	47714	6939	0	203984	59	33003
2004	Cultivated		50	0	3312	0	207	1034	2100	5178	123	803	0	412
	Wild		571	475	318729	11487	5054	3638	61180	2495	135	78380	353	27616
2003	Cultivated		0	0	410	20	86	1400	11070	2435	286	0	0	42
	Wild		546	1469	318143	39590	7627	4839	31802	6869	5	229866	135	37021
2002	Cultivated		0	0	282	26	80	1400	15779	8926	110	0	0	54
	Wild		1326	1471	169436	26473	4449	5086	41845	16612	0	202309	40	31573
2001	Cultivated		0	0	6521	19	90	700	21337	4941	210	0	0	356
	Wild		2109	1040	177681	41236	8085	4735	105099	47558	113	197634	17	37899
2000	Cultivated		0	0	149	0	0	700	18963	4248	0	0	0	10055
	Wild		1508	1911	117843	48674	5506	3730	70396	18770	95	148387	287	32358
1999	Cultivated				2600				47599	5487		10200		100
	Wild				145367				91435	87524		256839		58544
1998	Cultivated				35430				6445	2228		5000		200
	Wild				725984				258843	65490		181053		61794
1997	Cultivated				0							0		0
	Wild				227002							205418		61799
Total	Cultivated		52	0	55,634	65	589	6,277	157,009	40,535	744	17,734	0	11,582
	Wild		6,111	7,404	2,336,555	172,788	38,760	27,173	708,294	252,257	348	1,702,870	891	381,597
Percent	Cultivated		0.84%	0.00%	2.33%	0.04%	1.50%	18.77%	18.14%	13.84%	68.13%	1.03%	0.00%	2.95%
	Wild		99.16%	100.00%	97.67%	99.96%	98.50%	81.23%	81.86%	86.16%	31.87%	98.97%	100.00%	97.05%

Source: American Herbal Products Association, AHPA 2004-05 Tonnage Survey

Since the U.S.D.A. Food and Drug Administration took actions to restrict Hormone Replacement Therapy, market demand for black cohosh, a native medicinal plant used for menopausal symptoms, has been on the increase (Dog and others 2003). When consumers became aware that cohosh was effective for menopausal symptoms, retail sales sky-rocketed. From 1997 through 1998, retail sales of this medicinal plant increased more than 500 percent (Blumenthal 1999). Over 9 years (1997 – 2006), more than 97% of the 2.39 million pounds of black cohosh roots were harvested from the wild. Forest farming this important medicinal plant would reduce the pressures on native populations, and could be lucrative for private forest landowners.

Forest Foods: Most people don't think of the forest as a source of things to eat. But people have been collecting native plants for their personal consumption for generations. Recently, there has been a surge of interest in forest edibles, and markets are emerging and developing rapidly for these products. The potential is only limited by the diversity of plants that are edible. Edible and culinary products that can be farmed in the forests of Appalachia include mushrooms, ferns, fruits, leaves, and roots and tubers. Perhaps the most popular in Southern Appalachia are ramps (*Allium tricoccum*); wild onions that are harvested for a short period in the spring. Surprisingly, Southern Appalachian forests also are a source of maple syrup and berries.

Many edible mushrooms, such as shiitake (*Lentinula edodes*), maitake (*Grifola frondosa*), lion's mane (*Hericiium erinaceus*), and oyster (*Pleurotus* spp.) can be forest farmed for commercial gain. The shiitake mushroom is the most popular for small-scale cultivation. Production of

shiitake in this country started about 2 decades ago, when demand exceeded the ability of importers to fulfill orders, and the technology for landowner production became readily available and simple. As the market develops and more people begin to grow mushrooms, profit margins will decrease. Under-utilized and less well-known mushroom species may provide greater returns on investment, yet they may present additional risks as well. Successful forest farmers of mushrooms will figure out how to compete with established and experienced enterprises by finding niche markets and producing high-quality and low-cost products. Growing mushrooms can be very rewarding, but successful commercial producers are those who market them well.

Appalachian forests are the source of wild onions, locally known as ramps, the market for which is burgeoning. Once a local delicacy, shared at annual festivals, this forest food can now be purchased over the internet and in distant markets, such as New York City and Chicago. They are only available for a short period in the spring, before the tree canopy is completely developed. Ramps grow naturally under a forest canopy of beech, birch, maple, and/or tulip poplar. To forest farm ramps, the leaves are raked back to expose bare soil; seeds are then sown and then covered with leaf litter. It is also possible to transplant bulbs, if a natural patch is available. The plants are relatively slow growing, and it may take 5 years before harvest is feasible. Once they mature and produce seed and reproduce vegetatively, farming the forests with ramps should be fairly low-cost.

Surprisingly, some southern states produce maple syrup, and this may present a forest farming opportunity. According to 2002 Census data, there were 71 maple syrup farms in the south. Kentucky is one of three states in the south that have maple syrup farms, and it had the most sugar bushes. In 2002, 38 maple syrup farms could be found in Kentucky, with a total of 4,142 active taps. These farms produced approximately 416 gallons of syrup, representing about 9 percent of total maple syrup production in the southern region. At the same time, Virginia had 26 sugar bushes, with 28,864 taps. Virginia produced 91 percent of the total (4,824 gallons) maple syrup production in the south. Though this market may be limited, a landowner with a stand of sugar maple may want to consider this option.

Other Non-Timber Opportunities: Many forest products are harvested for use in floral displays or decorative crafts. The diversity of products available is limited only by the crafter's imagination. A variety of plant parts are harvested, including wood, boughs, leaves, vines, flowers, or whole plants. Forest farmers may manage their woodlots for these products and harvest raw materials to sell to crafters, or produce finished products to be sold at craft fairs, retail stores, or online. Decorative wreaths, commonly made from pines (*Pinus* spp.), hollies (*Ilex* spp.), junipers (*Juniperus* spp.), willows (*Salix* spp.), ivy (various species), grapevines (*Vitis* spp.), and smokevine (*Aristolochia macrophylla*), may present opportunities for enterprising forest landowners. Harvesting non-native invasive plants, such as kudzu (*Pueraria lobata*), can be lucrative, as well. Developing forest farming practices for these alternative products may be one of the greatest challenges.

FACED WITH CHALLENGES

Interest in farming the forests for botanicals is driven by a variety of forces. As the natural products industry grows, demand for raw materials will increase. And as interest in organic and

sustainably harvested products increase, the potential for forest farming increases, as well. Recent safety and quality issues with foreign imports have convinced some companies to purchase more domestically produced herbs. Consumers are driving demand for certified organic products, and as concerns about the conservation of wild-harvested herbs increases manufacturers are starting to source herbs that are certified to be harvested using sustainable practices. This has resulted in increased prices paid for quality cultivated material. The number of forest landowners interested in growing alternative crops has been increasing, as a result of this trend. Those interested in adopting forest farming of native plants are faced with new and often daunting challenges.

Production

Growing native plants should be simple, as they occur naturally in Appalachian forests. But, many questions remain unanswered for most native herbaceous plants. Ginseng is the major medicinal herb farmed in the forest, and there is a great deal of literature on the subject. There also is adequate information on growing goldenseal (*Hydrastis canadensis*). But, for other forest herbs forest farming information is lacking. Information may be available, but finding it is challenging. Companies that sell seed often can provide information on propagation. Before venturing into a new crop, it is wise to learn as much as possible about the new plant. Through trial and error, production practices can be developed and refined for the new plant.

Estimating how much production to expect presents a special challenge. Production figures are presented in much of the literature (Persons and Davis 2005; Jacobson and Burkhart 2005; Burkhart and Jacobson 2008; Hankins 2000). In one example, twelve and half pounds of ginseng seed, planted under wild-simulated conditions, yielded 80 pounds of dry roots after nine years (Persons and Davis 2005), representing a 540 percent increase in biomass. Another example indicated that a grower could expect 1150 percent increase in biomass over six years in a woods-cultivated scenario (Persons and Davis 2005). The final yields in both examples were presented in dry weight, which suggests that there was even greater biomass production over that period. Such yields from slow growing forest species may not be unrealistic and need to be further assessed.

Jacobson and Burkhart (2005) project yields for six non-timber forest products under two planting schemes. They estimate that under a woods cultivated scenario, a forest farmer can expect to produce about 40 pounds per acre of black cohosh root in three years. Under a wild-simulated scenario, they estimate black cohosh production to be about 17 pounds per acre. These estimates and others (Persons and Davis 2005) may not be supported by empirical evidence that is needed to accurately assess production figures. They do provide a good place to start assessing the potential for forest farming, but more pragmatic indications are needed to support such claims.

To exacerbate the situation, no metrics have been developed to allow for the inventory of below-ground biomass (i.e., roots) based on above-ground biomass (e.g., leaves, stems, etc.) for these herbaceous native medicinal plants. A forester can take measurements of the trees and estimate the volume of standing timber. But, there is no way to take measurements of a stand of ginseng, black cohosh, or other native medicinal plants and estimate the volume of merchantable roots.

Further, the empirical evidence is lacking to estimate mean annual growth or mortality in a stand of these medicinal plants. Under forest farming these are needed for a landowner to estimate how much can be harvested on a regular basis.

Markets

Finding and entering NTFP markets can be easier said than done. Most forest landowners who have harvested timber can identify places to sell products and potential markets. This may not be as simple for herbal medicines, forest foods, or other alternative forest products. Even though, herbal medicines have been gathered and traded in this country for more than 300 years, the markets for these products remain an enigma to most people. In many cases, transactions are based on long-term relationships, which can impede entry by new players.

Over the last decade there has been a surge of interest in foods from the forests. Most forest foods are not sold in typical grocery stores, although natural food stores may offer these products. Demand for unusual and tasty edible forest products may be small, but it is increasing. Some forest foods, such as ramps, have been highlighted on cooking shows and in gourmet magazines (Turczyn 2002). Many are sold over the Internet and a quick search will bring new opportunities to the entrepreneurial producer.

Economics

The economics of growing native plants under forest farming may not be attractive to private landowners. Most estimates of NTFP values and volumes are not based on consistent or reliable data, making it difficult to estimate the economic value of producing these crops. The production of only a few non-timber forest products are tracked regularly. Estimating production volumes and translating this into economic terms presents a challenge that needs to be addressed.

Most NTFPs are traded as commodities; large volumes sold at low prices. For a small forest landowner, producing for this scenario is challenging. To effectively serve NTFP markets may require larger volumes than possible for a small woodlot to produce. Though small-scale production may be possible, getting sufficient prices to make forest farming feasible may not be possible. Getting a high enough price on these products to cover costs and provide a profit may require developing long-term relationships with buyers and ensuring high quality and quantity. Forest farming cooperatively with other landowners may be warranted to get higher prices by being able to offer larger volumes.

Traditionally, NTFPs have been gathered from natural forests and the pricing structure reflects this. Typically, prices are not sufficient to warrant many inputs. Forest farming can require inputs in the form of land preparation, planting stock, fertilizer and pesticides, as well as machinery. Overcoming this challenge may mean keeping inputs to a minimum and finding ways to increase product value. Production systems that mimic natural processes may be the best approach. Producing high quality, consistent product that is certified organic (though the process of getting certified increases costs) may also be advisable.

CONCLUSIONS

Most contemporary discussions of forest farming include only medicinal plants, yet there may be a broader range of opportunities for landowners to farm their forests. A critical feature that distinguishes forest farming is that it incorporates shade-tolerant, non-timber forest resources with trees that form a closed canopy and may be grown for timber. Co-management of over-story trees with shade-tolerant understory plants is a major objective and challenge of forest farming. It will require new skills and expertise, and can increase income opportunities for the landowner. At the same time, forest farming can increase the diversity of plants while keeping trees standing longer.

Compared to traditional agricultural or forestry commodities, there may be few market structures in place, and relatively sparse information regarding production. Integrating forestry and farming will require broader knowledge to successfully manage the trees, understory and their interactions. Forest farming can take more time and energy, and landowners may lack the expertise to understand and produce quality and quantity needed by 'new' markets. But for the tenacious and patient entrepreneur, forest farming can be rewarding.

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PRODUCTION PHYSIOLOGY OF THREE NATIVE ORNAMENTAL SHRUBS INTERCROPPED IN A YOUNG LONGLEAF PINE PLANTATION

Donald L. Hagan¹, Shibu Jose¹, Mack Thetford², and Kimberly Bohn³

¹School of Forest Resources & Conservation, University of Florida, Gainesville, FL USA 32611

²Department of Environmental Horticulture, University of Florida, Milton, FL, USA 32583

³School of Forest Resources & Conservation, University of Florida, Milton, FL, USA 32583

Contact: donhagan@ufl.edu

Abstract: The production of woody floral products – the fresh or dried stems that are used for decorative purposes – may be an attractive option for southeastern landowners looking to generate income from small landholdings. Since many shrubs native to the understory of the longleaf pine ecosystem have market potential, one possibility is the intercropping of select species in the between-row spacing of young longleaf pine plantations. The objective of this study was to evaluate how competition affects the physiology, and thus the productivity of American beautyberry (*Callicarpa americana* L.), wax myrtle (*Morella cerifera* (L.) Small) and inkberry (*Ilex glabra* (L.) A.Gray) when intercropped in a longleaf pine (*Pinus palustris* Mill.) plantation in the southeastern United States. The effect of competition was assessed via comparisons of mortality, biomass, light transmittance, gas exchange and soil moisture between intercropping and monoculture (treeless) treatments. Overall, shrubs in the intercropping treatment performed worse than those in the monoculture, with higher mortality, and reductions in biomass of 75.5%, 50.6 %, and 68.7% for *C. americana*, *M. cerifera* and *I. glabra*, respectively. Root-shoot ratios for all species were significantly higher and soil moisture during dry periods was significantly lower in the intercropping treatment. Light transmittance below the pine canopy was high (57.7%) and *I. glabra* was the only species that exhibited reduced photosynthesis due to shading. These results suggest that the effect of shading is minimal and belowground competition is likely the most important determinant of productivity in this system.

Keywords: Intercropping, longleaf pine, ornamentals, woody florals, competition, physiology

INTRODUCTION

The interest in alternative cropping practices such as intercropping has been increasing in the United States over the years. However, the knowledge base required for the proper design and implementation of such systems is limited (Vandermeer 1992, Jose and Gordon 2008). This is due to the fact that the science and practice of temperate intercropping is relatively new, and that these systems, with their potential for interspecific interactions, are much more complex than conventional monocultures (Garrett and Buck 1997; Gillespie et al. 2000).

The productivity of a mixed-species cropping system is ultimately determined by the type and extent of interactions that occur within it (Zhang et al. 2003, Jose et al. 2006). In the broadest sense, these interactions can be classified as either competitive or facilitative, and divided into two main categories: aboveground and belowground (Ong et al. 1991; Schroth 1999; Jose et al.

2004). Paramount among aboveground interactions is shading (Boardman 1977), which, depending on the degree of canopy closure, the shade tolerance of the understory crop, and interactions with below-canopy microclimate, can have either a competitive or facilitative effect (Chirko et al. 1996; Jose et al. 2004). The typical leaf-level response to shading is a reduction in photosynthesis – the degree of which being inversely related to the plant's level of shade tolerance – but this reduction in CO₂ uptake may be offset by increased photosynthetic efficiency at lower light levels. Plants also acclimate to reduced light conditions through increases in specific leaf area or by an increase in carbon allocation to aboveground tissues (Chapin et al. 2002). The ability to quantify the relationship between shading and plant productivity is key to selecting the species that are best adapted to reduced-light conditions and for developing an understanding of how best to manage mixed-species system.

Resource limitations that arise due to belowground competition can result in an adjustment of carbon allocation patterns to favor root development over shoot development. The ratio of root biomass to shoot biomass is, therefore, a helpful diagnostic tool for determining whether aboveground or belowground competition is most prevalent in a given system (Chapin et al. 2002). Competition for water can cause loss of turgor and induce stomatal closure (Kho 2007). This reduces photosynthesis, resulting in decreased carbon uptake. Competition for water can also affect the mobility and thus the availability of soil nutrients (Baldwin 1975), which can further hinder photosynthesis and growth. Tissue analyses, particularly those that assess foliar nitrogen and chlorophyll concentrations, are effective means of quantifying plant nutritional status (Porro et al. 2000; Netto et al. 2005). As such, they are also useful in assessments of belowground interspecific competition in mixed-species systems (Caton et al. 2003). Instantaneous gas exchange measurements correlated with environmental parameters such as soil moisture can also be good indicators of belowground competition in a system (Miller and Pallardy 2001), but have not been extensively employed in field studies.

The inherent complexity of intercropping systems makes them more analogous to natural ecosystems than to conventional cropping systems. The most sustainable and productive intercropping systems, therefore, are often those that are modeled after native plant communities (Ewel 1999). Since many shrubs native to the understory of the longleaf pine (*Pinus palustris* Mill.) ecosystem have market potential as woody floral products, one exciting possibility is the intercropping of select species in the between-row spacing of young longleaf pine plantations. Such a system would provide yearly income, which would supplement the long-term returns from longleaf pine timber sales. The development of a longleaf pine-native woody ornamental intercropping system, however, is dependent upon an understanding of how the trees and shrubs interact in the context of a managed, mixed-species setting. Thus, the overall objective of this study was to evaluate how above and belowground competition would affect the productivity of three native shrub species: American beautyberry (*Callicarpa americana* L.) (Verbenaceae), wax myrtle (*Morella cerifera* (L.) Small) (Myricaceae), and inkberry (*Ilex glabra* (L.) A.Gray) (Aquifoliaceae) in such a system. The three specific objectives were:

1. Determine how PAR transmittance and soil water content vary in monoculture and intercropping systems.
2. Determine growth and biomass allocation patterns of the three shrub species with respect to shading and belowground competition from longleaf pine trees.

3. Quantify the effect of above and belowground competition on leaf-level physiological processes for the three shrub species.

Species native to the understory of the longleaf pine ecosystem were chosen for this study. It was hypothesized, therefore, that all would be well adapted to the shaded conditions of an intercropping system. Reductions in growth and yield, if observed, would likely be due to belowground competition with longleaf pine.

MATERIALS AND METHODS

Study Site and Experimental Design

This study was conducted on a private 15-year-old longleaf pine plantation in Santa Rosa County, Florida, USA (30°37' N, 87°2' W). The climate of the region is classified as temperate, with mild winters and hot, humid summers. Mean annual precipitation is 1645 mm. The soil is an ultisol and classified as a Fuquay sand (loamy, kaolinitic, thermic Arenic Plinthic Kandiudult), nutrient poor, deep, well-drained sand over loamy marine or fluviomarine deposits.

Trees in the study site were uniformly spaced, with approximately 3 meters between rows and 1.5 meters between stems within the row, a typical pre-thinning planting density for southern pines. Approximately 10% mortality, however, had occurred over the course of the 15 years due to hurricanes and pine beetles. At the initiation of the study (December 2005), mean tree height was approximately 6.1 meters and mean diameter at breast height (DBH) was 8.3 cm. Basal area was estimated at 12.6 m² ha⁻¹. Canopy coverage was estimated at 35% using canopy photographs.

In December 2005, containerized native woody ornamental shrubs were incorporated into the existing between-row spacing of the site, and as an equivalently spaced monoculture treatment in an adjacent open field. Selected species were American beautyberry (*Callicarpa americana*), wax myrtle (*Morella cerifera*), and inkberry (*Ilex glabra*). These species have not been extensively domesticated, but each produces an attractive stem that was identified as potentially marketable by local florists. *C. americana* produces long (up to 1 m) unbranched stems with clusters of purple berries at the base of each petiole. *M. cerifera* produces straight or crooked stems with small fragrant drupes and deep green foliage. *I. glabra* produces long (up to 1 m) sometimes branched stems with deep green foliage and black drupes (on female plants). Shrubs were given a year for proper establishment with dead or dying shrubs being replaced in the winter of 2006, prior to the initiation of the study.

The effect of intercropping on shrub productivity in this system was assessed via comparisons with the monoculture treatment. The trial was laid out as a split-plot completely randomized design with treatment (monoculture or intercropped) as the whole plot factor and shrub species as the split-plot factor. There were four replications, each consisting of six subplots (one for each species by treatment combination) with eight shrubs each. Subplots were 2 alleys wide (or equivalent distance in the monoculture) with shrubs planted in two rows of four at a spacing of 3 meters. As a control, four subplots of the same dimensions were established in the plantation and not planted with shrubs.

Fertilizer Application and Plot Maintenance

To simulate the effect of a slow-release fertilizer, three applications of ammonium sulfate fertilizer $(\text{NH}_4)_2\text{SO}_4$ (21% N) each at a rate of $146.5 \text{ kg N ha}^{-1}$ were uniformly hand applied at approximately 60 day intervals in a circular area of 325 cm^2 at the base of each shrub. The first application was on 21 March 2007, shortly after bud swelling and leaf emergence were first observed. Pesticide and herbicide application, along with manual weed removal, were conducted as needed throughout the growing season. Plots were non-irrigated, but supplemental water was uniformly provided to all shrubs when at least 20% showed signs of extreme drought stress. This occurred on three occasions during a particularly dry period from mid May to early June 2007.

Light Transmittance and Soil Water Content

Two Hobo[®] quantum sensors, wired to Micro Station data loggers (Onset Computer Corporation, Bourne, MA, USA) were installed at a height of 105 cm above ground level in each of the two experimental treatments (intercropping or monoculture). Automated measurements of photosynthetically active radiation (PAR) were taken at 30 minute intervals from May 2007 until October 2007.

Soil water potential (kPa) measurements were taken in conjunction with gas exchange measurements using tensiometers (Soil Measurement Systems, Tucson, Arizona, USA), set at depths of 20 and 50 cm at 20 cm from the base of one shrub (or shrubless control) per subplot. Biweekly measurements were taken from May 2007 until October 2007. Volumetric soil water content was measured using a 12 cm electronic time domain reflectometry (TDR) probe (Campbell Scientific Inc. Logan, UT, USA). Readings were taken for each shrub at three distances in the intercropping treatment (at the base of the tree, midway between tree and alley center and at alley center), and equivalent distances in monoculture plots. Measurements were taken at monthly intervals, beginning shortly after leaf emergence in early April and continuing until shrubs were harvested at the end of the growing season.

Biomass, Chlorophyll and Leaf Area Sampling

In order to shed light on the physiological processes that affect growth and yield in this system, two shrubs per species-plot combination (48 total) were selected for destructive harvesting in October 2007. For these shrubs, 20 leaves were randomly selected and analyzed for chlorophyll concentration with a hand-held SPAD-502 meter (Minolta Corp., Japan). Stem subsamples from each of the four cardinal directions were then harvested and separated into stem and leaf and (when applicable) fruit components. The remaining aboveground biomass was then harvested and all samples were transported to the lab where they were separately weighed. In the lab, subsample leaf area was determined on fresh leaves using a LICOR Li-3100C leaf area meter (Lincoln, Nebraska, USA).

Belowground biomass of the same 48 shrubs was harvested later. For this, a hole with a 70 cm radius centered on each shrub was excavated and roots were separated from those of non-target

species in the field on the basis of texture and color. Further separation was done in the lab, where roots were washed with water over a 1 mm mesh screen to remove soil and debris. All tissues were dried separately at 70°C for 48 hours. Specific leaf area (SLA) was determined by dividing LA by dry leaf weight. The ratio of leaf area to subsample biomass (g) was multiplied by the aboveground dry biomass of the respective shrub to obtain an estimate of whole plant LA. Dry weights were used to determine root:shoot biomass ratio for each shrub.

Pine Root Length Density

Soil cores (8 x 90 cm) were taken in control (shrubless) plots at 40, 80 and 120 cm from a tree, divided into 30 cm sections and sifted to separate pine roots from soil. Root length was determined by using the line intercept method described by Tennant (1975) and divided by soil core volume to determine root length density (RLD). Sampling was conducted after the growing season ended (November 2007) to prevent interference with water and nutrient uptake.

Gas Exchange Measurements

A LICOR 6400 (Lincoln, Nebraska, USA) infrared gas analyzer (IRGA) was used to create photosynthetic light response curves during the peak of the growing season (July 2007). These were done using the internal LED light source at 8 pre-set levels of descending PAR (1600, 1000, 700, 400, 100, 50, 25 and 0 $\mu\text{mol cm}^2 \text{sec}^{-1}$) on 6 plants per species by treatment combination. The IRGA was operated at a flow rate of 400 $\mu\text{mol CO}_2 \text{s}^{-1}$ and set to control chamber CO_2 concentration at 380 ppm. An effort was made to maintain chamber humidity as close as possible to ambient levels. Measurements were taken over a 4 day period during which several rainfall events maintained soil moisture at or near field capacity. This, it was assumed, would ensure that water stress would not be a major determinant of photosynthesis, thereby helping to isolate light level as the variable of interest. Curves were fit using a nonlinear Mitscherlich model, as described by Peek et al. (2002).

The LICOR 6400 was also used to measure net photosynthesis (A) ($\mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$) and stomatal conductance (g) ($\text{mm m}^{-2} \text{s}^{-1}$) of two shrubs per species-plot combination (48 total). Measurements were taken twice monthly on clear days between 1000 and 1300 hrs, beginning with the full expansion of new leaves in late May 2007 and continuing until the latter part of the growing season in September 2007. No measurements were taken within 48 hours of any significant rainfall event. The same plants were used for each set of measurements in a repeated measures design. The IRGA was operated in a survey mode with a transparent 0.785 cm^2 arabidopsis chamber, a flow rate of 400 $\mu\text{mol CO}_2 \text{s}^{-1}$ and with reference CO_2 set at 400 ppm.

Tree Growth

Diameter at breast height (DBH) was measured in February of 2006, 2007 and 2008 on all trees in the intercropping plots to monitor annual incremental growth.

Data Analysis

SPAD units were converted to chlorophyll concentration ($\mu\text{g Chl cm}^{-2}$) as described by Markwell et al. (1995). Data for biomass, root length density, specific leaf area and chlorophyll concentration were analyzed using a two-way analysis of variance (ANOVA) procedure using PROC GLM in SAS 9.1 (SAS Institute, Cary, NC, USA). Time-integrated measurements (gas exchange, soil moisture and PAR) were analyzed with a repeated-measures ANOVA using the PROC MIXED procedure in SAS 9.1. With the exception of RLD, all analyses were conducted within the framework of a split-plot, completely randomized experimental design. Specifically, treatment effects (intercropping vs. monoculture) were compared for each shrub species for each variable of interest. Log transformations were performed when necessary to improve data normality. Differences between means were considered significant at $\alpha < 0.05$ and Tukey's HSD post hoc test was used for pairwise comparisons.

RESULTS

Light Transmittance and Soil Water Content

Overall, PAR transmittance below the pine canopy averaged 57.7% over the 6 month time period from May to October 2007. The highest transmittance levels (64.8 and 62.0%) were observed in June and July, respectively. Values for other months were significantly lower, with August being the lowest at 52.4% (Figure 1). Significant variability was observed on a daily time scale, with periods of near 100% transmittance alternating with periods where transmittance was greatly reduced by shading (Figure 2).

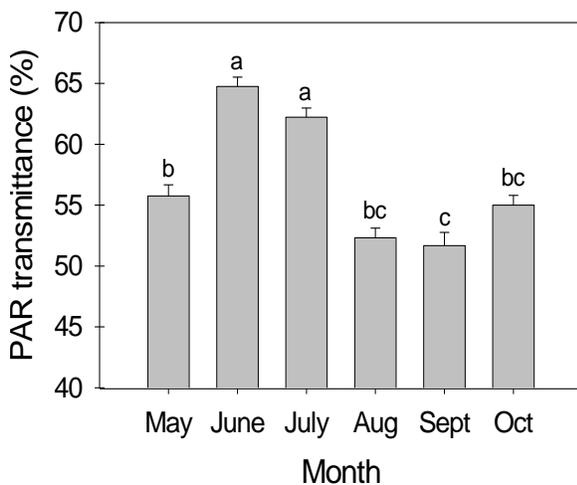


Figure 1. Mean transmittance (by month) of photosynthetically active radiation (PAR). Means with different lowercase letters are significantly different at $\alpha < 0.05$.

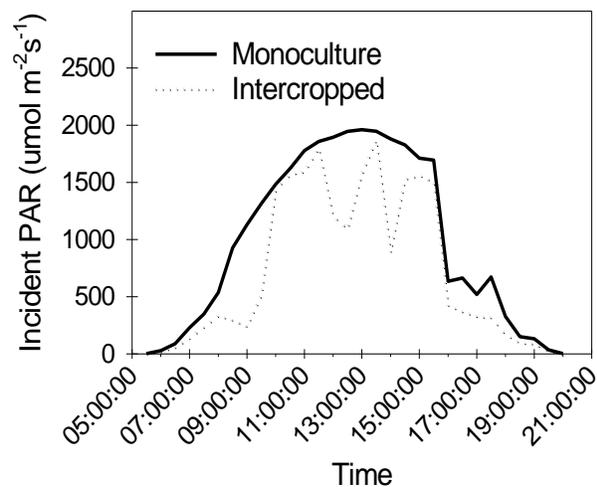


Figure 2. Typical patterns of incident PAR over the course of a cloud-free day in June 2007.

Soil water potential varied by date ($P < 0.0001$) and depth ($P < 0.0001$) and there was a significant treatment by depth interaction ($P = 0.0165$). At 20 cm, soil moisture was generally lower in the intercropping treatment, with the difference becoming statistically significant in late

August. At 50 cm, soil moisture was significantly higher in the intercropping treatment in late June and in early September (Figure 3). Volumetric water content showed significant variation by date ($P < 0.0001$) and distance from shrub base ($P < 0.0001$) and there was an interaction between treatment and distance ($P < 0.0001$) (Figure 4).

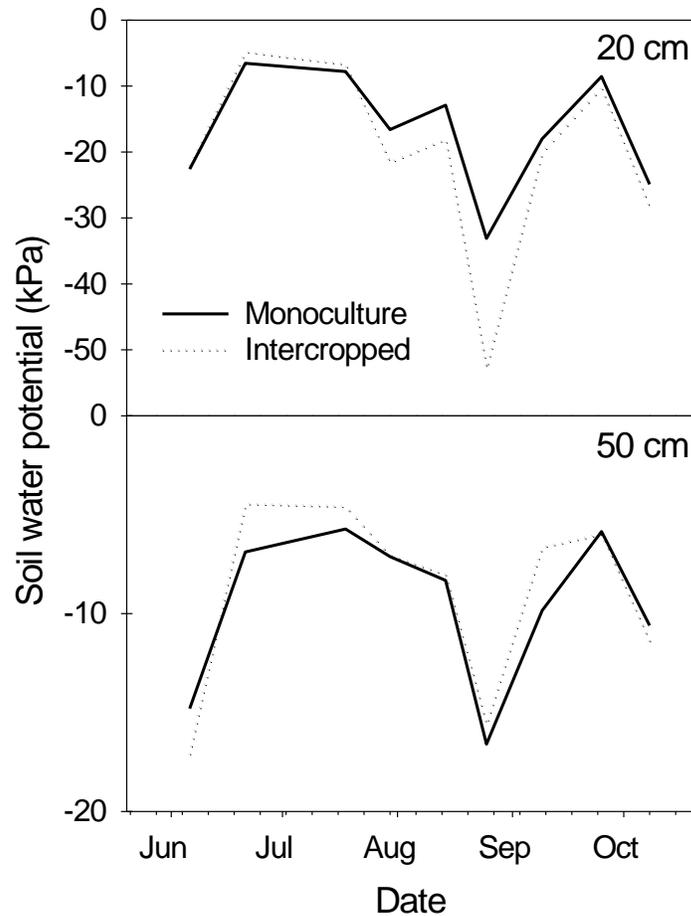


Figure 3. Soil water potential (kPa) at 20 cm (top) and 50 cm (bottom).

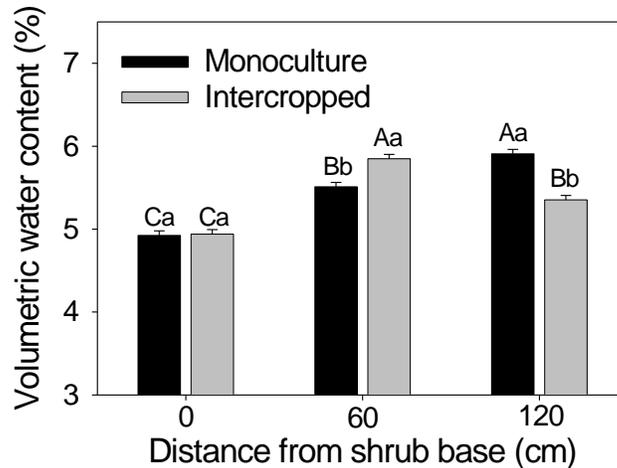


Figure 4. Mean (March to October) volumetric water content (%) at 0, 60 and 120 cm from shrub base. Within-treatment means with different uppercase letters are statistically different at $\alpha < 0.05$. Between-treatment means (by distance) with different lowercase letters are statistically different at $\alpha < 0.05$.

Survival, Growth and Biomass Allocation Patterns

Mortality was higher for all shrub species in the intercropping treatment, particularly so for *C. americana* (Table 1). Growth was also affected, with reductions in biomass in the intercropping treatment of 75.5% ($P = 0.0030$), 50.6 % ($P = 0.0200$), and 68.7% ($P = 0.0012$) for *C. americana*, *M. cerifera* and *I. glabra*, respectively. Differences in biomass allocation patterns were also observed, with root:shoot ratios being higher by 14% for *C. americana* ($P < 0.0001$), 6% for *M. cerifera* ($P = 0.0020$), and 11% for *I. glabra* ($P < 0.0001$) in the intercropping treatment (Figure 5).

Table 1. Survival (%) by species * treatment combination

Species	Treatment ¹	
	MC	IC
<i>C. americana</i>	97	53
<i>M. cerifera</i>	94	81
<i>I. glabra</i>	78	75

¹MC = monoculture, IC = intercropped

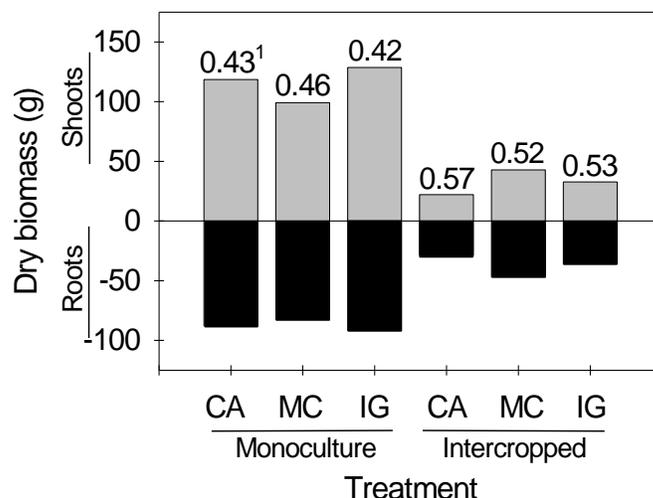


Figure 5. Above and belowground biomass for *C. americana* (CA), *M. cerifera* (MC) and *I. glabra* (IG). ¹Numbers above bars represent root:shoot ratios.

Overall, leaf area was higher in the monoculture, with reductions of 81.4% ($P = 0.0136$) and 78.3% ($P = 0.0022$) observed in the intercropping treatment for *C. americana* and *I. glabra*, respectively. SLA was significantly higher for all species in the intercropping treatment. Observed differences were 18.0% for *C. americana* ($P = 0.0303$), 14.2% for *M. cerifera* ($P = 0.0021$) and 12.4% for *I. glabra* ($P = 0.0449$). Chlorophyll concentrations were 42.6% lower for *C. americana* in the intercropping treatment ($P = 0.0114$), but there were no treatment effects for *M. cerifera* or *I. glabra* (Table 2).

Table 2. Mean leaf area, specific leaf area (SLA) and chlorophyll concentration (Chl).

Species	Treatment	Leaf area (cm ²)	SLA (cm ² g ⁻¹)	Chl (µg Chl cm ²)
<i>C. americana</i>	Monoculture	4896.9	82.9±4.0	14.9±1.1
<i>C. americana</i>	Intercropped	908.2	101.2±4.8	8.2±1.3
		(0.0136) ^{1,2}	(0.0303)	(0.0114)
<i>M. cerifera</i>	Monoculture	1806.3	59.7 ±1.3	13.7±0.9
<i>M. cerifera</i>	Intercropped	898.8	68.1 ±1.2	13.3±0.8
		(0.1106)	(0.0021)	(0.8576)
<i>I. glabra</i>	Monoculture	3125.3	62.5±2.6	32.4±2.6
<i>I. glabra</i>	Intercropped	676.9	70.3±2.3	28.0±2.3
		(0.0022)	(0.0449)	(0.2462)

¹ P -values given in parentheses. ²Leaf area P -values determined from log transformed data

Root length density for longleaf pine varied by distance in the alleyway ($P = 0.01$) and depth ($P < 0.0001$). Values decreased with increasing depth, and were highest (at all depths) at 120 cm

from the trees – a distance which coincides with the middle of the alley (Figure 6). In total, 81.1% of longleaf pine fine roots were confined to the uppermost 30 cm of the soil profile.

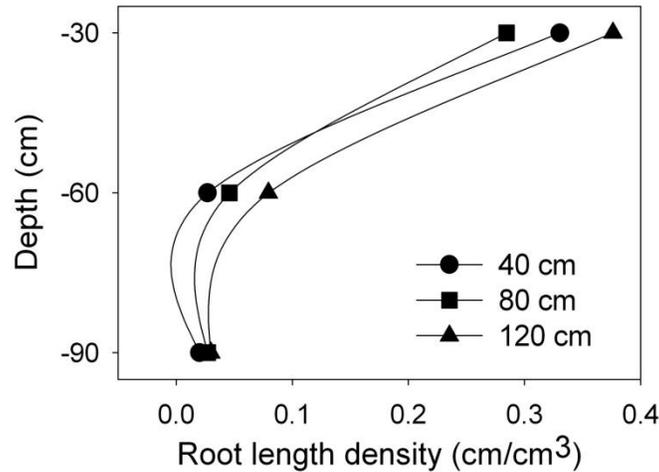


Figure 6. Mean root length density (RLD) for longleaf pine at three distances from a tree (40, 80 and 120 cm) and at three depths (30, 60 and 90 cm).

Photosynthesis and Stomatal Conductance

With soil moisture at field capacity, treatment differences in light saturated photosynthesis (A_{max}) were not observed for *C. americana* or *M. cerifera*. A significant reduction in A_{max} , however, was observed for *I. glabra* in the intercropping compared to the monoculture treatment. Quantum yield (A_{qe}) and light compensation point (LCP) values did not differ between species or treatments (Table 3 and Figure 7). Survey measurements of net photosynthesis showed significant variability by species ($P < 0.0001$), treatment ($P = 0.0042$) and date ($P < 0.0001$), and there were significant species*treatment and species*treatment*date interactions ($P = 0.0218$ and 0.0014 , respectively) (Figure 8). Both *M. cerifera* and *I. glabra* had positive relationships between stomatal conductance and soil water potential (Figure 9).

Table 3. Parameter estimates from the photosynthesis model: light saturated photosynthesis (A_{max}), quantum yield (A_{qe}), and light compensation point (LCP). Means and standard errors.

Species	Treatment	A_{max}	A_{qe}	LCP
<i>C. americana</i>	Monoculture	15.76±0.42	32.78±3.04	38.87±4.84
<i>C. americana</i>	Intercropped	12.43±0.35 (0.0681) ¹	39.64±4.37 (0.7717)	37.24±4.94 (0.9223)
<i>M. cerifera</i>	Monoculture	17.27±0.44	34.66±3.21	35.82±4.63
<i>M. cerifera</i>	Intercropped	13.79±0.39 (0.0626)	31.97±3.03 (0.7531)	48.42±5.03 (0.4516)
<i>I. glabra</i>	Monoculture	17.70±0.63	29.40±3.57	27.92±7.07
<i>I. glabra</i>	Intercropped	11.77±0.44 (0.0028)	34.72±4.71 (0.8604)	35.47±6.78 (0.7125)

¹P-values given in parentheses.

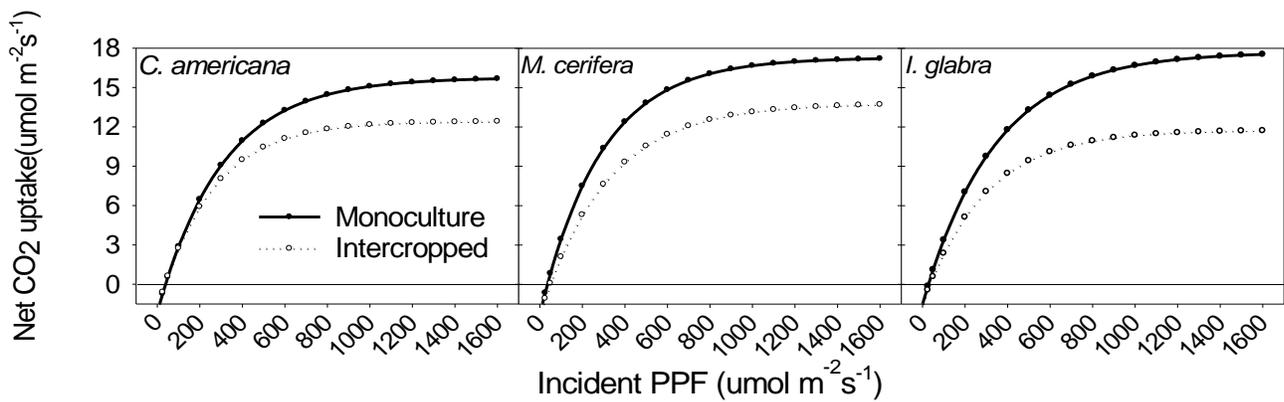


Figure 7. Photosynthetic light response curves fitted using parameter estimates (Table 3).

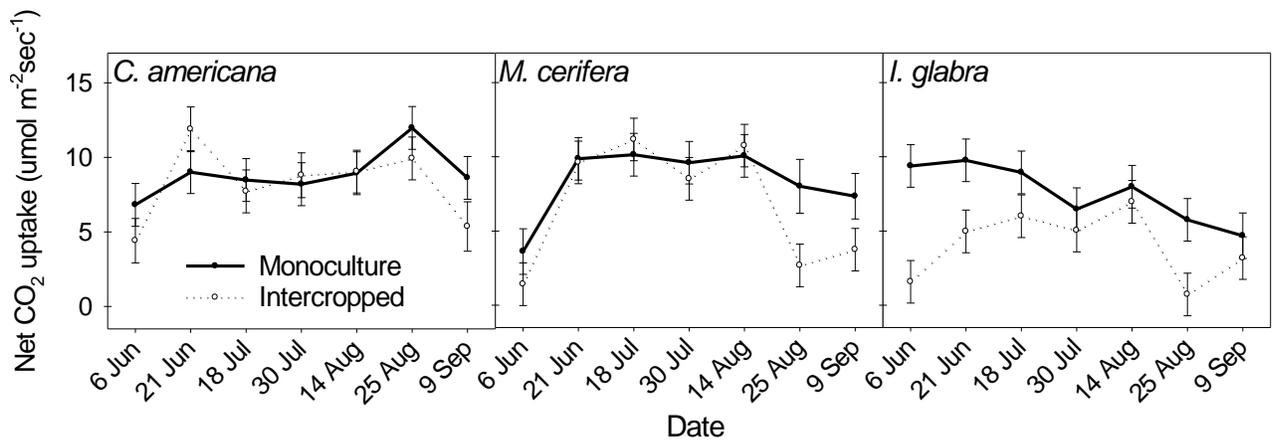


Figure 8. Treatment comparisons (by species) of biweekly incident photosynthesis measurements.

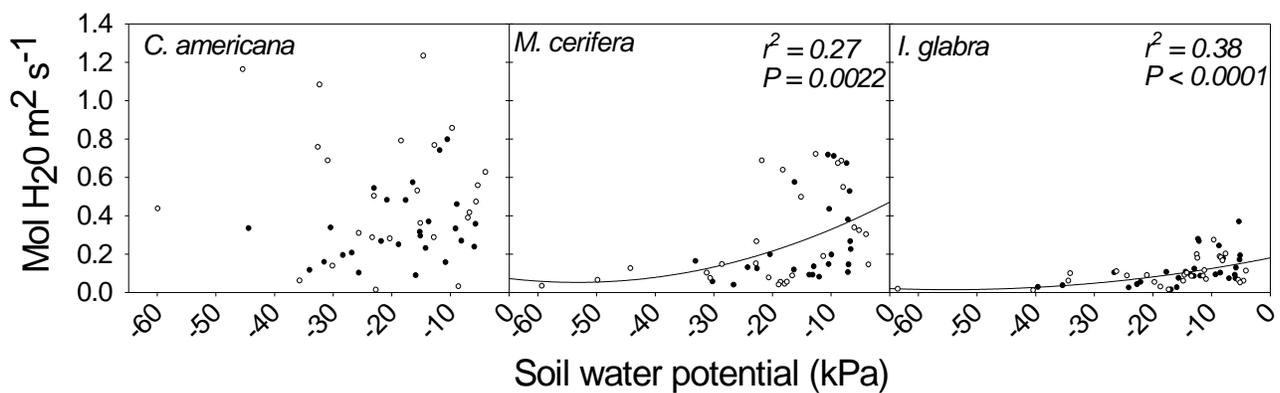


Figure 9. Relationship between soil water potential (kPa) and stomatal conductance ($\text{mol H}_2\text{O m}^{-2} \text{s}^{-1}$) for the three species.

Tree Growth and Mortality

Annual increment for longleaf pines in the study plots was 0.24 cm in 2006 and -0.01 cm in 2007. Species (shrub) effects were not observed between species or between species and control. There was no mortality in 2006 and 2% mortality in 2007 (7 trees).

DISCUSSION

Contrary to our hypothesis that shade-tolerant native understory species would perform well under longleaf pine trees, we observed increased mortality and reduced growth for all three shrub species in the intercropping system. Apparently, competition with longleaf pine was a major determinant of shrub productivity in this treatment (Jose et al. 2006). Despite supplemental fertilization, annual incremental growth of longleaf pine also decreased substantially, suggesting that intraspecific competition was a major stressor on the trees. This competition may have been magnified by water stress, as total rainfall for March – September 2007, at 55.2 cm, was only 47.1% of the 44 year average (NOAA National Climate Data Center).

While instantaneous gas exchange measurements at the leaf level do not adequately account for the factors (e.g. carbon allocation patterns, temporal variability in CO₂ uptake, *etc.*) that affect plant growth and mortality (Givnish 1988), they are useful for comparing instantaneous rates of CO₂ uptake under different field conditions. The typical photosynthetic response of plants grown under reduced light conditions is a reduction of light saturated photosynthesis (A_{max}) and light compensation point (LCP) and an increase in quantum yield (A_{qe}). For light demanding plants, the reduction in A_{max} can be substantial and result in significant decreases in carbon uptake. This is particularly true for plants with the C₄ photosynthetic pathway, which have a near linear relationship between photosynthetic rates and PAR interception. C₃ plants, however, typically reach A_{max} at 25-50% of full sunlight – a characteristic which presumably makes them better adapted to reduced-light conditions (Jose et al. 2004). For shade-tolerant or shade demanding C₃ plants, reductions in A_{max} are often minimal (compared to plants grown in full sun) and may be compensated for, in terms of carbon uptake, by the decreased LCP, increased A_{qe} and an increase in photosynthesis per unit leaf mass (Bazzaz 1979; Poorter and Evans 1998; Niinemets et al. 1999).

Observed patterns of PAR transmittance were comparable to those recorded in longleaf pine forests. Light transmittance estimates reported by Battaglia et al. (2003), for example were between 40 and 78%, with variability on a daily time scale largely attributed to the irregular canopy structure of the overstory. We observed an average transmittance of 57.7% in the intercropping treatment, with similar daily variability. As C₃ plants native to the partial shade of the longleaf pine ecosystem, *C. americana*, *M. cerifera* and *I. glabra* were assumed to be well-adapted to these conditions. Photosynthetic curves created for *C. americana* and *M. cerifera* under field capacity largely supported this assumption, as neither species had a statistically significant reduction in A_{max} in the intercropping treatment. There was, however, a significant reduction in A_{max} for *I. glabra*, suggesting a lower level of shade tolerance for this species. It should be emphasized, however, that all species had higher specific leaf area in the intercropping treatment – a typical response to shading (Chapin et al. 2002). Furthermore, observed differences in total leaf area indicate that light capture, and thus whole plant carbon uptake, was

reduced for all species (Givnish 1988). Quantum yield and light compensation point did not vary between treatments. Ambient photosynthetic rates for all species were consistently lower than their respective A_{\max} values. This is not unusual, as A_{\max} is a *potential* maximum level that is rarely attained due to resource limitations and/or environmental constraints (Bazzaz 1996).

The fact that all species allocated a greater % of carbon to roots than to shoots supports the argument that shading was not a major determinant of productivity in the intercropping treatment (Chapin et al. 2002). Belowground competitive vectors, therefore, are likely more responsible for the observed differences between treatments. Studies have shown that longleaf pine, once established, develops an extensive shallow lateral root system, often extending well beyond the area covered by the canopy (Heyward 1933; Brockway and Outcalt 1998). Since resource uptake is strongly correlated to root length density (van Noordwijk and Lusiana 1996; Green and Clothier 2002), this can result in significant intra- and interspecific competition in the comparatively nutrient-rich but often water-deprived upper soil horizons (Callaway and Walker 1997).

The proportion of longleaf pine fine roots in the upper 30 cm of soil of this system was more than double than that reported by Jose et al. (2006) – a difference that is likely due to age, spacing or soil characteristics. A highly uneven fine root distribution such as this indicates the presence of a shallow zone of very intense competition and a deeper zone where resources, particularly water, are underexploited. An intercropped shrub with a deeper root system would likely be able to exploit this niche and coexist favorably with longleaf pine. The shrub species chosen for this study, however, appear to have lacked such belowground complementarity. The lack of complementarity was likely magnified by the fact that the highest fine root length density for the pines was in the middle of the alley, presumably where the root systems of trees from the two adjacent rows overlapped.

Water stress can affect photosynthesis by inducing stomatal closure (Farquhar and Sharkey 1982), which in turn may inhibit gas exchange (Bennett and Sinclair 1998). It can also inhibit cell expansion and differentiation (Hsiao 1973), resulting in reduced growth. Since stomatal conductance for *M. cerifera* and *I. glabra* (two facultative wetland species) decreased with decreasing soil moisture, and soil moisture at 20 cm was generally lower in the intercropping treatment, it is possible that water stress was partially responsible for the observed treatment differences. In temperate agroforestry systems, mixed-species plantings, and natural longleaf pine forests, competition for water appears to be the rule, rather than the exception (Miller and Pallardy 2001; Harrington et al. 2003; Wanvestraut et al. 2004; Jose et al. 2006). This competition further magnifies the stresses created by drought, possibly requiring management interventions (i.e., irrigation, trenching, or “root barriers”) to minimize deleterious effects on the growth and yield of component species (Harrington et al. 2003; Wanvestraut et al. 2004; Zamora et al. 2008). Tree removal, however, was probably not necessary, given the openness of the canopy and the fact that the basal area was only 55% of the recommended level for a first thinning (12.6 vs. 22.9 m² ha⁻¹).

There was no evidence to suggest that the productivity of *C. americana*, an upland species, was affected by treatment-induced water stress. Nonetheless, high mortality and reduced growth in the intercropping treatment suggest that *C. americana* is, indeed, adversely affected by

competition from longleaf pine. Reduced chlorophyll content, while apparently having little effect on photosynthesis, could be evidence of interspecific competition for nitrogen. A companion fertilization study using labeled ^{15}N ammonium sulfate (Hagan et al. in review) further supports this notion, as foliar nitrogen was 28.9% lower and percent nitrogen derived from fertilizer was 50.8% higher in the intercropping treatment for this species (no such treatment differences were observed for *M. cerifera* or *I. glabra*). Nitrogen is an integral component of chlorophyll (Chappelle et al. 1984) and is essential for the synthesis of amino acids, enzymes and proteins (Sugiharto et al. 1990). While nitrogen deficiency may or may not affect photosynthetic capacity at the leaf level, it can slow the rate of leaf expansion, as well as limit leaf area and number (Ciompi et al. 1996). Nitrogen-based amino acids also serve as important overwinter reserves (Chapin et al. 1990). Competition for nitrogen would therefore have a deleterious effect on growth and yield particularly for a deciduous species such as *C. americana* which likely has a high early-season nitrogen demand.

CONCLUSIONS

It is clear, based on the results of this study, that the effective management of competition is essential to the viability of a longleaf pine/native woody ornamental intercropping system. Ideally this could be done in a manner that minimizes the deleterious effects of competition while retaining a high basal area. Irrigation, trenching or the installation of root barriers have also proven effective at reducing belowground competition (Harrington et al. 2003; Wanvestraut et al. 2004; Zamora et al. 2008) and should be considered in future studies. Future studies should also address the effect of other belowground interspecific processes (e.g. phosphorus competition) on shrub productivity.

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THIRTY MILLION AGROFORESTERS: RUSSIA'S FAMILY GARDENS

Leonid Sharashkin¹ and Michael Gold²

¹ Ringing Cedars Press, 848 N. Rainbow Blvd. #1947, Las Vegas, NV 89107 USA.

² University of Missouri Center for Agroforestry, 203 ABNR, Columbia, MO 65211 USA.

Contact: press@ringingcedars.com

Abstract: Today, over 30 million Russian households engage in food gardening and collectively produce over half of Russia's agricultural output, using less than 6% of agricultural land in the country. The small size of plots allocated for household production (typically 0.06 ha for urban and 0.25 ha for rural households) promoted extremely intensive growing practices and wide integration of perennial crops (especially fruit-bearing shrubs and trees) with annual crops. This resulted in the proliferation of highly diverse, multi-layer gardens. Our study of economic, agricultural, social, and cultural characteristics of family gardens in the Vladimir region (central part of European Russia) included an in-depth survey of 1,500 households. It confirmed gardens' most important contribution to the household and regional economy, with 95% of households either tending their own garden or benefiting from the gardens of others. These highly diverse, predominantly organic operations include, on average, 13 different vegetable crops and 7 different perennial fruit, nut, and berry crops grown on the same small plots, which can be seen as micro-scale agroforestry systems. It was also found that participation in food gardening does *not* decrease with growing income, which attests to the important social and cultural dimensions of the practice. The gardeners, who share strong agrarian ethics, see in working the land a symbol of self-reliance, a family space, an opportunity for social interaction and contact with living nature, and a continuation of a millennial tradition of living in union with Mother Earth.

Keywords: household, gardening, dacha, self-provisioning, self-sufficiency, homestead, family farm.

INTRODUCTION

Today's mainstream commercial agriculture continues to face formidable challenges. It has a heavy environmental footprint, often lacks social responsibility, and is highly dependent on heavy machinery, chemicals, availability of petroleum, and government subsidies. In search for more benign alternatives agroforesters and researchers in sustainable agriculture have been drawn to the study of home gardens, which often serve as examples of remarkable sustainability and productivity (e.g. Wojtkowski 1993; Kumar and Nair 2004).

Sustainability and productivity of micro-scale family agriculture is especially noticeable in contemporary Russia. Today, just as a hundred years ago, or a thousand years ago, the majority of Russia's agricultural output is coming *not* from large-scale commercial industrialized operations, but from household gardens. Russia's family gardens currently produce over half of the country's agricultural output and represent a major sector of the country's economy, involving two thirds of the population. Despite this prominence, the significance of household gardening has been continuously downplayed by most scholars and policy-makers, and this

practice has been viewed as a recent phenomenon, as an adjunct to the country's industrial agriculture, or as a temporary response to the hardships of Russia's economic transition (e.g., Seeth et al. 1998; Southworth 2006).

Our study of the current status of family agriculture, of Russia's agrarian history, and the results of our 2006 survey of 1,500 families in the Vladimir region show that gardens not only have high economic, social, and cultural significance, but also represent a highly sustainable practice embedded in the region's — and the country's — environmental, socioeconomic, and cultural context. The survey offers detailed information on the economic, agricultural, social, and cultural dimensions of gardening in the Vladimir region, including respondents' adherence to a wide range of agrarian values. Based on the results, family gardening can be seen as a highly sustainable, diversified, and culturally important small-scale agroforestry practice, which needs to be given due consideration by scholars and policy-makers.

METHODOLOGY

Our study included two parts. The first part was an overview of the current status of family gardening on the national scale, on the basis of available research and governmental statistics. These data helped paint the big picture, but it lacked fine detail. The second part was therefore a detailed survey of household gardening in one selected region -- the Vladimir region of central European Russia. The Vladimir region has a population of 1.46 million people (78% urban, 22% rural), and a territory of 29,100 km² (52% is forested and the rest is a mixture of agricultural lands and urban development). It lies in the temperate climate zone east of the Moscow region.

Since gardening is usually practiced by a household as a whole (rather than by separate individuals), our unit of observation was a *household*. We used multi-stage sampling technique, which yielded a random sample of 1,500 households. The survey questionnaire was developed especially for this study and was administered through face-to-face interviews. We have been able to achieve close to 80% response rate.

ECONOMIC DIMENSION

On the national scale family gardening stands out as Russia's *primary* agriculture. Over the last decade, the contribution of household food gardens to the country's national agricultural output consistently exceeded 50%, and represented around 2.3% of Russia's Gross Domestic Product (GDP). Gardener's contribution to the GDP (384 billion rubles -- approx. US\$14 bn) has been greater, for example, than the contribution to the GDP of the whole electric power generation industry (317 bn rubles); significantly greater than all of forestry, wood-processing, and pulp and paper industry combined (180 bn); significantly greater than the coal (54 bn), natural gas (63 bn), and oil refining (88 bn) industries combined (Rosstat 2006).

According to Russia's Federal Statistical Service Rosstat (2005), in 2004, Russian gardeners produced 33 million tons of potatoes (93% of total agricultural output of the country), 12 million tons of vegetables (80%), 3 million tons of fruit (81%), 17 million tons of milk (52%), and 3 million tons of meat (52%). All this output has been achieved by using less than 6% of

agricultural lands in the country (Rosstat 2007a) and by gardeners tending their plots part-time in a country much of the territory of which has mere 110 days of growing season per year. Of the 33 million garden-plots in 2005, 51% were in urban and peri-urban areas (and were worked predominantly by urban households), and the 49% were in rural areas. Of the more than 80,000 gardening associations in existence in 2006, more than half were formed prior to 1991, which serves as evidence that gardening *cannot* be seen as merely a temporary response to the economic crisis of the 1990s.

On the regional level, the picture is equally impressive. According to our 2006 survey of the Vladimir region, 78.1% of households have a garden of their own. An additional 16.7% of households use somebody else's gardens or garden output. *Therefore, a total of 94.8% of households of the Vladimir region either have their own garden or contribute to/benefit in some way from the gardens of others.* This figure attests to the remarkable degree of connectedness to the local soil and local food still maintained by families even in this highly urbanized and industrialized region. Twenty-six percent (26%) of all urban households in the region, and 42% of all rural households in the region satisfy at least 41% of their food consumption needs from the food they produce themselves.

Part of the reason why -- despite its obvious prominence -- household gardening is routinely "overlooked" by both policy-makers and many researchers is the fact that it is largely *subsistence* oriented rather than market oriented, and therefore does not fit into the "official" economy. According to the 2006 Census of Agriculture (Rosstat 2007a), 86.6% of rural gardeners (14.8 mln households) were growing for subsistence; for 12.8% it was a source of additional income, and only 0.6% relied on it as the primary source of monetary income. For urban gardeners, the purpose of production (subsistence vs. market) was not even reported, since the vast majority of urban growers are assumed to grow for subsistence only. According to the results of our survey from the Vladimir region, only 15% of the gardening households sell part of their produce, compared to 49% of families who share part of their harvest for free, and 100% of households who consume the greater part of what they grow. The prominence of subsistence and sharing has extremely important food security ramifications: thus, when American taxpayer dollars were being used in the early 1990s to send food aid to Russia, Russia actually continued to be more food secure (due to the proliferation of family gardens and sharing) than Western Europe or Japan (Sedik et al. 2003). The culture of sharing is also part of Russia's ancient tradition and worldview, as will be discussed below.

AGRICULTURAL AND AGROFORESTRY DIMENSION

It was the policy of the Soviet government (and to a large extent continues to be the reality to the present day) to put stringent limits on the size of the plots that were made available for family agriculture. As a result, the average size of household garden-plots is very small: 0.09 ha for urban families and 0.44 ha for rural households (Rosstat 2007b). The small size of the plot, coupled with the desire -- or necessity -- to grow a sizable share of your food supply yourself promoted extremely intensive cultivation practices, with a large number of annual (mostly vegetables) and perennial crops (berry shrubs and fruit trees) planted together.

Indeed, the Russian family garden-plots can be seen as miniature agroforestry systems, since their combination of annual and woody perennial plantings is *intentional, intensive, integrated,* and *interactive* (for a discussion of these four traits of an agroforestry system see Gold and Garrett 2008). Even though Russia's household gardens occupy less than 6% of the country's agricultural lands, they account for 59% of all perennial crop plantings and 65% of perennial berry, fruit and nut plantings in the country (Rosstat 2007a). The results of our survey in the Vladimir region show that only about 2% of region's households with a garden-plot limit their gardening activity to a single agricultural use (such as exclusively vegetable growing). The remaining 98% combine different agricultural uses. On average, each gardening household grows 13 different vegetable crops (including greens) and 7 different fruit, berry, and nut crops *on the same small plot*.

This high level of diversity certainly has important environmental sustainability benefits, which are further enhanced by the fact that 74% of rural gardeners and 37% of urban gardeners in the region stick to exclusively organic growing methods. The most popular fertilizer continues to be manure (in use by 86% of gardeners), the most popular method of weed control is manual weeding (90% of gardeners), while 52% of all gardeners (especially urbanites) do use pesticides for controlling pests.

Gardeners of the Vladimir region also play an important role in preserving heirloom varieties of agricultural plants through seed saving and exchange. While one third of gardeners now purchase all or most of their seeds on the market, the remaining two thirds practice seed saving at least to some extent. Eighteen percent (18%) of gardeners rely entirely or to a large extent on their own seeds, while 11% obtain seeds from their friends and neighbors.

SOCIAL AND CULTURAL DIMENSION

Both national-level statistics, research, the study of Russia's agrarian history, and the results of our survey of the Vladimir region confirm that the significance of family gardening goes well beyond its economic function. We have found that the rate of participation in food gardening *does not decrease* with household's growing income -- which further confirms that family gardening in Russia is not a temporary response to poverty. The gardening households of the Vladimir region see their gardens as an auxiliary source of food (77%), a way to maintain connection to the earth (74%), a hobby and recreation (73%), and family space for social interaction (70%). Our survey included a specially developed "agri-cultural" scale to measure the cultural importance of gardening and contact with Mother Earth for gardeners and non-gardeners alike (0 representing absolute lack of importance of the cultural dimension; 50 being the neutral point, and 100 standing for the greatest cultural and spiritual significance of gardening). The average score (among *all* residents of the Vladimir region, including those with no garden) was 73, illustrating that very strong agrarian ethics is still an important part of Russian culture, and also vindicating the views of economists such as Chayanov (Kremnev 1920; Chaianov 1925) and Schumacher (1975) who maintained that one of the primary functions of agriculture is maintaining Man's connection with nature, and making a piece of Earth beautiful. Indeed, even the word *dacha*, the Russian word for "garden", is based on the verb "to give", whereas the word *farm* derives from the verb "to take" -- which highlights the two very different mindsets and attitudes to the Earth and our place on it.

CONCLUSIONS

Today, gardening continues to be Russia's *primary* agriculture -- both in its economic significance and as a practice based on a millennia-long tradition of living a simple and self-sufficient, land based life. Russia's example shows that a highly decentralized, small-scale, sustainable, and culturally rich agroforestry food production system is possible today on a national scale. Russian gardeners are not dependent on government subsidies, petroleum availability, hired labor, or complex and industrialized food distribution networks, and demonstrate the viability -- and the benefits -- of small-scale family agriculture. These findings, coupled with a growing body of evidence confirming the attractiveness of small-scale growing methods even on purely economic grounds (e.g., Ohio State University 2008), call for a re-assessment of our outlook on agriculture, and offer a vision of a sustainable and beautiful agriculture of the future.

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ROOT GROWTH OF *CODONOPSIS LANCEOLATA* AND *PANAX GINSENG* IN SEVERAL FORESTS

Hyun-Seok Lee¹, Chul-Woo Kim¹, Mi-Jeong Jeong¹, Chan-Hoon Ahn¹, Imam Bagus¹, Myong-Jong Yi², Yong-Eui Choi², and Jae-Seon Yi²

¹Department of Forestry, Graduate School, ²College of Forest and Environmental Sciences, Kangwon National University, Chuncheon, Republic of Korea 200-701

Contact: jasonyi@kangwon.ac.kr

Abstract: *Codonopsis lanceolata* and *Panax ginseng* are important, recommendable short-term return forest products in Korea. Both roots are widely used as food and medicinal material. Three kinds of forest stand, i.e. oak, pine, and larch forest, were chosen for the comparison of root growth in farming land. One-year-old roots were investigated and soil samples were collected at the depth of 10 cm from the surface. pH, various inorganic matters (K, Na, Ca, and Mg) and organic matters were analyzed by several known methods. Oak forest was a 30-year-old one of which slope orientation was SW, average DBH 21.6 cm, height 14-15 m and density 1,000 trees/ha. Pine forest was a 35-year-old one of which slope orientation was NE, average DBH 22.2 cm, height 12-13 m and density 1,100 trees/ha. Larch forest was a 45-year-old one of which slope orientation was NE, average DBH 23.1 cm, height 14-15 m, and density 900 trees/ha. Lightness(Lux) inside forest and relative light(%) of each forest in summer were 7,460 and 7.85 for oak forest; 515 and 0.57 for pine forest; and 3,200 and 3.40 for larch forest, respectively. In *Codonopsis*, pine forest developed the longest root(27.8 mm) and the heaviest root(0.68 g) among three forests, while nursery produced 125-mm-long and 4.25-g root. In ginseng, oak forest showed the highest shoot growth(9.13 mm), while larch forest the lowest one(6.65 mm). Pine forest developed the longest root(8.52 mm), while oak forest the shortest root(6.99 mm). Root diameter was 3.66 mm in pine, and 3.02 mm in oak forest. A fresh root obtained was 0.23 g on average in pine and 0.13 in oak forest. Ginseng grown in pine forest showed little difference from that of nursery in all the traits. High calcium ion concentration(2.27 cmol/kg) in pine forest seemed to be related with the high root weight of *Codonopsis* and ginseng.

Key Words: root, length, diameter, weight, food, medicine, oak, pine, larch, calcium ion concentration

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THE SHORT-TERM INCOME CROP FOR THE UNDERSTORY OF *LARIX LEPTOLEPIS* PLANTATION

Chul-Woo Kim¹, Hyun-Seok Lee¹, Chan-Hoon Ahn¹ and Jae-Seon Yi²

¹Department of Forestry, Graduate School, ²College of Forest and Environmental Sciences,
Kangwon National University, Chuncheon, Republic of Korea 200-701

Contact: jasonyi@kangwon.ac.kr

Abstract: The forest floor of *Larix leptolepis* plantation is not easily invaded by shrub or herbaceous plants because of allelopathic substance and high acidity, especially in old and dense stand. The research is necessary for the establishment of the understory in *L. leptolepis* plantation to increase the short-term income of forest owners. *L. leptolepis* plantation for this test was 25- to 41-year-old. Average tree height was 17-25 m and diameter at breast height 16-30 cm. Soil texture was loam or sandy loam; pH 4.7-5.9; and relative light intensity 20-25%. This trial adopted three edible and/or medicinal herbs (*Ligularia stenocephala*, *Allium victorialis* var. *platyphyllum*, and *Panax ginseng*) and six woody species for medicine and/or food material (*Zanthoxylum schinifolium*, *Kalopanax pictus*, *Aralia elata*, *Hovenia dulcis*, and *Eleutherococcus sessiliflorus*). Seedlings were planted in 2002 with a spacing of 20x20 cm for herbs and 2x2 m for woody plants. The survival rate and productivity were investigated in the summer, 2003 and again in the summer, 2008. *L. stenocephala* showed high survival rate and leaf productivity up to 2-3 years after planting. However, such ratio and productivity decreased with increasing growing years. *A. victorialis* var. *platyphyllum* showed the decreasing survival rate, but the increasing leaf productivity by development of 3-5 stems instead of one per bulb. 29% of *Panax ginseng* survived and developed healthy-looking roots. *A. elata* developed new terminal and lateral buds without showing any change in survival rate after taking root. If managed properly, the plantation can produce a lot of edible sprouts every spring. In conclusion, three species, that is *A. victorialis* var. *platyphyllum*, *A. elata* and *P. ginseng*, are recommendable for the understory crop of *L. leptolepis* plantation to obtain early income.

Key Words: allelopathy, short-term return, understory crop, food, medicine, leaf, root, sprout

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SECTION 8

Agroforestry Education, Training, Extension and Technology Transfer

INCORPORATING AGROFORESTRY INTO TRADITIONAL FORESTRY CLASSES

Mike Demchik¹

¹College of Natural Resources, University of Wisconsin Stevens Point, Stevens Point, WI 54481
USA

Abstract: Agroforestry is a new topic to many undergraduates in Forestry programs. With the increasing importance of wood harvested from private lands and farm forests, an understanding of integrating timber harvest and agriculture is valuable for foresters working in the United States. With global sourcing of wood playing a larger role than ever in the United States wood product market, knowledge of agroforestry systems is essential. At University of Wisconsin Stevens Point, the concepts of agroforestry are being included in traditional forestry course with interesting results. These concepts have been included on an experimental basis in three courses: Silviculture, Regional Silviculture and International Resource Management. I will discuss the implementation of these modules at UWSP, student response to these modules and some observations on student acceptance and reluctance to accept these practices.

Key Words: SOTL, forestry, silviculture

INTRODUCTION

Forestry education has a relatively long history in the United States. With its humble beginnings as a one year program at the Biltmore Forest School in North Carolina (Schenck 1998), forestry has become a thriving career. Now, according to the Society of American Foresters, a total of 48 institutions offer accredited degrees in forestry in the United States (SAF 2009). Compared to forestry, agroforestry is a relatively new science in the United States (Nair 1993); however, the practice of agroforestry (in the form of conucos and kitchen gardens) may be one of the oldest forms of agriculture in the Americas (Healy et al. 1983; Esquivel and Hammer 1992). Internationally, agroforestry is becoming much more prevalent in college curricula, both as degrees and as individual courses (Zulberti 1990).

The objective of this paper is to discuss the inclusion of agroforestry modules in three classes at the University of Wisconsin Stevens Point (UWSP): Silviculture (For 432/632), Regional Silviculture (For 433) and International Resource Management (NRES 323/523). In For 432/632 and For 433, these modules are restricted to a single 50 minute session. In NRES 323/523, these modules are the focus of two 50 minute general overview sessions and several 50 minute case studies as well as a full 50 minute directed discussion. In this paper, I will discuss the implementation of these modules at UWSP, student response to these modules and some observations on student acceptance and reluctance to accept these practices.

METHODS

For increased implementation of agroforestry systems, further development in the area of education, research and human resources is necessary (MacDicken and Lantican 1990). One venue for this education is as modules in traditional forestry coursework. These classes generally contain relatively little on agroforestry. While forestry in the tropics may be presented, this is presented generally as “unsustainable timber mining” or as plantation forestry. In one of the most popular text on silviculture in the US, agroforestry is mentioned but the coverage is approximately one page. Unlike in the tropics, in the temperate zone, agroforestry is not nearly as widespread and is quite easy to ignore. For these reasons, most students in forestry do not have a strong understanding of agroforestry systems or practices.

In 2004, with my hire at the University of Wisconsin Stevens Point, I began incorporating agroforestry in the content of the Silviculture class For 432/632. After having worked for the previous 4.5 years as the Agroforestry Management Extension Specialist at University of Minnesota, I simply included it without much conscious thought that this was something that was rather new to the students. The following semester, I co-taught Regional Silviculture For 433 (a more advanced class to a subset of students in the Silviculture For 432/632 class). I incorporated a broader discussion on afforestation and agroforestry internationally, with a strong emphasis on Latin America. Once again, the students loved it. This was basically new content for them. This has become a standard part of the content for this course. Additionally, an indirect impact has been that student presentations, which are on topics of their selection (a main deliverable for students in this course), have increasingly targeted tropical and agroforestry systems. This indicates a rather strong interest in the topic.

International Resource Management, NRES 323/523 (a class that I co-teach), became the final testbed. With the prominence of agroforestry in the tropics, this is a quite logical topic to present. Agroforestry is the focus of two 50 minute general overview sessions and several 50 minute case studies as well as a full 50 minute directed discussion. For all three years that this has been taught, this has been one of the most well-received topics.

RESULTS AND DISCUSSION

During the first year that I taught For 432/632, this module was one of the ones that was a “hit” with the students. Three students came up to me after class and said (paraphrased), “You have just described what I want to do with my life.” All of these students had a farm background. One had been planting trees in the odd corners of his family farm for years. He said that his father did not “mind” but it has “gotten to be a bit more than a hobby now.” Another said that his family owned an orchard and they had always done this, but never had a name for it. The last student had come from a family that raised livestock, Christmas trees and timber. Virtually every time I have taught this module, I have had the same response from students. Generally, students with agricultural background (or an interest in agriculture) get the most out of this module. This has become a fixture in this course.

Strong student interest was demonstrated in both of the two traditional forestry content courses: Silviculture For 432/632 and Regional Silviculture For 433. In post-session informal discussions, students expressed that:

- They had never heard of agroforestry before
- They were unaware that this was a common system in the tropics
- They thought it could be an environmentally conservative practice
- They would like to know more about the system

In a survey delivered at the end of Silviculture For 432/632, in 2005, this was listed as a favorite topic by several of the students.

Students also demonstrated a strong interest in agroforestry in the International Resource Management NRES 323/523 course. During the general agroforestry overview, rapid fire questions were the norm during the first year the course was taught (2007). As part of a 50 minute tropical agriculture/agroforestry discussion session in 2009, a directed question was asked “What agricultural systems do you think should be used in Tropical America? And why?” For small parcels, students expressed that agroforestry was one of the most viable because it:

- Diversified risk
- Reduce erosion
- Potentially reduced input costs
- Possibly increase production

Observations

Over the course of the 5 times this content has been used in Silviculture For 432/632 and the three times it has been covered in International Resource Management NRES 323/523, I have recorded student comments regarding agroforestry. I have, unfortunately, not been as diligent with comments made during the Regional Silviculture For 433 course and no comments are included from this class. These comments have expressed both some extreme optimism and some reluctance to accept these practices.

Generally, those comments fall under the following categories: 1) environmental impacts and 2) economics/feasibility.

Environmental impacts

Generally, agroforestry is seen as more conservative of the environment than general agriculture. There were no comments that suggested that students felt otherwise. Comments have included:

- “This is the way agriculture should be practiced in the tropics”
- “Just looking at those pictures, you know that wildlife can do more on those (agroforestry) sites”
- “Erosion (shown in the photos) seems a lot less likely with the tree cover”

Economics/Feasibility

Students felt that this would be economically viable for small landowners in the tropics but some questioned whether it would make sense at the scale agriculture is practiced in the United States. Students also seemed to think that monoculture agriculture had its place in the United States and the tropics. Comments have included:

- “It seems like someone without much land could grow an awful lot of different things in one of these systems”
- “When we were in Mexico (this was a student that had participated in an international course offered at UWSP), we saw all kinds of different fruits at the markets... They probably made good money out of the fruit they sold.”
- “With urban farming, this would be great. We should design a system like this for our campus garden.”
- “This would work where people have... (a lot of labor)... but here in the US it would be really hard to pull something like this off with a corn field.”
- “These systems are nice, but a lot of people just want a job and they can work at these big farms as a worker and not have to be a farmer. Some people will like this better...”

Overall, inclusion of these modules was a valuable learning experience for the students. Generally, this content was new to most of the students in the class. The content was well received and the students were able to use the tools of ecology and biology that they had already learned to understand these systems. With the increasing globalization of the marketplace and increasing concern for environmental impacts of natural resource management, agroforestry seems poised to become more important both nationally and internationally. Increasing student awareness of agroforestry will potentially increase their ability to see agroforestry as a solution to natural resource management issues.

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INTRODUCTION TO PINE SILVOPASTURE IN THE SOUTHEAST: DEVELOPMENT AND DELIVERY OF AN ONLINE COURSE AND TECHNICAL RESOURCE

Jim Hamilton¹, Charles T. Barger², Kris Irwin³, and D.J. Moorhead²

¹Natural Resources Management, Haywood Community College, Clyde, NC 28721

²Center for Invasive Species & Ecosystem Health, University of Georgia, Tifton, GA 31793

³Warnell School of Forestry & Natural Resources, Athens, GA 30602

Contact: moorhead@uga.edu

Abstract: “Introduction to Pine Silvopasture in the Southeast” (<http://www.silvopasture.org>) is designed as a web-based independent-learning experience to provide students the opportunity to explore the various facets of silvopasture establishment and management. The course website has been developed as a companion resource to the technical handbook, *Silvopasture: Establishment & management principles for pine forests in the Southeastern United States*. The site is designed to enable natural resources professionals and the landowners they serve to understand and apply economic and ecological principals of Silvopasture. Educational modules have been developed focusing on specific topics related to silvopasture establishment and management and the three major components of any silvopasture system: the tree component, the forage component, and the livestock component. Each module has a respective list of competencies or knowledge-sets that participants should be familiar with upon reviewing learning objects within each module.

INTRODUCTION

The website www.silvopasture.org has been designed as an online independent-learning resource to provide visitors the opportunity to explore the various facets of pine silvopasture establishment and management. Pine silvopasture shows promise as a sustainable and profitable forest management option for landowners across the Southeast. Pine silvopasture systems have been established at several research stations in the southeastern United States and several landowners have successfully implemented silvopasture on their properties for decades. There are a number of online resources and publications that cover various components of silvopasture. However, more comprehensive information on the subject is conspicuously lacking from online sources. The National Agroforestry Center was interested in providing a more comprehensive resource for pine silvopasture in the southeastern US.

The website was developed to serve as a companion resource to the technical handbook, *Silvopasture: Establishment & management principles for pine forests in the Southeastern United States* which was released in 2008 by the National Agroforestry Center. The site will enable natural resource agency professionals and landowners to understand and apply the economic and ecological principals of Silvopasture. While there are a number of online publications and websites that review the basic concepts and specific components of silvopasture, this website was developed to provide a more comprehensive and interactive resource and provide more grounded recommendations for pine silvopasture establishment and

management. The website also has a function that allows users to register and complete built-in course assessments. Course developers are pursuing a mechanism to allow course participants to receive Continuing Education Units (CEUs) in the future.

Literature Review/Previous Research

Until recently, there have been limited distance-learning opportunities in forestry and natural resources management. Brack (2000) asserts that internet-based learning tools can be integrated into natural resource management programs to provide additional resources for professionals looking for continuing education opportunities in natural resource fields. Advances in information and communication technology (ICT) “offer increased flexibility and freedom from scheduling and spatial constraints”--especially for nontraditional students (Langin et al. 2006). The number of individuals receiving additional career training online is growing rapidly. In 2002 14 million Americans had used the internet for career training, by 2005 this number had grown to 21 million (Horrigan and Rainie, 2006). Distance learning through internet and/or hybrid classes allows individuals statewide, regionally, and even nationally the opportunity to receive education and continuing training in natural resources.

Several programs at land-grant universities have received USDA Cooperative State Research, Education and Extension Service (CSREES) funding to develop distance-learning opportunities for landowners and natural resource professionals. For example, CFEgroup (<http://cfegroup.org>) was developed by the Texas AgriLife Extension Service unit of the Department of Ecosystem Science and Management at Texas A&M University through funds from CSREES and the Renewable Resources Extension Act. *Forestandrange.org* (<http://www.forestandrange.org>) is a similar distance-learning collaboration between CSREES, the University of Tennessee, and a number of universities and organizations throughout the United States.

In 2008, the USDA National Agroforestry Center entered into an agreement with the Center for Invasive Species and Ecosystem Health “Bugwood Network” out of University of Georgia’s Warnell School of Forestry and Natural Resources to purchase the URL <http://www.silvopasture.org> and serve as the webmaster for the site. Reserving *Silvopasture.org* as a standalone URL serves as an easy marketing tool for the website that can be linked and shared.

Course Modules and Competencies

Seven modules have been developed that focus on specific topics related to silvopasture establishment and management which cover the three major components of any silvopasture system: the tree component, the forage component, and the livestock component. Each module has a respective list of competencies or knowledge-sets that participants should be familiar with upon reviewing learning objects within each module. The seven modules are:

Module 1: An Introduction to Silvopasture, an overview of silvopasture and economic considerations.

Module 2: Site Preparation and Tree Spacing, different site preparation methods and planting arrangements for establishing a silvopasture.

Module 3: Tree Species and Seedlings, descriptions of the three major pine species used in silvopasture in the southeast and advantages and disadvantages of bare-root and containerized seedlings.

Module 4: Canopy Management, tips on pruning and thinning the tree component for optimal timber and forage production.

Module 5: Cattle Management for Silvopasture, a description of fencing and rotational grazing systems that are required for optimal cattle management in a silvopasture.

Module 6: Silvopasture Forage Management, an overview of various types of forage that can be integrated into silvopasture and management considerations.

Module 7: Other benefits of Silvopasture, a summary of some of the various aesthetic and wildlife benefits of silvopasture.

Course Elements

The website allows users to access site content and complete the course asynchronously. Therefore, users can access and complete course content on their own schedule. As with many distance education courses, each learning unit or module consists of a reading assignment, a powerpoint presentation, additional course materials, and an evaluation instrument to assess learning. The reading assignments in each module of the course come from the 2008 technical handbook, *Silvopasture: Establishment & management principles for pine forests in the Southeastern United States*. While the entire handbook is accessible in pdf format on the homepage of the website, specific chapters and readings are extracted from this original document in pdf files to follow the material and objectives of each module. Powerpoint presentations are available as flash-enhanced movies with voiceover that were recorded with the popular screen-casting software, CAMTASIA. The original Powerpoints (without Flash enhancement) are also available for download as a shared resource for professionals. Each module has one or two presentations, standardized graphically, which consist of 8-12 slides. The information presented is general enough to be applicable to landowners and resource professionals throughout the United States. However, the website also provides specific management information to provide more detail than most of the currently available stand-alone online silvopasture resources.

Learning objects within each module consist of :

- Reading assignment(s): either linked or downloadable section of “Silvopasture: establishment and management principles for pine forests in the Southeastern US.”
- PowerPoint presentation(s) (with voice-over)
- An enhanced Flash object(s) covering concepts within the module (where applicable)
- A video ‘vignette’ demonstrating concepts in the field (where applicable) and/or interviews with silvopasture practitioners
- An assessment tool: a multiple choice online ‘assignment’ that must be completed to evaluate learning

The site also contains a photo gallery that illustrates various silvopasture practices and a list of links to other sites, organizations, and resources that focus on temperate agroforestry and silvopasture. Module Assessments at the end of each module are interactive multiple choice

quizzes that allow users to test their proficiency in the material covered within each module. By completing the assessment quizzes for each module, registered users will have the opportunity to apply for and receive continuing education credits. However, all course content and assessment instruments are available as training resources for individuals interested in learning more about silvopasture or natural resource professionals who may be seeking resources for workshops or other presentations.

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PRACTICUM IN FOREST FARMING AT THE MACDANIELS NUT GROVE

Kenneth W. Mudge¹ and Steve Gabriel¹

¹Department of Horticulture, 13 Plant Science Building, Cornell University, Ithaca, NY 14853
Contact: kwm2@cornell.edu

Abstract: The MacDaniels Nut Grove is a 7 acre woodlot associated with the Dilmun Hill Student Farm on the Cornell University campus. It was established by Professor Lawrence MacDaniels in 1923 for evaluation of clonal varieties of temperate nut trees including walnuts, hickories, Chinese chestnuts, filberts, as well as several fruit crops. The site was abandoned around the 1960s and it reverted to secondary forest. It was rediscovered in 2002 and has been undergoing renovation as an outdoor classroom for teaching, research and extension in forest farming ever since. The site has been the focus of a 2 credit agroforestry course, *Practicum in Forest Farming*. Using the methodology of experiential learning, students participate in various hands on activities and reading assignments. Each student keeps a journal in which they reflect on weekly activities and relate these to reading assignments. Students are involved in the planting and management of several non timber forest crops including medicinal herbs such as ginseng, food crops such as mushrooms and fruits, and shade loving ornamentals. During the fall of 2008 students were introduced to a permaculture design process that involved site assessment, including climate, water, landform, vegetation, wildlife, access and circulation, soils, and aesthetics. Based on the outcome of their site assessment and consideration of the long term goals for the site, each of several student groups created a design for future development. These designs are being integrated into a single master plan that will be implemented over time. A club called *Friends of MacDaniels Nut Grove*, consisting of students, alumni and others from the community contributes to year round and long term continuity.

CREATIVELY COMMUNICATING CONSERVATION COMPLEXITY

Gary Bentrup

USDA National Agroforestry Center - USFS Southern Research Station
N. 38th Street and East Campus Loop, Lincoln, NE 68583-0822
Contact: gbentrup@fs.fed.us

Abstract: Designing agroforestry practices to achieve multiple objectives can be a challenging task; often requiring resource professionals to scour numerous and diverse resources for scientific-based design information. To simplify this task, the recently released publication *Conservation Buffers: Design Guidelines for Buffers, Corridors, and Greenways* synthesizes over 1400 research articles into easy-to-understand rules-of-thumb for planning and designing buffers and other linear agroforestry practices. Over 80 illustrated guidelines describe specific ways that a vegetative buffer can be applied to protect soil, improve air and water quality, enhance fish and wildlife habitat, produce economic products, provide recreational opportunities or beautify the landscape.

Buffers and other agroforestry practices designed to achieve multiple objectives however, can result in complex conservation systems that can be challenging to communicate with landowners. Visual simulations offer a way to illustrate design alternatives so that landowners can easily understand this complexity. The *CanVis Visual Simulation Kit* provides image-editing software that can be used to create photo-realistic simulations of proposed agroforestry design and management scenarios. The communicative and non-threatening nature of simulations encourages landowners to invest time in the design process and offer feedback on alternatives, encouraging adoption and long-term support for the final action.

Together, *Conservation Buffers: Design Guidelines for Buffers, Corridors, and Greenways* and *CanVis* can be effectively used to design and communicate complex agroforestry systems that simultaneously satisfy multiple objectives.

Keywords: buffers, corridors, conservation planning, CanVis, design guidelines

INTRODUCTION

“...the overexploitation of one ecosystem service can lead to a disservice, a loss, or a reduction in benefit from another ecosystem service.” Covich (2004)

Landscapes that are designed to maximize a single purpose often do so at the detriment of other desired functions. A recent example is landscapes designed to maximize ethanol production which is causing unintended negative impacts including water quality and quantity problems (National Research Council 2008). Intense pressure on our limited land resources requires instead that we design multifunctional landscapes as a prerequisite for sustainable land use (Brandt and Vejre 2004). Agroforestry offers a way to create diversified, multipurpose plantings that can support many landowner and societal objectives. Designing agroforestry practices and

systems to achieve multiple objectives however, can be a challenging task. Resource professionals can feel overwhelmed trying to be experts in many disciplines and then ill-prepared to communicate complex design alternatives that achieve multifunctionality. Two products from the USDA National Agroforestry Center (NAC) can assist resource professionals with designing and communicating comprehensive agroforestry systems.

Science-based Guidelines for Designing Multifunctional Buffers

Many agroforestry practices are buffers or linear strips of vegetation placed in the landscape to provide a variety of ecological, economic, and social benefits to society. They are called by many names, including wildlife corridors, greenways, windbreaks, and filter strips to name just a few.

A large body of scientific knowledge exists that describe the ecological functions that buffers perform and variables that influence how well they provide the desired benefits. Unfortunately, this information is widely dispersed and is not easily accessible nor is it written to provide specific recommendations for design and management. Further, information for some functions is conflicting, inconclusive or as yet nonexistent. In addition, resource management guides developed from this information generally focus on only one resource concern; encouraging single-issue solutions and potentially leading to missed opportunities and overlooked negative impacts on other resources.

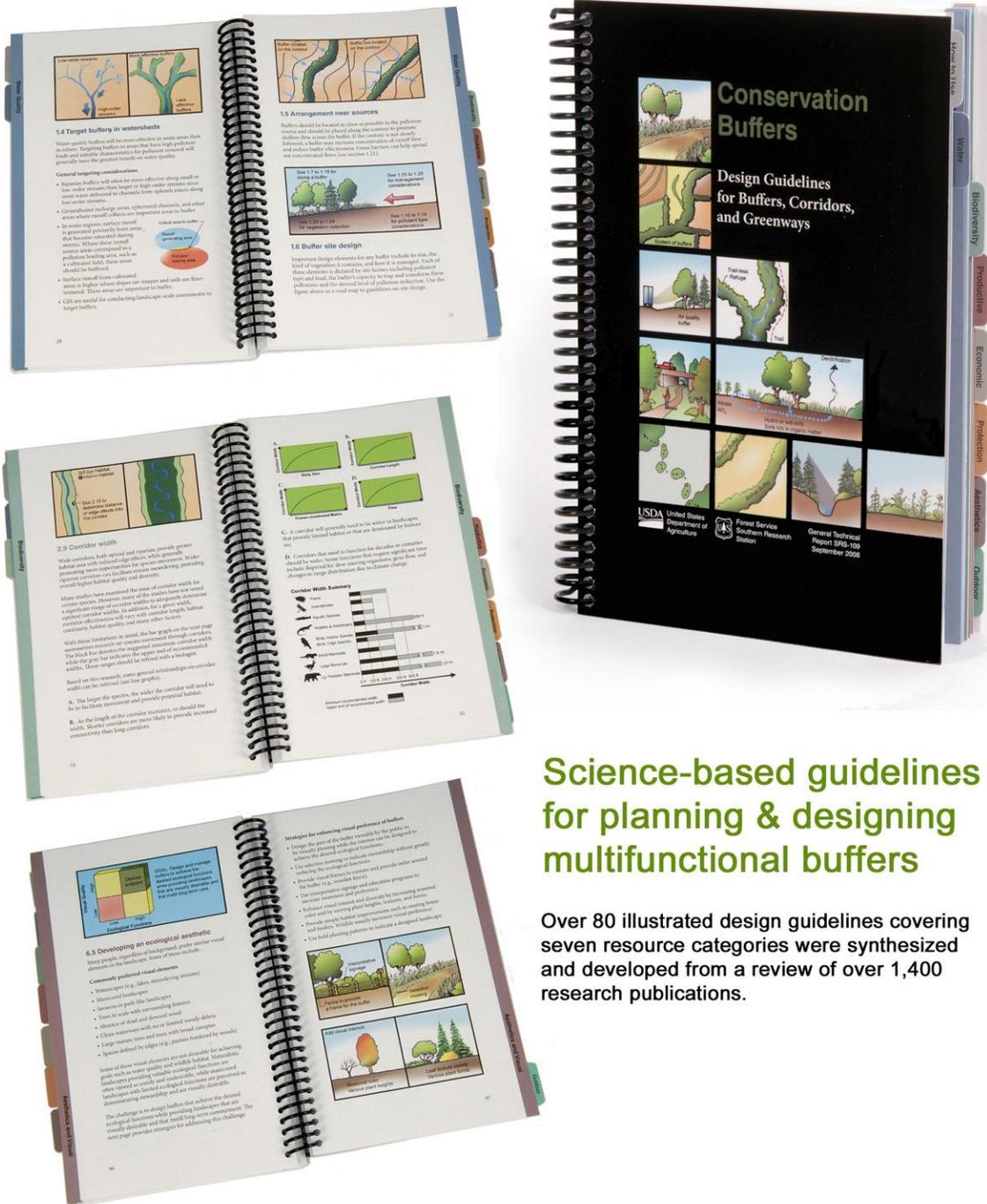
To address these problems, over 1400 research articles were analyzed, evaluated, synthesized and distilled into over 80 easy-to-understand guidelines for planning and designing buffers and other linear agroforestry practices (Fig. 1). The publication *Conservation Buffers: Design Guidelines for Buffers, Corridors, and Greenways* provides rules-of-thumb for:

- | | |
|---------------------------------------|--------------------------------------|
| ✓ Improving air and water quality | ✓ Enhancing economic productivity |
| ✓ Protecting soil | ✓ Providing recreation opportunities |
| ✓ Enhancing fish and wildlife habitat | ✓ Beautifying the landscape |

By pulling together all this information, synthesizing the best to-date science into guidelines and compiling them in one easily used tool, this publication will give resource professionals the information they need to consider in the planning and design of conservation buffers. With this comprehensive and field-friendly guide, users can assess the potential benefits and trade-offs a buffer might have on different resource concerns and then design buffers that can better provide multiple objectives while minimizing potential conflicts.

The content is crafted to be understandable by many audiences in order to facilitate communication among natural resource professionals, landowners, and other stakeholders. The guide was peer-reviewed and field-tested by over 100 scientists and resource professionals to

assess its scientific validity and utility. It is now available free to order or download through the website www.bufferguidelines.net which also provides a complete bibliography for each of the guidelines.



Science-based guidelines for planning & designing multifunctional buffers

Over 80 illustrated design guidelines covering seven resource categories were synthesized and developed from a review of over 1,400 research publications.

Fig. 1. Conservation Buffers: Design Guidelines for Buffers, Corridors, and Greenways

Visualizing Agroforestry Alternatives

Studies show that willingness of landowners and communities to adopt land stewardship practices is highly complex and surprisingly, many times based on something other than just ecology or economics. Being able to answer the question “*What will it look like?*” seems to be a key in the decision-making process especially for tree-based options that require long-term commitment (Dosskey and Wells 2000). Visual simulations can overcome these barriers by providing a modified image that portrays a change from an existing condition; however this technology is not widely used in the natural resources profession (Bentrup and Wells 2005).

To promote the use of visual simulations as an effective tool in agroforestry and other conservation planning and design, the USDA National Agroforestry Center developed the *CanVis Visual Simulation Kit*. The *Kit* consists of the following elements:

- *Visual Simulation Guide* – a multi-media, CD-reference manual on how to use image-editing software to create visual simulations for natural resource planning
- *CanVis* – an image-editing software for creating realistic simulations with minimal computer skills
- *CanVis Training* – multi-media lessons showing how to use the *CanVis* software

The *Visual Simulation Guide* provides instruction on how to plan a simulation project, acquire images, and edit an image (Fig. 2). To ensure that users can create accurate simulations, the guide offers extensive instruction on how to use perspective principles and scaling methods to correctly size and locate plant materials and other objects in the images. Ten agroforestry and natural resource planning projects are provided on the CD as working examples. These projects illustrate simulations with different levels of detail, from quick conceptual images to complex and detailed visual simulations. Videos are used to showcase these projects and users can develop and evaluate their skill by imitating these editing examples.

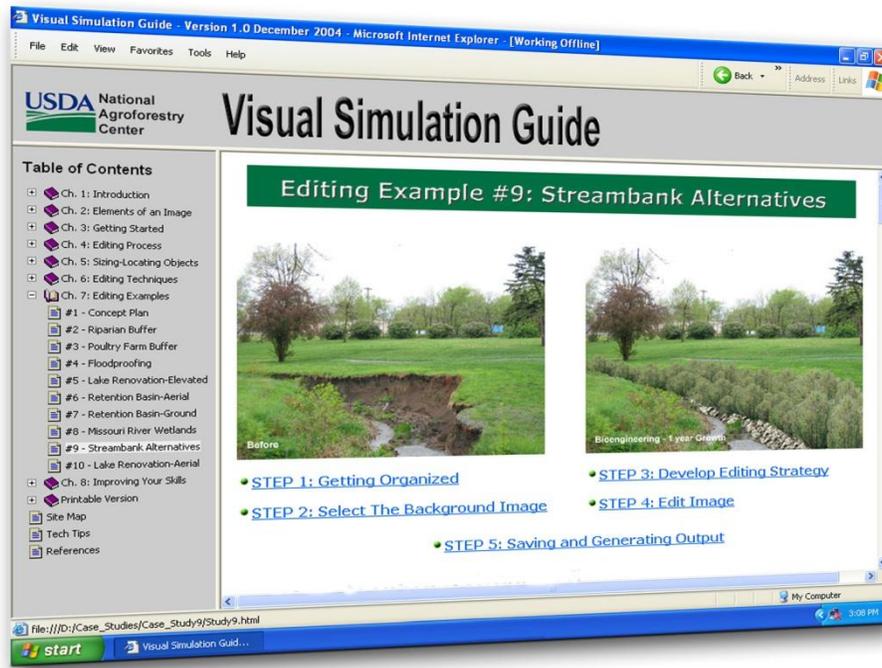


Fig. 2. Case studies are provided in the *Visual Simulation Guide* to serve as examples to emulate.

The *CanVis* program allows natural resource professionals to create realistic simulations with minimal computer skills. One of the main advantages of this program is its collection of existing object libraries that contain images of plant materials, agricultural features, people, wildlife, and park elements that can be quickly added to the base image. There are more than 500 images currently available in the object libraries, saving users' valuable time by not having to create plant images and other objects from scratch.

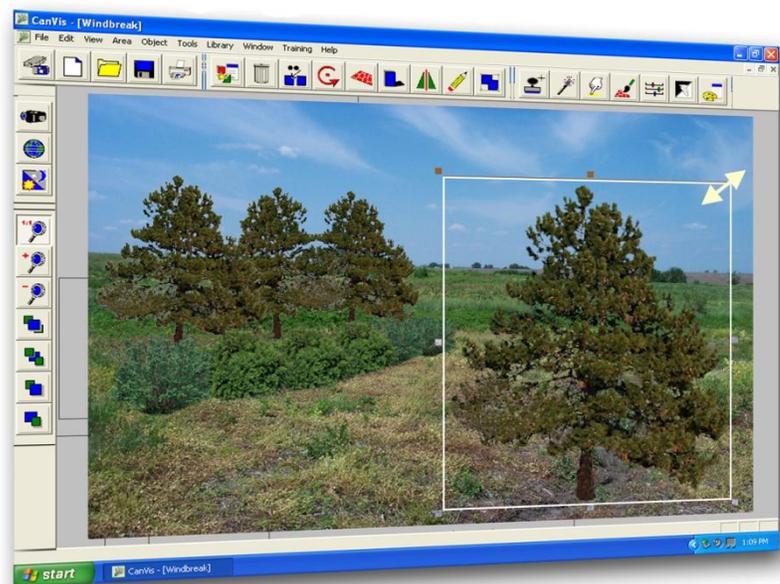


Fig. 3. The *CanVis* software can be used to create photo-realistic simulations.

Objects from these libraries can be inserted into an image, placed at the proper location, and resized to reflect the correct height. Users can also populate the libraries with their own, customized objects. For instance, the Mississippi Forest Service is populating their plant libraries with species to better reflect their region and recommendations while National Oceanic

and Atmospheric Administration (NOAA) is adding marine objects for coastal planning and management.

The *CanVis Visual Simulation Kit* enables natural resource professionals to readily show how the science is translated into management practices and alternatives on the ground and helps reduce any socio-economic or language barriers, a particularly valuable attribute in today's diverse and sometimes contentious planning environment (Fig. 4). Visual simulations promote sustainability by communicating ideas clearly, by inviting feedback on the alternatives, and by instilling a sense of shared ownership in the conservation system so that it is supported and maintained for long run.

Summary

“Products of science are best assessed not on their intrinsic interest or popularity in the scientific literature, but on the impact they have on the planning and management of real landscapes” (Hobbs 1997).

Together, *Conservation Buffers: Design Guidelines for Buffers, Corridors, and Greenways* and *CanVis* can hopefully be used to effectively design and communicate complex agroforestry systems that simultaneously satisfy diverse landowner and societal goals.

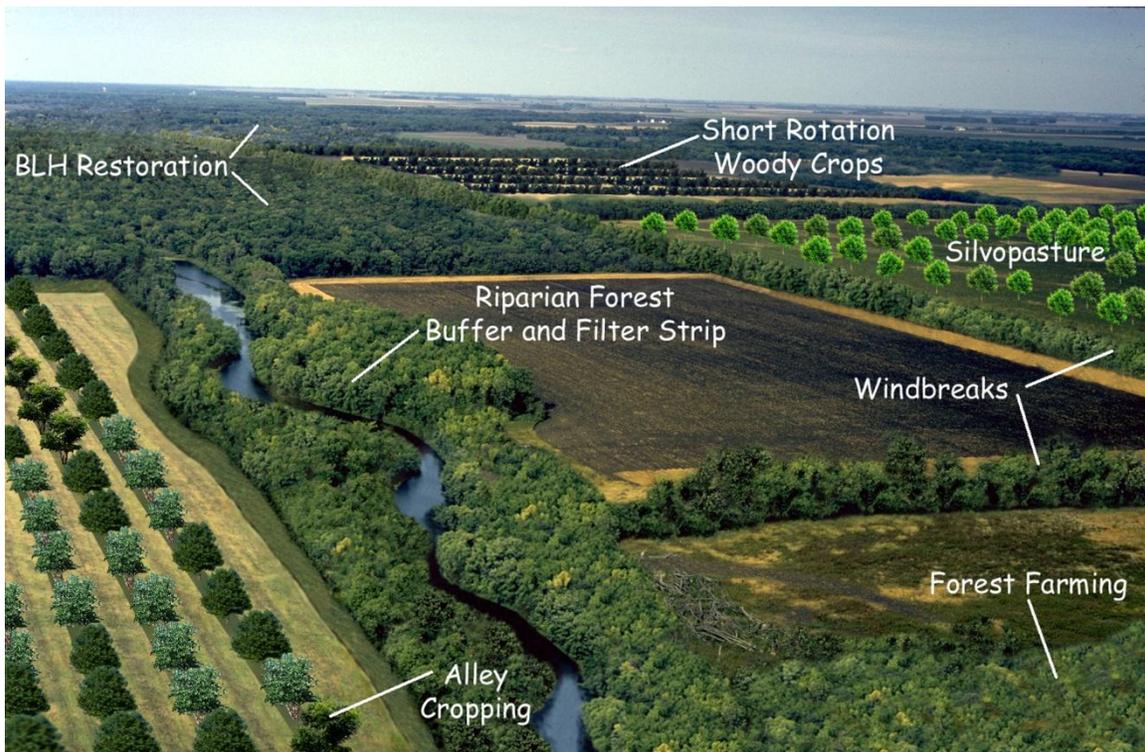


Fig. 4. Visual simulations can communicate complex agroforestry alternatives with landowners, encouraging participation in the design process and ultimately increasing adoption.

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PROFITABLE FARMS AND WOODLANDS: A PRACTICAL HANDBOOK IN AGROFORESTRY FOR UNDERSERVED AND LIMITED RESOURCES FARMERS AND WOODLAND OWNERS

Joshua Idassi

1890 Agroforestry Consortium Team, North Carolina A & T State University, The Cooperative Extension Program, PO Box 21928, Greensboro, NC 27420

Contact: joidassi@ncat.edu

Abstract: Many small farms and woodland owners are reluctant to produce tree-based products using traditional forestry practices because the time between planting and income generation is so long. Agroforestry offers advantages over forestry in producing agricultural products throughout the life of the tree so that income flow is not interrupted.

Agroforestry systems such as riparian buffers, alley cropping, windbreaks, silvopasture and forest farming provide significant economical and environmental protection opportunities for underserved and limited resources small farmers and woodland owners. Currently there are several practical agroforestry handbooks designed to be used by both forest and agricultural landowners and resource professionals. These manuals are bulky and practically too heavy to carry in the field. To guide small farmers and woodland owners in designing, establishing, managing and marketing agroforestry projects that are sustainable, the Agroforestry Consortium team is developing smaller and easy to carry agroforestry working manual that aims at educating small farmers and private woodland owners on productivity and sustainability. The manual will seek to achieve these goals by targeting natural resource educators and landowners to develop woodland management practices that are adequately diverse, integrated, profitable, healthy and sustainable. The manual will contain the following themes: an introduction; production methods; establishment costs; marketing; value-added processing; regulations and local resources.

Key words: underserved and limited resources farmers and woodland owners, practical handbook, profitable farms and woodlands, Agroforestry.

WWW.SILVOPASTURE.ORG: A WEB-BASED INDEPENDENT LEARNING COURSE FOR PINE SILVOPASTURE IN THE SOUTHEAST

Jim Hamilton¹, Charles T. Barger², Kris Irwin³, and D.J. Moorhead²

¹Natural Resources Management, Haywood Community College, Clyde, NC 28721

²Center for Invasive Species & Ecosystem Health, University of Georgia, Tifton, GA 31793

³Warnell School of Forestry & Natural Resources, Athens, GA 30602

Contact: moorhead@uga.edu

Abstract: Based on the technical handbook, "Silvopasture: Establishment & management principles for pine forests in the Southeastern United States", an online independent learning course has been developed to train natural resource managers and landowners on silvopasture applications and implementation. The web-based system uses graphic Flash interface modules, voice-over PowerPoint presentations, and video to deliver course content. Educational modules have been developed focusing on specific topics related to silvopasture establishment and management and the three major components of any silvopasture system: the tree component, the forage component, and the livestock component. Each module has a respective list of competencies or knowledge-sets that participants should be familiar with upon reviewing learning objects within each module. Individual students can login to the course to view the training modules and complete assessments at their own pace. Following successful completion of the course modules a program certificate and CFE credits will be awarded.

SILVOPASTURE DEMONSTRATION IN EAST TEXAS – EIGHTEEN YEAR OLD SYSTEM OF COWS AND TREES

Bruce Wight¹ and Ray Stoner²

¹National Agroforester, SDA National Agroforestry Center, 1945 North 38th Street, East Campus
– UNL, Lincoln, NE 68583

²Forester, NRCS, CNTSC, 501 W. Felix St., Bldg. 23, Fort Worth, TX 76115

Contact: ray.stoner@ftw.usda.gov

Abstract: Silvopasture systems can be promoted into the western edge of the southern pine region when landowners can see that grazing and timber production are compatible. This system was planted to demonstrate the possibility of producing forest products in a pine plantation system while managing grazing within the same pasture. Two ten acre plots within a large bahiagrass pasture were planted to loblolly pine seedlings in the winter of 1991. Livestock were not excluded from the plots, but grazing was managed as part of a five pasture rotational system. Survival and development of the pines were acceptable. In 2007, the plots were thinned to a stocking desirable for a silvopasture system and controlled burned. One plot was thinned using a conventional timber-oriented method of removing every fourth row and selectively thinning the remaining three, while the other removed four rows and retained two. At the time of the thinning, the forage within the plots was sparse due to shading. At age fifteen, both plots had pine stands that were fully stocked and able to support a commercial thinning. The differences between the two thinning methods demonstrated differences in residual timber stand quality and the speed at which the pasture grasses reoccupied the sites. Both plots demonstrated that manageable pine plantations can be developed while being grazed, if intensely managed and that thinning methods can determine the quality of both the grazing and timber resources.

SECTION 9

Agro-Ecosystem Interactions

BIOTIC INTERACTIONS IN ORGANIC FARM SYSTEMS

John E. Quinn¹, Ron. J. Johnson², and James R. Brandle¹

¹School of Natural Resources, University of Nebraska Lincoln, Lincoln, NE.

²Department of Forestry & Natural Resources, Clemson University, Clemson, SC.

Contact: jquinn2@unl.edu

Abstract: Fire, drought, and grazing were primary ecological drivers of the historical Great Plains' prairie ecosystem. The suppression of fire, a shift in grazing and cropping systems, and the introduction of windbreaks and other woody vegetation altered the landscape. The abundance, vertical diversity, and composition of woody species have noticeably increased. A subsequent shift has been documented in relative abundance of bird species in the state, with shrubland and edge species filling the ecological niche created with the conversion of many cropland acres to woodland. Shrubland and edge birds may fill an important functional role in agroecosystems.

Organic farms frequently have greater habitat heterogeneity than other farm types. Agroforestry is an important component of this habitat diversity. To quantify the effect of woody land-use and land-cover on biodiversity and to assess the functionality of avian species as predators in organic farm systems, avian and insect diversity were sampled on 23 organic farms in eastern Nebraska and Kansas in 2007 and 2008.

Species response to the presence and arrangement of woodland cover on farms is of great interest. An N-mixture model was used to estimate abundance and detectability of farmland bird species. Results from these analyses will be used to assess the functional role of birds and explore relationships between insect and bird communities to determine whether woodland edge bird species have the potential to effectively suppress crop pests on organic farms.

Key Words: Birds, Community, Woody Land Cover

INTRODUCTION

Biodiversity and associated ecosystem services are threatened locally and globally, a threat recognized internationally as a critical environmental issue (MA 2005). The maintenance of biodiversity is necessary to maintain resilient ecosystems and the continued provisioning of ecosystem services (Bengtsson et al. 2003). Successful conservation strategies will need to consider the whole landscape including the matrix around protected areas (Fahrig 2001, Murphy 2003). Agriculture is the dominant matrix of many landscapes (Schulte et al. 2006).

Agriculture is frequently faulted for habitat loss and resulting species decline (Main et al. 1999, Perrings et al. 2006). Agricultural practices today affect 70% of all threatened bird species (IUCN 2000). Improving the quality of the agricultural matrix may increase species survival rate and reduce the size of the patch needed to maintain a population (Fahrig 2001). The matrix can serve as a source of food and other resources; and as a wildlife corridor facilitating dispersal

among populations, essential for metapopulation persistence and the conservation of regional diversity (Matson et al. 1997).

Enhancing the quality of the matrix requires increased heterogeneity at the field and farm scale. Many agroforestry practices increase heterogeneity in a farm system. The presence of woody cover in the landscape increases local bird species richness (Pierce et al. 2001, Perkins et al. 2003) but the response of individual guilds and species vary (Pierce et al. 2001, Perkins et al. 2003). Richness (Pierce et al. 2001) and diversity (USFWS 1981) of woodland birds increased with increased presence of shelterbelts. Many woodland edge species respond positively to windbreaks (Johnson and Beck 1988, Pierce et al. 2001, Perkins et al. 2003), but many grassland birds avoid woody vegetation (Knopf 1994, Grant et al. 2004, Brennan and Kuvlesky 2005). Planning in relation to available woody and grassland habitats, landscape context, and species of interest is necessary to accommodate conservation needs of both woody and grassland species, and pest insect suppression in agroecosystems (Henningsen and Best, 2005).

Linear and non-linear woodlands are two categories of woody land cover types in agroecosystems. These woody landscape features can enhance beneficial interactions between crops and species. The presence of these two woody land cover types may have a strong influence on species abundance. Our objective in this paper is to examine the habitat relationships between farmland birds and woody landscape features at a local scale.

METHODS

Birds, insects, crop and non-crop vegetation were sampled at 358 points across twenty-three organic farms (Fig. 1) in eastern Nebraska and Kansas in 2007 and 2008. Surveys were conducted May 15-July 15 to assess richness, diversity and relative abundance across the different farm management types. Birds were surveyed during the first four hours after sunrise on two consecutive mornings. Counts were 5 minutes in duration and all birds heard or seen were recorded by species. Two observers conducted bird surveys at each point each morning, though at different times. Each point was sampled four times over a 48-hour period. The order and time of day in which point counts on each transect were conducted was varied to minimize these as confounding factors. Sticky traps (11.5 by 14 cm) were placed at each point to sample insect richness and diversity. Traps remained out for 48-hours and were collected after the final bird survey. Insects were transported to the lab and identified to functional groups using dissecting microscopes as needed. Surrounding land use and pertinent landscape variables including adjacent non-crop habitat was categorized in the field using modified Daubenmire classes (PC-LETM 2008).

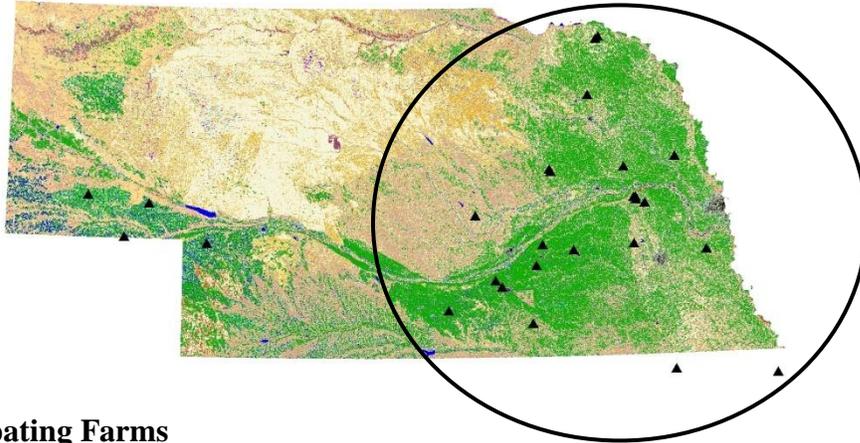


Figure 1. Participating Farms

We hypothesize that two types of woody land cover, linear (LWOOD) and non-linear (WOOD), would best predict the abundance of the Red-bellied Woodpecker *Melanerpes carolinus* (RBWO) and Orchard Oriole *Icterus spurius* (OROR), based on their habitat preferences. Both species move between woody vegetation and cropland for food and cover. A better understanding of what land cover types these species use would improve management goals. We include wind (WIND) as covariate of detectability. Ecological models are often flawed as a consequence of imperfect detection of individuals, reducing the value of management decisions based on the data. Using spatial and temporal replication, N-mixture models allow for an estimate of abundance, modeled as a random effect, from simple point-counts as well as accommodate for the probability of detection for each species despite imperfect detection (Royle 2004). This analysis technique allows for the development of clear and interpretable data to enable effective management.

Land use and land cover types can be included as covariates (X_i) influencing abundance (μ_i)(Eq 1.). Probability of detection (p_{it}) (Eq 2.) may vary other covariates (D_i) including date, wind speed, and observer (Royle 2004).

$$\text{Eq. 1 } \log(\mu_i) = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5$$

$$\text{Eq. 2 } \text{logit}(p_{it}) = a_0 + a_1D + a_2D$$

The best possible parameters were estimated using the optim function in the software package R (R Development). Likelihood models were fit under the negative binomial distribution. This distribution has been favored in previous N-mixture model efforts (Kery et al. 2005). Models were tested using Akaike's information criterion (AIC) model selection. Models were ranked and compared by delta AIC (Burnham and Anderson 1998). The best model was used to extract the estimated abundance and occurrence probability for the target species.

RESULTS

Ninety-six species of breeding birds were observed in the surveys. Individual farm richness ranged between 25 and 60 species. The top five models for Red-bellied Woodpecker and Orchard Oriole are presented in Tables 1 and 2. The top models had a weight greater than 0.58,

two times better than the next model. The best model for each species was used to construct abundance and occurrence parameters (Table 3) and model the relationship between species abundance and land cover type (Figs. 2,3).

RBWO Models	K	AIC	delta AIC	weight
Wood+Wind	5	761.3973	0.0000	0.5923
Wood+Lwood+Wind	6	763.2505	-1.8532	0.2345
Wind	4	764.5606	-3.1633	0.1218
Lwood+Wind	5	766.2885	-4.8912	0.0513
Wood	4	811.4912	-50.0939	0.0000

Table 1. Top RBWO Models

OROR Models	K	AIC	delta AIC	weight
Lwood+Wind	5	809.3092	0.0000	0.5817
Wood+Lwood+Wind	6	810.6886	-1.3794	0.2918
Lwood	4	813.6950	-4.3858	0.0649
Wood+Lwood	5	815.0176	-5.7084	0.0335
Wind	4	816.2527	-6.9435	0.0181

Table 2. Top OROR Models

Species/Model	Abundance Parameters				Detection Parameters	
RBWO	<u>b0</u>	<u>alpha</u>	<u>Lwood</u>	<u>Wood</u>	<u>a0</u>	<u>Wind</u>
Wood+Wind	0.1368	2.7890	NA	0.2046	-2.0090	-1.1543
OROR						
Lwood+Wind	0.7556	0.5820	0.2983	NA	-2.4255	-0.2295

Table 3. Estimated Abundance and Occurrence Probability

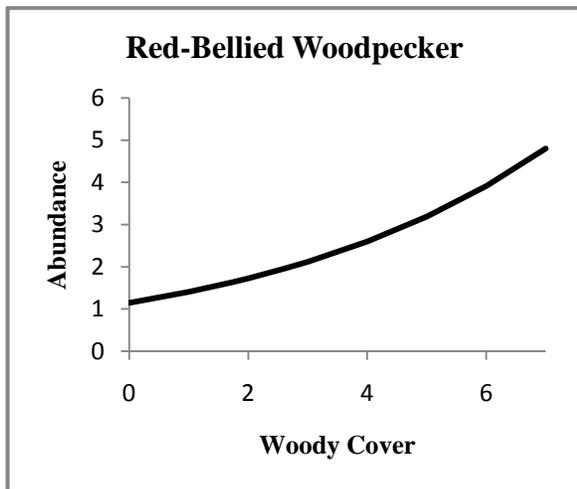


Figure 2

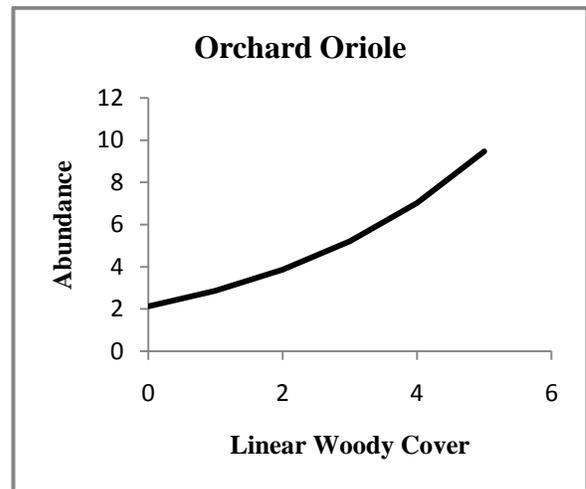


Figure 3

DISCUSSION

Woody landscape features are an important component of farmland sustainability. Their value in enhancing species diversity has been demonstrated (Pierce et al. 2001, Perkins et al. 2003). The optimal shape and arrangement of woody land cover for various species, however, remains unidentified. We have shown that different species using agroecosystems respond to different woody land cover shapes. The greatest difficulty for land managers is optimizing multiple goals. Different species provide multiple benefits to farm systems including biological control and aesthetic value. While food production is an essential component of farm management, farmland also has an essential role in protecting species and enhancing ecosystem services. Balancing multiple outputs from farm systems remains an elusive goal. The different responses of the two species presented here further complicates farm management goals but also demonstrates potential to focus management to conserve or enhance a species or guild if desired.

As ecological and economic parameters of agriculture shift, assessing and monitoring this dynamic landscape is essential to ensuring maintenance of natural and economic capital. The results of this research will be integrated into the Healthy Farm Index (Quinn et al. 2009). The Healthy Farm Index assesses biological, environmental, and socio-economic parameters' on working farm systems to guide to long-term sustainability. Recognizing the response of birds to land-cover variables is a first step in developing an effective means to optimize multiple goals. Birds have the potential to provide farmers an easy to use and accurate measure to monitor the health of their agroecosystem, encouraging the adoption of beneficial and sustainable farm practices.

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BIRD SPECIES DIVERSITY IN RIPARIAN BUFFERS, ROW CROP FIELDS, AND GRAZED PASTURES OF TWO AGRICULTURALLY DOMINATED WATERSHEDS

Sara A. Berges¹, Lisa A. Schulte¹, Thomas M. Isenhardt¹, and Richard C. Schultz¹

¹Department of Natural Resource Ecology and Management, Iowa State University, 339 Science II, Ames, IA 50011.

Contact: venables@iastate.edu

Abstract: A design goal associated with most riparian buffer systems is the enhancement of wildlife habitat. To determine whether this goal was being met, we compared breeding bird composition at five sites, including riparian buffers, nearby row crop fields, and an intensively grazed pasture along Bear Creek and Long Dick Creek in north-central Iowa, USA. The riparian buffers consisted of native grasses, forbs, and woody vegetation and represented three different ages (14+, 9, and 2 years old). At each site, 10 min point counts for breeding birds were conducted using 50 m fixed radius plots, which were visited eight times between May 15 and July 10, 2008. A total of 54 bird species were observed over all of the study sites. The installed riparian buffers incorporated in this study had higher bird abundance, richness, and diversity than the crop and pasture sites. The fewest species were detected within row crop fields (15 species) while the most species were observed on the oldest riparian buffer (42 species); intermediate numbers were observed on the 9 year-old (27 species) and 2 year-old (28 species) buffers and the pasture (23 species). Our results suggest that re-establishing native riparian vegetation in areas of intensive agriculture will provide habitat to a broader suite of bird species. In comparison to row crop and grazing land, the buffers contain a greater diversity of vegetative structure in both horizontal and vertical dimensions. Many birds are known to respond positively to such habitat heterogeneity.

Key Words: bird habitat, breeding birds, Iowa, point count, species richness

INTRODUCTION

Since Euro-American settlement, land cover in the U.S. Midwest has been converted from native landscapes to intensive agricultural production. This is especially true in Iowa, which has the smallest percentage of its original natural habitat remaining out of all 50 states. Tallgrass prairie once covered approximately 85% of the state. Due to agricultural and urban growth, it now covers less than 1% of its original extent (Cosner 2001). Loss of habitat has caused populations of grassland birds to decline (Murphy 2003). Across the Iowa prairie landscape, riparian areas were heavily manipulated and converted for agricultural use with the Midwest generally showing some of the greatest habitat loss in the United States (Brinson et al. 1981, National Research Council 2002). By converting riparian land to agricultural use, many of the natural functions have been lost, including filtering sediment and chemicals from surface and subsurface runoff,

stabilizing surface and streambank soil, and providing diverse wildlife habitat (Schultz et al. 2004). In recent decades, agricultural intensification has reduced habitat heterogeneity and farmland biodiversity (Benton et al. 2003).

Habitat loss and fragmentation have led to reduced available breeding habitat for many wildlife species, including many species of birds (Best et al. 1995). One way to enhance and increase potential habitat is to convert riparian areas from agricultural production to riparian buffers (Schultz et al. 2004). To assess whether this goal can be met, bird communities were compared between installed riparian buffers and the land cover of the surrounding matrix (row-crop fields and an intensively grazed pasture). Similar studies were conducted in these riparian areas in North-Central Iowa in 1994, 1997, and 1999. By comparing data from the past surveys to the 2008 survey, we can see how the bird communities on the same or similar aged sites change over time as established buffers grow and develop more species and structural diversity.

MATERIALS AND METHODS

Description of the study sites

The study was conducted in the Bear Creek and Long Dick Creek Watersheds in north-central Iowa. These watersheds are dominated by agricultural land use, primarily consisting of row-crop farming (corn and soybeans) and pasture. Bear Creek and Long Dick Creek watersheds are small (6941 ha and 9403 ha, respectively) drainage basins located within the Des Moines Lobe subregion of the Western Corn Belt Plains ecoregion. In general, the topography of this area is flat to gently rolling (Griffith et al. 1994).

Five sites were included in the study, including three different areas with riparian buffers, an area with intensively grazed pasture, and an area in row crops. The riparian buffer sites represent three different ages since planting (14+, 9, and 2). All buffers were composed of three-zones; a managed tree zone adjacent to the stream followed by a shrub zone and a native grass/forb zone adjacent to the crop field (Schultz et al. 2004). The tree zone included species such as silver maple (*Acer saccharinum* L.), green ash (*Fraxinus pennsylvanica* Marsh.), black walnut (*Juglans nigra* L.), willow (*Salix* spp), cottonwood hybrids (*Populus* spp., e.g., *Populus* clone NC-5326, a designated clone of the North Central Forest Experiment Station), red oak (*Quercus rubra* L.), bur oak (*Quercus macrocarpa* Michx.), and swamp white oak (*Quercus bicolor* Willd.). Shrub species included chokecherry (*Prunus virginiana* L.), Nanking cherry (*Prunus tomentosa* Thunb.), wild plum (*Prunus americana* Marsh.), red osier dogwood (*Cornus stolonifera* Michx.), and ninebark (*Physocarpus opulifolius* Max.). The grass zones consisted of mixtures of several native warm season grasses and up to 15 native forb species. The oldest site was a contiguous section consisting of a downstream segment planted in 1990 and an upstream segment planted in 1994; thus, vegetation on the entire site was at least 14 years old at the time of the study. The intensively grazed pasture was dominated by short bluegrass (*Poa pratensis*), but one large tree and a few small shrubs were present near the stream. The row crop area was located along the edge of a meander belt with

narrow areas between the meanders dominated by cool-season grasses and forbs. An example of a buffer, the pasture, and the crop site are shown in Figure 1.



Figure 1. Representative photos from the study area; the left photo is the 14+ aged buffer, the middle photo is of the pasture site, and the right photo is the crop site with grass in the meander belt.

Bird Surveys

All sites were surveyed for breeding birds eight times between May 15 and July 10, 2008 using 10 minute point counts with a 50 meter recording radius. At each site, three-to-seven non-overlapping point-count locations were placed randomly along each stream reach and extended across the stream on both sides, for a total of 21 survey plots. The number of plots per site was based on the length and complexity of the site. Surveys began at sunrise and ended by 9:30 a.m. Data were not collected on mornings with high winds or rain because these factors could affect bird activity. All birds seen or heard within each 10 minute point-count period were recorded. Non-resident migrant birds observed were recorded but were not included in the data analysis. To prevent recording the same individual more than once, the location of each observed individual was recorded on a diagram of each plot and notations were made if a bird flew from its initial location during the count period. To reduce temporal bias, the order in which the sites were surveyed was rotated between days. No attempt was made to establish whether the birds were nesting within the plots. Some of the birds may have been using the plots to feed or rest.

Habitat Sampling

Vegetation sampling occurred on all of the 21 survey locations during the first few weeks of September, 2008. Each plot was divided into subplots based on the dominant category of vegetation. The subplot categories were tree, grass/forb, shrub, shrub/grass, tree/shrub, and crop. The data collected for each subplot were canopy height, percent canopy cover (using a spherical densiometer), total number of trees, shrub density, percent grass/forb cover, and the dominant tree, shrub, grass, and forb species. Canopy cover was estimated for plots with trees or shrubs. Shrubs were defined as woody vegetation at least 0.3m tall and with a dbh < 5cm. Dominant vegetation subplots were delineated on aerial images of the 50 m radius plots and a Geographic Information System (GIS) was used to determine the percent of each plot in each of the dominant vegetation categories for use during analysis.

Data Analysis

Total bird abundance, species richness, and Shannon-Wiener Diversity were calculated for each of the survey plots. Total bird abundance was calculated for each plot by summing the maximum number of individuals of each species observed across all surveys at the location. Abundance was then averaged across each point count location to obtain a site-based estimate. Species richness was calculated by counting the total number of species observed across all surveys at each point count location; all plots were then averaged to obtain a site-based estimate. The Shannon-Wiener Diversity Index combines species richness and the relative abundances of species observed for an integrated measure of bird response (Molles 2008). A one-way ANOVA and a pairwise comparison using a Student-Newman-Keuls method were used to test for differences in diversity among the five sites with a significance level of $P < 0.05$. Regression analysis

was used to compare the results of the 2008 study to those from the previous studies. Statistical analysis was done using SigmaPlot 11.

RESULTS

In total, 2255 individuals from 54 bird species were observed across all surveys and locations. A total of 42 bird species was detected on the 14+ year-old, 27 species on the 9 year-old, 28 species on the 2 year-old riparian buffer sites, respectively, and 23 species in the pasture, and 14 species on the row-crop site.

The highest total bird abundance was in the 2 year-old buffer and the lowest was in the crop site (Figure 2). The buffer sites did not have significantly different total bird abundance when compared to each other, but significantly differed from the pasture (14+ yr, $P=0.007$; 9 yr, $P=0.007$; 2 yr, $P=0.003$) and crop sites (14+ yr, $P=0.005$; 9 yr, $P=0.007$; 2 yr, $P=0.002$).

Average species richness across all survey dates was highest in the 14+ year-old buffer and lowest in the crop site (Figure 2). The species richness data failed the normality test and so could not be compared in ANOVA.

The Shannon-Wiener Diversity Index was also highest in the 14+ year old buffer and lowest in the crop site (Figure 2). Diversity was not significantly different between the different ages of buffers. While the 14+ year-old buffer site was significantly more diverse than the pasture site ($P=0.043$), the 9 and 2 year-old buffers were not. All buffer sites had significantly higher diversity than the crop site (14+ yr, $P<0.001$; 9 yr, $P=0.012$; 2 yr, $P=0.002$).

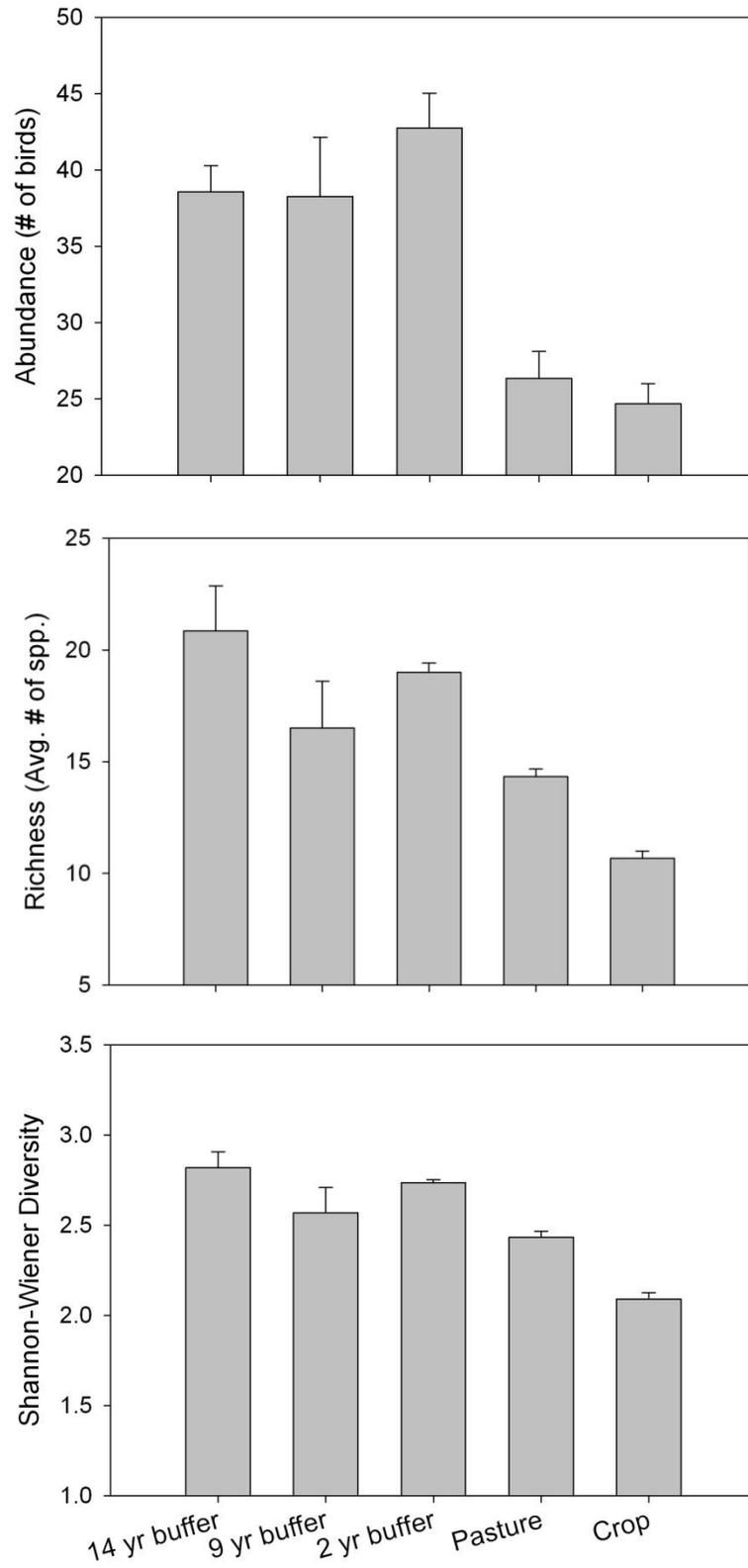


Figure 2. Differences in bird abundance, richness, and diversity at each of the 5 study sites.

The 14+ year-old buffer had the most vertical and horizontal stratification of all of the sites. It had a variety of sizes of trees and shrubs and so attracted more forest and edge species (i.e., Baltimore Oriole, Eastern Phoebe, Least Flycatcher, and Red-eyed Vireo). The 9 year-old buffer did not have many large trees and had many shrub and edge bird species such as Common Yellowthroats, American Goldfinches, and Gray Catbirds. The 2 year-old buffer had some large trees and shrubs that were there before the buffer was planted. The rest of the site was dominated by grasses, and so attracted more grassland birds such as Savanna Sparrows, Dickcissels, and Western Meadowlarks. The number of species on each of the buffer sites was similar, but the species were not necessarily the same.

The pasture and crop sites had less suitable habitat for many bird species. The pasture was dominated by bluegrass and had only one tree and a few small shrubs near the stream but had few other places to perch and no tall grass. Many of the birds found on the pasture were grassland birds (i.e., Western Meadowlark and Bobolink). Some birds made use of the only large tree in the pasture. Others came over periodically from the tall grass that was planted adjacent to the pasture on one side. The crop site had grass and small shrubs that could be suitable for birds, but this vegetation was in a narrow strip along the channel. The rest of the site was composed of corn crops that had not yet reached maturity. Most of the birds that used the site (i.e., Red-winged Blackbird, Song Sparrow, and Common Yellowthroat) were concentrated in the thin grass strip. The only bird species observed in the crop field consistently was Killdeer.

When comparing the buffers from the 2008 study to the past studies, there was a general trend of an increase in the number of bird species observed at a decreasing rate as the age of the buffer increased (Figure 3). The polynomial regression plot shows that 64.2 % of the variance is described by the age of the buffer ($P=0.041$).

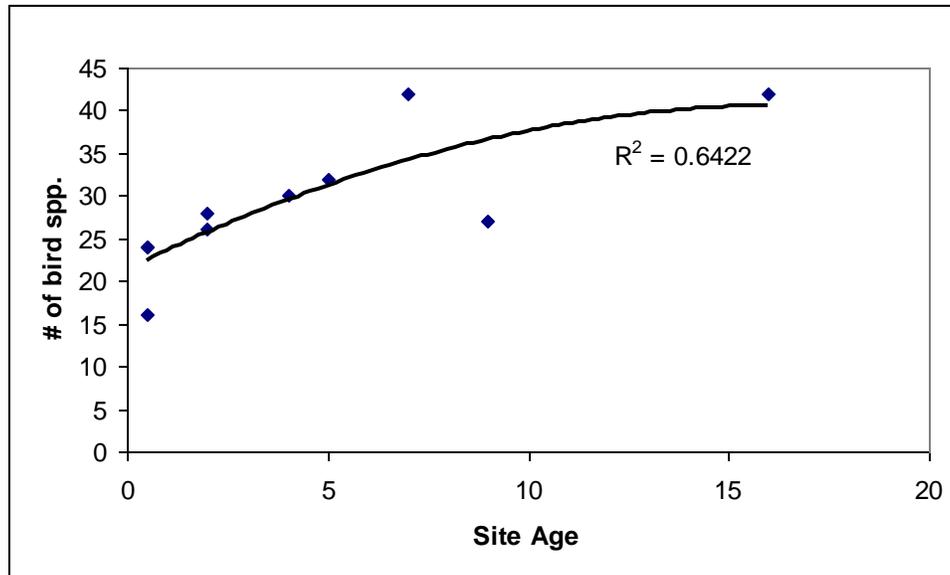


Figure 3. Polynomial regression showing combined total species richness data from the previous and recent surveys. Site age is the age since establishment at the time the survey was conducted.

DISCUSSION AND CONCLUSIONS

These results support the assumption that wildlife habitat can be improved by installing riparian buffers. The sites with little or no tree and shrub cover had lower bird species abundance, richness and diversity. In the highly modified and fragmented landscape of north-central Iowa, the installed riparian buffers incorporated in this study had higher bird abundance, richness, and diversity than the crop and pasture sites due to higher habitat heterogeneity. These sites vary in terms of width of riparian vegetation and degree of horizontal and vertical stratification. In general, bird species richness and abundance increase with amount and width of woody vegetation (Stauffer and Best 1980, Deschenes et al. 2003). Furthermore, different bird species exhibit affinities for different habitats (Dinsmore et al. 1984), which explains why certain species were more common on some sites rather than others. The narrow width of most of the buffers often attracts edge species because there is little interior for area sensitive species (Peak and Thompson 2006).

Total bird abundance was greatest in the riparian buffers, likely because of a greater availability of suitable habitat. The crop site had the lowest bird abundance. Because a large part of the landscape in Iowa is in row-crop agriculture, it is important to understand the habitat that it provides. Best et al. (2001) found that few species are residents of row-crop fields and many birds that use them only visit them for food and are more likely to do so when associated with an adjacent grass or wooded habitat.

Species richness was greatest in the 14 and 2 year-old buffers and so could support a wider variety of birds. Because habitat-use differs between species, the different aged buffers might have appealed to different species (Best et al. 1995). The pasture and crop

sites did not have much horizontal or vertical stratification and so could not support as many different species.

The Shannon-Wiener Diversity Index had the highest values in the buffer sites. All three buffer sites were significantly different from the crop site. Only the 14 year-old buffer was significantly different from the pasture site. This may be because species richness was more similar among the 9 and 2 year-old buffer and pasture than when compared to the crop site.

The regression analysis shows that a large number of species initially colonized the sites, but as the sites aged, fewer species were added. If the data continues to follow this trend, there will be a point at which species richness does not increase. This makes sense because buffers are not wide enough or large enough to provide adequate habitat for some forest species (Peak and Thompson 2006) or may have too many trees/shrubs for some grassland species (Best et al. 1995). The data show that maximum species richness for the buffer sites might be at or near the 42 species that were observed.

By planting trees, shrubs, and/or grass along streams, there is an increase in potential habitat for many bird species. Under the current economic environment in agriculture, annual rental rates for most land enrolled in the Conservation Reserve Program (CRP) and similar programs are not competitive with present crop prices. For this reason, much of the land enrolled in such programs are reverting back to agricultural production (Secchi et al. 2008), eliminating important habitat for breeding birds and other wildlife. Yet, the benefits of such conservation lands, including riparian buffers, are more than monetary for the landowner. Riparian buffers can improve water quality (Schultz et al. 2004), aesthetics, and, as this study has shown, provide habitat for many bird species. When compared to the surrounding agricultural matrix, buffers increase landscape heterogeneity and provide habitat to a broader suite of birds than found in agricultural lands alone (Benton et al. 2003). Given that such buffers comprise only a small portion of the landscape, usually in areas that may pose difficulties for maneuvering large farm equipment, the environmental services they offer are likely to offset lost crop revenues associated with their deployment (Schultz et al. 2004).

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EVALUATING PRODUCTIVITY OF MISSISSIPPI ALLEY CROPPING FOR PRODUCTION AND WILDLIFE HABITAT

Henry G. Gordon¹, John D. Kushla¹, W. Daryl Jones², Jeannie C. Jones²,
Robert K. Grala¹, Mark W. Shankle³, and Randy Saunders³

¹Department of Forestry

²Department of Wildlife and Fisheries

³North Mississippi Research and Extension Center

Mississippi State University

Contact: hgg5@msstate.edu

Abstract: Wildlife habitat values associated with agroforestry systems in Mississippi are not fully understood. Landscape matrix changes resulting in close location of various agricultural and tree crops can provide habitat more suitable for use by game wildlife. If agroforestry land management improves wildlife habitat quality to the extent that hunters are willing to pay higher premiums, landowners can generate additional economic return from hunting leases. This study examined the feasibility of improving habitat value by adopting agroforestry practices such as alley cropping. A completely randomized block design was utilized to ascertain production values for two different even-aged crop trees, shortleaf pine (*Pinus echinata* Mill.) and loblolly pine (*Pinus taeda* L.), and four different agricultural crops, corn (*Zea mays* L.), switchgrass (*Panicum virgatum* L.), grain sorghum (*Sorghum bicolor* L.), and soybeans (*Glycine max* L.). Breeding bird surveys and camera surveys were used to quantify wildlife use throughout the year and determine improvement in wildlife habitat quality produced by these tree and crop associations. Long-term monitoring will be necessary to investigate wildlife use and habitat value improvements in response to change in rotation of the crop tree stand.

Keywords: Alley cropping, Game wildlife, Hunting, Mississippi

THE RELATIONSHIP BETWEEN LANDSCAPE COMPLEXITY AND WILD BEE POLLINATION SERVICES TO CANOLA (*BRASSICA NAPUS*) IN THE ASPEN PARKLAND REGION OF CANADA

G. Bank¹, M. Wonneck², and S. Javorek³

¹Agriculture and Agri-Food Canada/PFRA, Room 600, 138-4TH Avenue, S.E,
CALGARY, AB T2G 4Z6

²PFRA

³Agriculture and Agri-Food Canada

Contact: bankg@agr.gc.ca

Abstract: Both wild and domesticated bees play important roles in the pollination of agricultural crops. Recent studies have shown that areas of intensive agriculture, with little uncultivated natural land, are suffering lower crop yields as a result of too few wild pollinators. Building on the relationships between landscape complexity and pollination services, researchers in northern Alberta, Canada, developed a model that predicts that the profitability of canola (*Brassica napus*) production in a hypothetical 576 ha area can be maximized when about 30% of the landscape is not cropped (i.e., left in a naturalized state). In Canada, canola is the most important crop that can benefit from insect-mediated pollination, as a percentage of area cultivated and in terms of production value. This multi-year study is designed to investigate how different configurations of non-cropped areas, such as shelterbelts, treed field margins, wooded areas, fencelines and wetlands affect pollination in canola. Our objectives are to: determine whether the amount and stability over time of pollination services to canola vary with landscape complexity; determine if insect-mediated pollination in canola economically significant; and, if so, to develop habitat design and management recommendations to optimize the economic return on pollination services provided by bees.

ESTABLISHMENT AND PRODUCTION FROM THINNED MATURE DECIDUOUS-FOREST SILVOPASTURES IN APPALACHIA

C.M. Feldhake, J.P.S. Neel and D.P. Belesky

USDA-ARS Appalachian Farming Systems Research Center
1224 Airport Road, Beaver, WV
Contact: charlie.feldhake@ars.usda.gov

Abstract: Past research has not adequately addressed effective management and utilization of silvopastures developed from the ubiquitous mature woodlots which comprise 40-50% of small Appalachian farm acreage. While some grazing in woodlots is common, a set of guidelines for optimal utilization of these areas is not. We thinned a white oak dominated mature second growth forested area establishing two 0.5 ha, eight-paddock, orchardgrass-perennial ryegrass-white clover silvopasture replications for comparison with two nearby open pasture replications. After thinning trees, silvopastures were limed, fertilized and seeded. Sheep were fed hay and corn scattered across the area to facilitate removal of residual understory and incorporation of applied materials into surface soil. We measured soil moisture in the top 15 cm using TDR and photosynthetically active radiation (PAR) using a system of 16, 1 m line Quantum Sensors during the subsequent growing seasons of 2004, 2005, and 2006. Paddocks were rotationally grazed by sheep with two 1 m² herbage mass samples taken prior to animal grazing. There was no significant difference in soil moisture between silvopastures and open pastures however, there was adequate rainfall to prevent drought all three years. The two silvopasture replications had residual tree stands of 14.1 and 15.6 m² ha⁻¹ diameter breast height allowing 42 and 51% of total daily incident PAR compared to measurements in the open field. Total forage mass yield from open pasture for 2004, 2005 and 2006 was 9.9, 10.5 and 10.2 t ha⁻¹ respectively and for silvopasture 8.5, 6.7 and 6.7 t ha⁻¹. Silvopastures received 47% of open pasture incident PAR yet yielded an average of 72% as much herbage mass as the open pastures. The silvopasture soils were managed for forage production only a few years unlike the open pastures which received roughly a century of better management. Soil limitations may have contributed to decreased forage yield in silvopastures in addition to reduced PAR.

Kew Words: C₃ forage, PAR, rotational grazing, sheep, woodlot

INTRODUCTION

In recent decades there is an emerging interest within the Eastern U.S. in developing deciduous-tree based silvopastoral systems to increase and diversify the income of small farms. These systems also provide potential environmental services such as microclimate modification for forages and livestock, improved wildlife habitat, and capture and recycling of nutrients leaching below the forage root zone. A number of research projects have developed silvopastures in the last three decades by planting trees such as

black walnut (*Juglans nigra* L.), black locust (*Robinia pseudoacacia* L.), or honey locust (*Gleditsia triacanthos* L.) into existing pastures as one strategy for studying optimal management.

Little has been done to develop silvopastures from existing forest because throughout the 20th century forest management increasingly emphasized wood production at the expense of other traditional products (Garrett et al. 2004). Animals are frequently allowed access to deciduous woodlots although little is done to manage these for forage production. In fact, Chandler (1940) states “It is widely recognized that the grazing of farm woodlands in the eastern United States is an undesirable practice”. However, there are many small farms in Appalachia with woodlots that are little utilized and farm income could be increased if guidelines were available for conversion of a portion of these lands into productive silvopastures.

MATERIALS AND METHODS

The research site was on a small hill-farm in southern West Virginia, USA (37°46'W 81°00'N 860 m.a.s.l.). The soil was a Dekalb (fine sandy loam, mixed, mesic Typic Hapludult). Two 0.5 ha silvopastures were established within a white oak (*Quercus alba* L.) dominated mature second growth forested area using a method described in detail by Neel et al. (2007) for a conifer forested area.

In summary, the forested area was thinned to the desired stand density, fenced, and mob grazed by sheep to remove the understory vegetation and break up the litter layer. Additional hay and corn was scatter over the area to ensure uniform site preparation by animals. The sheep were removed and the area limed, fertilized, and seeded with a mixture of orchardgrass (*Dactylis glomerata* L) white clover (*Trifolium repens* L.) and perennial ryegrass (*Lolium perenne* L.). The area was again scattered with hay and corn and sheep introduced to trample in the forage seed. Rep one (S1) was established in 2002 and rep two (S2) in 2003.

Both sites were fenced into eight grazing sub-paddocks along with two nearby open pasture sites (O1 and O2) for comparison. All four sites were rotationally grazed by sheep during 2004, 2005, and 2006 with two 1 m² herbage mass samples taken from each sub-paddock prior to animal grazing. Tree diameter at breast height (DBH) was measured for all trees within the silvopasture paddocks during the summer of 2006.

Soil moisture was measured for the top 15 cm in a 24 point grid in all four sites whenever more than a week passed without precipitation using a TRIME-FM portable TDR soil moisture meter (MESA Instruments, Medfield, MA). Photosynthetically active radiation (PAR) was measured for a week period several times during the summers of the study period using a system of 16 LI-COR LI-191-SB line quantum sensors (LI-COR, Lincoln, NE) and 21X data loggers (Campbell Scientific Logan, UT).

During an overcast summer day with full tree foliage expansion, upward hemispherical images were photographed in the center of each grazing sub-paddock using a Nikon Coolpix 995 digital camera with a Nikon FC-E8 Fisheye Converter and a self-leveling mount. Images were analyzed for open sky percent field-of-view and potential direct-beam transmitted solar radiation through the tree canopy as a function of day-of-year (DOY) using WinSCANOPY software (Regent Instruments Inc., Quebec Canada).

RESULTS

There was adequate precipitation to prevent drought all three years resulting in only 6 measurement dates where there had been no precipitation for over a week. One open field and one silvopasture had a slight north facing slope and one of each had a slight south facing slope. The data from all years were pooled and an analysis of variance showed no significant difference between silvopastures and pastures (Table 1). However, there was a slight but significant difference between north and south slopes.

Table 1. Average soil moisture for periods without rainfall for over a week comparing north (S1 and O2) with south (S2 and O1) sites and silvopasture (S1 and S2) with open (O1 and O2) pasture.

Soil Moisture (% by vol.)		
North	South	(p)
25.9	23.2	.05
Silvopasture	Open Pasture	(p)
25.0	24.1	.53

The S1 paddock had a slightly smaller total tree DBH than the S2 paddock and correspondingly had a slightly greater percent open sky in the above ground field-of-view (Table 2). Measurements of PAR were not done on the same days for the two silvopasture reps. Measurement of PAR in the open from an automated weather station showed the days when S1 paddocks were measured PAR was attenuated to 64 % of maximum possible but on days when S2 were measured the attenuation by clouds resulted in 55% of maximum possible. The actual PAR received is influenced both by differences in shading and differences in weather between measurement periods. Comparing differences in forage response to shading for different regions is therefore confounded by climate differences on a long and short term basis.

Table 2. Silvopasture tree basal area, resulting percent open sky in the field of view above forages, measured PAR in an open field as a percent of theoretically possible (With Clouds), percent of actual incident PAR received by forages (Under Trees), and percent of maximum possible PAR received by forages (Actual).

Treatment	Basal Area (m ² ha ⁻¹)	Open Sky (%)	Photosynthetically Active Radiation (PAR)		
			With Clouds (%)	Under Trees (%)	Actual (%)
O1	0	100	64	100	64
O1	0	100	55	100	55
S1	14.1	22.4	64	42	27
S2	15.6	21.0	55	51	28

Measurement under the trees showed the forage on the northern slope (S1) received 42 % as much PAR as the open while the southern slope site (S2) received more, 52% of the open, even though there was slightly less open sky in the forage field of view for the southern. This difference is partially due to the existence of an open lane to the south of the southern slope while there was only forest to the south of the northern slope.

The reason PAR under trees is much higher than the percent open sky is that trees cast the most shadow early and late in the day when solar radiation levels are much lower than midday. Gaps in the canopy nearly overhead make a disproportionate contribution to the amount of PAR received since the solar intensity is highest midday (Figure 1).

The yield from the silvopastures decreased relative to the open pasture in 2005 and 2006 more than in 2004 (Table 3). Over the three years, however, forage yield in the silvopastures was 72% of open pasture yield in spite of only receiving 47% as much daily PAR. This is consistent with the finding of Feldhake and Belesky (2009) that partially shaded forages utilize PAR much more efficiently than open-pasture grown. In open fields, C₃ forages do not efficiently utilize the high solar radiation levels found on cloudless days which opens the possibility of economic gain by capturing it with a tree-based crop.

Table 3. Season yield for the silvopasture compared to open pasture treatments.

Year	Yield (t ha ⁻¹)	
	Silvopasture	Open Pasture
2004	8.5	9.9
2005	6.7	10.5
2006	6.7	10.2



Figure 1. Photograph from a sub paddock at silvopasture rep 2 (S2) using a hemispheric lens showing how overhead gaps dominate the percent open sky at a given site. This site is 21% open sky overhead.

CONCLUSIONS

Dense maturing regrowth deciduous forests thinned to obstruct 78% of open sky in the field of view allowed 47% penetration of daily incident PAR and reduced forage production only 29% compared to open pasture. However, the pasture sites with which they were compared had soils managed for forage production for about a century and the sites left in forest were considered inferior for pasture. The silvopasture soils had only been limed and fertilized for a few years. Incident PAR for C₃ forage production may not have been the only limiting resource.

Disclaimer: Mention of equipment does not imply endorsement by USDA-ARS but is supplied to inform readers of how data was acquired.

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IMPROVING TALL FESCUE SHADE TOLERANCE: IDENTIFYING CANDIDATE GENOTYPES

David M. Burner¹ and Chuck P. West²

¹ USDA-ARS, Dale Bumpers Small Farms Research Center, 6883 South State Hwy. 23,
Booneville, AR 72927.

² University of Arkansas, 1366 W. Altheimer Drive, Fayetteville, AR 72704.

Contact: David.Burner@ars.usda.gov

Abstract: Tall fescue (*Schedonorus arundinaceus*) is genetically variable for many agronomic traits, so it might be possible to increase its persistence and productivity in shaded agroforestry applications. The objective of this research was to identify high yielding, shade-tolerant genotypes. Seed was obtained from eight families: seven plant introductions of European origin: 234718, 234720, 234882, 234884, 235018, 235019, 235036, and one cultivar (Kentucky 31). Two sequential experiments were conducted to select genotypes for dry mass yield during April to September. Experiment (Exp) 1 included 30 genotypes of each of the eight families randomly assigned to each of two microenvironments: artificially shaded with fabric and unshaded. Maximum and minimum yields were 93.9 and 47.1 g family⁻¹ for Kentucky 31 and 235036, respectively. After 1 yr, the proportion of vigorous survivors in Exp 1 was greater in the unshaded than shaded environment (0.40 and 0.09, respectively), and ranged from 0 to 0.56 (235036 and Kentucky 31, respectively). Forty robust genotypes (one later died) from four families (234718, 234720, 235019, and Kentucky 31) were selected from shaded and unshaded microenvironments of Exp 1, clonally propagated, and evaluated in pots for 2 yr in Exp 2. Shade-selected Kentucky 31 yielded more (31.0 g plant⁻¹) in shade than other shade-selected families (25.2 to 25.8 g plant⁻¹). Eleven genotypes in the top quartile (yield \geq 33.0 g plant⁻¹) were selected for further testing. All genotypes were endophyte (*Neotyphodium coenophialum*)-infected. Future research will include seed increases and measuring yield in shaded, water-deficit conditions of a tree understory.

Key Words: Endophyte, *Genetic variability*, *Lolium arundinaceum*, *Schedonorus arundinaceus*

INTRODUCTION

Tall fescue is a cool-season, open pollinated grass widely used for hay, pasture, soil conservation, and turf because of its adaptability, yield, persistence, and nutritive value. It has suboptimal productivity in tree shade. Hbage should be managed to maintain at least a 10 cm residue height in silvopastoral practices (Belesky et al. 2008). In alley cropping, orchardgrass (*Dactylus glomerata*) persisted better under loblolly pine (*Pinus taeda*) shade than tall fescue (Burner 2003), and usually had greater yield.

When grown in the shade, grass species tend to have lower photosynthetic efficiency; larger specific leaf area; greater leaf light transmission coefficient; more photosynthate

partitioned to aboveground biomass; more air space in leaf lamina; thinner, wider leaf blades; decreased leaf area ratio; shifts in proportions of root cell types; and reduced foliar starch concentration compared with unshaded microenvironments (Ciavarella et al. 2006; Wahl et al. 2001; Zhai et al. 2006). Cumulative herbage N recovery and cumulative N acquisition efficiency decreased, and herbage NO_3^- -N increased, when tall fescue was grown in shaded loblolly pine alleys relative to the unshaded control (Burner and MacKown 2005; 2006). In loblolly pine alleys (Burner and Belesky 2008), irradiance was a greater constraint than soil water to herbage specific leaf weight, leaf elongation rate, tillers plant^{-1} , mass tiller $^{-1}$, mass plant^{-1} , and total nonstructural carbohydrate (TNC) concentration. Irrigation generally failed to improve herbage productivity under intense shade (Burner and Belesky 2008).

Because of its wide adaptability and generally good performance, ‘Kentucky 31’ has historically been used as a check in tall fescue forage performance trials. Plant introductions (PI) and improved selections are an important source of germplasm for tall fescue cultivar development. In Kentucky, ‘S-170’, the predominant endophyte-free cultivar in Europe, and Kentucky 31 did not differ in total sugars, but S-170 matured earlier than Kentucky 31, and had lower seed yield, herbage digestibility, and fall vigor (R. Buckner and P. Burrus unpublished data). In Europe, distinct differences in morphology and agronomic characteristics of ecogeographic races have been reported for tall fescue (Robson and Jewiss 1968a, b). Twenty-six exotic PI from Europe, Central Asia, and Mediterranean area, and three U.S. cultivars, including Kentucky 31, differed in water soluble carbohydrate (WSC) concentration of summer herbage, yield, disease, relative maturity, and winter injury (Burner et al. 1988). Since U.S. cultivars and European PI did not differ in herbage regrowth yield (51 g plant^{-1}), and both these groups yielded more than those from Central Asia and Mediterranean area, breeding strategies for temperate U.S. should focus on domestic cultivars and European introductions (Burner et al. 1988).

Shade tolerance is an important trait for tall fescue turf. Germplasm screened in the National Turfgrass Evaluation Program is rated for turf quality, a subjective visual score of aesthetics (i.e. density, uniformity, texture, smoothness, growth habit and color), and functional use. The program annually screens entries under ‘densely shaded conditions,’ but experimental details on level of shading were not reported (Morris 2008). In August 2007, 113 entries ranged from a mean of 8.0 (‘Essential’ and ‘ATM’) to 3.3 (‘GWTF’), where 1 and 9 were worst and best scores, respectively. Kentucky 31 scored 5.0, significantly different from ‘best’ and ‘worst’ entries. Our objective was to identify high yielding, shade-tolerant genotypes of tall fescue.

MATERIALS & METHODS

Seed of Kentucky 31 was purchased locally and seed of seven PI was obtained from USDA-ARS-GRIN (2006). The seven PI were bunch types of European origin: 234718 (France), 234720 (France), 234882 (Switzerland), 234884 (Switzerland), 235018 (Germany), 235019 (Germany), and 235036 (Sweden). Two sequential experiments (Exp) were conducted to measure dry mass yield during April to September. Exp 1 was

conducted to evaluate families, and Exp 2 was conducted to evaluate selections from Exp 1.

Exp 1

Sixty seeds (genotypes) per family were planted into greenhouse peat pots containing a peat moss medium in December 2005. Thirty genotypes from each of the eight families were randomly assigned to one of two field treatments: artificially shaded with fabric and unshaded, and transplanted in March 2006. The shaded microenvironment was created using black woven shade fabric of unknown manufacturer and shade intensity. The fabric was mounted horizontally about 2.5 m above ground level, and a fabric panel also was mounted vertically along the south edge of the structure. The unshaded microenvironment was immediately adjacent to the south side of the shade structure and outside the shaded microenvironment. Soil in each microenvironment was an Enders silt loam (fine, mixed, active, thermic Typic Hapludult).

There were six different genotypes per family in each of five replications. The six genotypes per family were transplanted in a row, with 15 cm between plants within rows, and 50 cm between rows. Extra plants were used as buffers between replications and at row ends. Plants were clipped to uniform 8 cm height after transplanting, and received fertilizer topdressing of 100 kg N ha⁻¹, 44 kg P ha⁻¹, and 83 kg K ha⁻¹ in April 2006. Plants in both microenvironments were irrigated as needed with an oscillating sprinkler to minimize water-deficit, but timing and flow rate were not recorded.

Plants were harvested on 15 June, 1 August, and 5 September 2006. The six genotypes from each family row were clipped by hand to 8 cm stubble height, composited, oven dried at 60°C, weighed for dry mass yield, and yield expressed as g family⁻¹. After the 15 June harvest, plants received fertilizer topdressing of 100 kg N ha⁻¹, 44 kg P ha⁻¹, and 83 kg K ha⁻¹. After the 1 August harvest, plants received fertilizer topdressing of 200 kg N ha⁻¹. Surviving genotypes were counted and rated for vigor in March 2007.

Exp 2

Based on Exp 1 yields and observations, 40 of the most robust genotypes (visual basis) were selected from the following four families: 234718 ($n = 9$), 234720 ($n = 11$), 235019 ($n = 6$), and Kentucky 31 ($n = 14$). For each family, about one-half of the selections were from the shaded microenvironment and about one-half were from the unshaded microenvironment. The genotypes were clonally propagated by placing one tiller into each of four 14.5 cm-diameter pots containing about 1.8 L of a 1:1:1 mixture of silt loam soil : sand : peat moss. Pots were placed on benches about 0.7 m above ground level in the shade structure described in Exp 1. Plants were fertilized every two weeks with a water soluble fertilizer supplying 0.4 g N, 0.2 g P, and 0.3 g K per pot. Pots were kept continually moist by drip emitters connected to a watering timer.

Plants were harvested five times in 2007 at about 6 wk intervals (4 June, 2 July, 3 August, 11 September, and 1 November) to 5 cm stubble height, and weighed for dry

mass yield (g plant⁻¹). One genotype of 235019 subsequently died in late 2007. Genotypes were clonally propagated into fresh potting medium in fall 2007, one tiller per pot. The experiment was repeated as described above, except that clones were harvested four times at about 4 wk intervals in 2008 (19 May, 24 June, 26 July, and 16 September).

Environmental monitoring

Photosynthetically active radiation (PAR), measured 1.4 m above the soil surface, was continuously recorded at 0.5 h intervals from 1 July through 31 August 2006 (Exp 1), and 1 May through 30 September 2007 and 2008 (Exp 2) to characterize the microenvironments. The PAR was measured using Model 3668 quantum light sensors (Spectrum Technologies, Inc., Plainfield, IL). In 2006, two PAR sensors were placed in each of the shaded and unshaded microenvironments, and measurements were averaged at each recording interval. One (2007) or two PAR sensors (2008) were placed only in the shaded microenvironment (400 to 700 nm). Measurements were averaged at each recording interval in 2008. Shaded PAR was compared to that of an unshaded sensor located 470 m from the experimental area. The PAR data were expressed on a daily basis. In October 2008, genotypes were tested for endophyte using the tissue-print immunoblot method (Gwinn et al. 1991).

Statistical analysis

Daily PAR and soil temperature were presented as monthly means. Yield of each family (Exp 1) and genotype (Exp 2) was averaged across harvests within years. Analyses of variance of dry mass yield was conducted using a mixed linear model, Proc Mixed (SAS Inst. 2002). For Exp 1, fixed effects were microenvironment, family, and the family x microenvironment interaction. For Exp 2, fixed effects were year, family, selection microenvironment, and their interactions. Due to heterogeneity, Exp 2 yield was log-transformed for analysis of variance. For both experiments, random effects were replication and its interactions with fixed effects. Means were separated using the Tukey HSD test at $P \leq 0.05$ using (SAS Inst. 2002). The univariate procedure (SAS Inst. 2002) was used to test normality (Shapiro-Wilk test), and to identify genotypes in the top quartile (Exp 2). Untransformed means were presented for discussion purposes.

RESULTS & DISCUSSION

Environmental monitoring

Mean daily PAR of the shaded microenvironment varied relatively little from May to September (Fig. 1). The PAR of the shaded microenvironment was 0.41 (2006), 0.40 (2007), and 0.36 (2008) of the unshaded microenvironment (calculated from data of Fig. 1), indicating that the shade fabric provided about 60% shade. Mean daily PAR indicated that the microenvironment under shade fabric was relatively uniform compared to that provided by loblolly pine tree shade (Burner and Belesky 2008). Tall fescue can be grown under intense (83 to 89%) shade of loblolly pine (Burner and Belesky 2008), so this selection environment was rather mild.

All genotypes contained the endophyte, *Neotyphodium coenophialum* (Gwinn et al. 1991). This was important because the endophyte usually confers survival and productivity advantages to tall fescue (Malinowski et al. 2005).

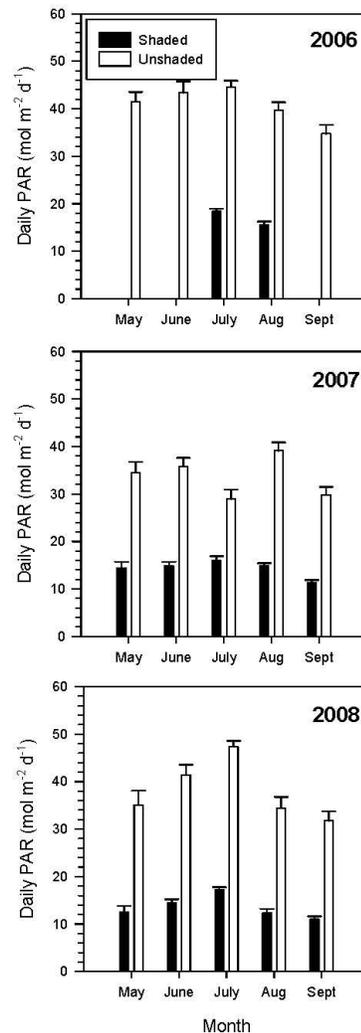


Figure 1. Mean daily photosynthetically active radiation (PAR) under the shade fabric and without shade for the May through September growth interval in 2006 to 2008. Vertical bars indicate standard error ($n = \text{number of days month}^{-1} \approx 30$).

Exp 1

Mean dry mass yield was 78.2 and 68.4 g family⁻¹ in unshaded and shaded microenvironments, respectively ($P = 0.01$). Compared to that of other studies with tall fescue (Burner and Belesky 2008; Burner and MacKown 2005), yield depression was relatively small perhaps because of the rather mild shade intensity (Fig. 1). There was a significant difference among families ($P < 0.001$), but the family x microenvironment

interaction was not significant ($P = 0.13$). Maximum and minimum yields were 93.9 and 47.1 g family⁻¹ for Kentucky 31 and 235036, respectively (Table 1).

Table 1. Mean dry mass yield of tall fescue plant introductions (PI) harvested on 15 June, 1 August, and 5 September 2006 in shaded and unshaded microenvironments (Exp 1).

PI	Dry mass yield (g family ⁻¹)
Kentucky 31	93.9 a ^a
234720	92.7 a
234718	88.3 ab
235019	73.7 a-c
235018	71.8 a-c
234882	65.4 b-d
234884	53.5 cd
235036	47.1 d

^a Means followed by a common letter do not differ by Tukey's HSD ($P > 0.05$).

Survival had a significant ($P < 0.001$) family x microenvironment interaction. Kentucky 31 had the greatest survival across microenvironments, while virtually all plants of PI 235036 died regardless of microenvironment (Table 2). Two PI (234718 and 234720) did not differ from Kentucky 31 in either microenvironment. Mean survival was about four times greater

Table 2. Mean survival of tall fescue plant introductions (PI) in shaded and unshaded microenvironments (Exp 1).

PI	Survival ^a	
	Unshaded	Shaded
Kentucky 31	0.80 a ^b	0.32 a ^b
234718	0.68 a	0.30 a
234720	0.65 a	0.08 ab
235018	0.35 b	0.00 b
234882	0.32 b	0.00 b
235019	0.32b	0.02 b
234884	0.05 c	0.02 b
235036	0.00 c	0.00 b

^a Survival = Number of vigorous survivors (2007) / number planted (2006). ^b Means within a microenvironment followed by a common letter do not differ by Tukey's HSD ($P > 0.05$).

($P < 0.001$) in the unshaded than shaded microenvironment (0.40 and 0.09, respectively), and ranged from 0 to 0.56 for 235036 and Kentucky 31, respectively (data not shown). Tall fescue exposed to combined stresses of intense shade and water stress in loblolly pine alleys had 67 to 75% survival (Burner and Belesky 2008).

Exp 2

All fixed effects except Exp 1 selection microenvironment and the year x family x selection microenvironment interaction were significant ($P \leq 0.04$) for dry mass yield. Shade yield of Kentucky 31 ($26.1 \text{ g plant}^{-1}$) was greater than that of 235019 ($17.7 \text{ g plant}^{-1}$) in 2007, but families did not differ in 2008 ($P \geq 0.89$). The family x selection microenvironment interaction was caused by a change in family ranking between selection microenvironments. Shade-selected Kentucky 31 yielded more ($31.0 \text{ g plant}^{-1}$) in shade than other shade-selected families (25.2 to $25.8 \text{ g plant}^{-1}$). However, unselected families did not differ ($P \geq 0.26$) in shaded yield (range 27.0 to $29.8 \text{ g plant}^{-1}$). Yield was nearly twice as great in 2008 ($40.1 \text{ g plant}^{-1}$) than in 2007 ($15.2 \text{ g plant}^{-1}$). It was unclear why the effect of Exp 1 selection environment was not significant. This might have been caused by an insufficient level of shade (Fig. 1).

Yield was not normally distributed ($P = 0.22$), but had peak frequencies at about 33.0 ($n = 7$) and $25.0 \text{ g plant}^{-1}$ ($n = 8$). Mean yield (Table 3) was $28.8 \text{ g plant}^{-1}$ with a range of $18.4 \text{ g plant}^{-1}$ (genotype 9, 234720) to $39.2 \text{ g plant}^{-1}$ (genotype 8, 234720). Standard deviation (SD) was 5.7 g plant^{-1} . Eleven genotypes in the top quartile (yield $\geq 33.0 \text{ g plant}^{-1}$), at or about 1 SD of the mean, were selected for further testing (two to four genotypes per family). Mean yield of all selections of 234720 and Kentucky 31 exceeded 1 SD of the mean. Selection was biased about 2:1 toward those from the unshaded microenvironment ($n = 7$) compared to those from the shaded microenvironment ($n = 4$) of Exp 1. This suggested that one year of shade evaluation in Exp 1 was ineffective for identifying shade tolerant genotypes. Mean yield was about one-half that of regrowth yield (51 g plant^{-1}) in an unshaded study (Burner et al. 1988). More testing is needed to verify yield of the selections.

In unshaded conditions, genetic variance is nearly twice that of environmental variance for tall fescue yield, indicating that yield is highly heritable (Burner et al., 1983). However, improving shade yield could be a challenge because shade responses could have a non-genetic component (Cookson and Granier 2006; Wahl et al. 2001). Despite their reproductive divergence (Beuselinck et al. 1983), European and Mediterranean tall fescue varieties can exhibit different temperature-induced growth responses in winter which are absent in other seasons (Robson and Jewiss 1968b). In a preliminary study, five well established tall fescue plants chosen at random from a meadow and highly-shaded loblolly pine alley did not differ in CO_2 exchange rate (CER) when grown in a greenhouse (DM Burner 2003 unpublished data). If low CER was reversible in this small sample, shade-induced yield differences might also be.

This study was a first step in identifying sources of shade tolerance in tall fescue populations. Further testing of these selections will be needed to measure heritability of yield in shaded, water-deficit conditions of a tree understory. We plan to collect half- or full-sib seed of these genotypes and assess progeny performance in tree alleys as part of a recurrent selection program. Vigorous, shade tolerant germplasm developed from this study could improve forage productivity in agroforestry practices.

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Table 3. Tall fescue genotypes selected from four plant introductions (PI) in Exp 1, and two-year mean dry mass yield under shade (Exp 2). Genotypes in the top quartile (mean yield ≥ 33.0 g) are highlighted. Horizontal solid line indicates mean (28.8 g plant⁻¹), and dashed lines indicate \pm one standard deviation (5.7 g plant⁻¹).

Genotype	PI ^a	Exp.1 envt. ^b	Yield ^c (g plant ⁻¹)
8	234720	U	39.2
7	234720	S	36.7
24	234720	U	36.6
36	Kentucky 31	S	36.5
1	Kentucky 31	U	36.4
31	Kentucky 31	U	35.7
17	Kentucky 31	S	35.5
22	234718	U	33.9
30	235019	U	33.7
10	234718	U	33.3
28	235019	S	33.2
37	Kentucky 31	S	32.8
2	234718	U	32.7
29	234718	U	32.3
5	234720	U	31.7
19	Kentucky 31	S	31.1
32	Kentucky 31	S	31.0
3	234718	S	30.8
26	234718	S	29.9
16	234720	S	28.1
39	234720	S	27.7
20	Kentucky 31	U	27.4
18	Kentucky 31	U	27.3
12	Kentucky 31	U	26.6
4	234720	S	25.9
34	Kentucky 31	U	25.9
35	Kentucky 31	S	25.9
38	235019	U	25.5
23	234720	U	24.7
33	234720	S	24.7
21	Kentucky 31	S	24.5
11	Kentucky 31	U	24.4
6	234718	S	23.4
15	235019	S	22.6
14	234718	S	20.4
27	234720	U	20.0
25	234718	U	19.7
13	235019	S	18.9
9	234720	S	18.4

^a USDA-ARS-GRIN (2006). ^b S and U are shaded and unshaded microenvironment, respectively. ^c Mean of harvests in 2007 ($n=5$) and 2008 ($n=4$).

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COMPETITION FOR APPLIED ¹⁵N FERTILIZER IN A LONGLEAF PINE/NATIVE WOODY ORNAMENTAL INTERCROPPING SYSTEM

Donald L. Hagan¹, Shibu Jose¹, Mack Thetford², and Kimberly Bohn³

¹School of Forest Resources & Conservation, University of Florida, Gainesville, FL USA
32611

²Department of Environmental Horticulture, University of Florida, Milton, FL, USA
32583

³School of Forest Resources & Conservation, University of Florida, Milton, FL, USA
32583

Contact: donhagan@ufl.edu

Abstract: The cultivation of ornamentals to produce woody floral products – the fresh or dried stems that are used for decorative purposes – may be an attractive option for southeastern landowners looking to generate income from small landholdings. Since many shrubs native to the understory of the longleaf pine (*Pinus palustris* Mill.) ecosystem have market potential, one possibility is the intercropping of select species in the between-row spacing of young longleaf pine plantations. The objective of this study was to evaluate how interspecific competition affects the fate of ¹⁵N fertilizer when American beautyberry (*Callicarpa americana* L.), wax myrtle (*Morella cerifera* (L.) Small) and inkberry (*Ilex glabra* (L.) A.Gray) are intercropped with longleaf pine. Nitrogen derived from fertilizer (NDF), utilization of fertilizer N (UFN) and recovery of fertilizer N (RFN_{soil}) were compared between agroforestry and monoculture (treeless) treatments to assess the effect of competition. Results varied by species, with NDF being higher for *C. americana* foliage and lower for all *M. cerifera* tissues in the agroforestry treatment. No effect was observed for *I. glabra*. UFN was lower for all species in the agroforestry treatment. RFN_{soil} was higher in the agroforestry treatment for *I. glabra*, but no treatment effects were observed for *C. americana* or *M. cerifera*. Overall, while it is clear that interspecific competition was present in the agroforestry treatment, the inefficiency of fertilizer use suggests that nitrogen was not the most limiting resource. Management interventions, particularly those that address competition for water, will likely be critical to the success of this system.

Keywords: ¹⁵N recovery, *Callicarpa americana*, competition, fertilizer use efficiency, *Ilex glabra*, *Morella cerifera*, *Pinus palustris*, woody florals

INTRODUCTION

The longleaf pine (*Pinus palustris* Mill.) ecosystem of the southeastern U.S.A. is one of the most threatened ecosystems in North America (Barnett 1999). Considerable attempts have been made in the recent past in increasing the forest cover under longleaf pine (Jose et al. 2006). For example, approximately 100,000 ha of longleaf pine plantations were established under the Conservation Reserve Program (CRP) in the Southeast during

1999-2000 (Hains et al. 2000). The diversity of groundlayer vegetation is what makes the longleaf pine ecosystem one of the most species-rich plant communities outside of the tropics (Walker and Silletti 2006). Interestingly, many of these species have potential as woody floral products – the fresh or dried stems used for decorative purposes such as wreaths and flower arrangements (Stamps et al. 1998; Venrick 2003; Josiah et al. 2004). While concerns over sustainability would likely rule out the wild harvest of stem material, the intercropping of select species in the between-row spacing of a longleaf pine plantation could be an attractive option for some landowners. Such a system would not only generate income, it would also provide an incentive to reintroduce native understory species, thereby enhancing the biodiversity of plantation forests (Hartley 2002).

By optimizing the use of resources in space and time, a well-designed intercropping system can be highly productive as well as ecologically and economically sustainable. Achieving this balance, however, is dependent upon the understanding, and subsequent management, of the interspecific interactions that affect the productivity of its component species. Of particular importance is minimizing competition, the interaction that occurs when both species simultaneously seek the same limiting resource. Competition in intercropping systems commonly occurs aboveground in the form of shading, or belowground in the form of overlapping zones of resource depletion in the rhizosphere (Schroth 1999; Jose et al. 2004).

The open canopy and high light transmittance that is characteristic of longleaf pine suggests that properly selected shrubs, when intercropped in the alleys between tree rows, would be minimally affected by shading (Battaglia et al. 2003; Hagan et al. in press). The extensive lateral root system of this species, however, creates the potential for interspecific competition belowground (Hagan et al. in press). Competition for nitrogen, typically the most limiting macronutrient in temperate cropping systems (Jose et al. 2004), could be intense under these conditions. This competition could be ameliorated or avoided, to some extent, through fertilization and by selecting species with patterns of nutrient uptake that differ, spatially or temporally, from longleaf pine. Ideally, such complementarity between root systems would create a “safety net” effect, in which the deeply rooted trees capture nutrients which leach beyond the shallow rooting zone of the shrubs (van Noordwijk et al. 1996; Allen et al. 2004b; Jose et al. 2006; Zamora et al. 2008). Increasing the fertilizer use efficiency of a system in this manner effectively reduces the amount of nitrogen that leaches down into groundwater – a common problem with ornamental production systems (Ristvey et al. 2004), which typically require higher fertilization rates than do conventional agronomic crops.

In this study, the nitrogen dynamics in a longleaf pine - native woody ornamental intercropping system were examined using ^{15}N -labeled ammonium sulfate ($(\text{NH}_4)_2\text{SO}_4$) fertilizer. Despite limited use in temperate intercropping applications, ^{15}N labeling techniques have proven to be effective means of tracing the movement of nitrogen in the tree-crop-soil system (Jose et al. 2000; Allen et al. 2004a; Allen et al. 2004b; Zamora et al. 2008). Knowledge of how fertilizer is cycled, in turn, can be used to determine what, if any, management interventions must be implemented to improve both crop yield and ecological sustainability.

The specific objective of this study was to examine how competition from longleaf pine would affect fertilizer uptake and use efficiency by three common native shrub species: American beautyberry (*Callicarpa americana* L.) (Verbenaceae), wax myrtle (*Morella cerifera* (L.) Small) (Myricaceae), and inkberry (*Ilex glabra* (L.) A.Gray) (Aquifoliaceae). We hypothesized that interspecific competition would force the shrubs to derive a greater percentage of their nitrogen from fertilizer and would leave less fertilizer remaining in the soil at the end of the growing season. Reduced fertilizer uptake or use efficiency by the shrubs (if observed) would likely be due to differences in biomass brought about by other resource limitations.

MATERIALS AND METHODS

Study Site and Experimental Design

This study was conducted on a private 15-year-old-longleaf pine plantation in Santa Rosa County, Florida, USA (30°37' N, 87°2' W). The climate of the region is classified as temperate, with mild winters and hot, humid summers. Mean annual precipitation is 1645 mm. The soil is an ultisol and classified as a Fuquay sand (loamy, kaolinitic, thermic Arenic Plinthic Kandiudult), a deep, well-drained sand over loamy marine or fluviomarine deposits.

Trees in the study site were uniformly spaced, with approximately 3 meters between rows and 1.5 meters between stems within the row. Mean diameter at breast height (DBH) at the initiation of the study (December 2005) was 8.3 cm. Mean basal area was 14 m² ha⁻¹. In December 2005, containerized native woody ornamental shrubs identified as having market potential were incorporated into the existing between-row spacing of the site, and as an equivalently spaced monoculture treatment in an adjacent open field. Selected species were American beautyberry (*Callicarpa americana*), wax myrtle (*Morella cerifera*) and inkberry (*Ilex glabra*). Shrubs were given a year for proper establishment with dead or dying shrubs being replaced in the winter of 2006, prior to the initiation of the study.

The effect of intercropping on the nitrogen dynamics of this system was assessed via comparisons with the monoculture treatment. The trial was laid out as a split-plot completely randomized design with treatment (monoculture or intercropped) as the whole plot factor and shrub species as the split-plot factor. There were four replications, each consisting of six subplots (one for each species by treatment combination) with eight shrubs each. Subplots were 2 alleys wide (or equivalent distance in the monoculture) with shrubs planted in two rows of four at a spacing of 3 meters. As a control, four subplots of the same dimensions were established in the plantation and not planted with shrubs.

Fertilizer Application and Plot Maintenance

To assess competition for nitrogen between component species, ¹⁵N ammonium sulfate ((NH₄)₂SO₄) at 5% atom enrichment was applied to two shrubs within each subplot. To

simulate the effect of a slow-release fertilizer, three applications at $146.5 \text{ kg N ha}^{-1}$ were applied at approximately 60 day intervals in a circular area of 325 cm^2 at the base of each shrub. The six remaining shrubs in each plot received non-enriched $(\text{NH}_4)_2\text{SO}_4$ at the same application rate. The first application was on 21 March 2007, shortly after bud swelling and new leaf development were first observed. Pesticide and herbicide application, along with manual weed removal, were conducted as needed throughout the growing season. Plots were non-irrigated, but supplemental water was uniformly provided to all shrubs when at least 20% showed signs of extreme drought stress. This occurred on 3 occasions during a particularly dry period from mid May to early June 2007.

Harvest and Sampling

At the end of the growing season, 90 cm soil cores were taken using a manual soil auger at the site of each plant that received labeled fertilizer. Cores were subdivided into 30 cm segments and subsamples of approximately 5g were taken. Additionally, each plant that received ^{15}N fertilizer was harvested and separated into leaf, stem, root and (when applicable) fruit components. *C. americana* was harvested in mid September, prior to leaf senescence while *I. glabra* and *M. cerifera* were harvested with the onset of cool weather (end of the growing season) in late October. Also following the growing season, pine foliar samples were harvested with a telescoping pruning saw from the four trees (two on each row) closest to the site of ^{15}N application. For this, the canopy was visually divided into upper and lower halves and samples collected from the four cardinal directions in each half (8 total samples/tree). Needles from the four trees were composited into a single sample.

All plant material was dried to constant weight at 70°C , weighed, subsampled and ground with a coffee grinder to a fine ($< 1 \text{ mm}$) particle size. The grinder was thoroughly cleaned and dried between samples to prevent cross-contamination. Soil subsamples were ground with a mortar and pestle until they reached a flour-like consistency.

All tissue and soil samples were analyzed by the Stable Isotope Facility at the University of California Davis (Davis, California, USA). Analyses were conducted using a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (Sercon Ltd., Cheshire, UK). The results of these analyses were then used to calculate percent plant nitrogen derived from fertilizer (NDF), percent utilization of fertilizer nitrogen (UFN) and percent recovery of fertilizer nitrogen in soil (RFN_{soil}).

Percent plant nitrogen derived from fertilizer (NDF), a measure of the amount of fertilizer that a plant obtains from labeled fertilizer was calculated using the following formula (Allen et al. 2004a):

$$\text{NDF (\%)} = 100 * (a-b)/(c-d),$$
 where $a = \%^{15}\text{N}$ abundance in plant tissue;
 $b =$ percent abundance in control (unlabeled) plant tissue;
 $c = \%^{15}\text{N}$ abundance of fertilizer (5%); and
 $d =$ natural abundance of ^{15}N (0.3663%).

Percent utilization of fertilizer nitrogen (UFN), a measure of fertilizer use efficiency, was calculated using the following formula (Allen et al. 2004a):

$$\text{UFN (\%)} = (\% \text{NDF} * S)/R,$$
 Where %NDF = the percentage of plant nitrogen derived from fertilizer;
 $S =$ the amount of nitrogen (g) in plant tissue; and
 $R =$ the amount of nitrogen (g) applied to each plant.

Percent recovery of fertilizer ^{15}N in soil (RFNsoil), a measure of ^{15}N fertilizer remaining in soil at the end of the growing season was determined at each depth using the following formula (Allen et al. 2004a):

$$\text{RFNsoil (\%)} = 100 * ((a-c)/(b-c)) * (Np/Nf)$$
 Where $a = \%^{15}\text{N}$ abundance in soil that received ^{15}N fertilizer;
 $b = \%^{15}\text{N}$ abundance in fertilizer (5%);
 $c =$ background ^{15}N abundance in unfertilized soil;
 $Np =$ total N of soil sample (g); and
 $Nf =$ total amount (g) of ^{15}N applied to soil as fertilizer.

Data Analysis

Data were analyzed using the PROC GLM procedure in SAS 9.1 (SAS Institute, Cary, NC, USA) within the framework for a split-plot completely randomized experimental design. Between-species comparisons were conducted for all isotopic analyses to determine which species were most effective at capturing and utilizing applied fertilizer. Logarithmic or arcsin transformations were performed when necessary to improve data normality. Tukey's HSD or Dunnett's post hoc tests were used for pairwise comparisons and differences between means were declared significant at $\alpha < 0.05$.

RESULTS

Biomass

Biomass production was significantly lower in the intercropping treatment compared to the monoculture (Table 1). Total biomass in the intercropping treatment was lower by 76.9%, ($P = 0.0030$), 53.8% ($P = 0.0200$) and 67.4% ($P = 0.0012$) for *C. americana*, *M. cerifera* and *I. glabra*, respectively. For foliage, reductions (in the above order) were 83.0% ($P = 0.0002$), 56.9% ($P = 0.0331$) and 76.0% ($P = 0.0030$). Stem biomass was reduced by 72.3% ($P = 0.0065$) for *C. americana* and 75.2% ($P = 0.0023$) for *I. glabra*. The 59.1% reduction observed for *M. cerifera* was not statistically significant. Root

biomass was 67.2% lower for *C. americana* ($P = 0.0052$) and 60.7% lower for *I. glabra* ($P = 0.0098$) in the intercropping treatment. The 43.2% reduction observed for *M. cerifera* was not statistically significant. Comparisons of fruit biomass for *C. americana* and *I. glabra* were not possible as only one individual from each species produced fruit in the intercropping treatment.

Table 1. Leaf, stem, root and total biomass for *C. americana*, *M. cerifera* and *I. glabra* in a longleaf pine-native shrub intercropping system in Florida, USA. Means and standard errors.

Species	Treatment	Biomass (g/plant)				
		Foliage	Stems	Roots	Fruits	Total
<i>C. americana</i>	Monoculture	52.9±9.0	43.2±10.8	87.8±11.6	20.0±5.1	206.3±29.8
<i>C. americana</i>	Intercropped	8.7±11.1 (0.0002) ¹	12.0±14.5 (0.0030)	28.8±15.8 (0.0052)	0.2	50.9±37.4 (0.0030)
<i>M. cerifera</i>	Monoculture	30.6±9.7	68.6±11.6	82.9±11.6		182.0±32.3
<i>M. cerifera</i>	Intercropped	13.2±8.3 (0.0331)	29.6±10.8 (0.0520)	47.0±11.7 (0.0768)		89.8±27.5 (0.0200)
<i>I. glabra</i>	Monoculture	42.0±8.3	86.0±11.6	92.1±12.6	4.2±5.6	220.6±29.8
<i>I. glabra</i>	Intercropped	9.7±8.2 (0.0030)	21.3±11.7 (0.0145)	36.2±11.6 (0.0052)	0.5	68.9±29.9 (0.0012)

¹ P -values given in parentheses.

Tissue Nitrogen Concentrations and Content

Comparisons of nitrogen concentration showed no treatment differences, for any tissue, for either *M. cerifera* or *I. glabra*. A significant treatment effect ($P = 0.0015$), however, was observed for *C. americana* roots, which had 1.01% nitrogen in the intercropping treatment compared to 2.55% in the monoculture (Figure 1).

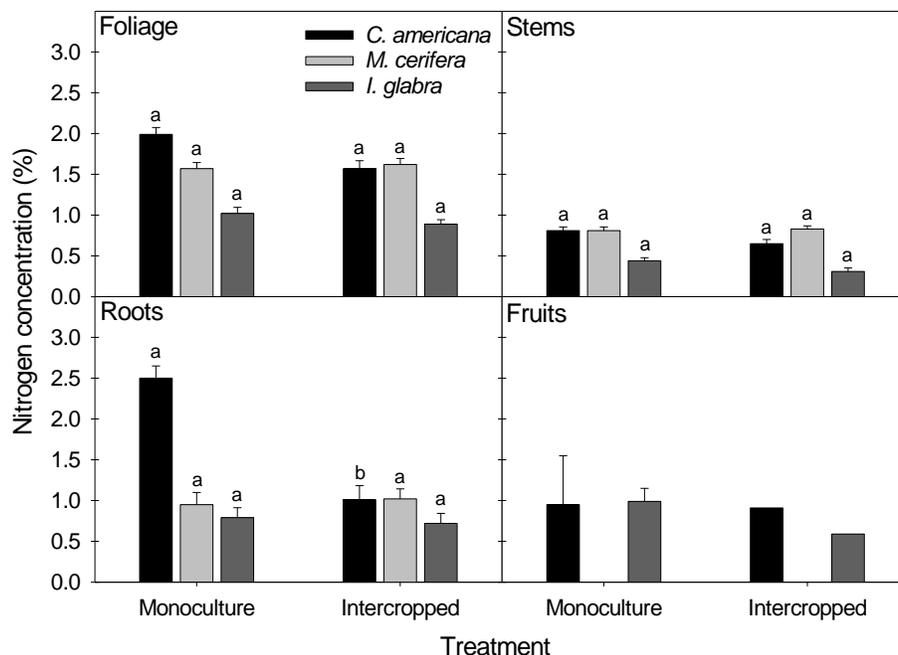


Figure 1. Mean nitrogen concentration (by tissue) for *C. americana*, *M. cerifera* and *I. glabra*. Between-treatment means (by species) with different letters are statistically different at $\alpha < 0.05$.

For *C. americana*, tissue nitrogen content was lower in the intercropping treatment for leaves ($P = 0.0049$), stems ($P = 0.0183$) and roots ($P = 0.0173$). A similar pattern was observed for *I. glabra* ($P = 0.0155$, $P = 0.0014$ and $P = 0.0318$, respectively). Nitrogen content for *M. cerifera* was lower in the intercropping treatment for leaves ($P = 0.0148$) and stems ($P = 0.0036$), but no statistically significant difference was observed for roots (Figure 2).

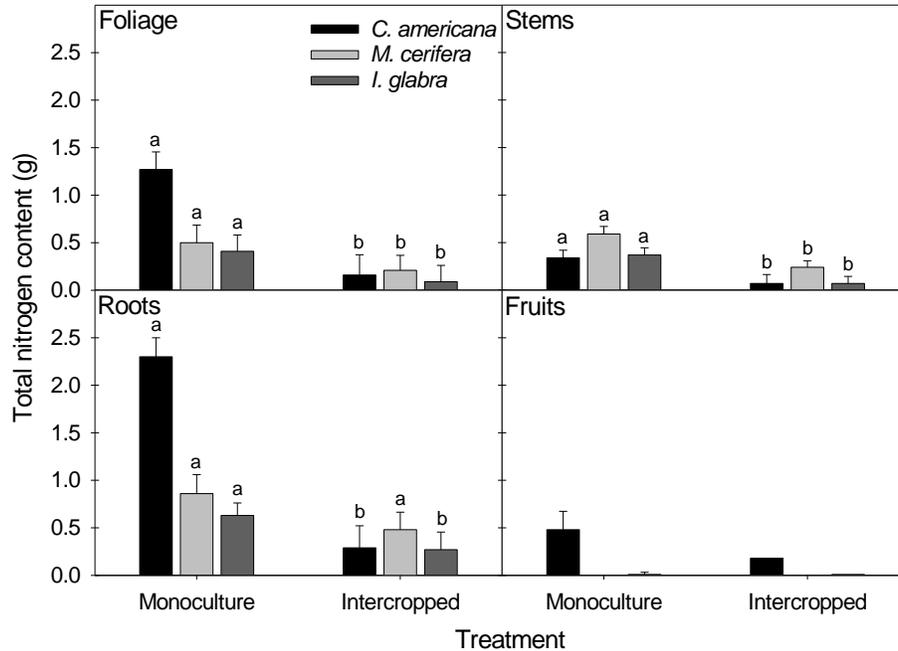


Figure 2. Total nitrogen content (by tissue) for *C. americana*, *M. cerifera* and *I. glabra*. Between-treatment means (by species) with different letters are statistically different at $\alpha < 0.05$.

Foliar nitrogen derived from fertilizer (NDF) values (by species) were 50.8% higher for *C. americana* ($P = 0.0482$) and 66.7% lower for *M. cerifera* ($P = 0.0294$) in the intercropping treatment compared to the monoculture. A similar pattern was observed for *M. cerifera* stems ($P = 0.0494$) and roots ($P = 0.0190$), which had significantly lower NDF values in the intercropping treatment (63.7% and 64.4%, respectively). No significant treatment differences were observed for *I. glabra* for any tissue. Within treatments, *M. cerifera* was the only species that was significantly different, with NDF values for all tissues being significantly lower than *C. americana* and *I. glabra* in the intercropping treatment (Figure 3).

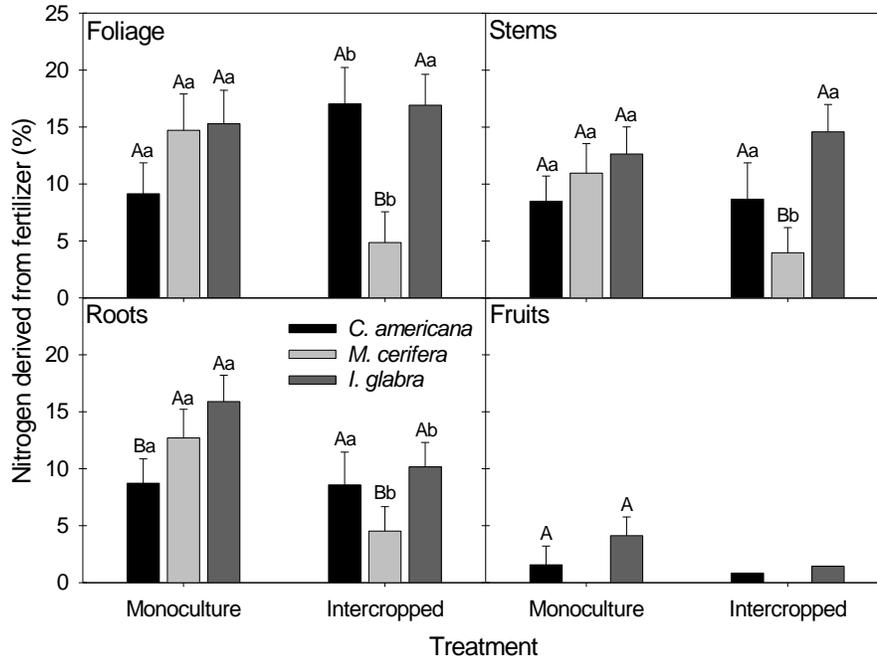


Figure 3. Percent nitrogen derived from fertilizer (NDF) (by tissue) for *C. americana*, *M. cerifera* and *I. glabra*. Within-treatment means with different uppercase letters are statistically different at $\alpha < 0.05$. Between-treatment means (by species) with different lowercase letters are statistically different at $\alpha < 0.05$.

Total utilization of fertilizer nitrogen (UFN) (all tissues combined) was significantly lower in the intercropping treatment ($P < 0.0001$), with species-wise reductions of 82.2%, 81.7% and 78.3% for *C. americana*, *M. cerifera* and *I. glabra*, respectively. Significant reductions in UFN were observed for all species, and were 77.8%, 71.4% and 83.1% for *C. americana*, 85.7%, 81.7% and 81.9% for *M. cerifera*, and 76.9%, 79.0% and 76.4% for *I. glabra*, for foliage, stems and roots, respectively. Within treatments, no significant differences in UFN were observed between species (Figure 4).

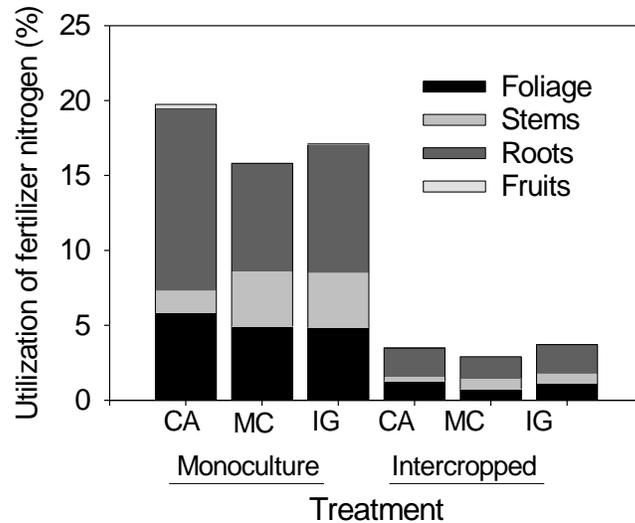


Figure 4. Percent utilization of fertilizer nitrogen (UFN) (by tissue) for *C. americana* (CA), *M. cerifera* (MC) and *I. glabra* (IG).

Recovery of Fertilizer N in Soil

RFN_{soil} varied by species ($P = 0.0007$) and depth ($P < 0.0001$) and there was an interaction between treatment and species ($P = 0.0001$). For *C. americana*, no differences between treatments were observed at any depth. For *M. cerifera*, no treatment differences were observed at 30 or 90 cm, but RFN_{soil} was higher in the intercropping treatment at the 60 cm depth. RFN_{soil} was significantly higher, at all depths, for *I. glabra* in the intercropping treatment, with differences of 61.9% at 30 cm and 79.1% at 60 cm. The magnitude of the difference at 90 cm (while significant) could not be determined, as negative RFN_{soil} values were observed in the monoculture – indicating a lower level of ¹⁵N enrichment than background soil. Between species, no significant differences in RFN_{soil} were observed, at any depth, in the intercropping treatment (Figure 5).

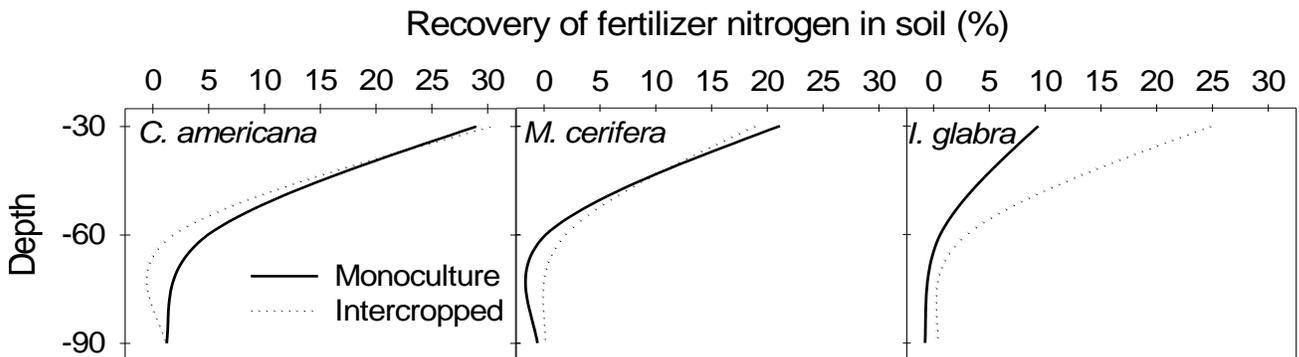


Figure 5. Recovery of fertilizer nitrogen in soil (RFNsoil) at three depths (30, 60 and 90 cm) for *C. americana*, *M. cerifera* and *I. glabra*.

In terms of total RFN_{soil} (RFN summed across the three depths) there was a significant species effect ($P = 0.0265$) and an interaction between treatment and species ($P = 0.0290$). The 33.2% RFN_{soil} observed for *C. americana*, was 41.2% higher than that observed for *I. glabra* and 37.7% higher than *M. cerifera*. *I. glabra* was the only species for which a significant treatment difference was observed, having 3.2 times more fertilizer remaining in the intercropping treatment than in the monoculture. Overall, mean RFN_{soil} in the intercropping treatment was 31.3% for *C. americana*, 20.6% for *M. cerifera* and for 29.7% *I. glabra*. Differences between species were not statistically significant.

Fertilizer N and Total N in Pine Foliage

Mean nitrogen concentration for pine foliage was 1.58%, 0.27% of which was derived from fertilizer. Extrapolating to canopy level as described by Baldwin and Saucier (1983) revealed that 20.9% of applied fertilizer N was in pine foliage at the end of the growing season. There was no effect of shrub species on nitrogen concentration or NDF in pine foliage.

DISCUSSION

Biomass production and allocation patterns observed in our study suggest that competition for resources was an important determinant of productivity for all three shrub species in the intercropping system. All species in the intercropping treatment produced less biomass and exhibited reduced carbon allocation to aboveground tissues and increased allocation to roots, a pattern which suggests that the limiting resources in this system were belowground (Chapin et al. 2002).

Reductions in biomass due to belowground interspecific competition are common in temperate intercropping systems, particularly those involving crops intercropped with large trees with shallow lateral root systems. In a pecan (*Carya illinoensis* K. Koch)-cotton (*Gossypium hirsutum* L.) alleycropping system in NW Florida, a 58% reduction in aboveground cotton biomass (compared to a root barrier treatment) was attributed to competition for nitrogen and water (Allen et al. 2004b; Wanvestraut et al. 2004). Similar effects were observed for maize (*Zea mays* L.) when intercropped with black walnut (*Juglans nigra* L.) and red oak (*Quercus rubra* L.) (Jose et al. 2000). While longleaf pine is known for its deep tap root, it too has an extensive lateral root system (Brockaway and Outcalt 1998). In a companion study conducted in the same plantation, Hagan et al. (in press) found that 81.1% of longleaf pine fine roots were in the uppermost 30 cm of soil – the same horizons exploited by the root systems of the intercropped shrubs. Interspecific competition for water was apparent in the companion study, which had the most pronounced effects on *M. cerifera* and *I. glabra* productivity.

Treatment effects on tissue nitrogen concentrations were observed only in *C. americana* roots – a fact that suggests that this species was more adversely affected by interspecific competition than the other two. Nitrogen stored in roots at the end of the growing season serves as an important reserve for spring tissue development (Chapin et al. 1990),

especially in deciduous species (Lamaze et al. 2003). Deciduous *C. americana* likely has a high early-season nitrogen requirement which, due to this decrease in storage, may have forced them to tap soil N sources, thus increasing the likelihood of competition with longleaf pine. While differences in nitrogen concentration between treatments were minimal, total nitrogen content was lower for all species, and most tissues, in the intercropping treatment. The only exception was *M. cerifera* roots, for which there was no treatment effect for either biomass or total nitrogen content. The observed treatment differences were primarily due to the reductions in total biomass.

It is generally believed (and was the basis of our hypothesis) that competition, by depleting native soil nitrogen levels, encourages intercropped plants to derive a greater proportion of their nitrogen from fertilizer sources. Substantial increases in NDF in this manner were observed in the above-mentioned intercropping systems (Jose et al. 2000; Allen et al. 2004b; Zamora et al. 2008). *C. americana*, however, was the only species in this system which supported our hypothesis, deriving 50.8% more of its foliar nitrogen from fertilizer in the intercropping treatment than in the monoculture. Since leaf development for this species was complete by May 15, it is possible that the most intense interspecific competition occurred in the weeks immediately following the first fertilizer application (March 21), thereby resulting in increased fertilizer utilization. The reasons why this pattern did not hold true for *C. americana* stems and roots, which had no treatment differences, is unknown.

The fact that no treatment differences were observed for any *I. glabra* tissue suggests that interspecific competition for nitrogen was less severe for this species. Perhaps this was the result of spatial or temporal complementarity between shrubs and trees or evidence of greater competitive ability (Schaller et al. 2003). The large *decrease* in NDF (despite no differences in N concentration) observed for all *M. cerifera* tissues in the intercropping treatment could be evidence of another trend. As a nitrogen-fixing actinorhizal shrub (Young 1992), *M. cerifera* derives a percentage of its nitrogen from the atmosphere, which at 0.3663% atom enrichment has a “dilution” effect on tissue ¹⁵N concentrations (Busse 2000; Robinson et al. 2001). Perhaps interspecific competition led this species to derive a greater percentage of its nitrogen from atmospheric sources instead of soil – resulting in reduced NDF. This is an intriguing possibility that deserves further study.

Differences in UFN for all species were likely functions of biomass differences, with plants in the intercropping treatment generally having lower values due to reduced growth, possibly caused by competition for water (Wanvestraut et al. 2004). As we hypothesized, these reductions in growth likely inhibited the shrubs’ ability to take up fertilizer thus further magnifying treatment differences for UFN (Allen et al. 2004b).

The thick E horizon characteristic of the Fuquay soil series has a very low cation exchange capacity and thus very little ability to retain applied fertilizer. Soil cores from all species/treatment combinations confirmed this, illustrating a pattern of decreasing fertilizer RFN_{soil} concentrations with depth. The combined effects of competition and spatiotemporal differences in nutrient uptake between species typically result in lower RFN_{soil} values in intercropping systems (Allen et al. 2004a; Allen et al. 2004b), which

was the foundation of our hypothesis. This pattern, however, was not observed. In this system, no treatment differences in total RFN_{soil} were observed for *C. americana* or *M. cerifera* and the opposite (lower RFN_{soil} in monoculture) was observed for *I. glabra*. It is possible that the decreased uptake (lower UFN) observed for shrubs in the intercropping treatment was offset by uptake by longleaf pine. Unfortunately this scenario, while plausible for *C. americana* and *M. cerifera*, does not adequately explain the differences observed for *I. glabra*. Perhaps this can be attributed to ecophysiological differences between species. In the aforementioned companion study, Hagan et al. (in press) found *I. glabra* to be the only species that was adversely affected, in terms of carbon assimilation, by both shading and competition for water. This combined with the period of late season growth (August – September) observed for this species in the monoculture, but not the intercropping treatment (Hagan et al. in press), may have contributed to the large disparity in total RFN_{soil} between treatments.

In the intercropping treatment, 83.9% more fertilizer ended up in pine foliage than in the shrubs themselves. This, however, is a conservative estimate of total fertilizer uptake, given the likelihood of storage in pine roots, stems and branches, which were not sampled. On one hand, fertilizer uptake by the pines represents nitrogen that was not lost to leaching, and therefore may be considered evidence of a “safety-net” effect – one of the most commonly touted benefits of intercropping (van Noordwijk et al. 1996; Allen et al. 2004a; Jose et al. 2006). However, given the shallow fine root distribution of the longleaf pines, it is likely that much of the fertilizer was obtained via interspecific competition, not by spatial complementarities between root systems. Any benefit that the trees received from this secondary fertilization, therefore, could potentially have been at the expense of shrub productivity. There was no evidence, based on RFN_{soil} data, of significant fertilizer uptake by trees in the deeper soil depths, although it is possible that some uptake occurred at depths greater than 90 cm.

It is clear that the effective management of belowground processes is essential for the viability of a longleaf pine/native woody ornamental intercropping system. Ideally this could be done in a manner that minimizes the deleterious effects of competition while retaining, to the greatest extent possible, the environmental benefits of intercropping. Of particular importance is the need to improve our understanding of how the nutrient requirements of selected species differ in space and time. This knowledge would not only aid in species selection, but also with nutrient management, as fertilizer applications could be better synchronized with demand, thus decreasing competition, increasing fertilizer use efficiency and decreasing loss. In this system, for example, only 24.3% of applied fertilizer could be accounted for in at the end of the growing season (3.4% in shrubs, 20.9% in trees). The remaining 75.7% either remained in soil or was lost, most likely due to leaching. It deserves reiteration, however, that the most commonly reported signs of competition for nitrogen (increased NDF and reduced RFN_{soil}) were, for the most part, not observed. This, combined with the low utilization of fertilizer nitrogen suggests that nitrogen was likely not the main determinant of productivity in this system. Future research should seek to further elucidate the effect of interspecific competition for water and other belowground resources on shrub growth.

CONCLUSIONS

Results indicate that competition with longleaf pine had a deleterious effect on the growth and productivity of three common understory shrub species, with biomass allocation patterns suggesting that the strongest competitive vectors were belowground. Increased NDF, which would suggest competition for nitrogen, was observed only in *C. americana*. Perhaps the fact that this species had a lower nitrogen concentration in roots in the intercropping treatment forced it to take up more fertilizer during leaf development rather than relying on stored reserves. No treatment effect for NDF was observed for *I. glabra*. Interestingly, NDF for all *M. cerifera* was lower in the intercropping treatment. This suggests, since nitrogen concentrations were not different between treatments, that this species obtained its nitrogen from another source – possibly biological nitrogen fixation. NDF for *M. cerifera* in the intercropping treatment was significantly lower than the other two species. UFN was higher for all species in the monoculture, reflecting the differences in biomass and indicating greater fertilizer use efficiency in the absence of competition. RFN_{soil} decreased with increasing depth, with little to no treatment differences observed for *C. americana* and *M. cerifera*, and significantly greater recovery, at all depths, for *I. glabra* in the intercropping treatment. Fertilizer uptake for pines, as a percentage of fertilizer applied, was estimated at 20.9%. Overall, while it is clear that interspecific competition was present in the intercropping system, the inefficiency of fertilizer use suggests that nitrogen was not the most limiting resource. Management interventions, particularly those that address competition for water, are likely critical to the success of this system.

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PHYSIOLOGICAL RESPONSES OF LEAVES OF *PANAX GINSENG* GROWN IN FOREST AND FIELD

Seong-Ryeol Jeon¹, Sang-Sup Han², and Jae-Seon Yi²

¹Department of Forestry, Graduate School, ² College of Forest and Environmental Sciences, Kangwon National University, Chuncheon, Republic of Korea 200-701

Contact: jasonyi@kangwon.ac.kr

Abstract: Forest grown ginseng (FGG) is recommended as one of the non-timber forest products in Korea. It catches public attention more and more, because field cultivated ginseng (FCG) has a lot of problems, including residual agricultural chemicals, while FGG is grown without such chemicals and some fertilizers. This is an investigation to find a suitable forest floor conditions in terms of light and temperature for cultivation of ginseng in the forest area by comparing physiological responses of FGG leaves with those of FCG. Ten ginseng plants were selected from a four-year-old plantation. FGG were grown in the *Quercus-Larix* mixed forest and FCG were cultivated under artificial shading with agricultural chemicals and fertilizers. Photosynthesis, stomatal transpiration rate and stomatal conductance were investigated and analyzed. The results were as follows:

- 1) The light compensation point for FGG and for FCG was $15.2 \mu\text{mol}^{-2}\text{s}^{-1}$ and $29.3 \mu\text{mol}^{-2}\text{s}^{-1}$; the light saturation point was $400 \mu\text{mol}^{-2}\text{s}^{-1}$ and $600 \mu\text{mol}^{-2}\text{s}^{-1}$; and the maximum net photosynthetic rate was $3.7 \mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$ and $5.4 \mu\text{molCO}_2\text{m}^{-2}\text{s}^{-1}$ under 25°C and $1,200 \mu\text{molm}^{-2}\text{s}^{-1}$, respectively.
- 2) The maximum net photosynthetic rate of FGG leaves appeared at 20°C to 25°C , while FCG leaves appeared at 30°C and rapidly decreased above 30°C .
- 3) The range of stomatal transpiration rate was 0.4 to $0.9 \text{ mmol H}_2\text{Om}^{-2}\text{s}^{-1}$ for FGG and 0.1 to $0.7 \text{ mmol H}_2\text{Om}^{-2}\text{s}^{-1}$ for FCG, respectively.
- 4) The range of stomatal conductance was 10 to $30 \text{ mmol H}_2\text{Om}^{-2}\text{s}^{-1}$ for FGG and 0 to $20 \text{ mmol H}_2\text{Om}^{-2}\text{s}^{-1}$ for FCG.
- 5) These research results suggest that *Panax ginseng* should be grown in a cool and shady forest area of which the temperature ranges around 25°C in average and below 30°C at maximum during the daytime.

Key Words: forest grown ginseng, field cultivated ginseng, non-timber forest products, photosynthesis, stomatal transpiration rate, stomatal conductance, cool and shady forest

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**PRELIMINARY DATA ON CHESTNUT PLANT VOLATILES AS
ATTRACTANTS FOR THE LESSER CHESTNUT WEEVIL,
CURCULIO SAYI (COLEOPTERA: CURCULIONIDAE)**

I.W. Keeseey, B.A. Barrett, and C.H. Lin

1-39 Agriculture Bldg, Columbia, MO, 65211

Contact: iwkf77@mizzou.edu

Abstract: Chestnut plant tissues from the leaf, catkin, bur and nut were presented to *Curculio sayi* in a Y-tube olfactometer bioassay to determine relative attractiveness of these tissues to the insect. Both male and female *C. sayi* were significantly attracted to catkins, burs and nuts. The volatile compounds associated with these three attractive tissues were identified using solid phase microextraction (SPME) and GC-MS.

CONTROLLING SWINE ODOR WITH WINDBREAKS

Chung-Ho Lin¹, Dusty D. Walter¹, Harold E. Garrett¹ and Robert N. Lerch²

¹Center for Agroforestry, University of Missouri, Columbia, MO 65211

² U.S. Department of Agriculture-Agricultural Research Service, Cropping Systems and Water Quality Research Unit, Columbia, Missouri 65211

Contact: walterw@missouri.edu

Abstract: Emissions of malodor from swine facilities are an increasing environmental concern for the swine producers and nearby local communities. Use of natural windbreaks for odor abatement is recent and the science in support of using windbreaks for this purpose is limited. To provide sound science to the study of windbreaks and odor control, the University of Missouri Center for Agroforestry initiated a study in 2007 to evaluate the effects of windbreaks on transport of odors. A 3-row windbreak configuration was implemented consisting of pitch-loblolly pine (*Pinus rigida* × *P. taeda*), a conifer, on the inside row closest to the farrowing house; red maple (*Acer rubrum*) alternating with pin oak (*Quercus palustris*) a deciduous hardwood species that retains many of its leaves throughout much of the winter, as the middle row and; Viburnum ‘Allegheny’ (*Viburnum rhytidophyllum* × *V. lantana*), a semi-evergreen shrub that quickly reaches heights of 10 to 15 feet, as the outside row. Before the windbreak takes effect, air samples are being taken at varying distances from the facility (up to a mile radius) to monitor the baseline background concentrations of odorous gasses including ammonia (NH₃), hydrogen sulfide (H₂S), major volatile organic compounds (VOCs) and particulates. The spatial distribution and temporal variation in concentrations of these malodorous compounds have been characterized and mapped. This baseline information will be used for evaluating the impact of the windbreak on odor concentrations and movement over time.

INTRODUCTION

Use of windbreaks for odor abatement is recent and the science in support of using windbreaks for this purpose is still being developed. Reports on the use of windbreak technologies adjacent to poultry house ventilatyon fans strongly suggest that significant quantities of compounds known to correlate highly with odor can be removed from the air (e.g., ammonia 46%; dust emissions 49%). However, the overall effect on reducing odor, based upon the literature, appears to be low (6%) (Malone et al., 2006). Variability in windbreak effectiveness is known to be related to its physical location, species composition, density, and geometric configuration. Additional studies have shown windbreaks to have an impact on odor plume dispersal (Lin et al., 2006).

The purpose of this project was to develop a windbreak design that has the highest probability for maximizing odor abatement by effectively using the limited science available in the literature and, Center for Agroforestry knowledge of windbreak technology for crop protection.

MATERIAL AND METHODS

In late October, 2007 after visiting and evaluating many sites, the principal investigator visited and came to an agreement with Newport Farms, LLC to conduct the odor abatement research on one of their farms. The facility chosen is located approximately 7 miles west of Novelty, MO on highway 156 on the Macon and Knox County line but in Macon County. The facility is now just over two-years-old and has minimal grade changes that resulted from construction. The “foot-print” (approximately 18 acres) is considerably larger than required, but other than this, the facility is ideal for the project. There are 5 buildings (see aerial view, Figure 1) ranging from 100 to 900 feet in length. The owners of the actual facility and land are Gary Chinn and Bill Roewe (Newport Farm, LLC). Management of the facility, however, is under the authority of Professional Swine Management, LLC, Carthage, IL.

A 3-row windbreak configuration was implemented consisting of a pitch/loblolly pine hybrid (*Pinus rigida* x *P. taeda*), a conifer, on the inside row closest to the farrowing house; pin oak (*Quercus palustris*), a deciduous hardwood species that retains many of its leaves throughout much of the winter alternated with red maple (*Acer rubrum*), as the middle row and, *Viburnum* ‘Allegheny’ (*Viburnum rhytidophyllum* X *V. lantana*), a semi-evergreen shrub that quickly reaches heights of 10 to 15 feet, as the outside row. Effectiveness of a windbreak is strongly correlated with height and density. Therefore, the largest plants available were used in establishing the windbreak. Since sufficiently large containerized pine, oak and maple were unavailable, the principal investigator located six to nine-foot trees (balled and burlapped - - see Figure 2). RPM (Root Production Method) ‘Allegheny’ viburnum were purchased and planted due to the fast growth of RPM containerized plants.

The inside pine row was positioned a minimum of 60 feet from the building. The row of pin oak/red maple was located 20 feet from the pine and the viburnum 20 feet to the outside of the pin oak/maple. Spacing between trees within a row was 15 feet, while shrubs (viburnum) were spaced at 8-foot intervals. With these species and spacing, a density of approximately 60% (40% optical porosity) will be maintained through proper pruning (i.e., 60% of wind striking the “break” will pass up and over; 40% will be allowed to pass through). In summarizing many studies, Tyndall and Colletti (2007) have suggested that windbreaks with an optical porosity of 40-50% are most effective at limiting dust and odor movement.

The 3-row configuration was placed parallel to and along all four sides of the farrowing house complex. Where necessary, a trip row (a row of pine and shrubs placed on the windward side to “trip” snow before it reaches the main windbreak), was positioned to avoid potential snow build-up problems. To maximize the growth response and create a state-of-the-art design, an automated drip irrigation system was installed.

Even though all trees were staked and tied to support them against wind and ice damage, a severe ice storm was experienced and a great deal of tree damage occurred during the winter of 2007-2008. Moreover, due to the unusually superficial root system of the pine

(in retrospect believed to be the result of the soil characteristics on the site where they were grown), pine mortality during the winter months was high and it was decided that all pine would be replaced. Replacement occurred November 2008 using RPM-grown, pitch/loblolly pine.

The measurements of emitted ammonia (NH₃) from swine facilities were made by a continuous flow NH₃ analyzer (Pranalytica Nitrolux 200). The concentrations of hydrogen sulfide (H₂S) were measured with a Jerome® 631-X Hydrogen Sulfide Analyzer (Arizona Instrument). Other major odorous volatile organic compounds (VOCs) emitted from the swine production facilities were sampled by passing 4 L of air through the conditioned thermal desorption tubes containing many layers of sorbent material (Anasorb CMS and Tenax GR, SKC Inc.). Analytes captured on the adsorbent tubes was desorbed from the sorbent at 300°C and analyzed by gas chromatography and mass spectrometry (GC-MS, Varian 3400x). Ventilation rates, air flow, and wind velocity were recorded during the sampling period to calculate the emission rates and flux of these odorous compounds. A Fluke 983 Particle Counter was acquired to determine both the concentration of particles (particles/m³) and the size distribution of the particulates (0.3 μM to 10 μm) under field conditions.

RESULTS AND DISCUSSION

Air sampling was performed in 2008 to monitor the effects of the windbreak on odor abatement. Sampling consisted of 4 to 6 visits each season (spring, summer, fall and winter), with samples collected at (1) a location just outside the exhaust fans, (2) between the exhaust fans and the inside row of the windbreak and, (3) at intervals of distances downwind from the windbreak (see Figure 3). Distances will vary based upon topography, presence of native forest stands, etc. Since it was impossible to find two matching sites to compare, it is necessary that comparisons in levels of odor-causing compounds be made between years, beginning with the year of establishment (i.e., 2008). This provides a quantitative assessment of changes occurring with the growth of the trees and developmental dynamics of the windbreak. We envision monitoring the site for a minimum of five years. To guarantee access to the site for this period of time, a formal agreement has been made between the University of Missouri and Professional Swine Management, LLC.

Table 1 identifies the concentration of NH₃ and H₂S expressed in parts per billion (ppb) measured on 9/19/2008 (15 sampling points plus 4 exhaust fan readings). All data collected to date is obviously preliminary in nature but is important in that it will be used to establish baselines to which future data sets will be compared. Without a baseline (i.e., concentrations without a significant effect from a windbreak), it would be impossible to establish an odor abatement effect as the windbreak grows and develops.

While it is clear from the literature that wind velocity and direction have significant effects on odor concentrations, no discernable trends are visible in our limited data set. However, it is obvious that at wind speeds of less than 10 miles per hour (we had winds

of 5.3 and 8 mph) concentrations of NH₃ and H₂S are significantly reduced over a distance of only 0.5 miles at this site (Figure 3, Table 1).

In addition to NH₃ and H₂S, it was our goal to identify and quantify more than 20 odorous volatile organic compounds (VOC's) believed to be present in emissions from swine production facilities. The identification and quantification of the VOC's (accomplished using Thermal Desorption GC-MS) is underway (Figure 4). However, to achieve our goal, we must first create a tentative identification of each compound by comparing their mass spectra and retention times (Figure 4). To secure a positive (100%) identification of each compound we must purchase "commercial standards" of each VOC that we tentatively identify using GC-MS and compare them to the standard. Based upon the detections and quantifications shown in Figure 4, it appears as though we will monitor more than 20 VOC's during this study. Moreover, based upon our findings in Figure 5, it appears that most of the VOC's drop out or, are significantly reduced in concentration, over very short distances. The concentration levels shown in red (i.e., highest concentrations) were measured at the exhaust fan. Concentrations shown in blue (Figure 5) were measured approximately 100 feet away just inside the wind break.

CONCLUSIONS

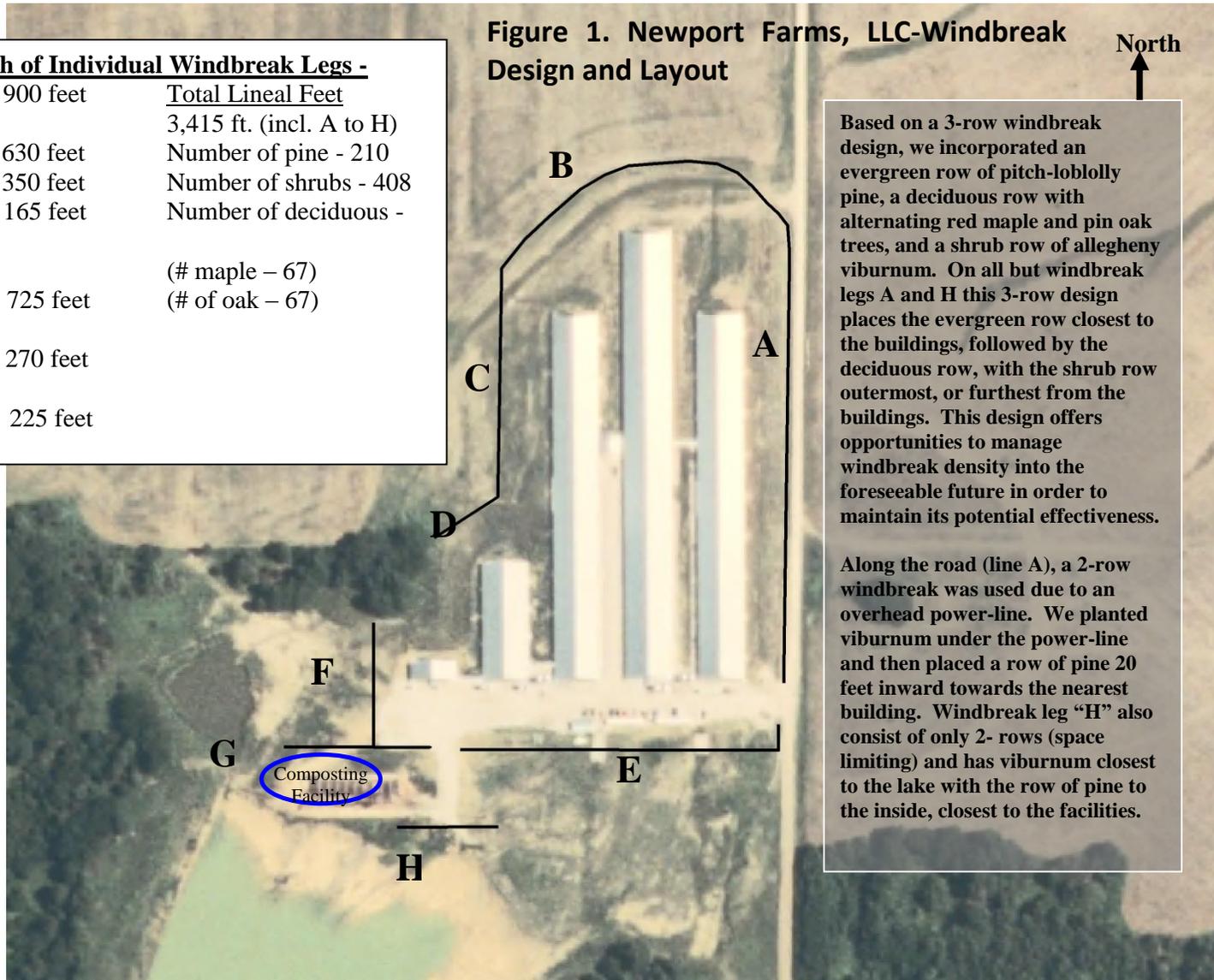
Before the windbreak takes effect, air samples are being taken at varying distances from facility (up to a mile radius) with our developed analytical methods to monitor the baseline concentrations of odorous gasses including ammonia (NH₃), hydrogen sulfide (H₂S), major volatile organic compounds (VOCs) and particulates. The spatial distribution and temporal variation in concentrations of these malodorous compounds have been successfully characterized and mapped. This baseline monitoring information will be used for evaluating the effect of the windbreak on odor concentrations and movement over time.

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<u>Length of Individual Windbreak Legs -</u>	
A -- 900 feet	<u>Total Lineal Feet</u> 3,415 ft. (incl. A to H)
B -- 630 feet	Number of pine - 210
C -- 350 feet	Number of shrubs - 408
D -- 165 feet	Number of deciduous - 134
E -- 725 feet	(# maple - 67)
F -- 270 feet	(# of oak - 67)
G -- 225 feet	

Figure 1. Newport Farms, LLC-Windbreak Design and Layout



Based on a 3-row windbreak design, we incorporated an evergreen row of pitch-loblolly pine, a deciduous row with alternating red maple and pin oak trees, and a shrub row of allegheny viburnum. On all but windbreak legs A and H this 3-row design places the evergreen row closest to the buildings, followed by the deciduous row, with the shrub row outermost, or furthest from the buildings. This design offers opportunities to manage windbreak density into the foreseeable future in order to maintain its potential effectiveness.

Along the road (line A), a 2-row windbreak was used due to an overhead power-line. We planted viburnum under the power-line and then placed a row of pine 20 feet inward towards the nearest building. Windbreak leg "H" also consist of only 2- rows (space limiting) and has viburnum closest to the lake with the row of pine to the inside, closest to the facilities.

Figure 2. Attached Photos of the Newport Farms LLC Windbreak Project following tree establishment (4-Images)



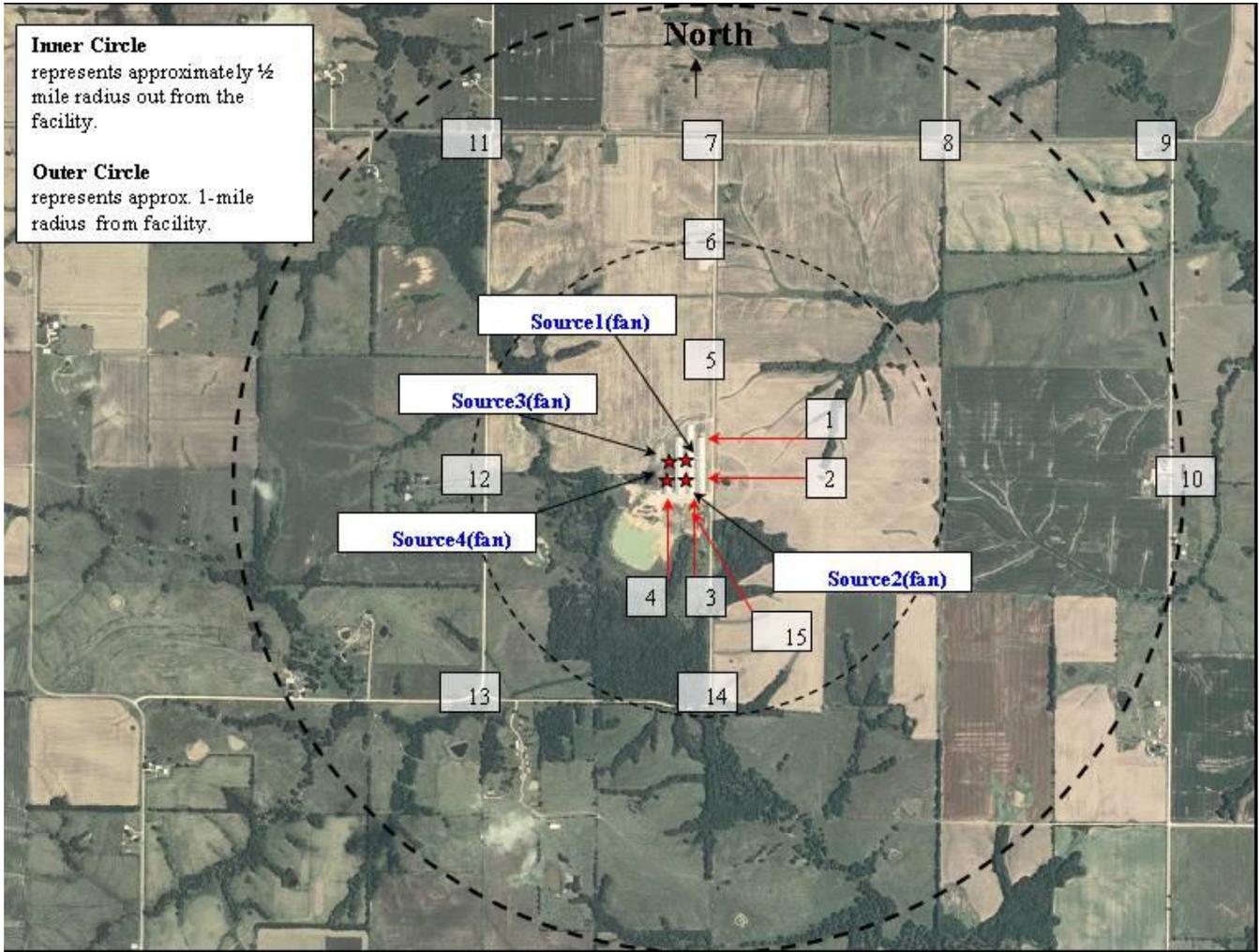


Figure 3. Identification of locations at which air samples were taken for determining NH₃ and H₂S concentrations.

Table 1 - - Ammonia (NH₃) and hydrogen sulfide concentrations (H₂S), in parts per billion (ppb) and their standard deviations (SD) at various distances from a swine CAFO located in northeast Missouri. Data was collected 9/19/2008, wind speed was 5.3 mph with wind direction from the south.

Sampling Point	NH₃(ppb)	SD (n=5)	H₂S(ppb)	SD (n=5)
1	136.20	16.00	0.20	0.03
2	363.00	45.21	115.00	7.07
3	75.94	13.16	0.12	0.01
4	33.28	4.60	0.03	0.01
5	24.38	1.30	0.07	0.02
6	15.46	0.61	0.01	0.01
7	8.85	0.17	0.02	0.01
8	22.58	1.09	0.02	0.00
9	14.12	0.59	0.02	0.01
10	15.13	0.42	0.02	0.00
11	5.26	0.57	0.02	0.01
12	4.49	0.18	0.02	0.01
13	6.02	0.09	0.01	0.01
14	9.44	0.50	0.01	0.01
15	20.48	1.77	0.02	0.00
Source1(Fan)	750.00	0.00	36.33	13.65
Source2(Fan)	1000.00	0.00	123.33	15.28
Source3(Fan)	3500.00	0.00	123.33	15.28
Source4(Fan)	500.00	0.00	35.33	3.21

Figure 4. Detection and quantification of swine, CAFO odorous volatile organic compounds (VOC) with Thermal Desorption GC-MS. Samples were collected near ventilation fan (Source Fan #3 - - Figure3) on 9/19/2008. Our current efforts are focused on validation and quantification of VOCs by comparing their mass spectra and retention times with commercial standards and NIST National Mass Spectral Library.

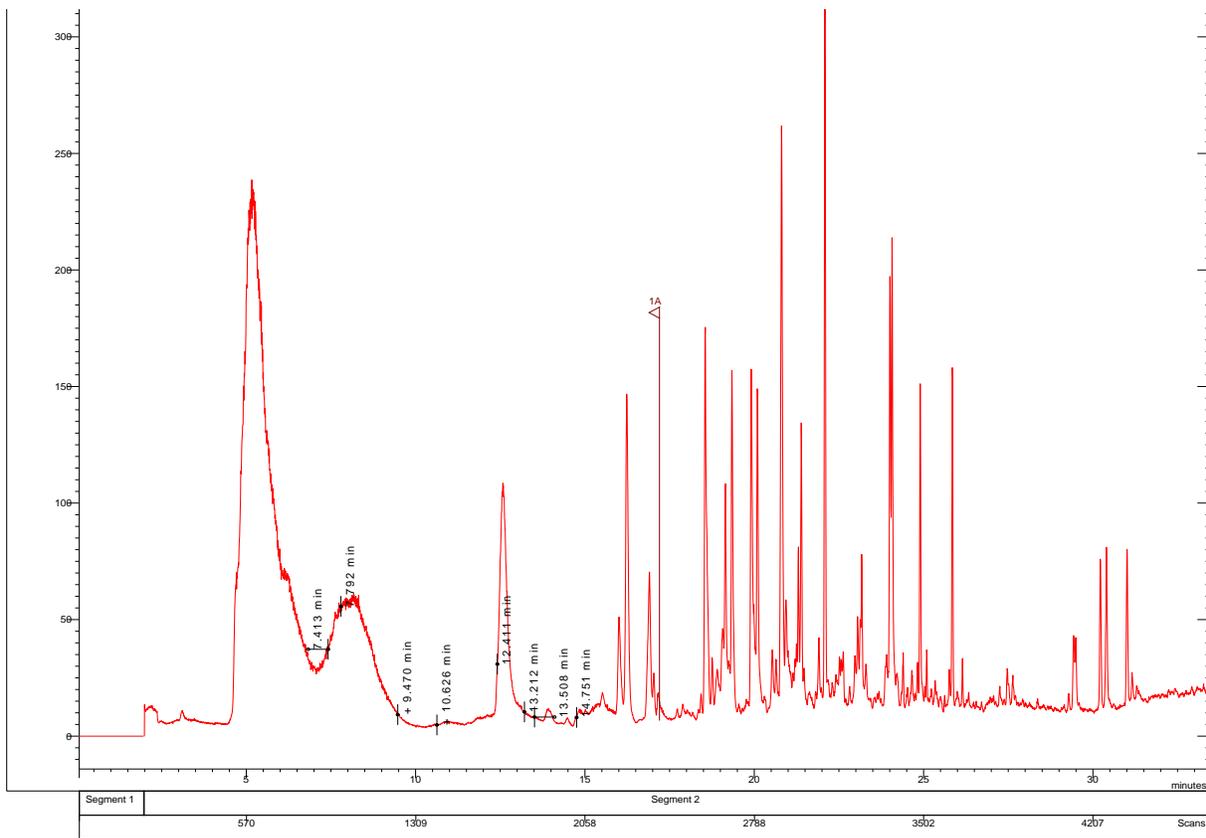
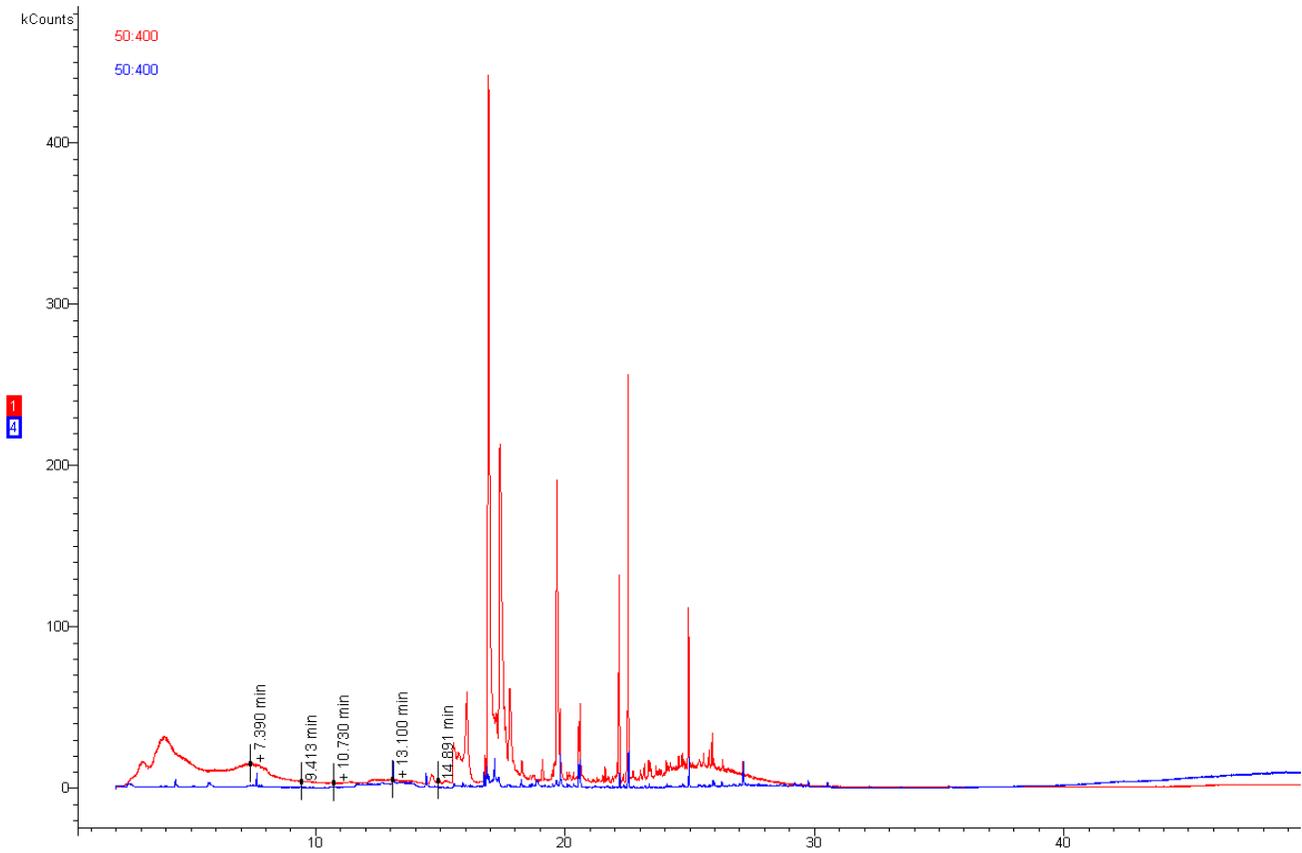


Figure 5. Detection and quantification of swine, CAFO odorous volatile organic compounds (VOC) with Thermal Desorption GC-MS. Readings represent concentrations of VOC's taken at an exhaust fan (shown in red) and at a distance of approximately 100 feet away (shown in blue) from the exhaust fan on 8-5-08.



RHIZODEGRADATION OF SULFAMETHAZINE AND TETRACYCLINE AND THE ASSOCIATED IMPACTS ON SOIL MICROBIAL ACTIVITIES

C.H. Lin¹, K.W. Goyne², R.J. Kremer³, R.N. Lerch³ and H.E. Garrett¹

¹Center for Agroforestry, University of Missouri

²Department of Soil, Environmental and Atmospheric Sciences, University of Missouri

³USDA-ARS, Cropping Systems and Water Quality Research Unit

Contact: Linchu@missouri.edu

Abstract: The use of sulfamethazine (SLF) and tetracycline (TC) to maintain animal health in swine, poultry or cattle feedlot operations results in significant application of these veterinary pharmaceuticals to the landscape during grazing or manure disposal operations. Drinking water sources contaminated by these veterinary antibiotics have raised public health concern in the US. Recent studies have demonstrated the benefits of using multi-species vegetated buffers to reduce the transport of the veterinary antibiotics. However, the fates of these antibiotics in vegetative buffers and their impact on the rhizosphere microbial activities have not been well documented. A growth chamber study was conducted to investigate the rhizodegradation of ³H-sulfamethazine and ³H-tetracycline and the relationship of degradation with soil enzyme activities in the rhizosphere of five selected plant species. The plant species included: 1) switchgrass, 2) eastern gammagrass, 3) orchardgrass, and 4) hybrid poplar. All plant treatments were grown in pots containing Mexico silt loam. Pots containing soil without plants were used as controls. Plants were grown to maturity (~3 months), and the rhizosphere soils were collected. Radio-labelled SLF or TC was then applied to the rhizosphere soils and incubated in the dark for five weeks. Among the plant species, hybrid poplar showed the highest capability for promoting degradation of SLF in the rhizosphere. The significantly higher SLF degradation rates in poplar rhizosphere may have been associated with its high enzymatic activities. When comparing the soil enzymatic activities between the antibiotic treatments, fluorescein diacetate hydrolytic and glucosaminidase enzyme activities were significantly lower in TC treated soils than in SF treated soils. The α -glucosidase activities were similar between the two antibiotics treatments. The hybrid poplar showing high rhizodegradation potential could be incorporated into buffer designs to mitigate the impacts of these two antibiotics in the environment.

INTRODUCTION

Antibiotics are widely used as animal feed supplements to promote the growth of food-producing animals and for therapeutic purposes. A significant proportion of the antibiotics consumed by livestock are excreted in urine or feces. One study demonstrated that up to 80% of an antibiotic dose may pass through the animal gastrointestinal tract and reside within manure (Thiele-Bruhn, 2003). It is generally agreed that widespread use of antibiotics has a high probability of causing environmental harm (Aga, 2008; Jørgensen and Halling-Sørensen, 2000).

Recently, the United States Geological Survey (USGS) reported the presence of several antibiotics in 139 streams across 30 states in the United States (Kolpin, 2002), and others have demonstrated the potential for antibiotics to exit agricultural fields during surface runoff events

(Burkhardt et al., 2005). Land application of manure and co-application of veterinary antibiotics is believed to be a primary source for antibiotic introduction into the environment and the development of antibiotic resistant bacteria (Jørgensen and Halling-Sørensen, 2000).

A well-designed vegetative buffer strip (VBS) is a cost-effective method to mitigate the loss of non-point source pollutants from crop land (Schultz et al., 2000). Mechanisms of pollutant removal within vegetative buffers include physical, chemical and biological processes. The ability of VBS to enhance water infiltration appears to be the initial mechanism by which VBS mitigate the transport of moderately sorbed organic pollutants (Krutz et al., 2004). Organic pollutants can also be intercepted by the roots and residue of the vegetation via sorption processes (Hoffman et al., 1995). Microorganisms growing in the root zone may metabolize organic pollutants through various biochemical mechanisms and oxidize them to CO₂(g) or other less harmful compounds (Mandelbaum et al., 1993). Perennial vegetation may improve soil characteristics (e.g., increased OM content and improved porosity) and enhance sorption and abiotic pollutant transformation in the rhizosphere (Mandelbaum et al., 1993).

Previous studies showed that plant take up less than 2% of antibiotics applied to the soil (Dolliver et al., 2007; Kumar et al., 2005). Therefore, rhizosphere enhanced biodegradation will be the predominant mitigation mechanism for removing antibiotics in the VBS systems. Rhizosphere enhanced biodegradation of organic pollutants has been reported frequently to enhance the degradation of specific contaminants. The objectives of this study are to (1) study the fates of two classes of antibiotics, tetracycline (TC) and sulfamethazine (SLF) in the rhizospheres of different plant species, and (2) screen for the plant species showing potential to enhance the rhizodegradation of these two classes of antibiotics. The identified species can be incorporated into the vegetative buffer design in the future to mitigate the contamination of antibiotics.

MATERIAL AND METHODS

Experimental Design

The experiment was conducted in an environmental-controlled growth chamber (Environmental Growth Chambers GC72 walk-in unit, Chagrin Falls, Ohio) with triplicate replications of four plant species: 1) switchgrass (*Panicum virgatum* L., **SW**); 2) eastern gamagrass (*Tripsacum dactyloides*; **EG**); orchardgrass (*Dactylis glomerata* L. **OR**); and 4) hybrid poplar (*Populus deltoids* X *Populus nigra*, clones 80X01038; **POP**). A control treatment with no plants (**CON**) was also included. Environmental conditions were as follows: light intensity of 1400 microEinsteins•m⁻²•sec⁻¹; light/dark period of 15/9 hours; humidity of 50%; and temperature at 25°C (light)/20°C (dark). Plants were allowed to grow to maturity (~3 months) in a mixture of 60% sand and 40% Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiaqualfs) collected from the A horizon of the soil profile. After three months of plant growth, the rhizosphere soil was separated from the plants, and a mixture of 3.5 μCi ³H- tetracycline or ³H-sulfamethazine (Figure 1, tetracycline [7-³H] 11Ci/mmol ; sulfamethazine [3,5-³H], Moravek Biochemicals Brea, CA) with addition of non-labeled antibiotics were then added to the 20 grams of soils to achieve concentration of 1000 μg/kg. An addition set of rhizosphere soils received the same concentration of non-radio labeled antibiotics was prepared for determination of the

β -glucosidase (GLU), glucosaminidase (GLA) and fluorescein diacetate hydrolytic (FDA) enzyme activities. The antibiotic treated soil was then incubated for 5 weeks at 25 °C in the dark. Soils were sampled periodically throughout the incubation period.

(A)

(B)

Figure 1. tetracycline (A) and sulfamethazine (B).

Chemical analysis

The ^3H -antibiotics and their degradation products were sequentially extracted with 250 mL of 90% ACN followed by 1 hour of sonication. Twenty-five μL of 100ppm terbutylazine [N-(1,1-dimethylethyl)-N'-ethyl-6-chloro-s-triazine-2,4-diamine] was added to each sample as an internal standard. The final extracts were concentrated to 500 μL and 5 μL of the extract was injected into a Shimadzu SCL-10Avp high performance liquid chromatography system (HPLC) (Columbia, MD). The ^3H -antibiotics and their degradation products were separated using a silica based Columbus C₈ column (4.6 mm x 250 mm, 5 μm ; Phenomenex, Torrance, CA). The radioactivity was detected by an in-line IN/US ScinFlow β -Ram Model 3 (Tampa, FL) flow scintillation analyzer (HPLC-FSA). The ^3H -antibiotics and their metabolites were eluted with a two-part mobile phase gradient mobile phase at a flow rate of 1 mL min⁻¹. Mobile phase A consisted of 0.1% H₃PO₄ buffer (pH =2.1), and mobile phase B was 100% ACN. The gradient started at 10% A, ramped linearly to 40% A at 30 min, 75% A at 40 min, 10 % A at 45 min, and held at 10% for 14 min. More than 66% of the applied ^3H was recovered by this extraction procedure.

Analysis of the internal standard terbutylazine was performed using a Varian 3400cx GC with a Hewlett Packard cross-linked methylsiloxane capillary column (12.5 m x 0.20 mm I.D.) coupled with a Varian Saturn 2000 ion trap MS system (Varian Inc., Walnut Creek, CA).

Microbial Enzyme Activity

To assess soil enzymatic activities, the antibiotic treated soil was incubated for 5 weeks at 25°C in the dark. Soils were sampled periodically throughout the incubation period for determination of the β -glucosidase (GLU), glucosaminidase (GLA) and fluorescein diacetate hydrolytic (FDA) enzyme activities. The GLU activities were quantified according to procedures described by Tabatabai (1994). The GLA enzyme activity was determined as described by Parham and Deng (2000). The FDA hydrolytic activity was determined by the enzymatic assay procedures described by Bandick and Dick (1999).

Degradation Kinetic First-Order Rate Law

If the reaction depends only on the first power of the concentration of one of the reactants, the rate is

$$-\frac{d[A]}{dt} = k[A].$$

This expression integrates and solves to the following:

$$\int_{A_0}^A \frac{d[A]}{[A]} = -k \int_0^t dt \xrightarrow{\text{solution}} [A] = [A_0]e^{-kt},$$

where k is called the first-order rate constant. This can be written as $\ln[A] = -kt + \ln[A_0]$. Plotting the natural logarithm of the concentration $[A]$ versus t for a particular reaction will, therefore, allow determination of whether or not the kinetics is first-order. If the reaction is first order, calculation of the slope of the line will yield the rate constant k .

The half-life ($t_{1/2}$) of the reaction is given by

$$\frac{[A]}{[A_0]} = \frac{1}{2} = e^{-kt_{1/2}} \quad \text{and} \quad t_{1/2} = -\frac{\ln(1/2)}{k} = \frac{0.6931}{k}.$$

RESULTS AND DISCUSSION

Degradation of Tetracycline

Tetracycline (TC) was rapidly degraded in the soils across all the treatments, and no traces of ^3H -labelled TC or its metabolites were detected in the soil samples after 120 hours (5 days) of incubation. Rapid degradation of TC with half-life of less than 26 hours was previously reported and the dissipation rates were accelerated by increased temperature, pH and light intensities (Liang et al., 1998; Loftin et al., 2008; Sanderson et al., 2005). Tetracycline antibiotics are known to be oxidatively unstable and hydrolysis of TC is increased significantly by increased temperature and pH (Liang et al., 1998). The reported half-life of tetracycline can be as low as 1.06 to 1.42 days at concentrations of 30 and 100 $\mu\text{g} \cdot \text{L}^{-1}$, respectively, in simulated microcosms at pH 7 (Sanderson et al., 2005). The increased dissipation rates of TC were also reported under the influence of atmospheric oxygen when dissolved in MeOH, forming more than fourteen different degradation products. The rapid degradation of TC and formation of two major ^3H degradates were observed in our samples even at time 0 (Figure 2).

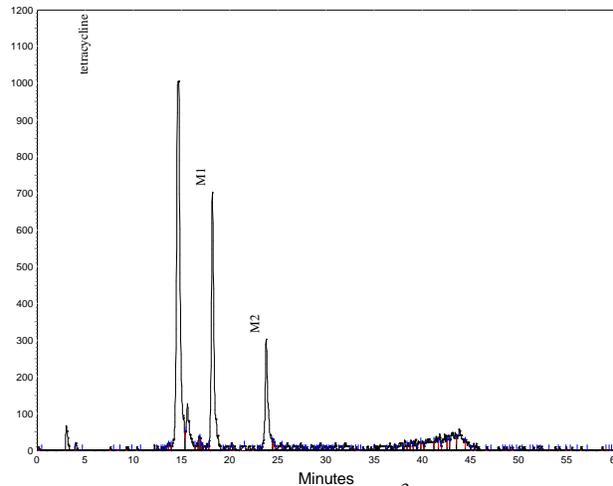


Figure 2. HPLC-FSA radiochromatograms of ^3H tetracycline and their metabolites extracted from rhizosphere soils.

Degradation of Sulfamethazine

The concentrations of SLF in the soil extract were successfully quantified with the developed HPLC-FSA method (Figure 3). An average of 66% of ^3H -SLF was recovered from the applied rhizosphere soils with the intensive extraction method employed. The extraction efficiency was comparable to the extraction efficiencies reported in other recent studies utilizing similar ultrasonic extraction or pressured liquid extraction (PLE) techniques (Aust et al., 2008; Blackwell et al., 2004; Stooß et al., 2006). The data illustrated in this work were normalized and corrected with the extraction recovery rates (Figure 4).

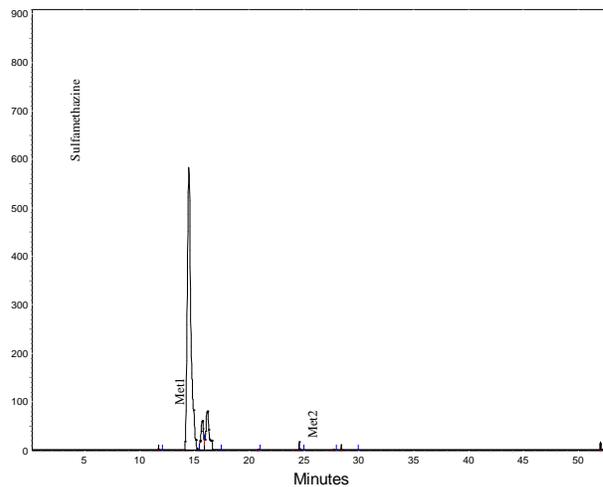


Figure 3. HPLC-FSA radiochromatograms of ^3H sulfamethazine and their metabolites extracted from rhizosphere soils.

The results suggested the soil extracted from POP rhizospheres showed the highest capability for promoting degradation of SLF (Figure 4). The estimated half-life of SLF ranged from 2.5 days

for POP to 16 days for SW. The degradation half-lives of SLF in the POP treatment was significantly lower than the other treated soils, and POP was the only treatment in which the half-life was lower than the control (5 days). Within the first 5 days, more than 85% of SLF was degraded in the soils collected from poplar rhizospheres, as compared to 50% in the control bulk soil treatment ($p = 0.028$). The enhanced rhizodegradation of SLF by POP was likely due to the greater microbial enzyme activities in the POP rhizosphere (see below).

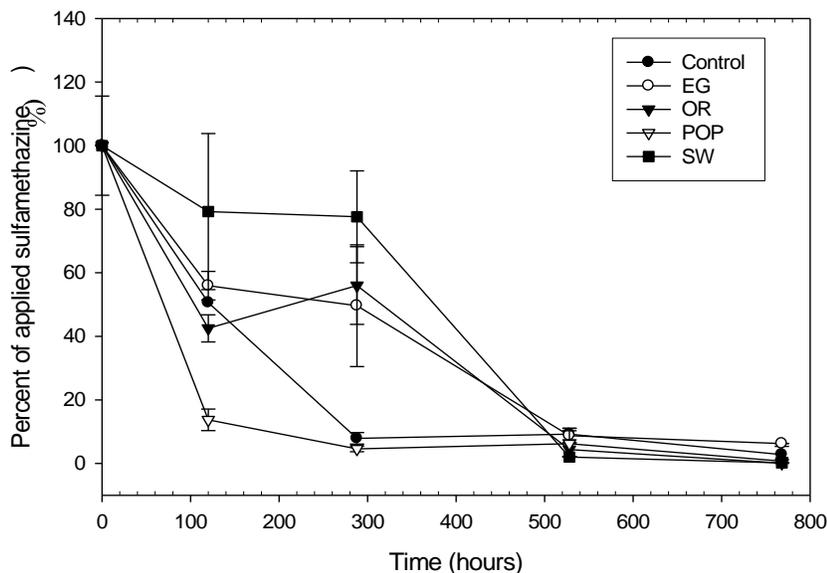


Figure 4. Dissipation of applied ³H-sulfamethazine over incubation period. Error bars represent standard deviation (n=3)

In contrast, the persistence of SLF in the grass rhizospheres was significantly longer compared to the control. We speculate that the SLF in grass treatments were likely adsorbed to a greater extent in the grass rhizospheres compared to that of the POP rhizosphere. This would lead to less SLF available for biodegradation. Thiele-Bruhn (2003 and 2004) has reported a high affinity of sulfonamides for organic matrices, and the increase in sorption was strongly correlated with decreased biodegradation of SLF due to the reduced bioavailability. We observed significantly greater adsorption coefficients for SLF in vegetative buffer soils than a row crop soil in a preliminary study.

Soil SLF half-lives ranging from 10 to 30 days with an average half-life of 18.6 days were reported by previous studies with much higher concentrations than those used in this study (Accinelli et al., 2008). Sulfamethazine can dissipate rapidly with a 4.2-d half-life when applied with the swine manure (Henderson et al., 2008).

The decline in SLF concentrations was found to follow-first order kinetics in all the soils collected from all the treatments ($R^2 > 0.90$), suggesting the dissipation rate of SLF was concentration dependent and mainly a result of microbial processes (Figure 5). Accinelli et al., 2008 also reported that SLF degradation followed first-order kinetics in silt loam and sandy soils. When predicted degradation rates calculated with the first order kinetic equations were compared

with actual degradation rates, the predicted values fit nicely for the control, POP and EG treatments (Figure 5). A lag in degradation was observed in the OR and SW treatments. This suggested that a more comprehensive model accounting for first-order degradation, lag phase, and kinetic sorption need to be developed for these treatments (Nielsen et al., 1996).

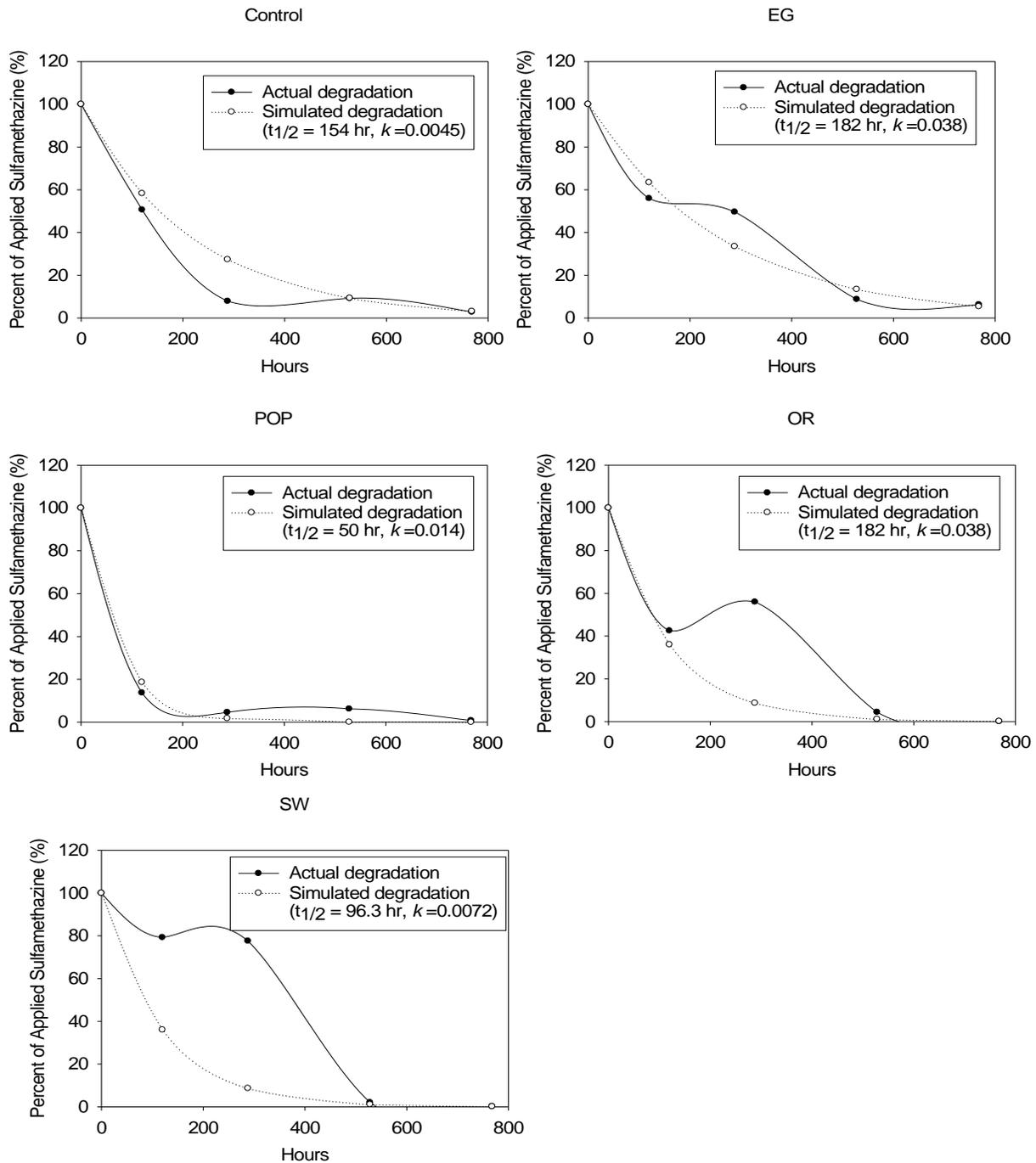


Figure 5. Actual vs. simulated degradation rates calculated with first-order kinetic equations.

Enzyme Activities

The FDA, GLA and GLU soil enzyme activities were significantly enhanced by EG, OR and SW treatments. When compared between antibiotic treatments, FDA and GLA soil enzyme activities were significantly lower in TC treated soils than in SLF treated soils. The GLU activities were similar between the two antibiotic treatments ($\alpha = 0.1$). For POP treatment, the FDA, GLU, GLA enzymatic activities were stimulated by 65-400% compared to the control. The difference in SLF degradation rates between POP and the other treatments was consistent with the significantly higher soil microbial activities in POP treatments. On the other hand, SLF was more resistant to degradation in grass treatments than in the control. Grasses rhizospheres were expected to have more organic molecules than control treatment for SLF adsorption. Therefore, we speculate that the effects of stimulated rhizosphere microbial activities by grass treatments, such as OR, were offset by the reduced bioavailability for SLF degradation. However, future work will include analysis of the soil organic matter content and determination of the sorption intensity of SLF to rhizospheres soil in order to test this hypothesis.

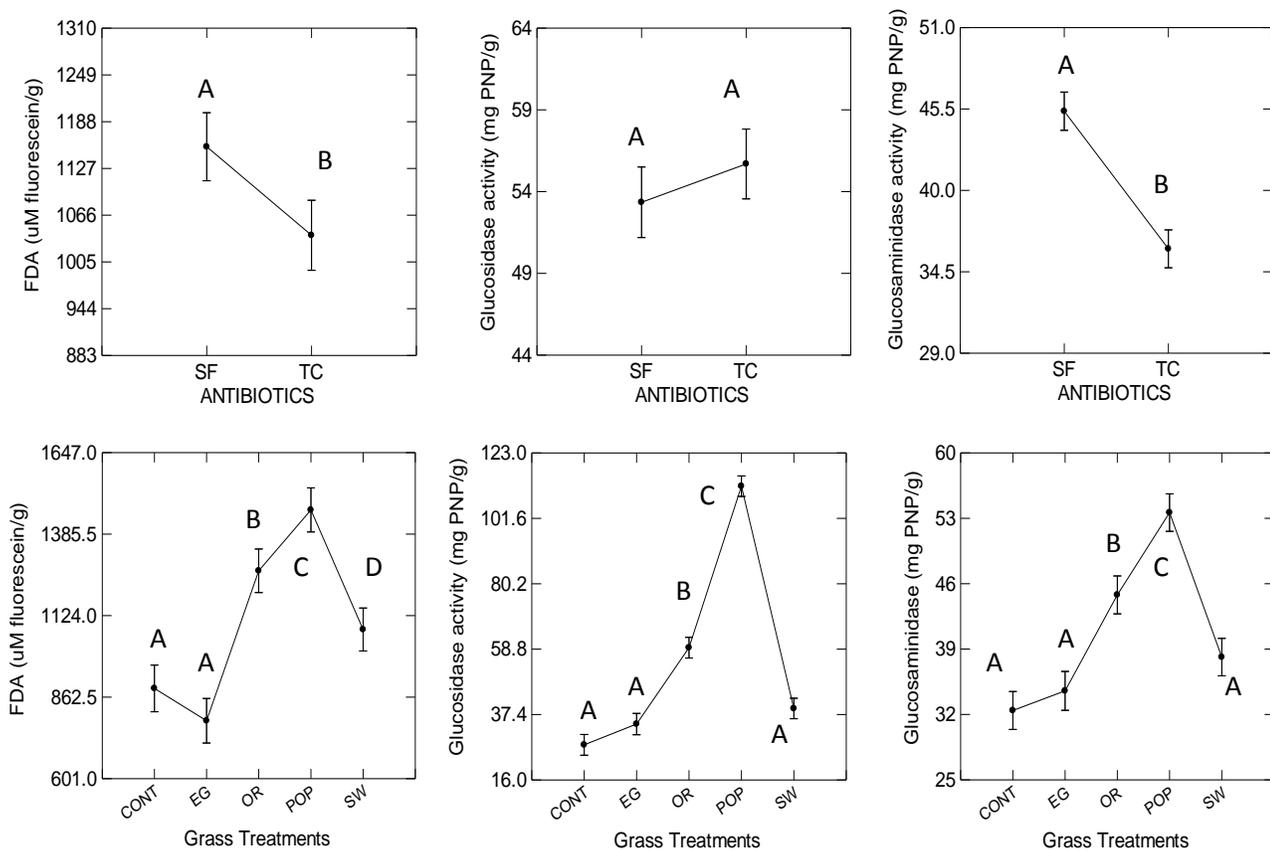


Figure 6. Effects of antibiotics and plant species on the FDA, GLU and GLA activities. Error bars represent 95% confidence interval. Different letters between treatments indicate significant differences at 90% confidence level using LSD test ($\alpha = 0.1$)

CONCLUSIONS

The effect of different plant species on degradation of antibiotics showed no treatment effect for TF because of its highly unstable nature in soil environments. For SLF, the POP treatment showed significantly increased degradation compared to the control or grass treatments. The POP treatment also had the highest soil enzyme activities, indicating that the hybrid poplar tested can stimulate microbial activity in the rhizospheres to a greater extent than grasses. This greater microbial activity likely was the reason for the enhanced SLF degradation observed in the POP treatment. Decreased SLF degradation of the grass treatments may have resulted from greater SLF sorption in the grass treatment rhizospheres, but this needs to be confirmed with additional studies. The developed knowledge will help us understanding the fate of the two antibiotics and their associated interaction with the soil microbial activities. The hybrid poplar showing high rhizodegradation potential in this study could be incorporated into buffer designs to mitigate the impacts of the antibiotics in the environment.

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TIMING OF PINE STRAW HARVEST AFFECTS SOIL AND NUTRIENT LOSSES

D.H. Pote¹ and T.C. Daniel²

¹USDA-ARS, 6883 South Highway 23, Booneville, AR 72927

²University of Arkansas

Contact: dan.pote@ars.usda.gov

Abstract: Pine straw is a valuable landscape mulch because it conserves soil moisture, moderates soil temperature, inhibits weed growth, and protects the soil surface against erosion, while retaining a loose structure that allows water, air, and fertilizer to easily reach the soil surface. As a result, marketing pine straw has become a multi-million dollar industry, but the loss of those mulching benefits from pine forests can increase runoff, soil erosion and nutrient losses in watersheds where pine straw is harvested. It may be helpful to harvest pine straw relatively early in the fall so that needles dropping later in the season will provide some soil cover throughout the remainder of the year and minimize the environmental impacts of harvesting. To test this hypothesis, runoff plots were constructed in a 17-year-old pine stand with basal area of approximately 42 m²/ha and trees planted on a 3.0 m X 1.5 m spacing. Each plot (2 m X 1 m) had 4% slope, aluminum borders to isolate runoff, and a runoff collector. Pine straw was removed from all 16 plots in early October, and eight of them were immediately covered with screen mesh that allowed light and water to reach the plot surface, but prevented additional pine needle accumulation. Two months later, simulated rainfall was applied (50 mm/h) to produce 20 minutes of runoff from each of the 16 plots for treatment comparisons. Results showed that harvesting early in the fall decreased soil and nutrient losses in runoff by allowing additional straw to accumulate late in the season and help protect the soil surface.

FIELD WINDBREAK / LIVING SNOW FENCE CROP YIELD ASSESSMENT

Gary Wyatt, Diomy Zamora and Jose Hernadez

University of Minnesota Extension, Extension Educators, Mankato, Brainerd and St. Paul, MN
Contact: wyatt@umn.edu

Abstract: Field windbreaks and living snow fences, when placed in the proper locations, can serve a useful purpose and be very beneficial in enhancing rural landscapes. It is important to record crop yields around these plantings using modern yield monitoring equipment to show producers where the yield differences are, including yield increases and other positive benefits of these plantings. This study funded by the Minnesota Department of Agriculture was designed to evaluate and document crop yields grown on one or both sides of field windbreaks or living snow fences for a 3 year period from 2005 to 2007. Yield data was collected from modern GPS/yield monitoring and mapping systems which are on the combines of the cooperating farmers. We have also conducted a survey of producers who have planted living snow fences to identify why they prioritized this practice on their farm and to document positive as well as negative comments about the plantings. Previous research suggests that there are yield advantages to conservation tree and shrub plantings. These plantings showed an increase in yield of 12% in corn and 8% in soybeans. We wanted to verify and update this research using various plantings in Minnesota with modern yield recording technology. If crop yields are higher or equal to field averages, more producers may be encouraged to establish these plantings on their farm. Field windbreaks and living snow fences reduce winter fatalities and accidents, benefit wildlife, enhance rural aesthetics, reduce blowing snow problems, reduce snow removal costs, protect top soil, and much more.

SECTION 10

Soil Quality

RIPARIAN FORESTS WITH AND WITHOUT GRASS FILTERS AS BUFFERS OF CONCENTRATED FLOW FROM CROP FIELDS

K.W. Knight¹, R.C. Schultz², C.M. Mabry², T.M. Isenhardt², and L. Long²

¹The Nature Conservancy, Skagit River Office, 410 N. 4th St., Mt. Vernon, WA 98273

²Dept. of Natural Resource Ecology and Management, Iowa State University, 339 Science II,
Ames, Iowa 50011-3221

Contact: rschultz@iastate.edu

Abstract: A vegetation inventory within naturally occurring forested riparian buffers (natural forest buffers) and a survey comparing buffering of concentrated flow paths (CFPs) by natural forest buffers with and without planted grass filters was conducted along first and second order streams in three northeast Missouri watersheds. Seven natural forest buffers without grass filters were inventoried and found to be composed of dense stands of mixed tree species with a forest floor cover comprised largely of unrooted woody plant debris, which does not adequately buffer concentrated runoff. Seventy-four CFPs were found in row crop fields along 10 natural forest buffers with or without grass filters established using USDA conservation practice standards. Natural forest buffers without grass filters dispersed 80% of CFPs before they reached the stream, while those with grass filters dispersed 100%. We estimated 473 metric tons of sediment moved to the buffers/filters via CFPs since last tillage. Nine of the 74 CFPs passed completely through natural forest buffers without grass filters, and accounted for 97 metric tons of the total estimated 473 metric tons. The average width of breached forest buffers without grass filters was 12.8 m, while the width of those not breached was 17.9 m. Average width of cool-season grass filters (CSGF) adjacent to forest buffers was 17.6 m, while average width of warm season grass filters (WSGF) was 22.1 m. These data, along with previous research, suggest that adding a grass filter along narrow natural forest buffers would improve water quality by reducing sediment loss to streams.

Key Words: Erosion; sediment transport; concentrated surface runoff; restoration

INTRODUCTION

Riparian buffers provide multiple environmental benefits to streams (Broadmeadow and Nesbitt, 2004; Lowrance *et al.*, 2002; Schultz *et al.*, 2004). Most of these benefits have been described from riparian buffers that were designed specifically as buffers, or from plot-scale experiments. Little is known about the ecological effectiveness of naturally occurring forested and grass riparian areas along streams, although it is often assumed they function much like designed riparian buffers. While Cooper *et al.* (1987) found that most of the sediment leaving agricultural fields was deposited within 100 m of the edge of the crop field in an adjacent natural forested riparian area, many naturally occurring riparian buffers along headwater streams in the agriculturally dominated landscapes of the Midwestern U.S are narrower than that. For example, in a study from Missouri, only 41, 53 and 66 percent of the stream lengths of first, second and third order streams, respectively, had riparian forest or other perennial plant community buffers as wide as even 61 m (Herring *et al.*, 2006). The ability of these narrow riparian forests, to

capture nutrients and slow surface runoff, especially from concentrated flow paths (CFPs), has not been determined. CFPs carry sediment and nutrients to streams through both rill erosion and ephemeral gullies (USDA Natural Resource Conservation Service, USDA-NRCS, 1998).

Grass filter strips have been shown to be effective at reducing sediment, nutrients and herbicides from sheet or inter-rill erosion (USDA-NRCS, 2005; Lee *et al.*, 2003; Rankins *et al.*, 2001). However, they and riparian buffers, individually, appear to be less effective when flow is from concentrated rill or ephemeral gullies (Dillaha *et al.*, 1986; Dosskey *et al.*, 2002; Helmers *et al.*, 2005). However, if grass filters are adjacent to naturally forested areas, research suggests that sediment loads from sheet and rill flow from adjacent crop fields can be reduced by 60-90% (Daniels and Gilliam, 1996).

In this study, we compared the environmental benefits associated with capturing surface runoff in narrow, naturally occurring forested riparian areas (natural forest buffers) with those associated with grass filters that meet USDA-NRCS criteria. The first objective of this study was to describe the vegetation composition in natural forest buffers along first and second order stream segments in northeast Missouri. The second objective was to compare the effectiveness of these natural forest buffers, with and without approved USDA-NRCS grass filters, to buffer CFPs from row crop fields to first and second order streams.

MATERIALS AND METHODS

The study was conducted in Crooked Creek (28,814 ha), Otter Creek (26,709 ha), and Long Branch Creek (26,487 ha) watersheds in the Claypan Prairie ecoregion of north-eastern Missouri (Figure 1) (Chapman *et al.*, 2001). Crooked, Otter, and Long Branch Creek watersheds are 58%, 66%, and 71% row crop land, respectively. Primary crops for this area are corn, soybeans, winter wheat, and grain sorghum, whose culture results in a significant portion of the year where the soil is bare and more susceptible to erosion from surface runoff (Watson, 1979; Young and Geller, 1995). Average annual precipitation for this region is 99-102 cm yr⁻¹, two-thirds of which falls between April and September (Watson, 1979; Young and Geller, 1995). The period of highest rainfall is also when most agrichemicals are applied and as a result the Claypan region has been identified as an area vulnerable to pesticide and nutrient contamination of surface water (Lerch and Blanchard, 2003).

Natural forest buffers 10-30 m wide and lengths of at least 402 m, without adjacent grass filters, were selected by examining aerial photos of all first and second order streams in the three watersheds using GIS. Property owners of farms totaling 8.8 km of buffers that met these criteria granted permission to access them. In addition, forest buffers with adjacent grass filters were located by contacting USDA-NRCS offices and were considered if the grass filter was established as either a grass filter strip (CP 21) or field border (CP 33) (USDA-NRCS, 2008). Except for length, the same site requirements as for the natural forest buffers without adjacent grass filters were used. These sites varied from 380 m to 2,800 m in length. All property owners with these grass filter strips agreed to participate in the study. Forest buffers with adjacent field borders were planted in warm-season grasses and forbs, and are referred to as warm-season grass filters (WSGF) while the sites enrolled as grass filter strips were planted to cool-season grasses and are referred to as cool-season grass filters (CSGF); WSGF and CSGF sites are referred to

collectively as grass filter sites. The total length of forest buffers with CSGF was 7.5 km and with WSGF was 3.4 km. CSGF were established between 2001 and 2004, and WSGF was established in spring 2006.

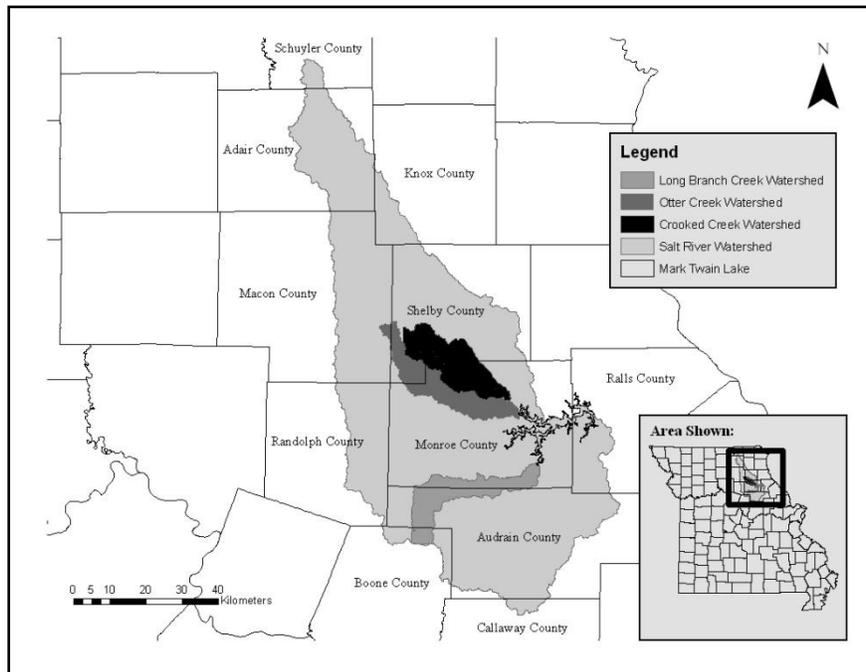


Figure 1. Map showing the location of Crooked Creek, Otter Creek, and Long Branch Creek Watersheds.

Natural forest buffer inventory plots (74 total) were placed every 134 m along the 402+ m length of buffer to ensure a minimum of 3 plots as suggested by USDA-NRCS (n.d.). The center point of each plot was placed halfway between the top of the stream bank and the edge of the forest canopy adjacent to the crop field. Sample plots were 0.008 ha (0.02 acre) circles with a fixed radius of 5.08 m. Plots were inventoried in September and October 2006 before leaf fall. In each plot, tree species and diameter at breast height (dbh) were recorded for all trees >2.5 cm dbh. Species and diameter were also recorded for saplings defined as <2.5 cm diameter and >1.5 m tall. Understory shrubs were identified to species and assigned to one of eight cover classes for each plot: 1 = 1-2 individuals or clusters with <5% cover, 2 = few to many individuals with <5% cover, 3 = numerous individuals throughout the plot with <5% cover, 4 = 5-15% cover, 5 = 16-25% cover, 6 = 26-50% cover, 7 = 51-75% cover, 8 = 76-100% cover. Within each sample plot, four smaller plots were used to measure seedling (<2.5 cm dbh and <1.5 m in height) density. Circular plots of 0.0004 ha (0.001 acre) with 2.28 m diameters were located at each of the four cardinal directions 2.5 m from the center of the larger sample plot. Seedling species were recorded in 296 of these smaller plots. In March 2007, forest floor cover was inventoried at the same plots where the seedlings had been measured the previous autumn. Percent cover was partitioned into rooted vegetation (woody plants, grass, forbs/weeds), woody plant debris (leaves, twigs, branches), bare soil, and total cover using the same percent cover scores used for

the shrub characterization. All but one site had not had cattle grazing for more than 5 yr, and 5 of the 7 sites had not been grazed in more than 15 yr.

The term concentrated flow path (CFP) is used in this study to describe the rills or ephemeral gullies observed in row crop fields. In late March and early April 2007, CFP surveys were completed by walking 6.7 km of natural forest buffers without grass filters and 10.9 km of natural forest buffers with grass filters. March and early April were chosen because this represented a time period when CFPs were easily visible and spring tillage and planting had not yet started. Also, the fields had not been tilled since the previous spring and in some cases where no-till farming was being practiced, even longer. CFPs were identified as any visible eroded flow path or channel in the crop field which intersected a buffer/filter. CFPs and/or sediment deposition areas that stopped in the crop field before reaching the buffer/filter edge were not considered for this study. CFPs that extended into the buffer/filter were followed to see if they extended through the buffer/filter and to the stream. Stream banks and natural forest buffers were also surveyed to determine if there were CFPs that had developed in the buffers but whose field source was not evident.

The length of identified CFPs was measured by pacing, and widths and depths measured with a tape at the top, one-third, two-thirds and bottom of the total length of the CFP. CFPs were traced upslope only as far as a channel was present. If a CFP became discontinuous, the first break in the channel was considered the top of the CFP. If the CFP divided in two or more channels, efforts were made to measure the volume of each channel. In cases where the CFP extended into the buffer/filter, the bottom was considered the point where the CFP left the crop field and entered the buffer/filter. Where only a sediment deposition fan met the grass filter or forest buffer, the bottom measurement of the CFP was made at the last point where a channel was present, just upslope of the sediment fan. The top measurement of the CFP was made 0.3 m below of the start of the channel to avoid trying to take a measurement at the nick point. The location of both the top and bottom of the CFP were recorded with GPS. Slope and depth of each channel were also measured from the bottom to the top of the CFP (USDA-NRCS, 2002). Finally, the distance the CFP or sediment deposition extended into the forest buffer or grass filter and the width of the buffer filter from the crop edge to stream edge were measured.

CFP measurements were used to estimate the amount of soil movement since the last time the CFP was covered by tillage operations. The four measurements of CFP width and depth were averaged and then combined with the total length measurement to estimate the total volume of each CFP. Average bulk density of soil and calculations were estimated using the formula $E = V(1442/1000)$, where V is the volume in m^3 , 1442 is the average weight of soil in $kg\ m^{-3}$, 1000 is the weight in kg per metric ton, and E is equal to metric tons of soil erosion or loss since the last tillage. For CFPs that were dispersed at the edge of buffer/filter or stopped within the buffer/filter before reaching the stream, the soil was considered to be transported to the buffer/filter, not to the stream channel (USDA-NRCS, 2002). For CFPs with a continuous channel to the stream, soil moved from the CFP was considered lost to the stream. Only soil movement or loss associated with the crop field portion of the CFP was considered in this study.

In May and July 2007, above-ground biomass, including rooted plant material and woody plant debris in the natural forest buffers and grass filters, was determined. These biomass samples

were taken from the edge of the forest buffer/filter, where the CFP interfaced with the forest buffer/filter. This was done to determine whether the amount and type of vegetation present where a CFP meets a buffer/filter is related to whether the CFP continues through or stops at or within the buffer/filter. All natural forest buffer and CSGF sites were sampled in late May and the WSGF were sampled in late July to obtain biomass samples representative of peak growth. GPS data collected during surveys in March and April 2007 was used to locate the point where the CFP interfaced with the buffer/filter in cases where the CFP had been covered by tillage operations and was no longer clearly visible. A 0.0004 ha (0.001 acre) circular plot was located at the edge of the natural forest buffer or grass filter for CFPs that stopped at the buffer/filter edge. For CFPs that had channels or sediment deposition areas extending into the buffer/filter but not all the way to the stream, the plot was located immediately down-slope of the channel or sediment fan in the vegetation that eventually stopped the CFP. For CFPs that extended all the way to the stream channel, a plot was randomly placed on either side of the CFP at the field edge of the buffer/filter. This procedure was judged appropriate to determine the nature of the vegetation that was at the CFP location originally before being removed by erosion. For each plot, percent cover scores were collected for woody stems, grass, weeds/forbs, woody plant debris (leaves, branches, etc.), and total cover using the same categories described for the forest floor and shrub cover characterization. Within the larger plot, two randomly located 0.25 m plots had vegetation clipped to the bare ground and woody plant debris gathered; vegetation was separated into grass, weeds/forbs, or woody plant debris categories. The harvested and separated vegetation was dried for 48 hours at 60°C, weighed and averaged.

One-way analysis of variance (ANOVA) was used to compare the four buffer categories for slope, length, and volume of CFPs, with the farm as the treatment level to test for differences in CFP slope, length and volume. Levene's test was used to determine if the variances were equal. If variances were considered unequal, Welch's ANOVA test was used for obtaining a p-value (JMP 6.0, 2005).

RESULTS AND DISCUSSION

Within the 74 sample plots, 474 trees were documented, distributed among nineteen species. The top 10 species in descending order were: *Quercus palustris*, *Ulmus* species, *Prunus* species, *Celtis occidentalis*, *Juglans nigra*, *Gleditsia triacanthos*, *Maclura pomifera*, *Acer saccharinum*, *Morus* species, and *Quercus imbricaria*. Average stand diameter for all trees sampled was 16.3 cm. There was an average of 788 trees ha⁻¹ for all plots with a standard deviation of 550. There was also an average of 309 saplings ha⁻¹ (SD 415) and 24,733 seedlings ha⁻¹ (SD 39,356). Sapling and seedling frequencies suggest that the natural forest buffers are regenerating successfully, although they may not maintain the same oak overstory dominance after the present overstory oak die. As pin oaks (*Quercus palustris*) were the dominant overstory tree, more oak seedlings and saplings were expected. Oak seedlings ranked third among all species, and saplings ranked fifth with only 12 saplings.

Average shrub cover per plot for the 74 sample plots was < 5%, but shrubs were found in 92% of plots. Major shrub species included *Symphoricarpos orbiculatur*, *Ribes missouriense*, *Sambucus canadensis*, *Rosa multiflora*, *Cornus drummondii*, and *Rhus glabra*. Of the 256 forest floor sample plots, most had good cover to protect against raindrop impact, with 51-75% of the cover

consisting of loose woody debris (leaves, twigs, branches, etc.), 20-45% rooted herbaceous plant cover, and < 5% bare ground. However, unrooted woody debris does not provide adequate resistance to lateral surface runoff (Daniels and Gilliam, 1996).

USDA-NRCS (2004) encourages high plant densities in the unmanaged forest area adjacent to stream in the riparian forest buffer practice. The average of 788 trees ha⁻¹ (avg. 16.3 cm dbh) found in this study is higher than the 550 trees ha⁻¹ (16 cm dbh) suggested as the stocking rate for riparian forest buffers (USDA-NRCS, 2004). The higher stocking rate observed in this study results in little perennial herbaceous forest floor cover except at the edge of the buffer where sunlight can provide enough energy for ground cover plant growth. While there are many species of shade-tolerant ephemeral species that may grow in these stands, their short lived morphology does not provide the persistent frictional surface needed to slow surface runoff.

Of the 74 CFPs observed, 45 were along the 6.7 km of natural forest buffers without planted CSGF or WSGF and 29 along the 10.9 km of natural forest buffers with grass filters (Table 1). Presence of CFPs in crop fields was not related to buffer types but rather slope, soil type, and cropping and conservation practices in crop fields (Figure 3). There were no significant differences in CFP metrics ($p > 0.05$) between the CFPs in the crop fields along any of the four riparian treatment categories (natural forest buffer without grass filter, forest buffer with CSGF, forest buffer with WSGF, forest buffer without grass filter and a breakthrough CFP). These results are important because they show that the average slope, length, and volumes of CFPs were not significantly different across any of the sampled sites. Additional information about CFP dimensions is shown in Table 2.

Table 1. Lengths, average widths and number of concentrated flow paths (CFPs) intercepted by naturally occurring forest buffers with and without planted grass filters (CSGF = cool-season grass filter, WSGF = warm-season grass filter). Numbers in parentheses are widths of the grass filters only.

Buffer Type	Distance Surveyed, km	Average Width (Grass filter only), m	# of CFPs
Natural Forest Buffer Without Grass Filter Not Breached by CFP	8.8	17.9	36
Natural Forest Buffer Without Grass Filter At Locations Breached by CFP	NA*	12.8	9
Forest Buffer + CSGF or WSGF	10.9	37.7	29
Forest Buffer + CSGF	7.5	35.5 (17.6)	8
Forest Buffer + WSGF	3.4	40.0 (22.1)	21

*Widths were measured at the point where the CFP breached the buffer. These portions were subsequently classified as not buffered.

Table 2. Average dimensions for 74 CFPs intersecting natural forest buffers with and without planted grass filters. Observations were in late March and early April 2007 in three watersheds in the Claypan region of northeastern Missouri.

Concentrated Flow Path (CFPs) Dimensions							
	Maximum	Upper Quartile	Median	Lower Quartile	Minimum	Mean	Standard Deviation
Length (m)	362	58	36	21	1.5	48.6	49.3
Depth (cm)	38	8	6	4	2	6.9	4.9
Width (cm)	412	102	78	49	20	89.3	62.0
Volume (m ³)	69	4	2	0.6	0.06	4.4	9.7
Slope (%)	10	4.5	4	2	1	3.7	1.98

Volume estimates based on all 74 CFPs indicate that 473 metric tons of soil had moved downslope to the buffers/filters since the last tillage. All 29 of the CFPs that intersected the forest buffers with grass filters were dispersed by the grass filters. However, nine of the 45 CFPs (20%) observed along the natural forest buffers without grass filters were not dispersed and passed completely through the natural forest buffers (Table 3). Volume estimates of soil loss from those nine CFPs equaled 97 metric tons, of which 50-90% was delivered to the stream channel (USDA-NRCS, 1998). One explanation for CFPs having continuous channels through some of the forest buffers without grass filters was their narrow width (12.8 m). In comparison, the average width for forest buffers without grass filters where the CFPs did not breach the buffer was 17.9 m. Those with a CSGF filter averaged 35.5 m wide and those with a WSGF which averaged 40.0 m (Table 1, Figure 4). Another reason may be the low percentage of rooted vegetation on the forest floor compared to that found in a grass filter. However, from personal observation, many edges of the natural forest buffer sites had a narrow buffer of cool-season grass or dense annual weeds because of increased sunlight. This may help explain why 80% of CFPs were still dispersed by the forest buffers.

To investigate vegetation density at various buffer edges, and attempt to understand why grass filters appear to better disperse CFPs, biomass was collected from the edge of the buffers/filters at CFP locations. While natural forest buffers had the highest average woody plant debris biomass, and therefore high amounts of total biomass, the woody plant debris biomass was not rooted plant material and could be washed away by concentrated surface runoff. If only rooted vegetation is considered, then grass filters had the highest total average biomass (Table 3). While grass biomass was much higher in the CSGF, we assume that both grass and forb biomass in the WSGF would increase as it matures.

Table 3. Mean dry weights for vegetation types in buffer categories. Buffer categories are: natural forest buffers with planted cool-season grass filters (CSGF) or warm-season grass filters (WSGF); natural forest buffers without grass filters (NFB) that were not breached; and locations in natural forest buffers completely breached by concentrated flow path channels (NFB/NB).

Vegetation Type	Biomass For Buffer Categories (g)			
	CSGF	WSGF	NFB	NFB/NB
Forb/Weed	0.9	21.8	17.6	17.2
Grass	54.4	23.9	23.3	26.2
Woody Plant Debris	1.2	0.2	21.7	14.4
Total	56.5	45.9	62.7	57.8
Total minus Woody Plant Debris	55.3	45.7	41.0	43.4

The CSGF sites were covered by tall fescue (*Festuca arundinacea*) and/or timothy (*Phleum pratense*) species while the WSGF areas were planted to a combination of forbs, little bluestem (*Schizachyrium scoparium*), sideoats grama (*Bouteloua curtipendula*), and switchgrass (*Panicum virgatum*). There was a large amount of foxtail (*Setaria faberi*), a cool-season annual grass species, present. In CSGF sites, CFPs or sediment deposition areas extended an average of 16.5% into the total filter width while in the WSGF they extended across 14.2% of the width on average. These percentages may be related to the young ages of the grass filters, especially the WSGF. CSGF sites had been established in 2001, 2002, and 2004, and WSGF sites were established in the spring of 2006, one year prior to this study. Annual observations should be made at these sites to determine the effectiveness of the grass filters at buffering CFPs. As the WSGF matures, the vegetation potentially could become more effective at slowing water at the field edge and depositing more sediment ahead of the filter, but the low percent cover scores for grass and high bare soil percentages in the WSGF may persist. The primary goal for the field borders is to promote habitat for upland birds which prefer less dense vegetation for habitat, especially for nesting and brood rearing. USDA-FSA (2006) suggests seeding for field borders be at much lighter rates than for CRP practices aimed at soil conservation and water quality enhancement. Future research should examine whether the lower seeding rates of field borders has an impact on their ability to disperse or buffer surface runoff or concentrated flow compared to other practices with higher seeding rates.

We also examined CFPs that formed exclusively within the natural forest buffers. These received their runoff from crop fields but no gullies had formed in the crop field. These CFPs were likely formed by sheet flow from the crop fields that converged and ran along the forest buffer edge before breaking through into the buffer. Twenty-four CFPs were observed originating within the 8.8 km of natural forest buffers without grass filters. Many of these CFPs appeared to be active, receiving runoff from the crop fields even though no associated CFPs were evident in the adjacent crop fields. Although 27 CFPs were also found originating within the forest buffers with grass filters, most of these CFPs appeared to no longer be active as they likely developed prior to the grass filter being planted and were no longer receiving significant concentrated surface runoff from the crop field. The presence of numerous CFPs within the

natural forest buffers again underscores that these narrow forest buffers are not providing adequate buffering to surface runoff if they are not also associated with grass filters.

SUMMARY AND CONCLUSIONS

Stocking rates for tree species in the naturally occurring forest buffers were greater than recommended rates by USDA-NRCS for riparian forest buffers. While these dense stands provide flood protection and shading and organic material to the streams, their high density seems to restrict the amount of rooted perennial herbaceous ground cover that is needed to provide resistance to surface runoff. Future studies should examine methods for manipulating these buffers to increase the amount of shade tolerant herbaceous species or more shade intolerant grasses and forbs.

Natural forest buffers with grass filters dispersed or buffered 100% of CFPs observed while natural forest buffers without grass filters dispersed or buffered 80% of CFPs. Based on volume estimates of the CFPs, 376 metric tons of soil moved to and were trapped by some of the natural forest buffers without grass filters and by all of them with grass filters. Ninety-seven metric tons were estimated lost to streams at natural forest buffer without grass filters where CFP channels were continuous to the stream. These forest buffers were only 12.8 m wide compared to the 17.9 m width for the forest buffers without grass filters and forest buffers with CSGF (35.5 m) or with WSGF (40.0 m) that trapped CFPs. These results suggest that width is a critical factor at determining buffer efficacy.

The three watersheds in our study area contain approximately 759 km of first and second order streams. The abundance of natural forests along these streams does provide substantial buffering capacity. However, given the ability of grass filters to disperse and buffer concentrated flow paths from crop fields as demonstrated in this study, adding more grass filters to compliment natural forest buffers could reduce the sediment loads in these watersheds.

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SOIL QUALITY IN A PECAN AGROFORESTRY SYSTEM IS IMPROVED WITH INTERCROPPED KURA CLOVER

Robert J. Kremer¹ and Robert Kussman²

¹ USDA, Agricultural Research Service, Cropping Systems & Water Quality Research Unit, 302 Natural Resources Bldg., University of Missouri, Columbia, MO 65211.

² Kussman Pecan & Cattle Farm, Dalton, MO 65246

Contact: kremerr@missouri.edu

Abstract: Intercropping alleys of agroforestry systems provides an income source until the tree crop produces harvestable yields. However, cultivation of annual crops soil organic matter and increases soil erosion, especially on sloping landscapes. Perennial crops maintain a continuous soil cover, maximize water infiltration, minimize soil erosion, and improve overall soil quality. The objective of this on-farm study was to assess the effects of a perennial legume, kura clover (*Trifolium ambiguum*), on various soil quality parameters in a recently established pecan (*Carya illinoensis*) orchard. The pecan-kura clover agroforestry system was established on deep loess soils of the Missouri River hills. These silt loams are on 3 to 10% slopes and can be highly erosive. Kura clover, intercropped eight years after pecan planting, was selected based on its perennial growth habit, nitrogen-fixing ability, winter hardiness, high forage quality, and soil conservation properties. Kura clover was seeded in 2002 and harvested for hay annually beginning 2003. During this period soil organic matter and activities of selected soil enzymes have steadily increased compared with cultivated and grass pasture control soils. Water-stable aggregation improved by 50%. Results illustrate that kura clover as the interplanted component improved soil fertility and biological activity through increased organic matter and improved soil structure, and yielded high quality forage valuable for the cattle-feeding operation. Pecan trees thrive in this system partly because soil quality is maintained or improved and, unlike other “living mulch” systems in which cover crops may suppress the main crop, kura clover does not compete with tree growth.

Key Words: aggregate stability, soil enzymes, microbial ecology, soil organic carbon, total nitrogen, cover crop, soil conservation.

INTRODUCTION

Approximately 500,000 to 700,000 kg of pecans were harvested annually in Missouri from 2005 to 2008 with an estimated value of \$1.5 to 2.25 million (NASS 2009). Pecans require 12-15 years growth after establishment as newly planted orchards before economic yields are realized. During the establishment period, the open area (“alley”) between tree rows could be managed for agricultural production to help sustain the agroforestry enterprise and simultaneously maintain soil quality and promote optimum tree growth. Cultivation of annual crops in the alleys might decrease soil organic matter and increase erosion especially on sloping landscapes. Perennial crops, however, maintain a continuous soil cover that, combined with trees, maximizes water infiltration, minimizes soil erosion, and improves overall soil quality. Therefore, planting forage species in the alleys may not only protect the soil resource by improving soil quality but also

provide a source of income during pecan establishment (Ares et al. 2006). Kura clover (*Trifolium ambiguum*) is a perennial, rhizomatous legume tolerant to adverse environmental conditions and has both high forage quality and soil conservation features (Speer and Allinson 1985, Taylor and Smith 1998). This unique cover crop is a potentially effective alley and forage crop in agricultural systems that integrate agroforestry production on erodible soils with a livestock component. The objective this research is to assess the effects of kura clover on soil quality properties in a pecan (*Carya illinoensis*) agroforestry system.

EXPERIMENTAL

A pecan-kura clover agroforestry system was established on the Kussman Pecan & Cattle Farm in Chariton County, MO (39°26' N, 93°08' W) on deep loess soils of the Menfro-Higginsville-Wakenda association. The silt loams are on 3-10% slopes and were eroded under previous row cropping (corn-soybean-wheat) and alfalfa-brome hay production until the fields were converted to idled grassland under the Conservation Reserve Program (CRP) in the mid-1980's. A pecan orchard was initiated in 1996 by planting stratified pecan nuts in 15-m rows using a nut planter. Trees were thinned to 1 per 10-20 m within rows; grafting of selected stock began in 1999. Kura clover (cultivars 'Rhizo' and 'Cossack') inoculated with *Rhizobium leguminosarum* bv *trifolii* was seeded (13.4 kg ha⁻¹) in disk-plowed alleys in April 1996. EPTC (1192 g a.i. ha⁻¹; 'Eptam 7E') was applied (pre-plant incorporated) to control grass. Haylage has been harvested from alleys annually beginning in 2003.

Soil sample collection for soil quality analyses began in 2002. Soils (10-cm depth) were collected annually following transects established across landscape features within the agroforestry site: summit and shoulder positions are Wakenda silt loam (fine-silty, mixed, mesic Typic Argiudolls) and backslopes are predominantly Knox silty clay loam (fine-silty, mixed, mesic Mollic Hapludalfs). Check sites for reference included 1) within tree rows (cool season grass cover since 1996); 2) adjacent unimproved permanent grass pasture (predominantly tall fescue (*Festuca arundinacea* Schreb.); and 3) adjacent field under long-term traditional cultivation (sampled in 2005 and 2006 only). Two soil cores at 0-10 cm depth were collected at 3 random points along each transect and within each reference site, and composited for each point. Soils were transported in a cooler at ambient soil temperature to the laboratory, sieved through 7-mm mesh, and analyzed for soil enzyme activity and wet aggregate stability (WSA) as soon as possible after collection. Soil enzymes included dehydrogenase and glucosidase (Tabatabai 1994); and glucosaminidase (Parham and Deng, 2003). Total organic C and total nitrogen contents were determined using dry combustion at 900C. Aggregate stability (WSA) was determined on aggregates >250 µm diam (Kremer and Li 2003).

RESULTS

Total soil organic C and total N increased in alleys across all landscape positions annually likely due to additions of C through rhizodeposition from roots of the perennial kura clover and N provided through nitrogen fixation (Table 1). The C and N increases are also reflected in a gradual decrease in soil C:N ratios within the alleys established with kura clover (Table 1).

Table 1. Total organic carbon, total nitrogen, and C:N in soils under kura clover and pecan, 2003 – 2006.

Landscape/Site	Organic C (g kg ⁻¹)	Total N (g kg ⁻¹)	C:N
2003			
Summit	23.13	2.42	9.48
Shoulder	18.6	2.04	9.18
Backslope	22.87	2.43	9.42
Tree Row	25.56	2.73	9.41
Unmanaged Grass	16.97	1.52	11.31
2004			
Summit	21.93	2.25	9.77
Shoulder	19.07	1.92	10.04
Backslope	24.63	2.54	9.66
Tree Row	19.60	2.06	9.49
Unmanaged Grass	16.17	1.42	11.62
2005			
Summit	26.43	2.62	10.02
Shoulder	21.20	2.13	9.97
Backslope	23.70	2.18	10.87
Tree Row	19.60	2.06	9.49
Unmanaged Grass	19.73	1.65	11.97
2006			
Summit	24.37	2.71	8.97
Shoulder	22.27	2.40	9.28
Backslope	25.53	2.73	9.41
Tree Row	30.83	3.08	10.04
Unmanaged Grass	22.47	1.95	11.48
Cultivated Check	8.40	0.66	12.84
<i>LSD (0.05)</i>	<i>7.50</i>	<i>0.75</i>	<i>1.43</i>

Trends for increased WSA (Fig. 1) in kura clover alleys suggested an effective sink developed for stabilizing the increased C and N. However, inconsistent increases in WSA in soil under kura clover may reflect impact of field equipment traffic during hay harvests and other seasonal operations. WSA values for the cultivated check illustrate the impact of losses of C and soil structure during prolonged intensive agricultural operations, which apparently was restored on similar soils through alley cropping with kura clover.

Soil enzyme activities, as indicators of soil quality, were highest under kura clover. Dehydrogenase activity (Fig. 2) represents metabolic activity of the total viable microbial biomass; glucosidase reflects organic C degradative activity, which is critical for C cycling during decomposition in soils (Fig. 3). Both dehydrogenase and glucosidase activities increased gradually over the five year assessment but maintained high levels especially later in the sequence. The relative values somewhat reflected the inherent soil properties of the landscape positions -- the summit with less erosion revealed highest activities whereas the severely eroded shoulder was generally lower until 2006 when values equaled or exceeded the backslope,

containing colluvial deposits. These results demonstrate the ability of established kura clover stands to restore soil quality (biological activity) on soils degraded by intensive cultivation.

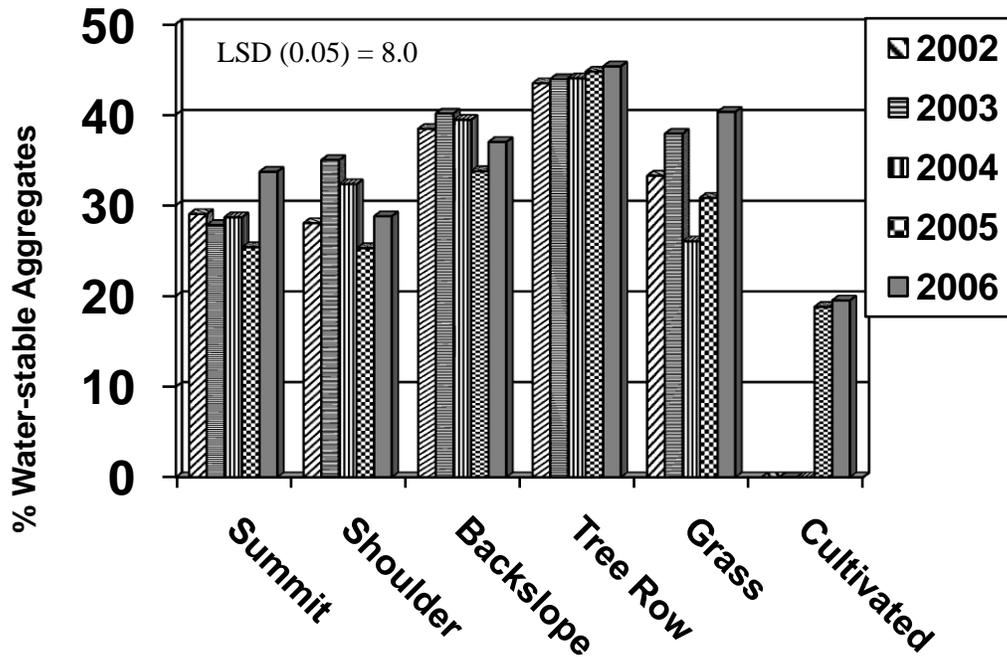


Figure 1. Water-stable soil aggregation developed under kura clover across various landscape positions in a pecan agroforestry system, 2002 -2006. Data for soils from CRP (grass) and traditional cultivated systems are included for reference.

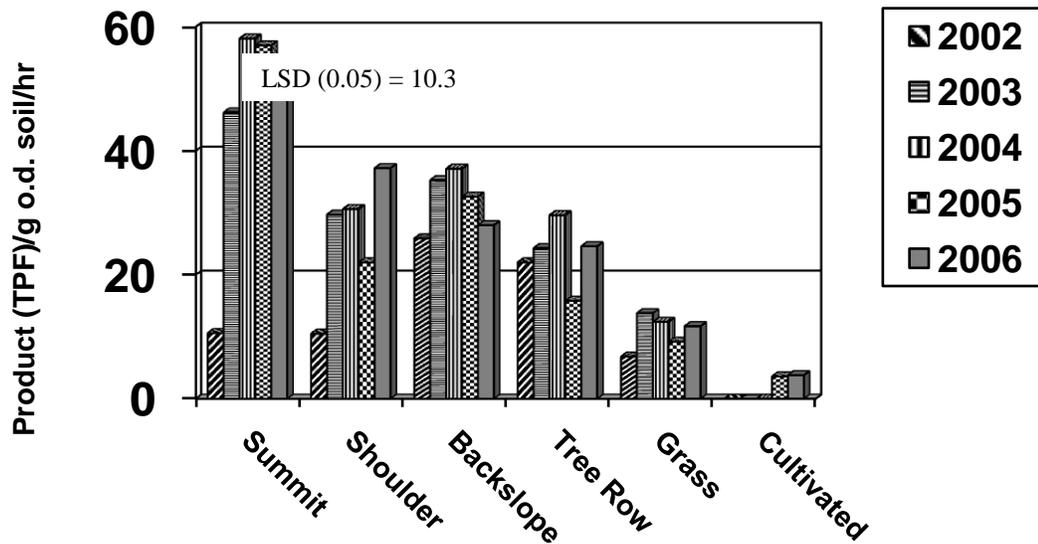


Figure 2. Soil dehydrogenase activity in kura clover alleys across various landscape positions in a pecan agroforestry system, 2002 -2006. Data for soils from CRP (grass) and traditional cultivated systems are included for reference. TPF, triphenyl formazam, product for quantitating dehydrogenase activity.

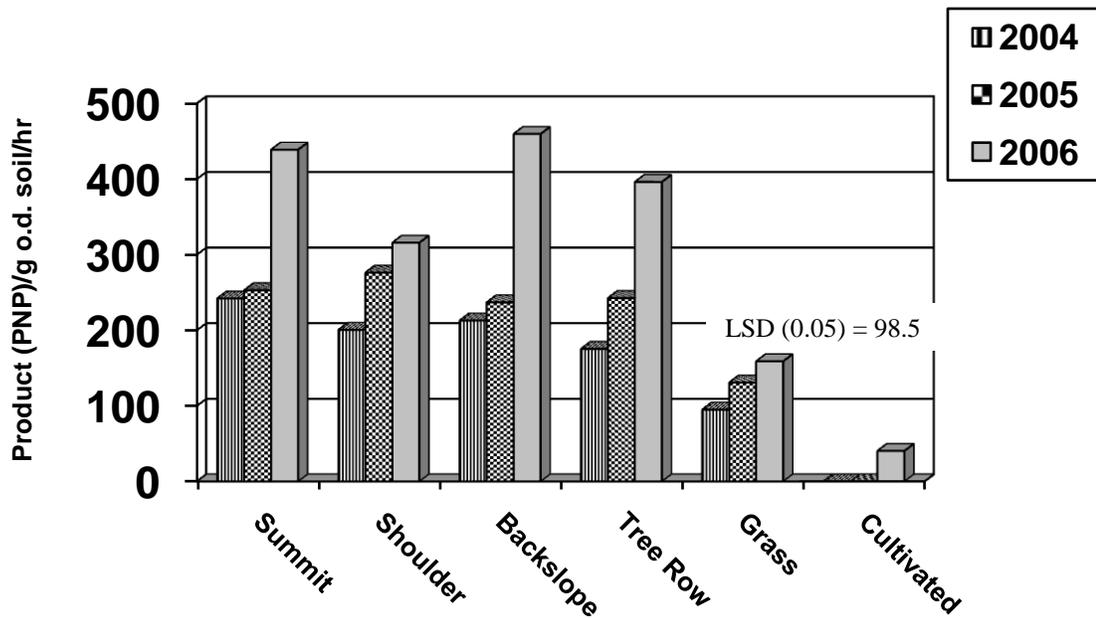


Figure 3. Soil glucosidase activity in kura clover alleys across various landscape positions in a pecan agroforestry system, 2004 -2006. Data for soils from CRP (grass) and traditional cultivated systems are included for reference. PNP, *p*-nitrophenol, product for quantitating glucosidase activity.

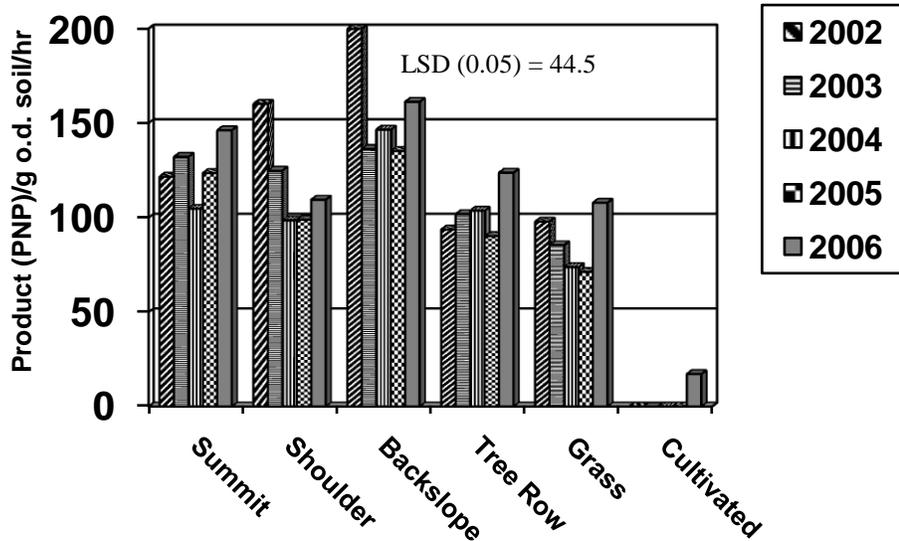


Figure 4. Soil glucosaminidase activity in kura clover alleys across various landscape positions in a pecan agroforestry system, 2002 -2006. Data for soils from CRP (grass) and traditional cultivated systems are included for reference. PNP, *p*-nitrophenol, product for quantitating glucosaminidase activity.

Soil glucosaminidase activity (Fig. 4) indicates mineralization of nitrogen from organic substances, including dead microbial biomass, eventually available for plant uptake. The apparent high microbial populations that developed under kura clover contributed to readily available N for plants including pecan trees in the agroforestry system. Lower N mineralization rates are shown for unimproved tree row and grass sites and extremely low values for the cultivated site illustrates the benefit of perennial cover cropping on this silt loam soil association.

DISCUSSION

Soil quality indicators of soil organic matter, aggregate stability, and selected enzyme activities have steadily increased annually in the kura clover intercropped area since 2002, compared with grass pasture and cultivated sites on similar soils and landscapes. High proportions of WSA indicate excellent soil structure, low erosion potential, good water infiltration, and high microbial activity. Previous studies on grassland ecosystems and sustainable agricultural and agroforestry systems with pin oak (*Quercus palustris* Muenchh.) have demonstrated the value of high WSA in contributing to increased soil organic C and N and enhancing soil microbial processes measured as soil enzyme activities (Kremer and Li 2003; Udawatta et al. 2008). Consistent trends in higher enzyme activity, i.e., β -glucosidase, validate these as good indicators of management-induced changes in soil quality (Bandick and Dick 1999). As a ‘model cover crop’, (Reicosky and Forcella 1998), kura clover improved soil fertility, biological activity, and soil structure, and yielded a high quality forage valuable for the cattle-feeding operation. Forage yields range from 10 – 16.5 Mg ha⁻¹ for 2 – 3 cuttings per season. The inherent persistence of kura clover should provide long-term forage availability for both harvest and grazing (Contreras-Govea et al. 2006).

Pecan trees, under proper management, apparently thrive in this system partly because, unlike other “living mulch” systems in which the cover crop may suppress growth of the main crop, kura clover does not compete with tree growth. By improving soil properties, kura clover likely enhances the tree root environment and ultimately overall growth. Kura clover was successfully established and common problems with seedling vigor and stand persistence were minimal. Based on build up soil organic matter with a favorable C:N ratio, high N-mineralizing activity, and the benefit of N fixation by kura clover, critical N requirements for proper pecan development (Reid and Hunt 2000) may be largely met in this system. The total agroforestry system is improving soil properties and productivity (improved nutrient cycling), providing economic benefits while pecan trees mature, reducing dependence on synthetic chemicals, and providing wildlife and bee foraging habitats.

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EFFECTS OF GROWDCOVER MANAGEMENT PRACTICES IN A FRASER FIR (*ABIES FRASERI*)-COVER CROP INTERCROPPING SYSTEM ON SOIL MICROBIAL BIOMASS AND COMMUNITY CATABOLIC DIVERSITY

Paligwende Nikiema¹, Pascal Nzokou¹, and David Rothstein¹, and Mathieu Gouajio²

¹Department of Forestry, Michigan State University, 126 Natural Resources, East Lansing, MI 48824

²Department of Horticulture, Michigan State University, A428 Plant and Soil Sciences, East Lansing, MI 48824

Contact: nikiemap@msu.edu

Abstract: Soil microbial biomass carbon (SMB-C) and nitrogen (SMB-N) as well as microbial community-level physiological profiling (CLPP) were investigated in an intercropping system involving Fraser fir, two leguminous (Dutch white clover and alfalfa) and a non-leguminous (perennial rye grass) cover crops. For each cover crop, two competition-management practices, banding and no banding, were evaluated. Conventionally-managed plots were used as controls. Soil microbial biomass was assessed at the 0-15, 15-30 and 30-35 cm soil depths and CLPP at the 0-15 cm soil depth. Cover cropping had limited early effects on soil organic carbon. However, significant increase of total soil nitrogen at the surface soil layer was observed. The leguminous cover crops with banding yielded higher SMB-C and SMB-N than the non legume. SMB-C and SMB-N significantly decreased with soil depth. Plots managed with bands averaged 559 mg SMB-C kg⁻¹ dry soil, and plots without bands averaged 536 mg C kg⁻¹ dry soil. For SMB-N, plots managed with bands averaged 83 mg N kg⁻¹ dry soil, while plots without bands averaged 79 mg N kg⁻¹ dry soil. Leguminous cover crops significantly improved microbial community diversity compared to the controls. Multivariate analysis showed that the microbial communities in plots with cover crops had a catabolic potential that differed from that of control, with the communities from the leguminous cover crops with bandings exhibiting the strongest dissimilarity. These results suggest that cover cropping with proper management can provide a good environment for microbial development and be an alternative approach to sustainable tree production.

Key Words: low-input system, soil fertility, sustainability, plantation, agroforestry

INTRODUCTION

In recent years, there has been increasing interest in the use of management practices that maintain soil productivity and environmental quality while improving farm profitability (Baributsa 2006). Intercropping legume and/or non-legume cover crops is a practice that has been widely investigated as a practical way to achieve sustainable production (Walsh et al. 1996). Cover crops not only reduce soil erosion but also add organic matter to the soil, conserve soil humus, improve soil aeration and structure, and improve soil nutrient status. Because of

these benefits, intercropping cover crops with cereal crops (Sainju and Singh 1997, Macdonald et al. 2005) and orchard trees (Sanchez et al. 2007) is increasingly becoming a common practice. In low-input production systems, soil management generally involves the use of mowed, tilled or killed cover crops, animal manures, composts and the application of organic fertilizers to increase soil organic matter levels and steadily release available nutrients to the trees as the organic matter breaks down (Sanchez et al. 2007). In this process, the action of soil organisms is a major determinant of nutrient cycling rates and plant growth. Planting either cereal or legume cover crops in the interspaces of plantations increases plant residue inputs to soils (Dinesh et al. 2004) and therefore may stimulate soil microbial activity and increase mineralizable C and N (Mendes et al. 1999). It is also well documented that farming systems and management practices greatly influence microbial populations and activities in soil (Bossio et al. 1998).

Soil microbial biomass and activity respond rapidly to changes in agronomic practices and other disturbances (Lundquist et al. 1999), and have been used to ascertain early changes in soil fertility due to different soil management practices (Doran and Zeiss 2000, Wang and Wang 2008). In fact, changes in microbial biomass and diversity are often used as rapid indicators of changes in soil organic matter content and soil fertility level.

The effects of growing leguminous and non-leguminous cover crops and incorporating the residues into the soil after tilling or killing them have been extensively studied for several agronomic crops. However, very little information is available concerning microbial biomass and diversity in Fraser fir (*Abies fraseri* Push [Choir]) production systems where the green manure cover crops are not only intercropped but regularly mowed, thus leaving the plant residues on the soil surface. Such information could be potentially useful to Christmas tree growers who conventionally use high amounts of commercial nitrogen fertilizers and herbicides for soil fertility management and weed control. The goal of this study was to examine the effects of various cover crop management practices on soil characteristics and microbial properties in Fraser fir production systems. We hypothesized that the overall site chemical and biological conditions; particularly soil organic carbon, total soil nitrogen, microbial biomass and microbial catabolic diversity would be increased in the cover crop managed plots compared to the conventional system.

MATERIALS AND METHODS

Research site and plant materials

A field experiment was established at the Tree Research Center (TRC) (42.67°N, 84.46°W) on the campus of Michigan State University in East Lansing, Michigan. The local climate is mild during summer with an average temperature of 15.5 °C and cold during winter with an average temperature of -6.6 °C. Annual average precipitation is 853 mm with rainfall distributed fairly evenly throughout the year. The experiment was located in a fenced area to limit the impact of deer browsing, attracted by the leguminous cover crops. Soil at this site is classified (FAO) as a fine-loamy, mixed, active, mesic Aquic Glossudalf (Rothstein 2005). The soil type is moderately well drained, with high available water capacity and medium surface runoff.

Experimental design

The field was 32.92×51.21m (108×168 ft) in size, and the experiment was established as a randomized complete block design with three replications. Three cover crops were selected for this trial: two legumes (Dutch white clover [*Trifolium repens*] and alfalfa [*Medicago sativa*]), and one grass (perennial rye grass [*Lolium perenne*]). Two ground management types, no bands (NB) and bands (B) were assigned to each cover crop species. The band treatments consisted of intercropping the cover crop between the tree rows while maintaining a clear band of 60 cm centered on the tree row (Fig. 1-a). The no band treatments consisted of growing each cover crop in a continuous patch in the plot (Fig. 1-b). Plots managed conventionally (CONV), with no cover crop and weeds completely controlled with glyphosate (active ingredient concentration =1.1kg ha⁻¹) were included as control (Figure 1-c). Thus, the agronomic treatments were as follows: Dutch white clover with bands (DWCB), Dutch white clover with no bands (DWCNB), alfalfa with bands (ALFB), alfalfa with no bands (ALFNB), perennial rye grass with bands (PRGB) and perennial rye grass with no bands (PRGNB). Trees were established at 1.8 x 1.8 m spacing, and each plot contained 7 x 5 trees for a total of 35 trees per plot.

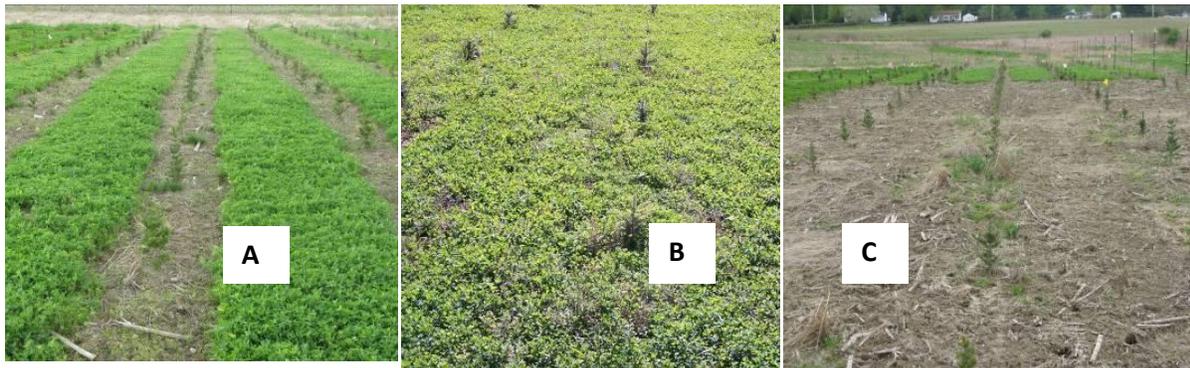


Figure 1: Banding (A), no banding (B) and conventional (C) plots in our cover crop plots

Fraser fir transplants (plugs+2) were obtained from a local commercial nursery, and machine planted with a Whitfield planter, into a chisel plowed and dragged field soil on May 8, 2007. Plants in border rows were used as a buffer and not included in measurements, therefore restricting data collection to the area of the remaining 15 interior trees in each plot. Seeds of common Dutch white clover, alfalfa (SS 100 brand) and perennial rye (VNS), purchased from Michigan State Seeds (Grand Ledge, Michigan) were hand-seeded, either to the entire plot or between the tree rows leaving bands along the tree rows, at a rate of 28 kg ha⁻¹ for clover and alfalfa and 13 kg ha⁻¹ for rye. Once the cover crops were fully established, mechanical mowing was performed every three weeks (3 inches above the ground) to control cover crop growth, minimize the competition with the trees, and add green manure to the soil. Glyphosate was sprayed twice (June 5 and July 26, 2007) during the growing season to control weed in the conventional (control) plots and the banded treatments.

Soil sampling and soil chemical characteristics

Fifteen randomly-selected soil sub-samples per plot were collected with a 2.5 cm diameter auger and composited. Soil samples were collected in mid-October 2007, corresponding to the end of

the growing season. In the cover crop plots with bands, nine (9) cores of soil were collected within the cover crop zone and six (6) cores within the bare ground zone, proportional to the area of each banding zone. The sampling depths were 0-15, 15-30, and 30-45 cm. Total C and N of soil samples were determined by combustion with an elemental analyzer (Model ECS 4010, COSTECH Analytical, Valencia, CA).

Microbial biomass analysis

Soil microbial biomass C was estimated by extracting 10 g oven-dry equivalents of field moist mineral soil samples in 0.5 M K₂SO₄ (1:4 w/v), by the chloroform fumigation-extraction method described by Brookes et al. (1985). Total dissolved C and N were determined by oxidative combustion-infrared analysis and oxidative combustion-chemiluminescence, respectively (Shimadzu Corp., Kyoto, Japan). Microbial biomass C and N were calculated as the difference between C and N in the fumigated and non-fumigated samples using 0.45 as a correction factor for SMB-C and 0.54 as a correction factor for SMB-N.

Microbial community-level physiological profile analysis

The functional diversity of the soil microbial community was measured using a BIOLOGTM system. Substrate-utilization patterns of the soil microbial population were determined using BIOLOGTM ECO-plates (BIOLOGTM, California) by a procedure adapted from Garland and Mills (1991). The absorbance of wells at 590 nm was measured over a 10-day period, and absorbance of the tetrazolium dye reactions in each well recorded at 0, 24, 96, 120, 168, and 240 h using an automated plate reader. Microbial activity in each micro-plate, expressed as average well color development (AWCD), was calculated for each sample at each time point by dividing the sum of the optical density data by 31 (number of substrates). We used an OD of 0.25 as the threshold for a positive response (Garland 1997) to calculate richness (R), or the total number of oxidized C substrates, a Shannon-Weaver index (H') of metabolic diversity and evenness of response (E), at 120 h since it was the shortest incubation time that allowed the best resolution among treatments.

Data analysis

Data were analyzed as a randomized complete block design (RCBD) using Proc Mixed in Statistical Software Package SAS version 9.1 (SAS 2002-2003). We used Fisher's Least Significant Difference Test to make pair-wise comparisons of individual treatment means. Significance for the overall treatment effects and pair-wise comparisons was accepted at $\alpha=0.05$. The AWCD, R, H' and E data were subjected to a one-way ANOVA in SAS. The standardized OD values obtained from each of the 31 substrates for each treatment were further analyzed using multivariate techniques (principal component analysis and cluster variable analysis for similarity) to differentiate among microbial communities based on substrate utilization profiles.

RESULTS AND DISCUSSION

Soil organic carbon and nitrogen

Although the control had the lowest mean soil total C concentration, it was not significantly different ($P > 0.05$) from any of the other treatment means (Table 1). No specific trend was observed between treatments at the 15-30 cm and 30-45 cm depths. There was a significant decrease in soil total carbon with soil depth ($P < 0.001$), certainly due to decreases in plant-derived in deeper soil layers. Total soil N was significantly higher in soils under cover crop treatments compared to conventional control plots at the 0-15 cm depth. Similar to organic carbon, there was no statistical difference of organic N in deeper soil core specimens. The C:N ratio values followed the same trend, generally decreasing significantly with soil depth ($P < 0.001$), without any statistical difference among treatments at each depth ($P > 0.05$).

Table 1: Soil total carbon, total nitrogen and C:N ratio as influenced by groundcover management

Groundcover management	Total C (%)			Total N (%)			C:N ratio		
	0-15cm	15-30cm	30-45cm	0-15cm	15-30cm	30-45cm	0-15cm	15-30cm	30-45cm
ALFB	2.07 ^a	1.51 ^a	0.58 ^a	0.18 ^b	0.14 ^a	0.06 ^a	12.26 ^a	10.92 ^a	9.96 ^a
ALFNB	2.23 ^a	1.62 ^a	0.71 ^a	0.19 ^b	0.14 ^a	0.07 ^a	12.06 ^a	11.44 ^a	10.52 ^a
CONV	1.99 ^a	1.58 ^a	0.56 ^a	0.16 ^a	0.14 ^a	0.05 ^a	12.49 ^a	11.29 ^a	11.50 ^a
DWCB	2.14 ^a	1.56 ^a	0.62 ^a	0.19 ^b	0.14 ^a	0.06 ^a	11.57 ^a	11.16 ^a	10.68 ^a
DWCNB	2.38 ^a	1.65 ^a	0.61 ^a	0.20 ^b	0.15 ^a	0.06 ^a	11.93 ^a	11.24 ^a	10.00 ^a
PRGB	2.11 ^a	1.66 ^a	0.69 ^a	0.18 ^b	0.15 ^a	0.06 ^a	11.98 ^a	11.01 ^a	10.90 ^a
PRGNB	2.27 ^a	1.49 ^a	0.59 ^a	0.18 ^b	0.13 ^a	0.05 ^a	12.44 ^a	11.32 ^a	11.77 ^a

[†]Treatments are: Conventionally managed (CONV), Dutch white clover with banding (DWCB), Dutch white clover with no banding (DWCNB), alfalfa with banding (ALFB), alfalfa with no banding (ALFNB), perennial rye grass with banding (PRGB), and perennial rye grass with no banding (PRGNB). * *Treatments with the same letter at each soil depth are not statistically different.*

It has been reported that long term cover cropping markedly influence soil organic C and N levels (Dinesh et al. 2004, Sanchez et al. 2007). We did not observe significant changes in soil total soil C as affected by our groundcover management, which is not unexpected due to the very short nature of the study. However, our groundcover management practices had an early effect on soil total N, probably due to greater N input from the cover crop residues.

Soil microbial biomass

Soil microbial biomass C and N as well as C:N ratio measured at 0-15, 15-30 and 30-45 cm depths of soil are shown in Fig. 2 (a, b & c). Groundcover treatments significantly affected soil microbial biomass (SMB-C and SMB-N) at the 0-15 cm depth ($P < 0.001$). However, no statistical difference was observed among groundcover treatments for both SBM-C and SMB-N at the 15-30 cm and 30-45 cm depths (Fig. 2-a; 2-b). At the 0-15cm depth, ALFB and ALFNB averaged 49% and 35% higher SMB-C compared to CONV controls (Fig. 2-a). Similarly, SMB-N in ALFB and ALFNB plots was 80% and 53% higher than in CONV treatments (Fig. 2-b). SMB-C and SMB-N were also significantly higher in all Dutch white clover and perennial rye grass plots (banded and non-banded) compared to the CONV plots. SMB-C was 57% and 49% higher, and

SMB-N was 80% and 76% higher in DWCB and DWCNB than in CONV. For PRGB treatments, SMB-C was 15% and SMB-N was 33% higher than in CONV while PRGNB yielded 19% and 40% SMB-C and SMB-N, respectively, higher than in CONV. Results obtained indicate that creating bands did not significantly affect SMB-C or SMB-N in both legume and non legume cover crop treatments. SMB-C and SMB-N in plots managed with bands averaged 558.8 mg C kg⁻¹ dry soil and 83.2 mg N kg⁻¹ dry soil while plots without bands averaged 535.8 mg C kg⁻¹ dry soil and 79.3 mg N kg⁻¹ dry soil, respectively.

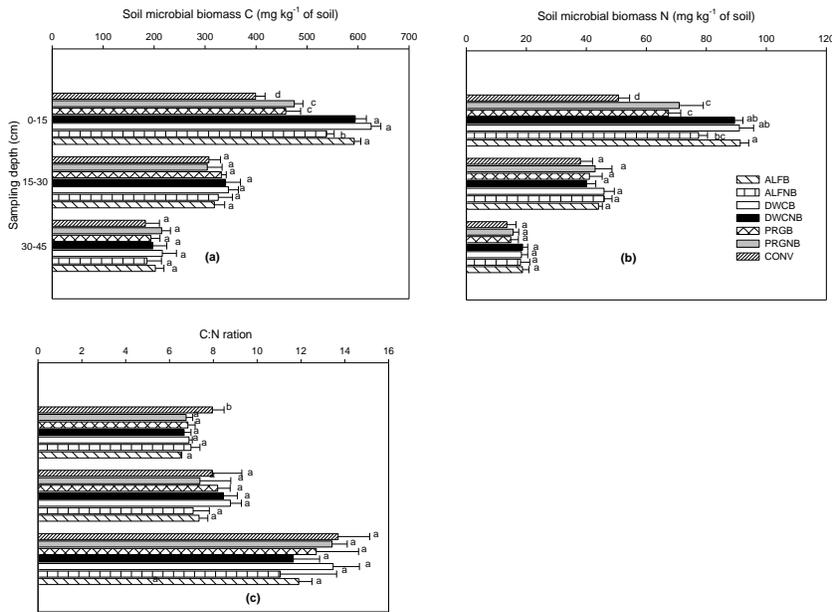


Figure 2: Soil microbial biomass carbon (a), microbial biomass nitrogen (b) and microbial biomass C:N ratio (c) as influenced by groundcover management. †Treatments are: Conventionally managed (CONV), Dutch white clover with banding (DWCB), Dutch white clover with no banding (DWCNB), alfalfa with banding (ALFB), alfalfa with no banding (ALFNB), perennial rye grass with banding (PRGB), and perennial rye grass with no banding (PRGNB). * Treatments with the same letter at each soil depth are not statistically different at $P > 0.05$. NS: treatment means are not significant.

Soil microbial biomass C: N ratio is often used to describe the structure and state of the microbial biomass (Moore et al. 2000). Bacteria and fungi generally comprise 90% of the total soil microbial biomass (Six et al. 2006) and the substrate quality is known to have a major influence on fungal: bacterial ratios, with low quality substrates (high C: N ratio) favoring fungi and high quality (low C: N ratio) substrates favoring bacteria (Bossuyt et al. 2001). High soil microbial biomass C: N ratio generally indicates higher fungi with respect to bacteria populations in this soil (Moore et al. 2000).

Across all treatments, SMB-C and SMB-N decreased with soil depth for all cover crop treatments (Fig 2-a and 2-b), and legume cover crops treatments generally yielded the highest microbial biomass C compared to grass cover crop and the conventional treatments. However, soil microbial biomass C: N ratio significantly ($P < 0.05$) increased with soil depth (Fig. 2-c), ranging from 6.5-7.1; 7.1-8.8 and 11.1-13.7 at the 0-15, 15-30 and 30-45 cm soil depths, respectively. This trend is the opposite of that observed for soil total C:N and could indicate a

shift in community composition, perhaps from a bacterial-dominated community on the top soil layer to a fungal-dominated community in deeper soil layers.

Community-level physiological profile of microbial communities

The color response in a given well is related to the number of microorganisms (functional diversity) which are able to use the substrate within the well as a sole carbon source, and are therefore used to assess microbial community structure in a given ecosystem (Garland and Mills 1991). Average well color development (AWCD) recorded as optical density (OD) and the number of well response expressed as the catabolic diversity from all groundcover management treatment followed the same pattern (sigmoidal curve) throughout the incubation period (Fig.3-a and 3-b) and the rate of increase varied with different treatments. However, both the AWCD and the catabolic diversity of communities from control plots were lower than the cover crop managed plots. These results suggest that microbial communities from the cover crop plots had higher substrate utilization rate than the control plots. Perennial rye grass plots treated with bands showed significantly higher overall AWCD values throughout the incubation period compared to perennial rye grass plots with unbanded treatments. However, the AWCD recorded from the two legume cover crop treatments, irrespective of the management type, were not statistically different. The number of well responses (catabolic richness) followed the same pattern as AWCD throughout incubation (Fig.3-b).

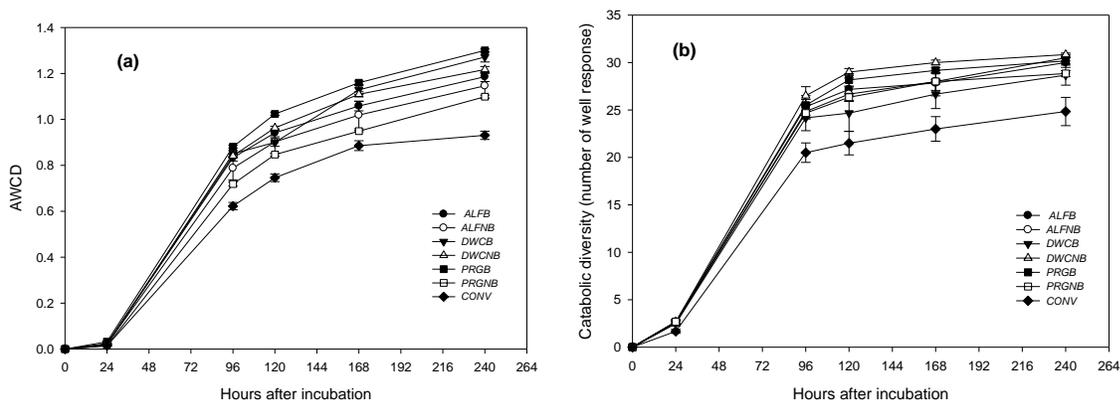


Figure 3: (a) Average well color development (AWCD) and (b) average catabolic diversity obtained from BIOLOG™ ecoplate incubation of all groundcover treatments in a Fraser fir plantation. Treatments are: Conventionally managed (CONV), Dutch white clover with banding (DWCB), Dutch white clover with no banding (DWCNB), alfalfa with banding (ALFB), alfalfa with no banding (ALFNB), perennial rye grass with banding (PRGB), and perennial rye grass with no banding (PRGNB).

In all the soil samples from the different groundcover treatments, only a few wells showed no color response after 96 h of incubation. Microbial community richness was significantly lower in the conventional plots than in all cover crop treatments ($P < 0.01$). Significant differences among treatments ($P < 0.01$) were found in catabolic richness, Shannon diversity and evenness (Fig. 4-a, b and c). All cover crop treatments, both with bands and no bands, had significantly higher ($P < 0.001$) microbial species catabolic richness levels than the conventional treatments (Fig. 4-a). However, there were no significant difference in microbial catabolic richness among cover crop treatments ($P > 0.05$).

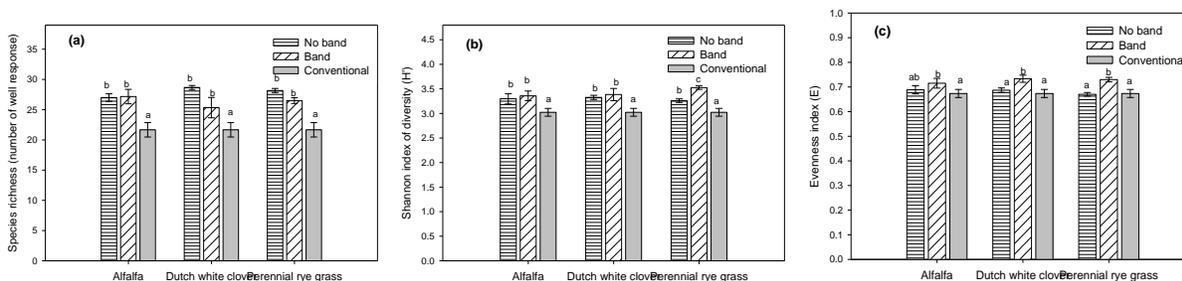


Figure 4: (a) Species richness (S), (b) Shannon index of diversity (H') and (c) Evenness index (E) as influence by different groundcover management. †Treatments are: Conventionally managed (CONV), Dutch white clover with banding (DWCB), Dutch white clover with no banding (DWCNB), alfalfa with banding (ALFB), alfalfa with no banding (ALFNB), perennial rye grass with banding (PRGB), and perennial rye grass with no banding (PRGNB). *Treatments with the same letter at each soil depth are not statistically different.

Plots managed with both legume cover crops, either with or without bands, had significantly higher Shannon-Weaver index means than the control. Similarly, the H' value was significantly higher in the banded non-legume cover plots than the control plots. Conversely, no statistical difference was found ($P > 0.05$) between plots managed with perennial rye grass without banding and the conventional plots. There was a statistically significant difference in H' between PRGB and PRGNB, suggesting that rye grass with banding management could develop a more diverse microbial catabolic diversity than rye without banding and control treatments, while for both legume cover crops, there was no significant difference in Shannon-Weaver index level between banding and no banding treatments. Using CLPP and genetic community structure, Wu et al. (2008) found that different agricultural practices in a given soil type greatly affect soil bacterial diversity and community structures. Mäder et al. (2002) found a significantly higher value for H' in organic systems compared to conventional farming systems.

In general, microbial species catabolic response was found to be significantly different among the various groundcover management practices ($P = 0.01$). Microbial species evenness index was the highest in DWCB and PRGB plots. The plots managed with DWCB and PRGB showed significant differences in microbial species evenness index compared to all other groundcover treatments, including conventional.

In order to determine the extent of differentiation between the conventional and the cover crop treatments with regard to carbon source utilization, the OD data from the various treatments were subjected to multivariate analysis (principal component and similarity distance cluster analyses). The trends observed on soil microbial biomass and CLPP data were supported by results from the multivariate analysis. Contrasting patterns were apparent between the cover crop treatments and the controls as a result of the different groundcover management practices (Fig 4-a&b).

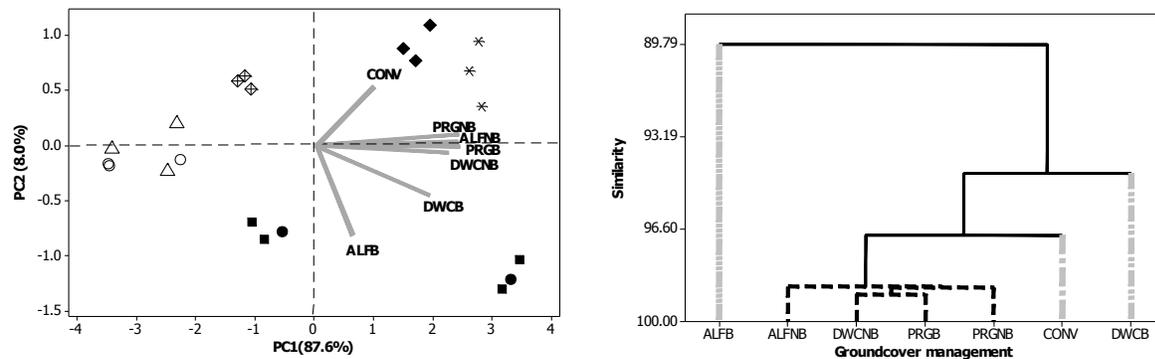


Figure 4: (a) PCA and (b) Cluster analysis performed on BIOLOG™ of soil extracts from different groundcover management treatments. †Treatments are: Conventionally managed (CONV), Dutch white clover with banding (DWCB), Dutch white clover with no banding (DWCNB), alfalfa with banding (ALFB), alfalfa with no banding (ALFNB), perennial rye grass with banding (PRGB), and perennial rye grass with no banding (PRGNB).

The separation of groundcover treatments in PC space can be related to differences in carbon source utilization by examining the correlation of the original variables to the PCs. The principal component analysis showed that the first principal component had high coordinate values (Eigen value) of 6.30 which explained 90.0% of the total variance in the data. The second principal component had variance 0.08 and accounted for 7.9% of the data variability. Together, the first two components of this PCA accounted for 97.9% of the variation in the data, with good discrimination ($P < 0.05$). The plots managed with the two legume cover crops with banding exhibited dissimilar patterns of substrate utilization.

Consistent with the soil microbial biomass data, CLPP profiles also showed that groundcover management with cover crops stimulated the development of a diverse microbial population to a larger extent than did CONV management. It is possible that low organic matter and nitrogen concentration as well as low plant root exudates in CONV management could be responsible for the low catabolic diversity of microbial population found on the CONV. This was consistent with previous observations that management practice and host plants influence bacterial community structures (Bossio *et al.* 1998, Buckley and Schmidt 2001).

CONCLUSIONS

This study investigated the effects of various groundcover management practices on soil microbial biomass in a Fraser fir tree production system. Overall, the results demonstrated the potential for various groundcover management practices to increase soil microbial biomass and soil organic matter in the top soil layer (0-15cm). However, we observed no significant effects of the groundcover management practices on soil moisture content, soil pH and soil organic C at this specific depth. Moreover, no significant differences were found on the effect of our groundcover treatments on all the various parameters in the deeper soil layers (15-30 and 30-45 cm). As expected, soil moisture, soil organic carbon and nitrogen significantly decreased with soil depth.

Analysis of the soil microbial biomass carbon and nitrogen data indicated that leguminous cover crops (alfalfa and Dutch white clover) significantly increased soil microbial biomass C and N at

the soil surface layer (0-15 cm depth). Perennial rye, a non leguminous cover crop, also increased soil microbial biomass C and N, but at a much lower level compared to the legume cover crops. Cover cropping, management practices (banding and no banding) and cover crop species all affected soil bacterial diversity and communities at different levels. A significant shift in the structure of soil bacterial communities was associated with groundcover management practices.

The study also indicated that groundcover management with leguminous cover crops was more efficient at improving soil microbial biomass quotients than non-leguminous cover crops due to the quality and quantity of the green manure mowed and returned into the system. These preliminary results indicate that inclusion of leguminous or non-leguminous cover crops into Fraser fir production systems can lead to healthier soil by improving soil organic matter compared to conventional practices. The microbial community diversity as well as nitrogen fluxes, and their effect on tree growth are being investigated to confirm these trends and determine the overall impact of these management practices on Fraser fir production.

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EXPERIENCES FROM SOUTHERN QUEBEC PROVIDE ECOLOGICAL INSIGHTS FOR THE IMPLEMENTATION OF TREE-BASED INTERCROPPING SYSTEMS

David Rivest¹, Vincent Chiffлот², Simon Lacombe³, Alain Cogliastro⁴, Robert Bradley³, Anne Vanasse¹, Damase Khasa² and Alain Olivier¹

¹ Département de phytologie, Université Laval, Québec (QC), Canada.

² Département des sciences du bois et de la forêt, Université Laval, Québec (QC), Canada.

³ Département de biologie, Université de Sherbrooke, Sherbrooke (QC), Canada.

⁴ Institut de recherche en biologie végétale, Université de Montréal & Jardin botanique de Montréal, Montréal (QC), Canada.

Contact: alain.olivier@fsaa.ulaval.ca

Abstract: Recent experiments in Quebec aimed to provide scientific arguments favouring the adoption of tree-based intercropping (TBI) systems in eastern Canada's rural landscape. The specific objectives of this research were to: (1) test whether a soybean intercrop between tree rows increases soil microbial biomass C, soil N fertility and tree growth compared to a harrowing treatment between tree rows; (2) determine the effects of the soybean intercrop on the diversity of arbuscular mycorrhizal fungi (assessed using SSU rRNA genes) compared to harrowing; and (3) determine whether TBI increases soil microbial beta-diversity (assessed using extractable phospholipid fatty acid (PLFA) profiles) compared to an adjacent conventional monocropping system. The TBI field was set in 2000 in southwestern Quebec using alternating rows of hybrid poplars (*Populus* spp.) and hardwood species spaced 8 m apart. Soybean (*Glycine max* L. (Merr.)) was grown between tree rows since 2004. During the 2005-2006 study period, soil microbial biomass C and N availability were higher in the soybean intercrop treatment or on par with those in the harrowing treatment. Hybrid poplar biomass increment in the soybean intercrop treatment was greater by 51 % to that in the harrowing treatment and diagnostic of leaf nutrient status indicated that hybrid poplars were positively affected by the increase in N supply provided through intercrop management. The arbuscular mycorrhizal fungal diversity, as expressed by the Shannon-Wiener indices, were 0.82 for the soybean and 0.70 for hybrid poplar under the soybean intercrop treatment, and 0.53 for hybrid poplar under the harrowing treatment. The neighboring trees and soybean plants hosted different arbuscular mycorrhizal fungal communities, suggesting that TBI systems may enhance arbuscular mycorrhizal fungal richness compared to monocultures. The soil microbial beta-diversity, based on a measure of dispersion among the PLFA profiles within each sampled grid, was higher in the TBI than in the conventional soybean monocropping system, suggesting that TBI systems could play an important ecological role in the conservation of microbial functions (e.g., nutrient cycling), even in the face of wide variations of environmental conditions and inputs.

Key Words: arbuscular mycorrhizal fungi, hybrid poplar, soil microbial beta-diversity, soil quality, soybean, tree growth

INTRODUCTION

Tree-based intercropping systems (TBI), that combine widely spaced rows of trees and agricultural field crops, have shown great potential in terms of biodiversity conservation, carbon sequestration and water quality enhancement (Thevathasan et al. 2004). Interactions between trees and intercrops growing in close proximity may also include positive effects on soil quality and nutrient availability (Jose et al. 2007). These effects will depend on factors such as fertilization of the intercrop and mulching to prevent weed competition near tree rows. In this study, the effects of a soybean intercrop on indices of soil quality such as microbial biomass and inorganic N, as well as on hybrid poplar growth, were measured.

Because of their role in plant nutrient uptake and growth, arbuscular mycorrhizal fungi are of particular importance in agricultural and tree plantations systems. It has been pointed out that crop plants may facilitate mycorrhizal colonization and growth of recently planted tree seedlings (Enkhtuya and Vosatka 2005). In turn, the trees in TBI systems, as well as the adjacent herbaceous strip below them, could act as a permanent reservoir of arbuscular mycorrhizal fungal propagules (Ingleby et al. 2007), potentially benefiting future crop plants. In this study, molecular approaches were used to provide insights into the community diversity of arbuscular mycorrhizal fungi.

It is also known that the integration of trees into cropping systems may increase soil organic matter content due to the deposition of tree leaves and the turnover of their fine roots (Peichl et al. 2006), which may help to improve soil microbial activity. Differences in litter quality between trees and crops may also result in the development of distinct microbial communities, especially when compared to the rows of trees (Mungai et al. 2005). Soil microbial diversity is an important aspect of soil quality since it may ensure higher redundancy and stability of soil ecological functions. In this experiment, soil microbial beta-diversity was studied using extractable phospholipids fatty acids analysis.

The objective was to provide ecological insights on the interest of implementing TBI systems in southern Quebec, where they had not been tested yet.

MATERIAL AND METHODS

Experimental site and field operations

The experimental site was established near the town of St-Rémi (45°14' N, 73°40' W), in southern Quebec, Canada. Alternating rows of hybrid poplars (*P. nigra* x *P. maximowiczii*) and high-valued hardwood species (*Juglans nigra* L., *Fraxinus americana* L.), spaced 8 m apart, were planted in 2000. Twenty-cm cuttings of hybrid poplars were planted every 2 m along the row. Seedlings of hardwood species were planted every 3 m along the rows. In the winter of 2006, a thinning permitted the spacing between hybrid poplars in each row to be increased from 2 to 6 m.

Two treatments were introduced in June 2004: a TBI system comprising a soybean intercrop and a harrowed tree plantation system without intercrop. Each plot was bounded on each side with a row of hardwood species, with two alleys in the middle separated by one row of hybrid poplars.

Soybean (cv. S03-W4) was sown with a no-till planter on June 11, 2005 and July 3, 2006. Before sowing, the soil was amended with a N-P₂O₅-K₂O fertilizer (300 kg ha⁻¹ of 5-27-24 in 2005 and 275 kg ha⁻¹ of 9-24-21 in 2006). In the harrowing treatment, the herbaceous vegetation was harrowed (0-10 cm depth) on June 1 and July 14 in 2005, and on June 26 in 2006. Along each tree row, herbaceous vegetation was controlled by means of a 1.5 m-wide black polythene-film mulch.

Soil sampling and analyses

For soil microbial biomass C and inorganic N, 16 soil cores (33 mm diameter, 0-15 cm depth) were collected in each of eight 288 m² (18 m x 16 m) plots on several dates along transects at 0 m (beneath the mulch), 2 m and 5 m from hybrid poplar rows (east side), and bulked into two composite samples per distance. Sampling dates were June 27, August 8, October 2, 2005, and July 30, August 29, September 21, 2006 for microbial biomass C, and July 20, September 6, 2005, and July 30, August 29, September 21, 2006 for inorganic N.

Microbial biomass C was determined by substrate-induced respirometry (SIR) (Anderson and Domsch 1978). Fresh subsamples (ca. 32 g dry mass equiv.) were placed into 500 ml plastic containers and amended with ground and sieved (65 μm) glucose (1000 μg C g⁻¹) (Bradley and Fyles 1995). The amendments were applied as 250 mg mixtures with talc and dispersed throughout the soil subsamples using a spatula. Amended subsamples were transferred into 126 ml gas sampling jars and left uncovered for 100 min to reach optimum SIR rates. Subsamples were then flushed for 5 min with ambient air, sealed for 30 min, and headspace air was analyzed for CO₂ concentration using a GC. SIR rates were converted to microbial biomass C using equations derived by Anderson and Domsch (1978).

Inorganic N (NH₄⁺-N and NO₃⁻-N) concentrations were determined by extracting fresh soil subsamples (ca. 20 g) in 100 ml of 1 M KCl solution (1 h on a reciprocal shaker), filtering the extracts (Whatman No. 5), and analyzing the filtrates colorimetrically for NH₄⁺ and NO₃⁻ using a Technicon autoanalyzer (Pulse Instrumentation, Saskatoon, SK, Canada).

For the study of the diversity of arbuscular mycorrhizal fungi, soil cores were collected from twelve 864 m² (54 m x 16 m) plots on July 20, 2005. Live roots were collected from each of the 192 samples. Details on the analysis procedure are provided in Chiffot et al. (2009).

For the study of the microbial beta-diversity, a rectangular grid of 56 sampling points, spaced 1 m apart, was established between tree rows. Soil cores (10 cm wide, 15 cm deep) were collected in late August 2006. Details on the analysis procedure are provided in Lacombe et al. (2009).

Hybrid poplar biomass increment and nitrogen response efficiency

Hybrid poplar height and diameter at breast height (DBH) were measured at the end of each growing season (November) between 2004 and 2006. The aboveground biomass (stem + branches) of each tree was estimated following a generalized hybrid poplar biomass equation by Ben Brahim et al. (2000). In each plot, the total hybrid poplar biomass increment (Mg DM ha^{-1}) was calculated as the increase in dry mass between November 2004 and November 2006. This value was scaled up assuming a stand density of 313 and 104 hybrid poplars ha^{-1} in 2005 and 2006, respectively.

The ratio of plant production to available N, referred as nitrogen response efficiency (NRE, Bridgham et al. 1995), was estimated in each plot, assuming that net N-mineralization (ammonification + nitrification) over a 28 d aerobic incubation constituted a good index of plant-available N. The amounts of mineralized N were averaged across the five incubation periods, converted to an areal basis using bulk density, then reported in kg ha^{-1} and multiplied by the number of growing-days, assuming a frost-free period of 161 days in 2005 and 158 days in 2006, respectively.

Statistical analyses

Within each sampling date, the effects of treatment and distance from the hybrid poplar row on soil microbial C and inorganic N were tested by means of analysis of variance (ANOVA) for a randomized complete block, split-plot design with the treatment as the main plot, and distance as the subplot factor. The effects of treatments on hybrid poplar biomass increment and NRE were analyzed using one-way ANOVA. Significantly different means were separated using Tukey's multiple comparison test.

Arbuscular mycorrhizal fungal diversity was evaluated using the Shannon-Wiener index. Two-way ANOVA and Tukey's multiple comparison test were used to compare diversity among hosts (hybrid poplars and soybean) and distances from the hybrid poplar row (0.5, 2, 3.5 and 5 m). Univariate ANOVA tests following multivariate analyses of variance (MANOVA) were performed to assess the effect of soybean on the relative abundance of phylotypes associated with hybrid poplar roots.

Regarding soil microbial beta-diversity, the multivariate data set was analyzed with PERMDISP software (Anderson 2004), a non-parametric and multivariate permutational extension of Levene's test for equality of variances.

RESULTS

Effects of a soybean intercrop on soil microbial biomass C, soil N fertility and tree growth

During the 2005-2006 study period, soil microbial biomass ranged from 0.23 to 0.92 $\text{g C}_{\text{mic}} \text{kg}^{-1}$. Across all distances from hybrid poplar trunks, soil microbial biomass C in the soybean intercrop treatment was on par with that in the harrowing treatment in all of the six sampling dates, except

for the last one in September 2006, when microbial biomass was 27 % higher in the soybean intercrop plots than in the harrowing plots ($P = 0.04$).

During the same period of time, soil N availability was also higher in the soybean intercrop treatment or on par with that in the harrowing treatment. Soil inorganic N, that ranged from 3.5 to 38.4 $\mu\text{g mg}^{-1}$, was higher, across all distances, in the soybean intercrop treatment than in the harrowing in two of the five sampling dates (July and August 2006, $P = 0.001$ and $P = 0.04$, respectively).

Hybrid poplar biomass increment in the soybean intercrop treatment was greater by 51 % to that in the harrowing treatment (6.29 vs 4.17 Mg ha^{-1} , $P = 0.01$). NRE in the TBI treatment was 47 % higher than that in the harrowing treatment (17.70 vs 12.05 $\text{kg dry mass kg}^{-1} \text{N}_{\text{mineralized}}$, $P = 0.007$).

Effects of a soybean intercrop on the diversity of arbuscular mycorrhizal fungi

The highest arbuscular mycorrhizal fungal diversity occurred under the soybean intercrop and the lowest under the hybrid poplars of the harrowing treatment. The arbuscular mycorrhizal fungal diversity, as expressed by the Shannon-Wiener indices, were 0.82 for soybean and 0.70 for hybrid poplar under the soybean intercrop treatment, and 0.53 for hybrid poplar under the harrowing treatment. However, differences between the hosts and between distances from the trunk were not statistically significant.

The arbuscular mycorrhizal fungal community structure was also studied for soybean and hybrid poplars under the TBI system, and for hybrid poplars under the harrowing treatment. Under the TBI system, nine phylotypes were associated with soybean roots and ten with hybrid poplar roots, among which seven were common to both plants. Eight phylotypes were found on hybrid poplar roots under the harrowing treatment.

Analysis of the composition of the arbuscular mycorrhizal fungal phylotypes by MANOVA showed a significant effect of the plantation system (soybean intercrop or harrowing) on the arbuscular mycorrhizal fungal community of hybrid poplar roots ($F=4.81$, $P=0.0276$).

Effects of a TBI system on soil microbial beta-diversity

The soil microbial beta-diversity in the St-Rémi site, based on a measure of dispersion among the PLFA profiles within each sampled grid, was higher in the TBI system than in the conventional soybean monocropping system. According to the PERMDISP procedure, a significantly higher dispersion of PLFA profiles was observed in the TBI system than in the conventional soybean monocropping system.

DISCUSSION

Effects of a soybean intercrop on soil microbial biomass C, soil N fertility and tree growth

Soil microbial biomass tended to be higher in the soybean intercrop plots than in the harrowing plots at the end of the first growing season, and was higher in the soybean intercrop than in the harrowing treatment at the end of the second growing season. This could be due to a greater quantity and higher quality of plant litter. The litter inputs in the harrowing plots mainly came from hybrid poplar and some weeds while, in soybean intercrop plots, they came from both hybrid poplar and soybean residues. Since soybean litter is generally of higher lability than tree litter (Mungai and Motavalli 2006), soybean residues would result in higher nutrient turnover rates that would benefit hybrid poplar growth.

The increase in soil inorganic N in the soybean intercrop plots on some sampling dates is consistent with observations made by Wang et al. (2005) in subtropical TBI systems. Since the amount of fertilizer that was applied in the present study was relatively low (it was designed to deliver no more than 15 % of total crop requirement), the increase in soil NO_3^- in 2006 was due to the decomposition and mineralization of soybean residues that had been incorporated in June 2006. Thus, soybean intercrop would have the potential to improve soil nutrient supply for the trees.

It also seems that the soybean intercrop treatment may outperform the harrowing treatment in terms of hybrid poplar growth, since hybrid poplar biomass increment was greater in the soybean intercrop treatment. Diagnostic of leaf nutrient status indicated that hybrid poplars were positively affected by the increase in N supply provided through intercrop management.

Effects of a soybean intercrop on the diversity of arbuscular mycorrhizal fungi

The results of the study show that the diversity of arbuscular mycorrhizal fungi was not statistically different from one host to another. However, co-occurring trees and crops showed differences in their respective arbuscular mycorrhizal fungal communities. Jansa et al. (2002) pointed out that the Shannon-Wiener index may not properly reflect the community structure, especially when the differences in abundance between the species are large, as was the case in the present study. Nevertheless, the diversity of arbuscular mycorrhizal fungal phylotypes tended to be higher in soybean roots than in hybrid poplar roots. This supports the idea that arbuscular mycorrhizal fungi would show host preference in the presence of co-occurring plant roots.

The results of the study also suggest that intercropping hybrid poplars with soybean positively affects the diversity of arbuscular mycorrhizal fungi colonizing tree roots as compared to the harrowing treatment. Although not statistically significant, the diversity of arbuscular mycorrhizal fungal phylotypes found on hybrid poplar roots tended to be higher under the TBI system than under the harrowing treatment. The possible role of co-occurring roots of soybean in facilitating arbuscular mycorrhizal fungal colonization of trees via ERM links (Enkhtuya and Vosatka 2005) should be considered.

Effects of a TBI system on soil microbial beta-diversity

The higher heterogeneity that was observed in the TBI system as compared to the conventional soybean monocropping system suggests that TBI systems could play an important ecological role in the resistance of microbial functions (e.g. nutrient cycling) to a wide variation of environmental conditions and inputs.

CONCLUSION

This study provided some evidence that TBI systems involving a soybean intercrop treatment, as compared to the harrowing treatment, could lead to increased soil quality by increasing microbial biomass and N fertility. It also showed that the soybean intercrop management significantly benefited hybrid poplar growth.

This study also suggests that a soybean intercrop could positively affect the arbuscular mycorrhizal fungal community structure of hybrid poplars, as compared to the harrowing treatment. The enhancement of soil microbial diversity could result in a greater conservation of microbial functions in the face of environmental stresses.

All these results suggest that TBI systems could be a valuable alternative to conventional tree plantation in terms of ecological functions and tree growth.

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SECTION 1 1

Production and Management

SEASONAL DIFFERENCES IN CLEAR-SKY NIGHTTIME FORAGE TEMPERATURE IN PROXIMITY TO DECIDUOUS TREES

C.M. Feldhake

USDA-ARS, Appalachian Farming Systems Research Center,
1224 Airport Rd., Beaver, WV, 25813
Contact: Charlie.feldhake@ars.usda.gov

Abstract: Considerable research has been done on daytime forage shading by silvopasture trees since solar radiation is required for photosynthesis. However, trees also impact nighttime temperature on clear nights when trees also effectively shade forages from cold skies. Appalachia has a temperate climate and deciduous-tree silvopasture nighttime temperature patterns will differ between spring before tree leaves emerge and summer when trees are in full canopy. Longwave radiation sensors, which simulate forage (surface) temperature, were installed in triplicate at four locations differing in obstruction to open sky by trees. An open pasture site (O) had 90% exposure to open sky during summer. A site within an adjacent closed-canopy second growth mixed hardwood forest (F), with only small canopy gaps, had 10% exposure to open sky. Two intermediate sites within a 15 X 50m gap cleared into the forest had 20 and 40% exposure to open sky respectively (G2 and G4). Air temperature was recorded at 2m at all sites. Temperatures were measured every 10s and hourly averages recorded from 1-Feb.-2008 through 10-July-2008. Summer differences between surface and air temperature in response to radiation cooling during clear night hours were -6.7, -2.9, -1.5, and -0.7°C for sites O, G4, G2, and F respectively. Respective late winter and early spring temperature differences were -6.3, -6.4, -5.7 and -4.3°C. There was a threefold difference between longwave radiation forage cooling at O compared to F in summer compared to early spring. Also, summer surface-air temperature differentials increased linearly as sky exposure increased. During tree leafless periods, temperature differentials were constant down to 40% sky exposure but decreased exponential approaching 10% sky exposure. During periods with full cloud cover there were no site temperature differences between air and surface during either season. These results suggest different forage management strategies in response to different forage nighttime temperatures may be warranted.

Key Words: Appalachia, cloudiness, forage, longwave radiation, silvopasture

INTRODUCTION

Longwave radiation loss at night has been a concern in agriculture and forestry primarily in relation to damage caused by radiation frost. Providing a vegetative cover over plants needing protection minimizes the risk of radiation frost damage since the cover remains near air temperature which is much warmer than a clear night sky (Carsmori ete al., 1996; Scowcroft et al., 2000; Langvall and Orlander, 2001). Radiation frost is a concern at ground surface level since air density increases as it cools so ground surface temperatures can become considerable cooler than the standard air temperature measured with weather stations at 2m height.

A sensor has been developed that measures temperature to which forage canopies are exposed during radiation frost events (Feldhake, 2002). Temperature measured closely tracked forage canopy temperature measured with an infrared thermometer during nighttime. There was a linear relationship between the percent open sky to which forage was exposed on clear nights and the depression of forage canopy temperature below air temperature measured at a 2 m height.

However, clear sky radiation cooling affects biological processes in ways other than frost damage. Other process in silvopasture systems such as forage canopy respiration and tree litter decomposition are affected by temperature. The Q_{10} , (rate of increase in biological processes with 10 degree increase in temperature) has been extensively studied for over a century and itself varies over different temperature ranges (Yuste et al. 2004).

In silvopastures shading of solar radiation by trees results in decreased understory temperatures during the daytime while shading from open sky longwave radiation loss results in increased nighttime temperature.

Deciduous trees provide a changing annual microclimate since the amount of open sky obscured varies greatly between periods with leaf filled tree canopies and periods with bare branches.

MATERIALS AND METHODS

This research was done at the interface of a pasture and mature second growth mixed hardwood forest, dominated by white oak (*Quercus alba*), red oak (*Quercus rubra*), red maple (*Acer rubra*), and yellow poplar (*Liriodendron tulipifera*), in southern West Virginia (37°46'W latitude 81°00'N longitude 860 m.a.s.l.). A 15m wide by 50m deep gap had been previously cleared into the forest from the pasture edge and established with forage to simulate silvopastures with varying degrees of influence from mature trees. Four measurement sites were chosen to give different exposure to open sky. A 90 % exposure site was in the adjacent open pasture (O), a 40% exposure site was in the center of the gap (G4), a 20% exposure site was at the deepest edge of the gap (G2), and a 10% exposure site was within the second growth forest (F).

At each site three radiation frost potential (RFP) sensors (Feldhake 2001) were installed. These sensors provide a temperature value representative of a 10 cm height forage canopy temperature. The sensors are comprised of a copper-constantan thermocouple epoxyed to the bottom center of a 5.3 cm square sheet metal that is thermally isolated from the metal rod to which it is attached for placement into the ground. A shielded thermocouple placed at 2m height gave a reference air temperature at each site. Measurements from all sensors were recorded using a Campbell 21X data logger (Campbell Scientific, Logan, UT) at 10 s intervals with 5 min and hourly averages.

RESULTS

The difference between under-tree surface and air temperature is influenced not only by the amount of sky obstruction by tree vegetative parts (leaves and branches in summer, branches only in winter) but also by cloud cover. At the open pasture treeless site (O) the summer surface-air temperature differential ranged from a maximum -8 °C to 0 °C on heavily overcast

nights (Fig. 1). The distribution for each hour across all summer dates was fairly uniform reflecting the distribution of cloud cover in this humid-climate area. There tended to be a smaller surface-air temperature differential near dawn since this area commonly has fog which acts like cloud cover.

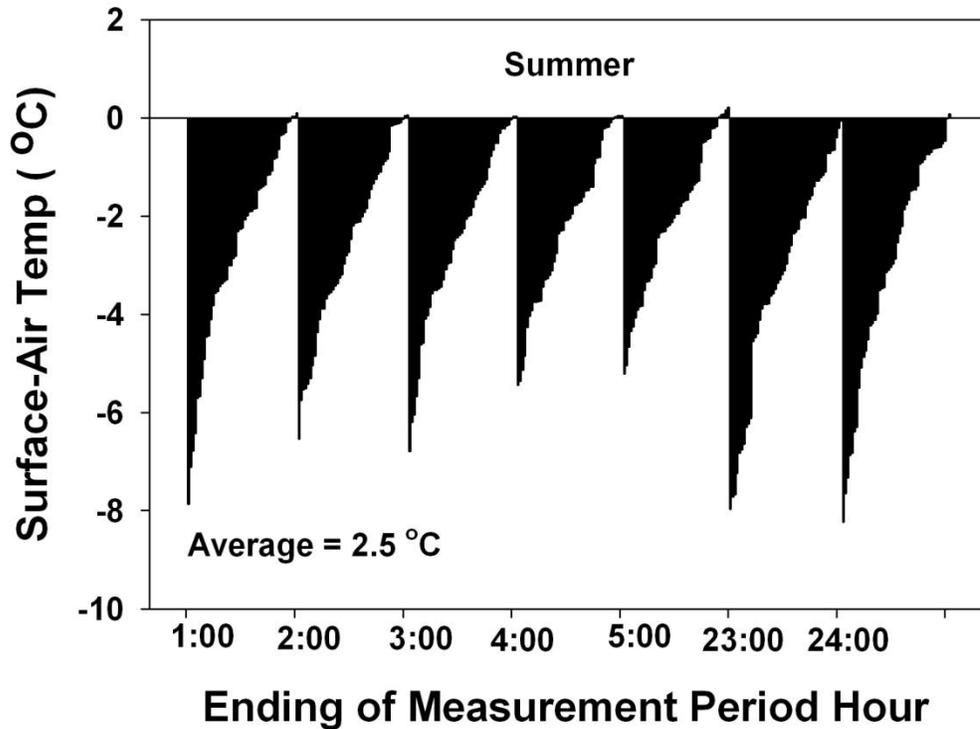
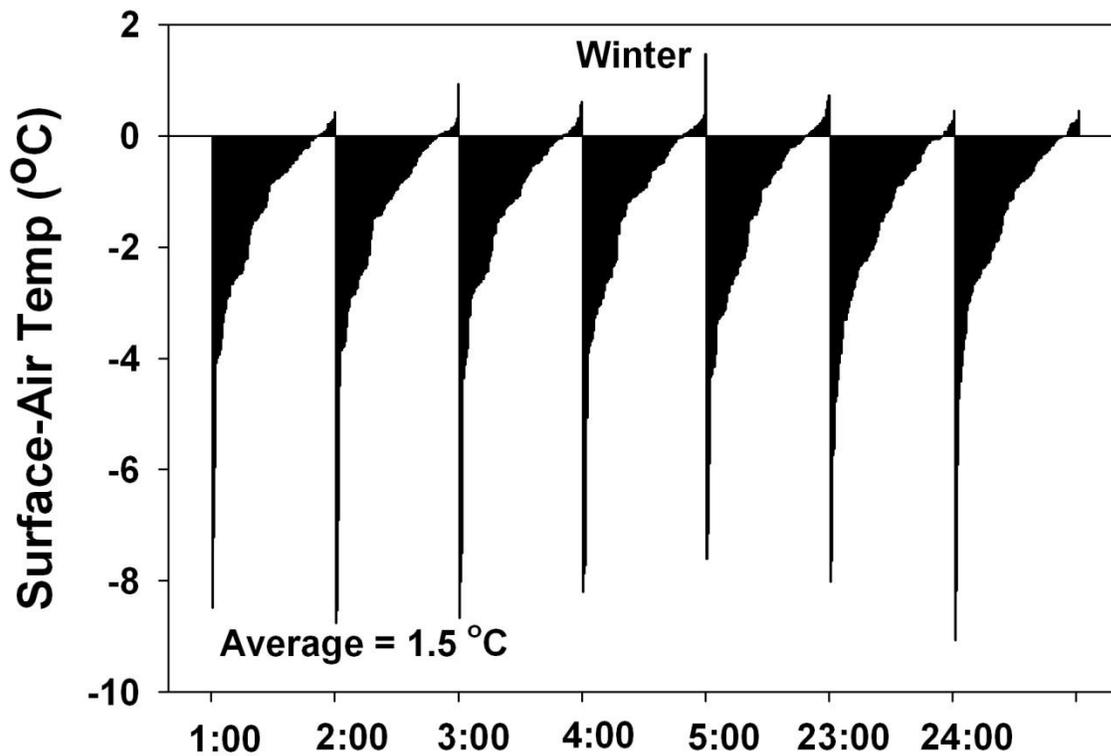


Figure 1. Distribution of hourly surface-air temperature differences for the open (O) site for the period 22-May-2008 through 10-July-2008.

In winter there are sometimes positive surface-air temperature differentials likely because the ground is covered with largely senesced grass and without transpiration the ground will heat more on sunny days relative to during summer (Fig. 2). The largest surface-air temperature differentials are around 8 °C as in the summer however the distribution is skewed toward smaller surface-air temperature in general relative to summer suggesting a greater degree of nighttime cloudiness.



Ending of Measurement Period Hour

Figure 2. Distribution of hourly surface-air temperature differences for the open (O) site for the period 1-Feb-2008 through 20-April-2008.

In order to analyze tree influence on nighttime surface-air temperature differential, the 36 largest hourly differentials for summer and winter respectively were averaged. When plotted as a function of summertime percent open sky for each site, a very different relationship results for each season. The summer response is linear as theory predicts (Fig. 3). In winter, however, the surface-air temperature is not impacted by trees until approaching down to the 20 percent summer open sky value when it begins to increase exponentially. There are likely two factors contributing to this relationship. The first is that in proximity to trees wind movement is suppressed more than in an open field allowing a more stable boundary layer which facilitated more efficient radiative cooling of the surface. This offsets some of the re-radiation of thermal energy from sparse tree branches. The second factor is that trees exposed to open sky will produce more leaves relative to branches thus a closed forest will have more branches to re-radiate thermal energy and decrease the surface-air temperature differential.

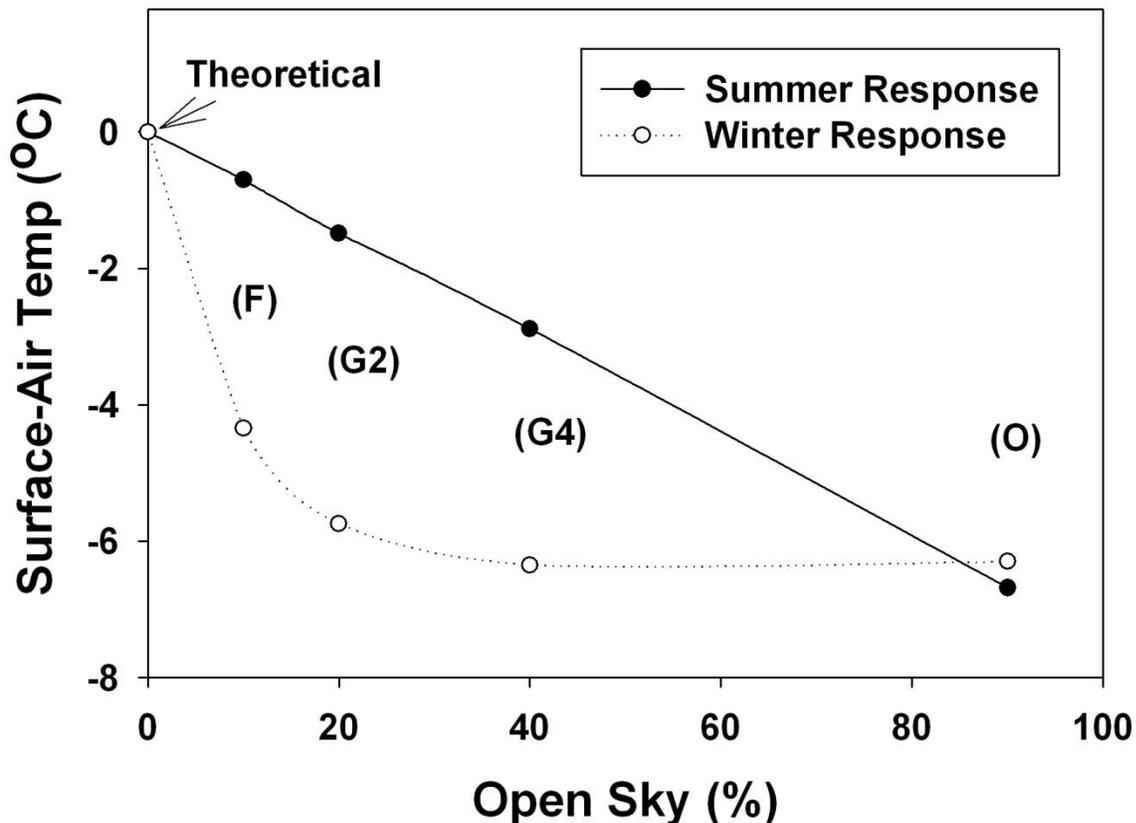


Figure 3. Average clear-sky surface-air temperature differences for summer and winter at the four measurement sites designated as forested (F), 20% open sky (G2), 40% open sky (G4), and open field (O) along with the theoretical complete sky obstruction value.

CONCLUSIONS

In the humid Appalachian region, there are more relatively clear sky nights that allow cooling of forages in open fields in summer than in winter. Deciduous tree silvopastures provide a linear increase in forage canopy temperature with sky obstruction relative to open fields in summer which can contribute to higher nighttime plant respiration. Nighttime warming under trees will also decrease dew deposition and impact the hydrologic budget and possibly the incidence of disease. During the winter deciduous trees have little impact on the nighttime surface-air temperature differential although the effect increases rapidly at very high tree densities. During cloudy periods trees have little impact on surface-air temperature differential during both summer and winter. These results suggest different forage management strategies during summer in response to different forage nighttime temperatures may be warranted depending on local frequency of clear skies.

Disclaimer: Mention of equipment does not imply endorsement by USDA-ARS but is supplied to inform readers of how data was acquired.

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MICROCLIMATE MODIFICATION BY TREE WINDBREAKS IN FLORIDA FARMS

Bijay Tamang^{1, *}, Donald L Rockwood¹ and Michael G. Andreu²

¹ PO Box 110410, School of Forest Resources and Conservation, University of Florida, Gainesville, FL 32611

² SFRC, University of Florida, Gulf Coast REC — Plant City, 1200 N Park Road, Plant City, FL 33563

*Contact: bijay@ufl.edu

Abstract: Florida citrus and vegetable crops generate billions in revenue every year. However, winds, freezes, hurricanes, and citrus canker (*Xanthomonas campestris*) impact production. Windbreaks located perpendicular to the prevailing wind can reduce soil erosion and increase irrigation efficiency and farm production mostly by simply modifying microclimate. Windbreaks can also control the spread of pathogens such as citrus canker. To study how tree windbreaks modify microclimate in southern Florida, weather stations were established in 2008 along transects behind a 1-row eastern redcedar (*Juniperus virginiana*) windbreak at the Southwest Florida Research and Education Center (SWFREC/University of Florida) at Immokalee, and a 1-row cadaghi (*Corymbia torelliana*) windbreak at C&B Farms, Clewiston, to assess spatial variation in wind speed, temperature, and relative humidity at 2m above the ground. The windbreaks significantly reduced wind speed; minimum wind speed was at two times the windbreak height (2H) behind dense (17% porosity) redcedar and at 6H behind relatively porous (20% porosity) cadaghi when the wind direction was nearly perpendicular to the windbreak. Wind speed at 2H behind eastern redcedar was approximately 5% of the open wind speed and at 6H behind cadaghi was approximately 3-30%. Wind speed at 14H behind cadaghi and redcedar windbreak was approximately 60% and 80% of the open wind speed, respectively. Temperature behind both windbreaks was relatively warmer than in the open. However, the extent of temperature and relative humidity modification was less compared to wind speed. Windbreaks are an effective use of forest trees to modify microclimate and appreciably enhance Florida farm production.

Key Words: Agroforestry, shelterbelt, porosity, wind reduction; microclimate modification

INTRODUCTION

Damages to crops by high winds and nutrient loss through soil erosion are widely recognized in agricultural systems. This has been a major problem in areas where top soil contains the nutrients. Studies have shown that wind transported soil contains more nutrient than the top soil from where it is derived from (Nuberg 1998, Sudmeyer and Scott 2002). Strong wind also reduces flowering, increases flower shedding, reduces pollination and increases endosperm abortion in some fruit trees such as cherry. Finally, high winds may reduce the number of pollinators such as bees (Peri and Bloomberg 2002).

Windbreaks are widely used to reduce the impact of high winds. They have proved to be promising for sustainable agriculture and provides both sustainable production and conservation attributes. Well designed windbreaks located in the direction of prevailing wind increase both crop and livestock productions, reduce wind erosion, provide shelter for structures and livestock, improve microclimate and improve irrigation efficiency. Windbreaks also control the spread of pathogen such as citrus canker (*Xanthomonas campestris*). In addition, they increase nitrogen uptake leading to better plant growth and yield (Shah and Kalra 1970).

Florida is the major citrus producer and one of the leading vegetable producers in the U.S. (FDACS 2007). Both productions are profitable and generates about \$20 billion annually. Citrus alone contributed about \$9.29 billion in 2003/04 season (Hodges et al. 2006). Agriculture in Florida is still profitable exporting products to other US states and 140 countries across the globe (FDACS 2007).

Increase in disease incidences in citrus (canker and greening), impact of high winds (including hurricanes) and freezing temperatures have threatened Florida agriculture recently. Limited information is available on citrus greening and growers are exploring new ways to control it. Citrus canker is caused by bacteria and spread through wind and rain splashes. The spores are carried to nearby trees/areas by rain splash and wind. Its spread intensifies during catastrophic events such as hurricane.

During 2004 hurricane season, more than 80,000 acres of commercial citrus were believed to be infected or exposed to citrus canker and infected trees were removed and destroyed (about 120,000 trees per week). Hurricane Wilma in October 2005 further spread the disease from about 32,000 infected acres that remained to be destroyed and experts believed that additional 168,000 to 220,000 acres had to be destroyed to eradicate the disease. Due to citrus canker and greening disease in 2004/2005, experts suggest that the state will never reach the level of citrus production prior to 2003.

Windbreaks are widely used in South America and Australia for canker control and are effective in controlling both spatial and temporal spread (Leite and Mohan 1990, Smith and Papacek 1991, Gottwald and Timmer 1995). Citrus growers in Florida are following the same practices and are introducing windbreaks in their groves. Due to urgency, growers are using non-native fast-growing species such as cadaghi (*Corymbia torelliana*) and other eucalypts. Growers seem to prefer cadaghi because of its fast growth, dense canopy and lower branch retention. In Florida, the species has been successfully planted in windbreaks.

This study evaluated the effectiveness of established eastern redcedar (*Juniperus virginiana*) and cadaghi windbreaks and studied the extent of microclimate modification in the protected area.

MATERIALS AND METHODS

Study Area

The study was conducted at SWFREC and C&B Farms, Clewiston. SWFREC has a 20-year-old eastern redcedar windbreak which marks the northern boundary of the property. At C&B Farms,

several cadaghi windbreaks divide the farm into blocks. Windbreaks are planted approximately every 305m (1000ft) and are of various ages. Sugarcane windbreaks planted within the blocks further divide the farm into sub-blocks. Windbreak 1 which marks the northern boundary is the oldest windbreak (20-years-old). Windbreak 2 is south of windbreak 1 by about 305m. The characteristics of the windbreaks are given in Table 1.

Table 1: Characteristics of the windbreaks in the study area

Windbreak	No. of rows	Age (Yrs)	Height (m)	DBH (cm)	Porosity (%)	Crown length (m)	Spacing (m)
Eastern redcedar	Single	20	7.3	14.6	17	6.9	1.2
Cadaghi WB 1	Single	20	17.5	40.5	20	13.9	2.3
Cadaghi WB 2	Single	8	10.3	24.6	39	9.4	4.9

Methods

Automated weather stations were installed at 2H (distance equivalent to twice the windbreak height H), 6H, 10H and 14H along two separate transects on the leeward side of the windbreak at SWFREC between January and June of 2008. At C&B Farms, established sugarcane windbreaks provided open space only for a transect. Measurement stations were established between Windbreak 1 and Windbreak 2 along a transect perpendicular to both the windbreaks. Automated weather stations were installed at 2H, 6H and 10H from windbreak 1. Another series of stations were installed at 2H, 6H and 8H from windbreak 2 along the same transect. Stations at 10H, 6H and 2H from windbreak 1 were approximately at 15H, 23H and 31H from windbreak 2. Similarly, stations at 8H, 6H and 2H from windbreak 2 are approximately at 13H, 14H and 16H from windbreak 1.

At each monitoring station wind speed, temperature and relative humidity were measured at a height of 2m above the ground. Wind speed was measured using HOBO wind speed smart sensors (Part: S-WSA-M003) and temperature/relative humidity was measured using HOBO temperature/relative humidity sensor (Part: S-THA-M002). Automatic measurements were taken every 30 seconds and recorded in HOBO micro station data logger (Part: H21-002) and hourly averages were computed. A reference station at each site also measured wind speed and temperature/relative humidity at 2m above the ground. Wind direction was also measured at 2m at reference stations using wind speed and direction smart sensor (Part: S-WCA-M003).

Collected data were filtered by wind direction and used in the analysis only when the wind direction was between 0 and 180 degrees to the windbreak. Measured wind speed, temperature and relative humidity on the leeward side of the windbreak were divided by the field wind speed, temperature and relative humidity during that interval, respectively, to calculate relative wind speed, temperature and relative humidity. Relative values were used to study patterns in the protected area behind the windbreak.

RESULTS AND DISCUSSION

Wind Speed Reduction

Wind speed behind the windbreaks never reached the open wind speed when the wind was from the north. Minimum wind speed was generally recorded at 2H behind redcedar windbreak. Wind speed at 2H was less than 5% of the open when the wind direction was nearly perpendicular to the windbreak (90 ± 15 degrees). When the direction was 90 ± 45 degrees to the windbreak, relative wind speed at 14H behind redcedar windbreak was mostly less than 80% of the open wind speed (Fig. 1). Relative wind speed at 2H was always lower than 17%. Wind was not detected at 2H when the open wind speed was below 2.5m/s.

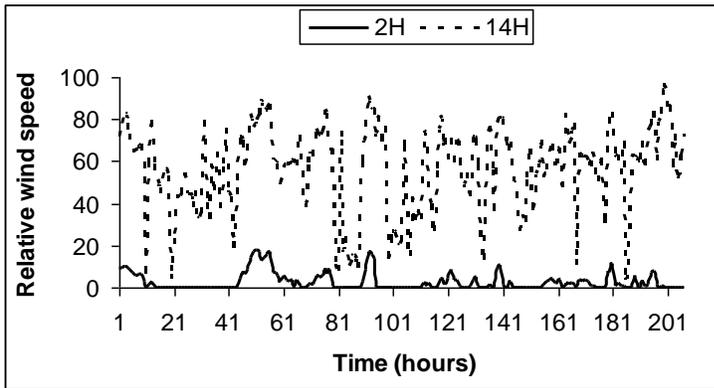


Fig. 1. Relative wind speed at 2H and 14H behind eastern redcedar windbreak when the wind direction was 90 ± 45 degrees.

When the wind direction was within 45 degrees to the windbreak, relative wind speed at 14H remained more or less the same (Fig. 1 and 2). However, there was a significant increase in wind speed at 2H compared to when wind direction was 90 ± 45 degrees.

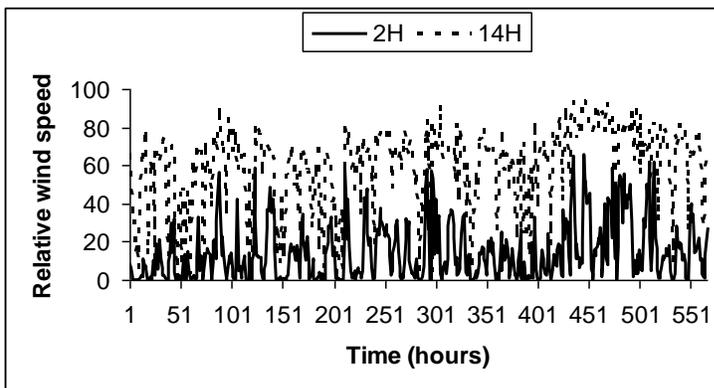


Fig. 2. Relative wind speed at 2H and 14H behind eastern redcedar windbreak when the wind direction was within 45 degrees to the windbreak.

At C&B farms, the maximum wind speed recorded behind windbreak 1 was about 95% of the open wind speed. In contrast to SWFREC, the minimum wind speed was generally recorded at 6H when the wind direction was nearly perpendicular (90 ± 15 degrees) (Fig. 3). Wind speed

gradually increased up to 14H, but wind speed at 14H was still 30% less than the open. As the wind approached windbreak 2, it slightly decreased again at 16H.

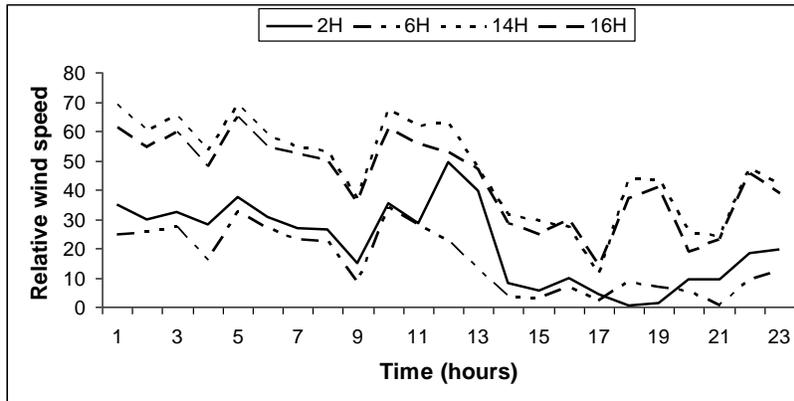


Fig. 3. Relative wind speed at different distances from the windbreak at C&B Farms when the wind direction was nearly perpendicular (90 ± 15 degrees) to the windbreak and when open wind speed was greater than 2m/s.

Wind reduction in the current study was higher than observed in Denmark where the wind speed was 86% at 7H (Foereid et al. 2002). Other studies have recorded wind speeds between 40-100% in the protected zone (Brenner et al. 1995, Zhang et al. 1995), but the wind speed measured in the protected area during the study was always lower than in those studies. It is likely that the dense windbreaks in the study area were more effective in reducing wind speed. Taller windbreak also provided protection up to a longer distance. Others have found extremely variable wind reduction in the protected zone (Zhang et al. 1995).

One of the reasons for planting windbreaks around citrus groves is to reduce wind speed below 8m/s. Winds above 8m/s forced canker bacteria into leaf stomates and damaged plant parts and fruit (Graham et al. 2004). When the open wind speed was 8.1m/s, eastern redcedar reduced it to 2.2m/s at 2H and 6.3m/s at 14H when the wind direction was 25 degrees to the windbreak. If the direction is perpendicular to the windbreak, windbreaks can potentially reduce winds above 8m/s to lower levels. Since wind speed reduction is generally equivalent to windbreak density (Cleugh et al. 2002), wind speed reduction in the current study is within the expected range.

Temperature and Relative Humidity Modification

Changes in temperature and relative humidity were less compared to wind speed. Under normal weather conditions, daytime temperature near the windbreak was a few degrees warmer than in the open (Fig. 4a). Temperature at 14H was more or less similar to open temperature. Temperatures at 2H and 6H were similar and generally warmer than at 10H and 14H (Fig. 4).

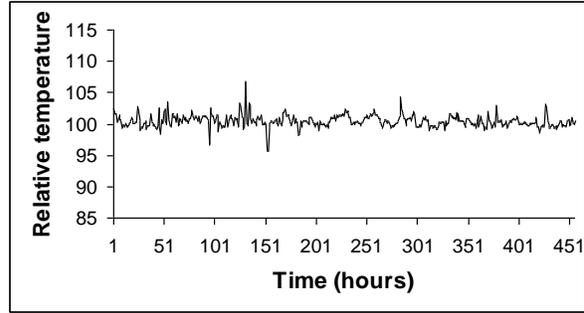
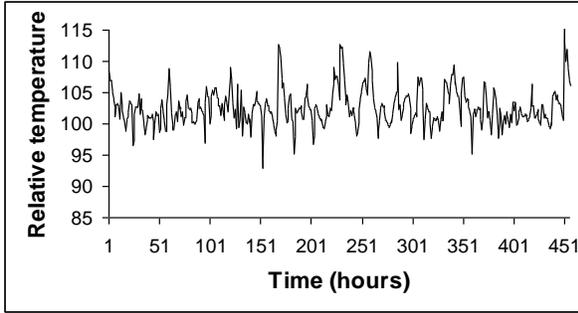


Fig. 4. Diurnal (6AM-5PM) temperature behind redcedar windbreak (a) at 2H (left) and (b) at 14H (right)

The opposite pattern was observed at night. Temperatures at 10H and 14H were generally warmer than at 2H and 6H (Fig. 5). Temperatures at 2H and 6H were generally lower than in the open. Similarly, temperature at 14H was generally warmer than the open when the open wind speed was less than 3m/s. When the open wind speed was greater than 3m/s temperature at 14H was either equal to or lower than the open.

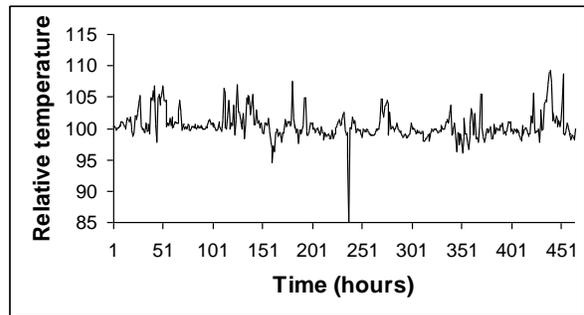
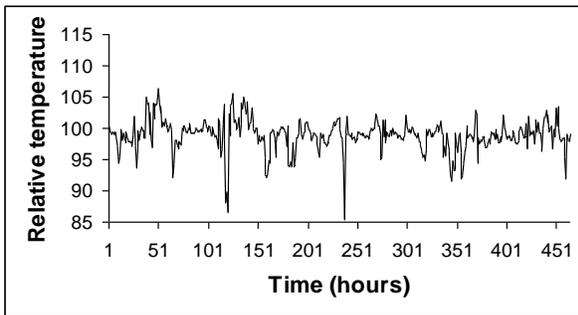


Fig. 5. Night time (6PM-5AM) temperature behind redcedar windbreak (a) at 2H (left) and (b) at 14H (right).

During the cold fronts, temperature at 2H was relatively cooler than the stations further away from the windbreak when the open wind speed was lower than 2m/s. When the wind speed was greater than that, temperature at 2H was almost similar to other stations (Fig. 6).

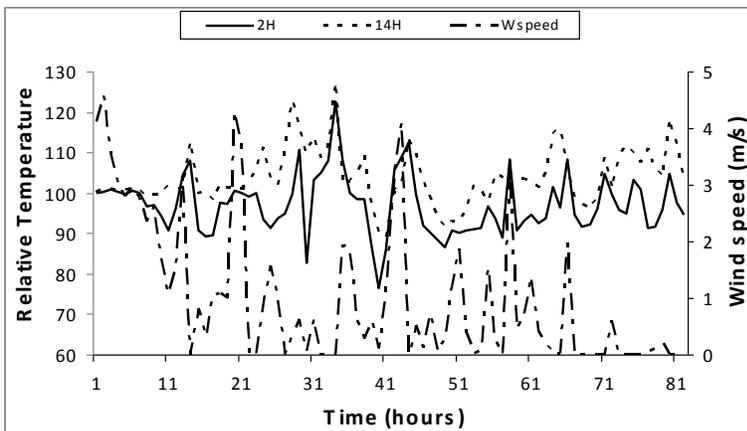


Fig. 6. Relative temperature at 2H and 14H behind eastern redcedar windbreak during cold fronts

All stations showed similar patterns in relative humidity during the study period (Fig. 7). Relative humidities at 2H and 6H were slightly lower and at 10H and 14H were slightly higher than the open till the end of February at both sites. But beginning March, relative humidities at all stations were generally higher than in the open.

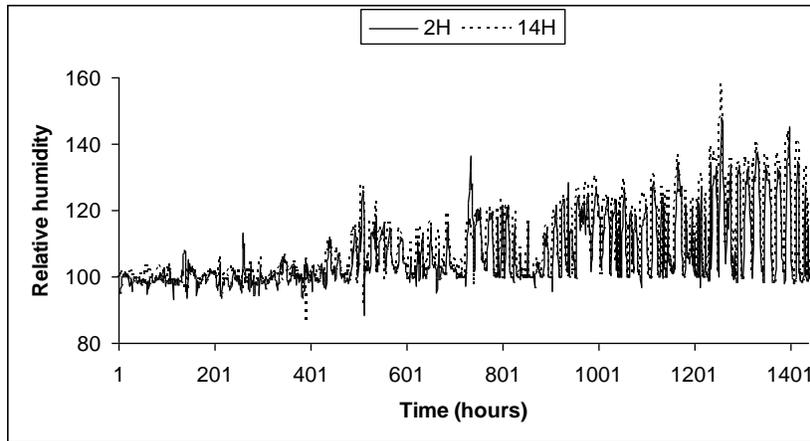


Fig. 7. Relative humidity at different distances from the windbreak during the study

Wind speed reduction in the protected area changed temperature and relative humidity. The temperature and humidity patterns observed in the current study are consistent with other studies. Foereid et al. (2002) also observed higher temperature near willow windbreak in Denmark. Temperature increased during the day but decreased at night near the windbreak. Relative humidity also increased in the sheltered area during the day (Sudmeyer et al. 2002). However, compared to wind speed reduction, temperature and humidity modifications are limited to shorter distance. Wind speed reduction can be expected up to 25-30H, but temperature and humidity modification extends up to 10-12H behind the windbreak (Cleugh et al. 2002).

CONCLUSIONS

Windbreaks have the potential to modify microclimate behind the windbreak. Modified microclimate enhances crop growth and final yields. At the same time windbreaks can also control the spread of pathogens such as citrus canker. They maintain the productivity of the agricultural systems by conserving soil and nutrients and at the same time can provide many ecological services.

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FORAGE PRODUCTION UNDER THINNED DOUGLAS-FIR FOREST

Sam Angima¹

¹Oregon State University Extension, 29 SE 2nd St., Newport, OR 97365

Contact: sam.angima@oregonstate.edu

Abstract: In the Pacific Northwest, trees may take up to 60 years to mature for harvest. This ties up land for other commercial purposes. Depending on tree species, commercial thinning opens up the tree canopy to reduce competition among trees. In Douglas-fir forests, commercial thinning reduces the tree density per acre from 450 to 200. Under the trees, the space created by thinning allows desirable forages for livestock to thrive. These forages can be invigorated by applying nitrogen in early spring and the resultant feed used for grazing or hayed to support livestock. This study investigated how much forage could be produced under 25-year old and 55-year old Douglas-fir thinned forest when fertilized with nitrogen (N) at 75 lbs/acre in early spring. Cumulative forage dry matter yields averaged 2.14 and 1.27 tons/acre for forages growing under 25- and 55-year old trees, respectively. Cumulative forage grown on open space with similar treatments yielded 4.15 tons/acre dry matter which is 27% higher than estimates from the USDA soil survey of 3 tons/acre in similar soil and climatic conditions. Currently, animal stocking rate is one beef cow/calf to two acres. If woodland owners adopted silvopastoral systems like this one, a new animal stocking rate of 4 and 6.5 acres per cow/calf unit under the 25- and 55-year silvopastoral systems respectively, is recommended. This, however, will depend on location and aspect of the land. Using thinned forestland for forage production is another way to diversify agriculture and increase income for forest landowners.

Key words: Forages, Douglas fir, nitrogen, perennial rye, livestock, stocking rates, commercial thinning, Pacific Northwest, soil survey.

INTRODUCTION

In the Pacific Northwest, timber is a major crop bringing income to many small scale farms. The dominant and most productive tree species is Douglas-fir (*Pseudotsuga menziesii*). Douglas-fir is planted at a density of 400-500 trees/acre. Depending on location and management, commercial thinning at 15-20 years reduces stocking density to 170 - 200 trees/acre with average spacing of 10 by 15 feet. At this stage, live tree crowns are about 30% allowing sunlight to penetrate to the ground promoting grass growth and other understory plants (Emmigham and Green 2003). Trees are harvested at age 40-60 years when they are fully mature.

Forty years is a long time to wait to harvest logs for income. However, planned forestry (agroforestry) might provide better economic returns if thinned forests can be utilized for forage production to provide supplemental income. Economic analyses by Kurtz (2000), Kallenbach (2006) have demonstrated that well planned forestry can provide above average long-term returns on investments. One of the five recognized agroforestry practices is silvopasture, which is the growing of perennial grasses and/or grass-legume mixes in a forest stand for livestock pasture. In this system, the trees not only provide long-term investment, but also provide the

animals shade in summer and serve as windbreak in winter. In turn, the forage base provides feed for beef cattle which ultimately provides livestock sales for short term income (Kallenbach et al. 2006).

Research has shown different relationships between trees and the forage. Clason (1999) found that timber and forage growth benefited from fertilization due to suppression of competing vegetation in a commercial loblolly pine plantation, while other research shows that without careful management, competition from many forage species reduces tree growth. For example, fescue can reduce height of black walnut (*Juglans nigra* L.) by 45% compared to no ground cover due to competition for nutrients and moisture (Kallenbach et al. 2006). In western Oregon, forage production under Douglas-fir trees tended to increase with increasing degree of tree aggregation from single-tree grids to cluster grids (Sharro 1991). Because of the hilly nature of the landscapes in this region, trees are planted in cluster grids.

Forage growth is a function of light interception and temperature. Silvopastoral systems provide forages with an environment where both solar radiation and temperature vary spatially on daily and seasonal time scales (Sharro 1991). The light quantity and quality reaching plants affect their morphology and dry matter allocation. Conifers have been found to reflect and scatter much less far-red light therefore enhancing carbohydrate buildup in forages growing in the understory. These forages usually receive about 40% less photosynthetically active radiation (PAR) but consistently produce over 60% of biomass compared to sites receiving 100% PAR (Feldhake et al. 2005).

Our objective was to determine how much forage can grow under 25- and 55-year old thinned Douglas-fir stands as a basis for recommending silvopastoral systems to small woodland owners in the Pacific Northwest USA who need to diversify their income base.

RESEARCH DESIGN

This study was conducted on-farm near Harlan, Oregon (44° 33' 07 N and 123° 48' 23 W). The soil type at this location is Eilertsen silt loam. Average annual precipitation is 92 inches/year with mean annual temperature of 54 °F. Three treatments were setup (South-side - SS, Center - CC, and North-side - NN) based on location of forage plots in relation to edge of the woodlot and aspect. The SS treatments were at the edge of the woodlot on the south-most section that gets more sun, the CC treatments were located 100 feet from the SS treatments towards the center of the woodlot, and the NN treatments were located 200 feet away from the SS treatments and received the least amount of sunlight. This set up was used for both the 25- and 55-year old trees. Average tree height was 65 feet and 100 feet for the 25- and 55-year old trees respectively. The treatments were replicated three times in a randomized block design for a total of 18 plots. The control plots were set out in the open without trees. The plots measured 10 by 33 feet and were fertilized with 75 lb N/acre once on April 1st of 2007 and 2008.

The site was gated and no animals were allowed to graze until after each harvest. The forage grasses were a mixer of perennial ryegrass and orchardgrass. Cumulative annual forage yield data were collected for two years (2007-08) and harvesting was done a day before the farmer turned in his animals for grazing. At harvest, a 42-inch swath was removed from the center of

each plot with a flail type mower, weighed, and recorded. Wet forage yields were adjusted to dry weight by drying a subsample to constant weight at 135°F. All data were subject to analysis of variance using SAS (SAS 1997). A Fisher protected LSD test procedure was used for mean separations at $P < 0.05$.

RESULTS AND DISCUSSION

Growing conditions

Climatic conditions at the study area favored rapid forage growth in spring and early summer, but the late summer dry period reduced growth substantially. The use of nitrogen invigorated the forages and they competed and grew well suppressing weeds. Harlan, Oregon has good cool weather that favors growth of cool season forages even during summer with average high temperatures of 65 °F.

Forage yields

Cumulative forage yields generally decreased as you moved deep into the woodlot from the South. As expected, forage yield from the control (4.15 tons/acre) was significantly higher than all other treatments (Table 1). Differences in cumulative yield were not significant for the forages growing under 55-year old trees. However, for the 25-year old trees, treatments at the south end of the woodlot had significantly higher forage yields than those towards the north end but not with those at the center (Table 1). These observations may be related to how plants invest nitrogen in the different components of the photosynthetic apparatus. The investment of nutrients follows the pathway where plants will modify their biomass allocation to aboveground structures if carbon gain is negatively affected by low light levels. Biomass allocation to aboveground structures is attained by increase in specific leaf area which in turn increases light interception by orienting blades horizontally (Fernandez et al. 2004). Since forages in the SS treatments had more light, they allocated more to biomass buildup than those beyond the center of the woodlot.

Table 1. Average dry matter forage yield for perennial ryegrass and orchardgrass mix fertilized with 75 lb N/acre under a thinned Douglas-fir forest in Harlan, Oregon.

Treatments	Silvopastoral System	
	Under 25-yr Old Trees	Under 55-yr Old Trees
	----- tons/acre)-----	
South-side Plots (SS)	2.53b†	1.49bc
Center Plots (CC)	2.12bc	1.27bc
North-side Plots (NN)	1.76cd	1.04c
Control	4.15a	4.15a
LSD	0.59	0.59

†Within columns, means followed by the same letter are not significantly different at $P = 0.05$ by Fisher's protected LSD.

Silvopasture studies in the Midwest USA have shown cumulative forage production to be about 20% more in open fields compared to where pasture is grown under trees although forage quality was found to be greater in the silvopasture system compared to the open field system (Kallenbach et al. 2006). The increased forage quality under shade can partially offset reduced forage productivity under the trees. In our study, forage yield was reduced by 39%, 49% and 58% under the 25-year trees and 64%, 69%, and 75% under the 55-year old trees for the SS, CC, and NN locations respectively, compared to forage growth without trees. Cool season grasses such as orchardgrass and perennial rye have been shown to tolerate shade of up to 80% (Lin et al. 1999).

Average stocking rate for beef cattle in western Oregon is one cow/calf to two acres of pasture. This means that during spring, summer, and part of earlier fall, woodlot owners can utilize thinned forests for forage production to raise more livestock or sale hay. Based on cumulative average forage production without trees of 4.15 tons/acre and 2.14 tons/acre under the 25-year trees and 1.27 tons/acre under the 55-year old trees, in this time period, beef producers can set aside 4 and 6.5 acres per cow/calf unit under the 25- and 55-year silvopastoral systems respectively. Kallenbach (2006) shows that beef animals raised under silvopastoral systems had equal average daily gain (ADG) and gain/acre as animals grazed on open field system with gain/acre being influenced by both cumulative forage production and forage. Kephart and Buxton (1993) reported that perennial cool season grasses grown under shade produced more CP and less NDF than same grasses under full sunlight. Therefore, at this stocking rate we do not expect widespread feed supplementation for animals being raised under this silvopastoral system.

CONCLUSION

1. Cumulative forage production for a perennial rye - orchardgrass mix grown under 25- and 55-year old Douglas-fir trees and fertilized with 75 lb N/acre was reduced by an average of 48%, and 69% respectively, compared to similar pastures without shade. Forage production under shade was influenced by exposure to the South and age of the trees.

2. Woodland owners could potentially derive substantial future income from their forests if they adopted well managed silvopastoral systems after commercially thinning their Douglas-fir forests. Animal stocking rate could go as high as 4 and 6.5 acres per cow/calf unit under the 25- and 55-year silvopastoral systems respectively. Success of individual systems will ultimately depend on location, management, and aspect of the property in relation to the southern sun.

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NUT PRODUCTIVITY AND SPACING REQUIREMENTS OF EASTERN BLACK WALNUT CULTIVARS USED IN MIDWESTERN AGROFORESTRY-BASED PLANTINGS

Mark V. Coggeshall¹ and Michele R. Warmund²

¹University of Missouri Center for Agroforestry, 1-66 Agriculture Building, Columbia, MO

²Division of Plant Sciences, University of Missouri

Contact: coggeshallm@missouri.edu

Abstract: Twenty eastern black walnut (*Juglans nigra* L.) nut cultivars were field grafted in 1996 at the Horticulture and Agroforestry Research Center in New Franklin, MO (latitude 39° 04' N, longitude 92° 74' W). Each cultivar was represented by 2 to 4 ramets. Annual nut production commenced for all cultivars by 2002 and total numbers of nuts were recorded by individual tree from 2002 through 2008. Nut weights and percent kernel information on an individual tree basis were determined over three different years for use in calculating total nut yields for each cultivar. Mean cultivar nut yields were expressed as the total number of nuts produced during the seven year period per tree multiplied by the mean number of nuts per kg. Cumulative nut yields ranged from 7.1 to 72.5 kg. per tree, depending upon cultivar.

Total tree heights and crown widths were determined for each tree in August 2008. Cultivar mean tree height and crown widths ranged from 6.5 to 8.6 and 6.4 to 9.3 meters, respectively. Cultivar-specific growth rates can determine the number of years to crown closure in orchard settings, which will ultimately impact nut yields due to shading effects. For these 20 cultivars, the rate of crown spread ranged from 0.58 to 0.85 m. per year, assuming significant crown width development began three years after grafting. Based upon these rates of crown spread, the number of years to crown closure in a 9.1 x 9.1 m. orchard is anticipated between 14 and 19 years after grafting, depending upon cultivar.

After 13 growing seasons, 'Sparrow', 'Hay', 'South Fork', 'Emma K' and 'Schessler' were the best producing nut cultivars in this collection, based upon cumulative nut yields, while 'Football', 'Daniel', 'Kwik Krop', 'Sparks 147' and 'Bowser' were the poorest producers.

MURDOCH LAKE AGROFORESTRY PROJECT

Doug Macaulay¹, Florance Niemi², and Nora Paulovich³

¹Alberta Woodlot Extension Program, Alberta Agriculture and Rural Development, Main Floor, Airdrie Agriculture Centre, 97 East Lake Ramp NE, Airdrie, AB, Canada, T4A 0C3.

²Daishowa-Marubeni International Ltd, Postal Bag 6500, Peace River, AB, Canada, T8S 1V5.

³North Peace Applied Research Association, Box 750, Manning, AB T0H 2M0

Contact: doug.macaulay@gov.ab.ca

Abstract: Intercropping has the potential to provide Alberta's farmers with many benefits from moisture trapping to increased crop production. In the Peace River Region of Alberta many farmers raise cattle and grow forage crops. Folks in our region continue to clear land and remove trees so they can farm every acre. However, with the loss of wooded areas exposed forage crops dry out quickly in the summer and cattle are exposed to nasty winter winds.

This field demonstration was designed back in 2002 to show landowners the potential benefits of combining tree crops with traditional agricultural practices. The project area covers 60 acres of land and is surrounded by an eight-foot deer fence and borders a waterfowl rich wetland. A total of 17 000 Walker Poplar hybrids were planted in 2004 with half being planted with plastic mulch and the other half without. The project is setup in three different blocks with one consisting of hay only, the second with hay and trees and the other with trees only and these are repeated three times over the sixty acres. Over the years tree and hay yields were measured. The main purpose of the site is to get local landowners thinking about how they can apply a similar agroforestry system to their farm. The demonstration has attracted folks from across Alberta and British Columbia and is becoming more widely recognized every year. It has also inspired some other agroforestry projects in the region.

Key Words: intercropping, hybrid poplar, tree crop, plastic mulch, forage production

INTRODUCTION

This agroforestry demonstration near Murdoch Lake has been an extremely successful demonstration for local landowners, professionals and landowners from further a-field. Its intent demonstrates the opportunities landowners have to combine tree production with standard agricultural practices. This project has been an excellent learning experience, providing insight into natural enemies for agro-forestry projects, such as voles and competing vegetation, which necessitate the need for innovative strategies.

The initial collaborators for this project include:

North Peace Applied Research Association (NPARA)

Prairie Farm Rehabilitation Administration (PFRA)

Ducks Unlimited Canada (DUC)

Alberta Agriculture and Rural Development (AAFRD)

Daishowa-Marubeni International Ltd. (DMI)

Through subsequent participation, Alberta Environmentally Sustainable Agriculture (AESAs) and Reduced Tillage Linkages (RTL) became project partners; and in 2005, the Woodlot Extension Program (WEP) provided an agroforestry specialist, Doug Macaulay, for northern Alberta, and WEP became an active participant.

The project is located on the SE quarter of Section 16-89-23-W5M, about 60 kilometers north of Peace River near the hamlet of Deadwood. It encompasses an area of about 60 acres (24 hectares). Approximately half of this area is seeded to a mixed hay crop, and half planted to hybrid poplar trees (Walker) at a planting density of 1600 stems per hectare. A total of 17,352 trees were planted.



Photo courtesy of Doug Macaulay, Woodlot Extension Program

The basic design of the demonstration is to have three “treatments” represented in each of three replications (Figure 1):

1. one third of each replicate has ‘hay only’,
2. one third of each replicate has ‘trees only’, and
3. one third of each replicate has alternating strips of 6 rows of trees, with an equal size strip of hay.

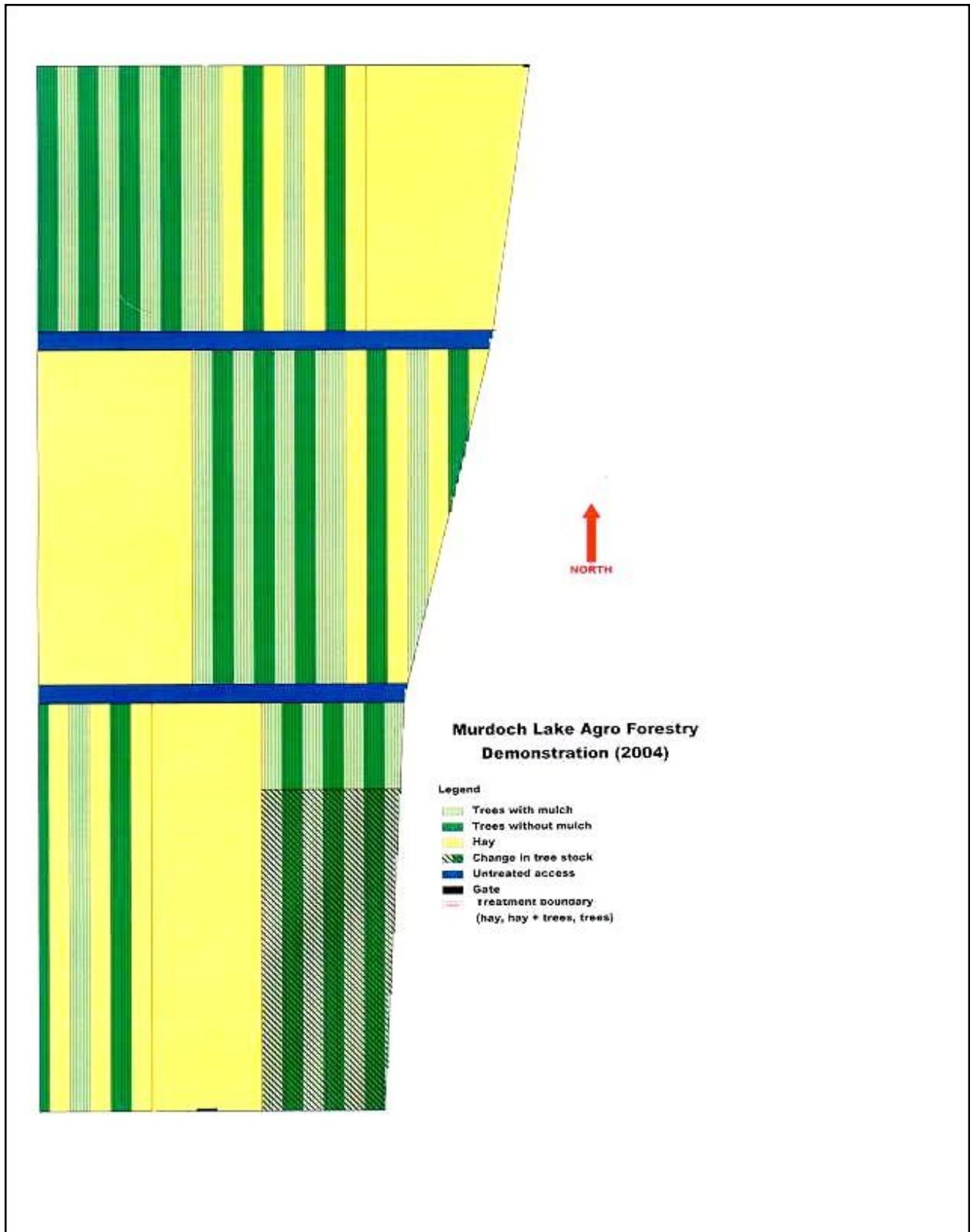


Figure 1. Map showing layout of Murdoch Lake Demonstration.

Each replication is about 8 hectare in size, and each treatment within each replicate about 2.4 hectare. Strips between replications and around the project perimeter are retained for access and are therefore non-treatment areas and total about 2.4 hectare. Total treatment area planted to trees and hay is shown in Table1.

Table 1. Treatment Area Planted to Trees vs Seeded to Hay*

Replicate →	1		2		3	
Treatment ↓	Trees (ha)	Hay (ha)	Trees (ha)	Hay (ha)	Trees (ha)	Hay (ha)
Trees	2.4	0	2.4	0	2.4	0
Trees+Hay	1.2	1.2	1.2	1.2	1.2	1.2
Hay	0	2.4	0	2.4	0	2.4
Total per Rep	3.6	3.6	3.6	3.6	3.6	3.6
Total Trees	10.8 ha					
Total Hay	10.8 ha					

*Strips left for access are also seeded to hay and make up the remaining 2.4 hectares.

In addition to the three basic treatments, half of the trees (8,676) had plastic mulch applied, and half did not. Those without the plastic mulch had competing vegetation controlled by mechanical and chemical means. The purpose of including the plastic mulch was to provide a basis for landowners to determine whether the initial cost to apply mulch was offset by increased tree productivity and cost of repeated entries to control vegetation in non-mulched trees.

The initial hypothesis of this project was that, by alternating hay and tree production in the same field, the overall productivity of the site would increase. The trees would retain snow fall, increasing available soil moisture for hay production; hay strips would allow the trees to have access to more sunlight therefore stimulate increased tree growth. Although only preliminary results in hay yield and tree growth are available, reasonable forecasts can be made regarding the costs and benefits of such an operation.

Key Adaptations made to the Original Project

There were several significant changes to the original project:

1. Prior to establishment, all collaborators agreed to replicate the treatments to provide a basis for statistical analysis rather than establish the site purely for demonstration purposes. In hindsight, this was an excellent decision. It provides more credibility to the hay yield and tree growth rates, plus creates an interest by other professionals to use the site for other related research questions.
2. During the first fall/winter after planting (2004), voles, feeding on the bark and phloem of the young trees (and living under the mulch safe from predators) girdled most of the trees. When the girdling was observed the following spring, the decision was made to cut

off every stem below the girdle to allow new stems to coppice from the stump. This was done in May 2005 by summer students with some trepidation due to the young age of the trees. The decision, however, was a wise one. All decapitated trees re-sprouted with multiple stems; a small number of trees not cut off, because the girdle did not totally encompass the stem, subsequently died.

3. Innovative strategies were implemented to reduce the vole population including nesting boxes for raptors, brush piles for weasels and compressing the mulch with quads.
4. The year following the decapitation, all trees had to be “singled” due to the coppicing of multiple stems. In May, 2006 summer students singled every tree by leaving the dominant stem and removing all others. A small portion of trees had to be singled again in 2007.
5. Introduction of grazing was to have occurred in 2007. In the spring of 2007, and again in 2008, the decision was made to delay the grazing until 2009 to provide for additional growth on the smaller (unmulched) trees. A meeting was held in October of 2008, and all collaborators agreed to move ahead with the grazing in 2009.
6. Permanent Sample Plots (PSPs) were established in Year 2 rather than Year 1; and measured in year 2 and 4 instead of annually. PSPs will be measured in the spring of 2009 prior to the introduction of grazing. Collaborators will decide on tree measurement interval in conjunction with the grazing protocol when it is developed.

Technology Transfer

Technology transfer to date has included:

1. Tours - There has been a minimum of one tour annually since the establishment of the site in 2004, with two tours in 2006 and three in 2007. Tours are often accompanied by a member of the local press with subsequent articles in local papers. Tour guides/speakers for the Murdoch Lake demo include representatives from the collaborators, usually someone from NPARA and/or DMI. NPARA has regularly included Murdoch Lake in the annual tours they provide for landowners to showcase their research projects. The tours have generated significant interest in this type of planting both from landowners and professionals, and usually result in subsequent communications as individuals request further information and follow-up.
2. NPARA publications – Articles have occurred in the 2005, 2006 and 2007 Annual Reports to date, and the “2005 Trials” booklet.
3. Article in Ducks Unlimited Newsletter (summer 2004)
4. WEP Murdoch Lake Brochures – The first brochure was prepared by Doug Macaulay in 2006, and has been updated regularly.

5. Presentations at WEP workshops and conferences – Since 2005 Doug Macaulay hosted several workshops on behalf of WEP. A presentation on the Murdoch Lake Demonstration was prepared for these workshops.
6. Newsletters prepared and circulated by WEP
7. A sign erected at the demonstration site - This detailed sign showing the treatment layout and the collaborators was provided and erected by Alberta AAFRD in October 2004.
8. News articles in local papers such as the “Peace River Record Gazette” and the “Peace Country Sun”.

Collection and Housing of Data

Hay data is collected and analyzed by NPARA; tree data is collected and analyzed by DMI. It was decided that the complete data would be housed both at NPARA and DMI. Others can request the data as required.

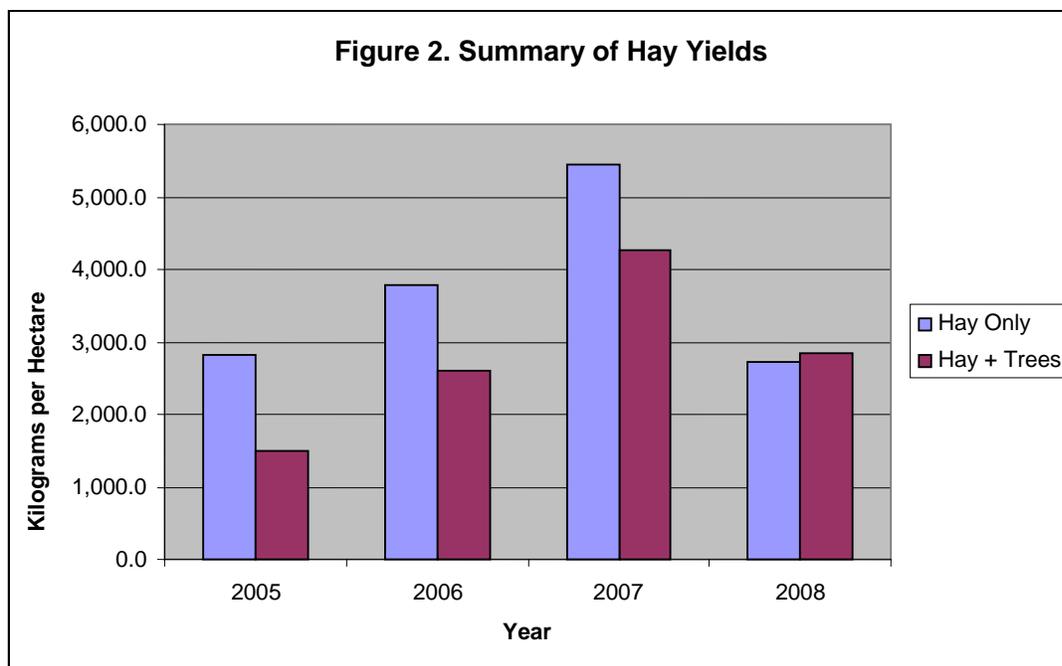
RESULTS

Hay

NPARA is responsible for all hay activities. As requested by DUC, hay cannot be harvested until after July 15 due to the potential for nesting birds earlier in the season.

The first year of harvest was 2005. In 2005, 2006 and 2007, amount of hay by treatment was determined by the weight and number of round hay bales. In 2008, NPARA used random sampling with “quarter meter cuts”. Small plots (1x1m) were placed at random within each treatment; the hay was clipped by hand, dried and weighed. Based on this sampling, a yield in pounds per acre was calculated for each treatment. Because of the operational difficulty of gathering accurate information using farm sized equipment, NPARA decided that the latter method is preferred and will continue with this method in the future.

To date there appears to be no significant trend in hay yields over the two hay treatments (hay only vs. hay with trees). Hay yields are summarized in Figure 2.

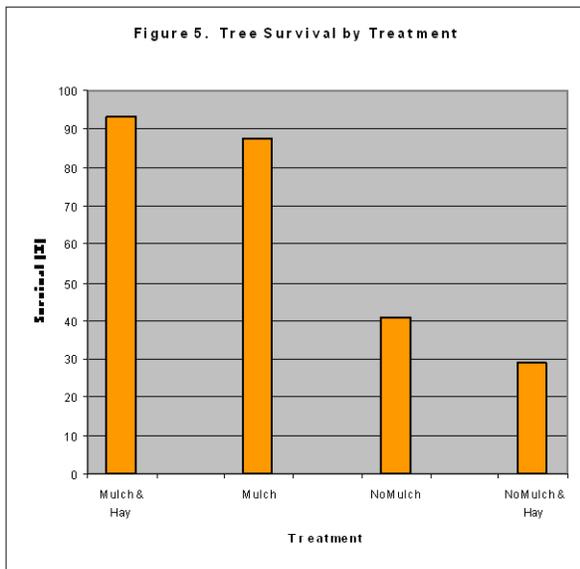
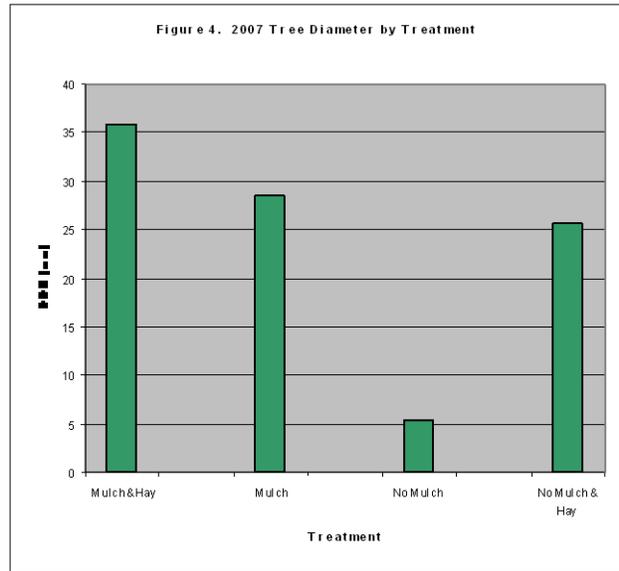
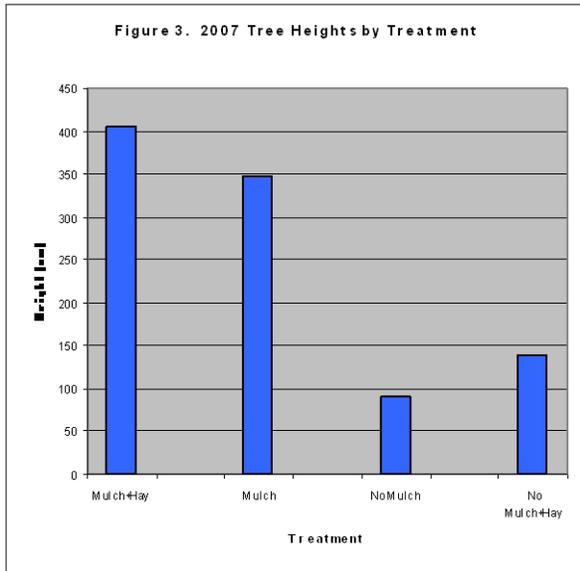


Trees

DMI is responsible for all tree activities. Permanent sample plots were established in 2005, and the heights and diameters of trees within these plots measured in 2005 and 2007. It was deemed adequate to measure trees every two years rather than every year as initially planned. They will be re-measured in 2009.

Tree growth in mulched vs. unmulched trees is significantly different, but the difference at this point in time between the ‘trees and hay’ and the ‘trees only’ is not significant.

Figures 3, 4 and 5 summarize tree heights, diameters and survival in the four treatment combinations: “trees only” with and without mulch, and “trees and hay” with and without mulch.



Grazing

As previously stated, grazing has been delayed until 2009 because of the slow growth rate of the unmulched trees and the concern of compromising the value of the demonstration site. Presently, proposals are being developed to layout specifically how this grazing should occur. Collaborators agree that it is imperative to ensure the integrity of the existing study is not compromised, but at the same time, a feasible operational method of including livestock into agro-forestry must be demonstrated.

ESTABLISHMENT AND MAINTENANCE COSTS

In communications with landowners, and others potentially interested in agroforestry, a key focus is the cost to establish and maintain the tree portion of the demonstration. To provide that information, the inputs and costs were determined, and per unit costs calculated so individuals could extrapolate costs to a variety of scenarios. The project costs and inputs are outlined in Tables 2 and 3, respectively.

Table 2. Summary of Input Costs

Item or Activity	Year 1 (2004)	Year 2 (2005)	Year 3 (2006)	Year 4 (2007)	Year 5 (2008)	Total
Fence	35,392.97	0.00	0.00	0.00	0.00	35,392.97
Seedlings	5,862.60	0.00	0.00	0.00	0.00	5,862.60
Site prep, chemical	1,137.50	0.00	0.00	0.00	0.00	1,137.50
Site prep, mechanical	1,067.32	0.00	0.00	0.00	0.00	1,067.32
Tree planting						
<i>plot layout</i>	1,960.00	0.00	0.00	0.00	0.00	1,960.00
<i>mechanical marking</i>	1,319.75	0.00	0.00	0.00	0.00	1,319.75
<i>planting</i>	6,060.00	0.00	0.00	0.00	0.00	6,060.00
Plastic mulch (41 rolls)	7,339.00	0.00	0.00	0.00	0.00	7,339.00
Application of mulch	6,759.00	0.00	0.00	0.00	0.00	6,759.00
Fertilization	1,064.75	0.00	0.00	0.00	0.00	1,064.75
Turf grass seed	437.00	0.00	0.00	0.00	0.00	437.00
Weeding and Maintenance						
<i>mowing</i>	0.00	2,600.00	1,105.00	0.00	0.00	3,705.00
<i>pre-emergent</i>	0.00	0.00	0.00	0.00	0.00	0.00
<i>in-row chemical</i>	0.00	3,175.00	2,750.00	0.00	0.00	5,925.00
<i>decap, singling</i>	0.00	2,788.00	3,063.00	1,250.00	0.00	7,101.00
Monitoring						
<i>establish PSPs</i>	0.00	763.00	0.00	0.00	0.00	763.00
<i>data collection</i>		750.00	0.00	888.00	0.00	1,638.00
<i>sign, raptor boxes</i>		260.00	0.00	150.00	0.00	410.00
Project Administration*	2,654.00	367.00	180.00	180.00	180.00	3,561.00

* Administration cost is calculated as 5% of the original estimated project cost

Table 3. Summary of Project Details

Total area (ha)	24.0
Total treed area (ha)	10.8
Grass treatment area (ha)	10.8
Grass access area (ha)	2.4
Total number of trees	17,352
Tree spacing	2.5m x 2.5m
Planting density (trees per ha)	1,600
Total area of PSPs (ha)	0.63
Number of trees in PSPs	1,005
Number of trees mulched	8,676
Area (ha) of mulched trees	5.40

Using the information from Tables 2 and 3, unit costs were calculated on a ‘per hectare’ and a ‘per tree’ basis. These figures are presented in Table 4.

Table 4. Summary of Costs per Unit per Entry

Activity	Cost per Hectare (\$)	Cost per Tree (\$)
Planting stock	542.83	0.34
Site prep, chemical	105.32	0.07
Site prep, mechanical	98.83	0.06
Plot layout	181.48	0.11
Mechanical marking	122.20	0.08
Planting	561.11	0.35
Plastic mulch	1,359.07	0.85
Application of mulch	1,251.67	0.78
Fertilization	98.59	0.06
Mowing	343.06	0.21
Pre-emergent herbicide	no data	no data
In-row chemical herbicide	274.31	0.17
Decapitation, singling (pruning)	219.17	0.14
Establishment of PSPs for tree data	70.65	0.04
Data collection*	1,200.00	0.81

* Unit costs of data collection calculated using PSP area and number of trees measured

COMPARISON OF ACTUAL COSTS TO ORIGINAL ESTIMATES

There were significant variances from the original cost estimates to the actual costs. This comparison is summarized in Table 5. Some of the key causes of the variances include:

1. Material and labor costs rose substantially between the time the project was initiated to actual establishment. This resulted in a negative variance for the erection of the fence.
2. Use of a replicated design, rather than a simple demonstration, resulted in several negative variances. Replication adds to the cost of both establishment and maintenance activities because of the increased level of complexity and the shorter rows for manipulating equipment. In particular, the cost of the mulch application is about seven times the original estimate. This is probably due to a combination of factors including inclement weather, weekend interference, coordinating labor from three organizations, as well as an original underestimation of cost, but the most significant impact was the amount of time spent turning and aligning equipment.
3. Fewer entries in the unmulched trees for vegetation control resulted in a positive variance, but also compromised the demonstration by exacerbating the poorer performance of the unmulched trees compared to the mulched trees.
4. Need for innovative responses to unplanned events resulted in unplanned expenses. The impact of voles on the trees the winter following planting required immediate action or the tree mortality would have been close to 100%. The cost to decapitate and

subsequently single almost every tree planted was not included in the original proposal, but was necessary to save the project.

Costs pertaining specifically to the grass component of the demonstration have not been included.

Table 5. Comparison of Actual Cost with Original Estimate

Item	Actual Cost (\$'s)	Original Estimate (\$'s)	Variance (\$'s)	Explanation of Variance
Fence	35,392.97	26,000.00	(9,392.97)	Cost of fencing materials and labor increased significantly from the first quote obtained for the proposal to the initiation of the project.
Seedlings (17,362)	5,862.60	5,631.00	(231.60)	The number of trees required increased from 16,500 to 17,352 due to going from 100 to 1600 stems per hectare. Purpose of change was to obtain crown closure earlier, plus the trees are intended as pulp wood.
Site prep for trees, chemical	1,137.50	840.00	(297.50)	Initial underestimate of cost. Efficiencies gained by working the whole field.
Site prep for trees, mechanical	1,067.32	2,592.00	1,524.68	Initial overestimate of cost. Efficiencies gained by working the whole field.
Tree planting	9,339.75	6,930.00	(2,409.75)	Increased due to the increased number of trees, as well as underestimating the time involved to lay out the treatment areas and mark the planting spots accordingly.
Plastic mulch (41 rolls)	7,339.00	3,060.00	(4,279.00)	Original estimate was 17; actual purchase was 41. Used a total of 52 rolls of mulch; remainder provided by PFRA and NPARA.
Application of mulch	6,759.00	960.00	(5,799.00)	Original 6 days was an underestimate. Time was spent turning and aligning the machine. In addition, weather was rainy so application was inefficient.
Tree fertilization	1,064.75	6,270.00	5,205.25	Fertilization occurred in the first year only.
Turf grass seed (5 bags)	437.00	437.00	0.00	No variance.
Mow/cultivate between tree rows	3,705.00	12,000.00	8,295.00	Mowing and cultivation did not occur as frequently as it should have; some entries are not documented here because the work was completed by NPARA, or DMI in conjunction with test site maintenance.
Pre-emergent herbicide	0.00	504.00	504.00	Weather and time did not provide the opportunity to apply a pre-emergent herbicide.
In-row herbicide	5,925.00	4,500.00	(1,425.00)	Underestimate of cost of applications of glyphosate with shrouded sprayer, and clopyralid over the top of the trees.
Decapitation and singling	7,101.00		(7,101.00)	Not in the original estimate, but was necessary in order to save the trees, and therefore the whole project, from certain death by vole girdling.
Monitoring	2,401.00	1,500.00	(901.00)	Time required to measure the trees was underestimated.
Sub-Total	87,531.89	71,224.00	(16,307.89)	
Project Administration	3,561.00	3,561.00	0.00	No variance. Calculated as 5% of the total estimated cost of \$71,224
Total	91,092.89	74,785.00	(16,307.89)	

FUTURE BENEFIT OF THE MURDOCH LAKE DEMONSTRATION

The Murdoch Lake Agroforestry Demonstration will continue to be used as a demonstration of one option of how trees can be incorporated into “normal” agricultural practices. The project collaborators will continue to work together to encourage opportunities for technology transfer, and make decisions regarding the on-going maintenance of the site. A plan is being developed for the introduction of grazing during the summer of 2009.

Additional future benefit will be gained from the site, as the success of the demo to date has encouraged others to come forward with suggestions of research questions that could be linked to the base demonstration. Currently PFRA is preparing a proposal to include other studies which would incorporate a better understanding of the science behind the demonstration. They propose looking at site utilization criteria such as root distribution, soil moisture gradients, hay yield relative to distance from trees, and others. PFRA also brought forward suggestions for expanding the extension role of the demonstration including the use of video.

GRASS PRODUCTION IN AN ALLEY-CROPPING CONFIGURATION

Wayne Geyer¹, Charles Barden¹, and Walter Fick²

¹Forestry Division, Kansas State University, Manhattan, Kansas 66506

²Department of Agronomy, Kansas State University, Manhattan, Kansas 66506

Contact: wgeyer@ksu.edu

Abstract: Combining hardwoods trees and agricultural crops in an alley-cropping system has the potential of increasing total biomass and financial yields. In the central part of the USA black walnut is a prime candidate for this system. In Kansas, on the western edge of the hardwood timber production zone, various agronomic crops have been studied. Forage production with brome grass, especially during the later years in the rotation in the plains area, did not suppress tree growth with proper management.

We established a 2.5 acre, 300-tree study near Manhattan, Kansas in a sandy loam soil in 1995. The climate is continental having a precipitation amount of about 31 inches a year. Drought and abundant amounts of precipitation were experienced. Trees were planted 8 ft apart alternating between black walnut and Scotch pine in rows 40 wide. Pine was harvested at 6 to 10 years. Plastic mulching was used to control weeds. Grain, forage, and horticultural crops were replicated 3 times in 300 ft- long rows and planted in the alleys.

This study presents only the yearly forage yields from plantation establishment through the 14th year. Grass production remained high, except during very dry years. Border reductions in dry summers were noticed after 10 years. Measurements taken during the 12th through 14th years showed about a 20 % reduction in grass biomass. Total height of the dominant walnut trees near the grass was reduced as compared to the soybean comparison trials.

Keywords: Smooth brome grass, Black walnut, Yield, Tree growth

INTEGRATED MANAGEMENT OF MULTISTRATA PRODUCTION SYSTEMS UNDER NEWLY ESTABLISHED RAMPT MODELS OF ROADSIDE AND SLOPELAND AGROFORESTRY

M. Abul Hossain¹, M. Mohidul Hasan², M. Samiul Ahsan Talucder³, M. Shajebur Rahman², Imtiaz Ahmed², Raihan Ahmed, M. Saiful Islam² and M. Tazul Islam⁴

¹Department of Agroforestry, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh. ²Former post graduate students, Department of Agroforestry, BAU, Mymensingh-2202, Bangladesh. ³Department of Agroforestry, Sylhet Agricultural University, Sylhet-3100, Bangladesh. ⁴Graduate Training Institute, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh.

Contact: abulhossainbauaf@yahoo.com

Abstract: The alarming food crisis of the world demands immediate necessary steps for the development of sustainable systems for more food production and food security in an overpopulated country like Bangladesh. There are presence of huge fallow and wastelands along the sides and slopelands of the network of roads, highways, railways, irrigation canals, embankments, farm and homestead boundaries etc. in plain lands, and also in the riparian and hilly areas of Bangladesh. With a view to bringing these fallowlands under planned development and integrated cultivation along with soil conservation, landscape development and environmental benefits, the newly developed models, commonly termed as Roadside Agroforest Multistoried Production Technologies (RAMPT), have been established at Bangladesh Agricultural University Campus, Mymensingh, Bangladesh. The models have been designed to utilize every inch of land, accommodate increased number of suitable species for higher economic return, encourage biodiversity with integration of various types of MPTS including *Azadirachta* and *Sesbania*, herbaceous crops, spices, medicine and oil, biodiesel yielding plants, increase soil fertility and check soil erosion, and finally to maintain healthy environment. The models are also replicable to other similar slopelands such as raised farmland, homestead, office premise or institutional boundary slopes, embankment and hill slopes, etc. and pond, lake, canal or river sides as well. The managed models have appeared as attractive and effective multistoried production and insect repellent systems, and are expected to be sustainable, since *Sesbania* is continuously adding leaf biomasses and N₂ to the systems along with regular yield of flower vegetables, forage and fuel wood.

Key Words: Sustainable, live fence, MPTS, Neem (*Azadirachta*), Bakphul (*Sesbania*), Biodisel (*Jatropha*), food (vegetable), pruning, pollarding

INTRODUCTION

The agricultural land of Bangladesh is being decreased day by day (Haque 1996) due to conversion of agricultural land into institutional and housing areas, industrial areas, roads and highways, railways etc. The losses due to decreasing condition of agricultural land can be compensated by increasing intensity of production per unit area following the agroforestry

technologies. This involves selection of suitable species, appropriate production technologies and effective management systems. In an overpopulated country like Bangladesh, the production of multipurpose trees and shrubs (MPTS) in suitable places following the principles of agroforestry is very effective to obtain maximum benefits from minimum land. Multipurpose trees including both fruit and non-fruit species yield timber, fuel wood, fruit and forage (Hossain 1996). Therefore, selection of suitable MPTS and herbaceous species as well as their effective management practices may enhance production by intensive utilization of every inch of land through judicious accommodation of increased number of species per unit area. Suitable management technologies should be followed to obtain the desired characters / structures of trees to suit a particular agroforestry system (Hossain 1994).

There remain huge fallowlands and wastelands and the sides of roads, highways, railways, embankments, homesteads, farm houses and farm boundaries, pond sides, lake and river sides, etc. These lands are needed to be brought under production systems (Hossain 2006, 2007). Again crop land 'ails' (bunds) as well as farm and homestead boundaries have to be used under specialized planting systems to reduce friction and / or negative effects on others' land (Hossain 1994, 1996, 2007). The large trees grown by commonly followed roadside plantation practices seriously affect the adjacent crop fields, hence demanding the modification of the existing systems. The sustainable multistoried production and agroforest management technologies in roadsides, embankment sides and in farmlands will be a breakthrough in these regards. With all these views, the relevant project works were undertaken to establish multistoried production technologies (Hossain 2007) along roadsides and farm slopelands to utilize every inch of land, to accommodate increased number of suitable species for higher economic return, to encourage biodiversity with various types of MPTS, herbaceous crops, spices, oil yielding and medicinal plants, to check soil erosion, and finally to maintain healthy environment. Some of the results of these studies have been outlined in this article.

METHODOLOGY

The field works were carried out along roadsides of Bangladesh Agricultural University Farm Areas, Mymensingh-2202, Bangladesh. The initial work was outlined for the establishment of the novel roadside agroforest models termed as RAMPT-1, RAMPT-2 and RAMPT-3 which were reported elsewhere (Hossain 2006, 2007). The models have also been adjusted in farmland boundaries. The training and pruning of growing plants have been done according to Hossain (1994, 1996). To achieve all the objectives stated above, soil working and leveling were done following clearing of roughages, gravels, brick parts etc. before stepwise development and plantation for multistoried production systems. The initial protection was given by living poles, thorny branches, bamboos and nylon net fencing, followed by the development of live fences through plantation of *Acalypha* cuttings and then by lemon stem cuttings leaving necessary distance from footpath / foot walk / side way (Hossain 2007). Both these live fences simultaneously resulting beautification, protection and / or production of fruits (citron). The 1st row of Neem/Mehogini were planted inner/outer side of the live fences having plant to plant distance of 5 m, followed by production of *Jatropha*, turmeric, chilli, tomato, stem amaranth, okra, sunflower, country bean, kidney bean *Eryngium*, Indian spinach etc. on first flat bed until the establishment of selected MPTS. Alternate to Neem/Mahogany plants Bakphul trees have been grown along the 1st slopes of RAMPT models at 5 m distances in combination with

alternate plantation of *Jatropha* (Biodiesel yielding plant) stem cuttings. Both the 1st and 2nd flat beds of RAMPT models were cultivated with turmeric, chillies, beans, lady's finger, sweet gourd, bitter gourd, tomato, stem amaranth etc. The above mentioned MPTS were included in this study for their high qualities and multipurpose uses as reported by Khan and Alam (1996), Openshaw (2000) and Hossain (2007).

All these plantations have appeared as effective multistoried production systems (Fig. 1 and Fig. 2) which are expected to be sustainable since *Bakphul* is adding a huge quantity of leaf biomasses and N₂ to the systems. In addition, the wind blown nutrients are being trapped by the multistoried plant canopies developed along roadsides / farm boundaries and added to the soil naturally by rain water. Therefore, during the 1st year and 2nd year at development of the system, none or low dose of manure was necessary. The *Neem* plants are now in the young tree stage along with the maturing *Bakphul* trees. No disease or insect infestation was noticed in the system probably due to insect repellent system developed by the growing *Neem* / *Mahogany* plants. Pruning and pollarding were done according to Hossain (1994, 2007). Other relevant methods and designs are mentioned with the following relevant experimental results.

RESULTS AND DISCUSSION

Roadside and soil management for RAMPT models at initial and subsequent stages

After the initial development of roadsides and plantation under RAMPT models (Hossain 2007), the structures of roadsides were again managed properly with soil working during March to April of each year following winter crop harvest. In Bangladesh, the roadsides are usually damaged and washed out during rainy season that result into small to big ditches (Fig. 3 and Fig. 4) and sometimes become the causal factor of accidents of the vehicles. The poor and illiterate farmers also cut their roadsides to expand the crop lands. The practices under RAMPT models remove these problems since the sides are well managed for additional and better crop harvest (Fig. 1 and Fig. 2) by the farmers.



Fig. 1. An established 'RAMPT' model (RAMPT-2) showing front live fence of *Acalypha* followed by lemon hedge cum fruit (citron) production line. Behind the live fence a pollarded and pruned *Bakphul* tree is seen in between the *Neem* trees with plenty of regenerated shoots.



Fig. 2. The outer side (towards crop fields and opposite to that of Fig. 1) of 'RAMPT'-2 model showing 3rd year's cultivation of sweet gourd and bitter gourd on ground and the beans trailing on *Bakphul* trees. Note that the managed trees cast less shades on crop fields.



Fig. 3. A village roadsides having unplanned plantation of banana by the farmers gradually reducing the road surface areas. Part of the roadside has also been damaged. The ‘RAMPT-1’ model can save this roadside as well as help the farmers with regular income generation throughout the year.



Fig. 4. The raised roadsides having no plantation is also being damaged due to formation of a hole and narrow ditch by rain water. This might cause the accident and damage of vehicles and lives which can be saved following ‘RAMPT’ plantation model as suggested by Hossain (2007).

Management and production of MPTS (Multipurpose trees and shrubs)

Neem (*Azadirachta indica* A. Juss.) and Mahogany (*Swietenia macrophylla* King.) saplings and trees

Neem leaves are so much useful to the peoples (mostly for medicinal purposes) that they take away leaves and twigs, even the whole saplings. The branches and growing tops of larger saplings/young trees are also broken and taken away. That is why success of establishment of Neem trees is very low. Each year thousands of Neem sapling are planted of which only a few percentages are established and some times it tends to be zero. Hence, initially ‘thorn protection technique’ as we call it, was followed by enclosing the saplings with thorny branches of *Acacia albida*, *Zizyphus mauritiana*, *Perkinsonia aculeata* and *Citrus* spp. etc. This ensured almost a 100% survival rates grown under RAMPT models at Bangladesh Agricultural University, Mymensingh (Hossain 2006, 2007) as compared to very few success rate (Fig. 5A) under cage protection, because the cages were broken by cattle and taken away by the poor villagers for their fire purposes.

The mahogany saplings did not require such attention as that of Neem saplings for its growth and development. A 100% standing trees were recorded in the RAMPT model area with good growth (Fig. 5B). In this case, thorn protection at sapling stage and stick supporting at later stages led the plants standing with straight growing and healthy appearance.

Bakphul (*Sesbania grandiflora* (Linn.) Poir.) trees

Bakphul trees were found to grow naturally well and uniformly branched and appeared very nice looking increasing the beautification of the areas. This is a very fast growing trees which yielded flower vegetable and forage (pruned shoots) within one year of growth. But its branches are weak and are easily broken during flower collection by the outsiders. Hence, branch pruning and

pollarding were followed to make the plants stout. The pruned and pollarded trees along with regeneration of new shoots are seen in Fig. 1. Similar to that of Neem saplings, the survival rates of Bakphul trees are very poor when grown out side the RAMPT model areas (Fig. 5C).

Jatropha (*Jatropha curcas* L.)

Since these plants are not browsed by animals, very good growth having almost 100% survival rate with healthy appearance was obtained under RAMPT models (Fig. 5D).

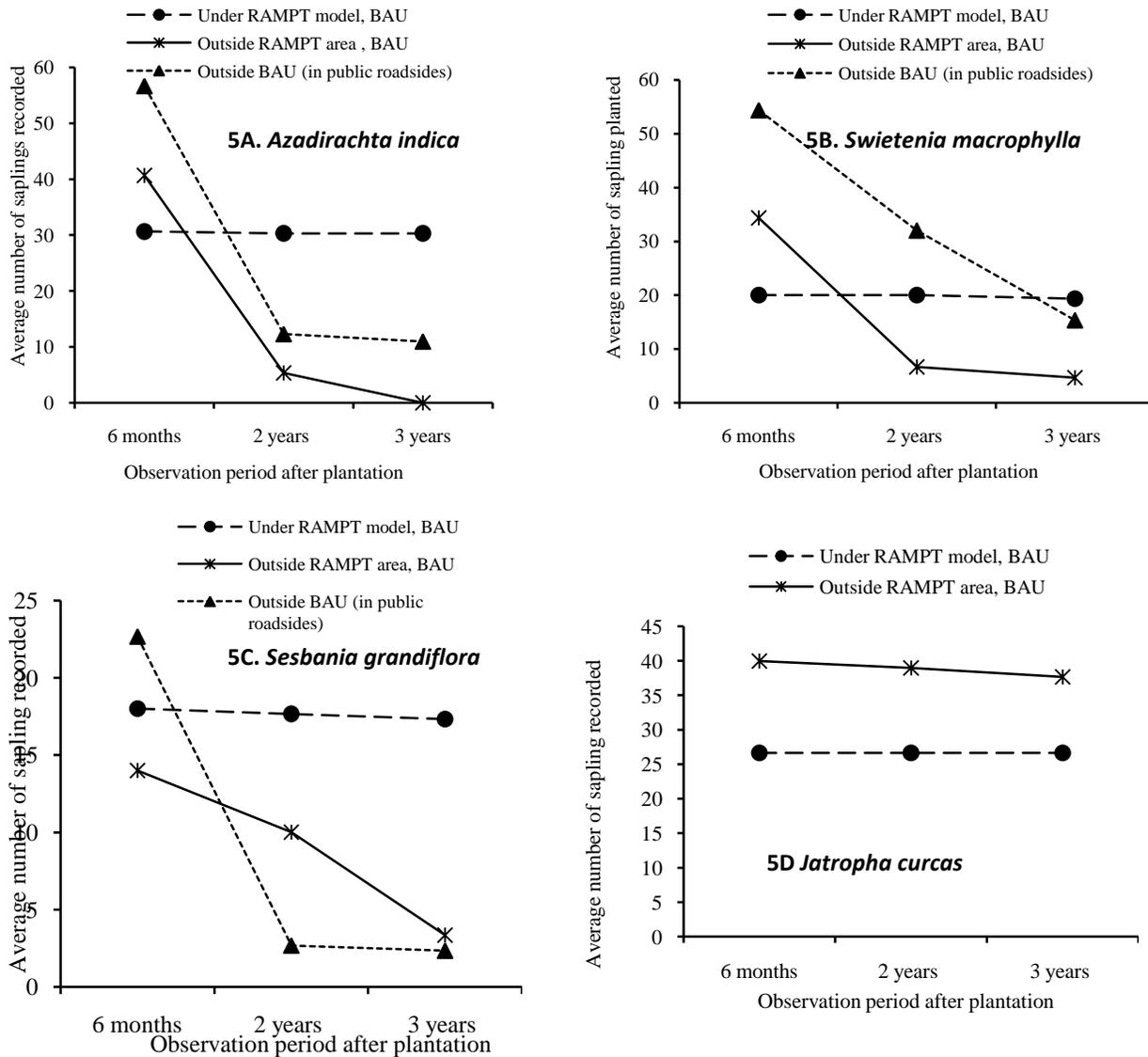


Fig. 5 (A-D). Showing survival rates of selected MPTS planted under different management practices

Pruning of the sapling/young tree branches and pollarding of MPTS

These practices made the plant stout with excessive shoot regeneration, hence increasing forage production. In fact, pruning and pollarding of Neem, Jatropha and Bakphul markedly influenced and enhanced shoot regeneration and made the plants stout and uniform in appearance. In all cases, pruning off all the branches at 1/3 to 2/3rd parts leaving 2/3 to 1/3rd basal area of branches showed better performances in regeneration, new shoot growth and higher shoot biomass production than those of severely pollarded or intact plants. This is in good conformity with report of Hossain (2007) on pruning of Neem, Bakphul and Jatropha plants.

Under-storied crop production with Neem, Mahogany and Bakphul trees

The tree species along with understoried crops and live fences (Fig. 1 and Fig. 2) formed a multistrata arrangement with simultaneous or intermittent yields throughout the year. Therefore, the farmers may receive regular incomes throughout the year along with environmental benefits and, in the long run, a huge quantity of quality timber for the nation. According to Hossain (2006) crop management encourages good growth of tree species (Fig. 6). Some of the experimental results are presented below.

Experiments with Mahogany (*Swietenia macrophylla*)

Crops such as okra, chilli, amaranth and Indian spinach were grown around Mahogany. Irrigation was given as and when found necessary. For this, soils around the saplings were prepared by spading, weeding, soil mulching etc. The interaction effect revealed that there was no significant difference in growth attributes of mahogany saplings due to the competition with crops (Fig. 7). Plant height and yield of different crops grown under *S. macrophylla* were found better under soil managed and manured conditions with poor result under unmanured condition. These results indicate that growth and yield of crops were not significantly affected by the competition of mahogany saplings at their early stages of growth.

Experiments with Neem (*Azadirachta indica*)

The results shown in Fig. 6 indicate that the growth and development of Neem sapling were significantly influenced by crop species and different soil management practices. The highest plant and branch length of Neem were found in soil managed with manure and both without crop and with crop condition.

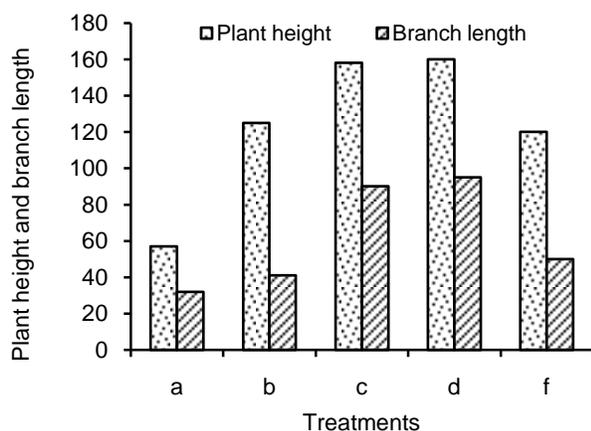


Fig. 6. Plant height and branch length of Neem grown with country bean (after Hossain 2006)

a = Unmanaged, b = + Soil management (- Manure, -Fertilizer, - Crop), c = + Soil Management (+ Manure, - Crop), d = + Soil Management, + Manure, + Crop, f = + Soil Management, - Manure, + Crop

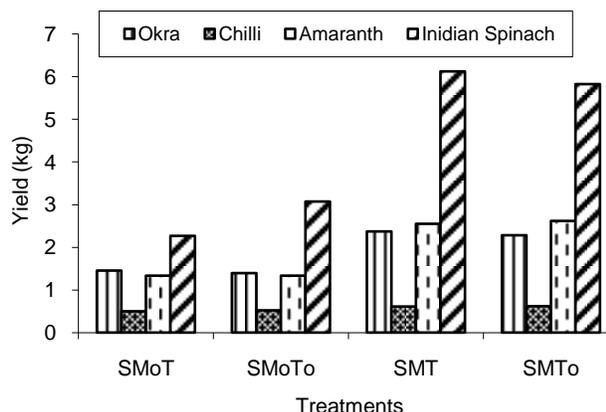


Fig. 7. Interaction effect of mahogany sapling on the yield of different crops

SMoT = Soil managed without manure with mahogany
 SMoTo = Soil managed without manure without mahogany
 SMT = Soil managed with manure with mahogany
 SMTTo = Soil managed with manure without mahogany

The results also showed that, in unmanaged soil condition without crop the growth of Neem was very poor, while better results were obtained when the soil around tree bases were managed. It was also revealed that, when Neem plants were grown in association with crops, no significant difference was observed in growth attributes due to the competition with crops. Plant height and yield of different crops grown under Neem plants also showed better results in soil managed condition (Table 1). These results encourage growing of vegetable crops along with Neem saplings at early stages of growth for mutual benefits in roadside agroforestry systems.

Table 1. Effect of Neem saplings on the plant height and yield per plot of different crops

Treatment	Okra		Chilli		Amaranth		Eryngium	
	Plant height (cm)	Yield (g)						
N = With Neem	134.33	1667.83	68.00	697.16	84.00 a	2385.16	26.33 a	33.33a
N ₀ = Without Neem	132.16	1661.66	65.16	694.33	81.16 b	2381.50	24.16 b	30.83 b
Level of Significance	NS	NS	NS	NS	*	NS	**	**
LSD _{0.05}					2.196		0.781	1.053

Mean values in a column having the similar letter (s) do not differ significantly whereas mean values having dissimilar letter (s) differ significantly as per (DMRT), ** Significant at 1% level of probability, * Significant at 5% level of probability, NS = Not significant

Experiments with Bakphul (*Sesbania grandiflora*)

The experimental results with *Sesbania grandiflora* (Figs. 8-11) clearly indicate that in case of shoot tip condition the development of new branches showed significant variation in intact and pollarded shoot tip. The number was 464.00 in pollarded shoot tip and 300.00 in intact shoot tip at 60 DAP. Again, in case of branch pruning condition, the maximum (513.17) number of new branches were observed in severely pruned stocks i.e. at lower + upper branch pruning levels at 60 DAP and minimum branch number (288.67) was recorded in no pruning condition at same DAP.

Similarly the number of leaves in new branches was significantly influenced by all pruning and pollarding treatments. The maximum leaf number was 975.78 in pollarded shoot tip and 633.67 in intact shoot tip at 60 DAP. Again, severe pruning levels produced the highest leaf number (1063.16) and no pruning level produced the lowest number of leaves (652.33) at 60 DAP. On the other hand the treatment of pollarded shoot tip with lower + upper branch pruned off condition produced the highest leaf number (1126.67) followed by the treatment of intact tip with lower + upper branch pruned off condition produced 999.224 leaves at 60 DAP. Whereas control treatment produced only 447.002 leaves at the same DAP.

The results presented in this study are in good conformity with other researchers. In this study it was observed that severe pruning/pollarding condition i.e. pollarded shoot tip with lower + upper branch pruning levels always produced higher number of buds, branches and leaves (resulting in increase in forage production) followed by the treatment of intact tip with lower + upper branch pruning level. According to Bisla *et al.* (1990) hard pruning resulted in significantly higher number of secondary and tertiary shoots and the largest leaf area. However, the results of the present study showed partial difference with the findings of Bisht *et al.* (1998) who observed that pollarding of *G. optiva* at 2 m height but leaving the main shoot intact produced maximum fuel and fodder.

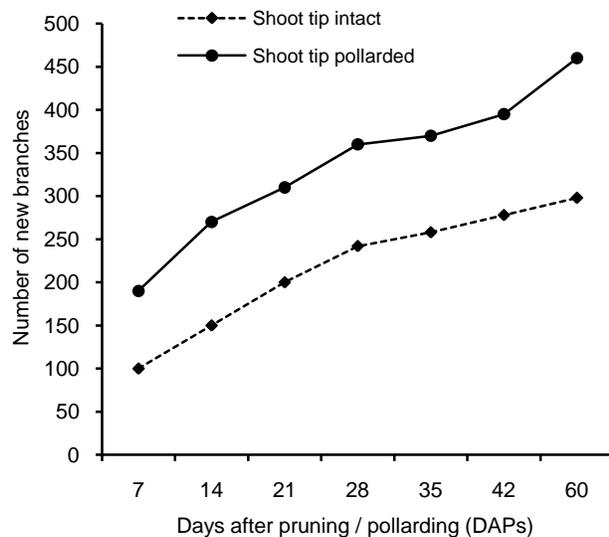


Fig. 8. Effect of shoot tip conditions on the number of new branches at different DAPs in *Sesbania grandiflora*

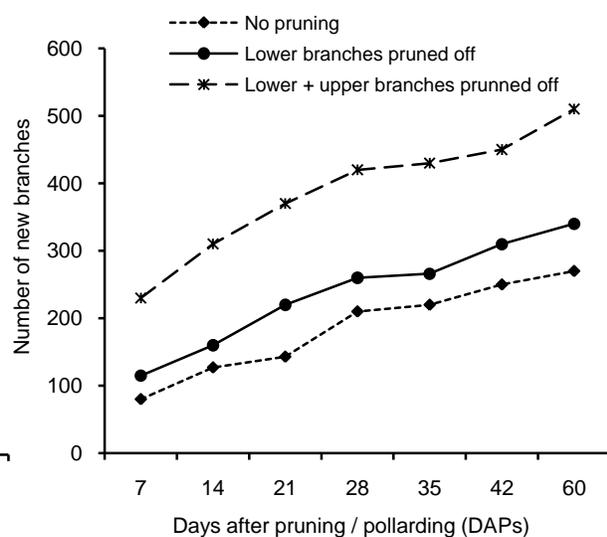


Fig. 9. Effect of branch pruning levels on the number of new branches at different DAPs in *Sesbania grandiflora*

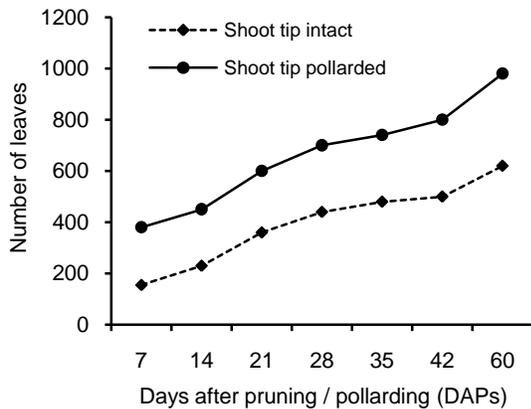


Fig. 10. Effect of shoot tip conditions on the number of leaves in new branches at different DAPs in *Sesbania grandiflora*

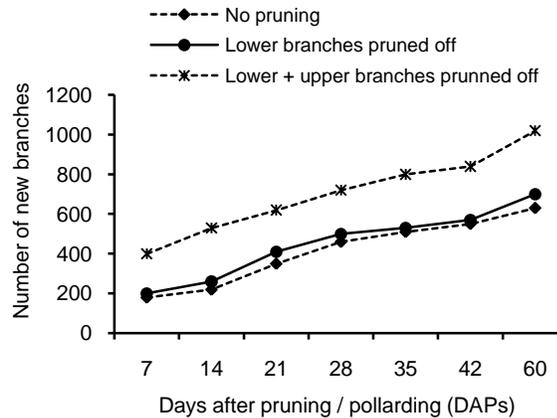


Fig. 11. Effect of branch pruning levels on the number of leaves in new branches at different DAPs in *Sesbania grandiflora*

Tipu *et al.* (2006) observed that the higher pruning height (150 cm) significantly had higher number of buds than that of lower pruning heights in the stocks of *Leucaena leucocephala*. Similarly the stocks with higher pruning height (150 cm) always produced higher number of branches as well as leaves than those with lower pruning heights (100 cm). These results along with other raw data clearly indicate that the pruning of branches and pollarding of upper levels of Neem, Jatropha and Bakphul markedly enhanced shoot regeneration resulting the plants into stout, good looking and uniform in appearance, as well as, higher production of shoot biomass compared to control plants.

Crop output and regular income generation under RAMPT models

After establishing the RAMPT-2 models along BAU farm roadsides, approximately 40 sq.meter (0.01 acre) land area under this model was intensively cultivated and protected approximately 30 m long roadsides was required for this model area. The standard crop management practices were followed according to Razzaque *et al.* (2000). The harvested crops were sold at retail prices and the total output and the sold price are shown in Table 2. Meanwhile, the vegetable prices have been increased by 10-15% and therefore, the total calculated income now might stand at approximately 2500/ taka instead of taka 2216.80. If a farmer possesses one acre of land near a medium or high way, he may get about 60-100 m of roadsides from his square to rectangular sized crop fields. Taking minimum (60 m) possible length of roadsides, he will get double income than that shown above. Hence, he might earn an additional income of taka 5000/- (2500/- × 2) annually without using his own lands.

According to Amin *et al.* (1996) Bangladesh has got approximately 7400 km of highways / railways which will be equivalent to a maximum of approximately 14,800 km roadsides suitable for 'RAMPT-2 and RAMPT-3' models. If, for example, 1/3rd of these roadsides are allowed to use for other purposes / system loss, then 2/3rd parts i.e. approximately 9,900 km roadsides could be brought under RAMPT-2 and RAMPT-3 models. If 60 m roadsides is given to one landless farmer, it will involve approximately 1.7 lac farmers for the said roadsides. However, if 16000

km district council roads (Amin et al. 1996) are used for RAMPT-1 model along with larger embankment sides, pond sides etc. for RAMPT-2 and 3, it will certainly exceeds 2 lac (0.2 million) farmers, who will earn 100 crore taka ($2,00,000 \times 5000/- = 100,00,00,000/-$ taka) annually creating job opportunities for 25000 farmers according to their existing per day income in Bangladesh. These figures are expected to be further increased since many more highways, railways and embankments have been established after the reports of Amin et al. (1996). As stated above, this is possible for vegetable and lemon (citron) production immediately without disturbing other existing systems in Bangladesh.

Table 2. Observed / calculated outputs of different MPTS and crops obtained from selected unit area (40 sqm (0.01 acre) of roadsides under RAMPT model during 2nd year of studies

Production periods	Crops grown (2-4 sqm area used per crop)	RAMPT beds	Total yield of each crop (kg)	Total price (Taka)
April–September	Chilli	1 st flat bed	1.36	40.80
”	Okra	”	3.32	49.50
”	Amaranth	”	4.50	45.00
”	<i>Eryngium</i>	”	0.50	25.00
”	Lemon	”	0.50	20.00
”	Indian spinach	2 nd flat bed	10.50	52.50
”	Papaya	”	36.00	540.00
October – March	Sweet guard	”	120.00	1200.00
”	Bitter gourd	”	2.20	44.00
”	Tomato	”	3.50	35.00
”	Bakphul (as vegetable)	”	5.50	165.00
”	Neem leaf	”	-	-
”	<i>Jatropha</i>	1 st slope	-	-
”	Bakphul (as forage and fuel woods)	”	-	-
Total =				2216.80

- Not recorded in 2nd year. This being done subsequently. Note that in addition to control of tree canopy, papaya, chilli, kakrol (*Momodica*) etc. shade tolerant species will be cultivated subsequently.

In addition to vegetable production, the system will yield very high value timber of Neem (*Azadirachta indica*) trees earning crores of taka in future. Their leaves will be utilized as insecticidal purposes in addition to its natural beautification and air purification (Tewari 1992). Similarly a huge quantify of forages will be produced from Bakphul trees that will enhance cattle (milk / meat food) production in this fodder crisis loaded country like Bangladesh. The systems will also yield fuel woods for the farmers and roughages for manure preparation at regular intervals. Therefore, large programs the said established and tested models may be started throughout this country without further delay for food security, environment benefits and reduction in unemployment problems of Bangladesh.

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INTEGRATING SILVOPASTURES INTO CURRENT FORAGE-LIVESTOCK SYSTEMS

Robert Kallenbach

Division of Plant Sciences, University of Missouri, Columbia, MO 65211

Contact: kallenbachr@missouri.edu

Abstract: Prior research has demonstrated that grazing forage within tree stands can be a viable production practice. Most studies to date have compared whole systems of silvopasture practice to systems where livestock have no access to silvopastures. A more likely scenario is that a portion of the farm would be converted to silvopasture practice and the rest of pasture acreage remain under traditional management. Our objective was to determine the impact of introducing silvopasture as part of an integrated forage-livestock system. This experiment had two treatments. In one treatment, cow-calf pairs grazed traditional “open” pastures and in the other they were grazed in a system where approximately 25% of the land area was under silvopasture practice. The silvopastures included a 10 to 12 year old pine-walnut plantation and a 6-year old mixed hardwood plantation. Angus crossed fall-calving cows and their calves rotationally grazed a mixture of tall fescue, alfalfa and red clover in a year-round systems trial. Cow body condition and weights were collected at breeding, at weaning, and in mid-summer. Calf weights were measured at birth and at weaning. Cows in the integrated silvopasture system lost approximately 10% less weight over winter, and were 12% less likely to experience calving difficulty. In addition, calves in the integrated silvopasture system were 25 kg/hd heavier at weaning compared to their counterparts in the traditional system. By integrating silvopasture practice into traditional pasture systems, cow-calf producers could lower winter feeding costs, decrease calving problems and produce heavier calves.

Keywords: Cow-calf production, beef, pasture systems

INTRODUCTION

More than 20% (20.2 million head) of the beef cattle in the USA are raised in the lower Midwest (USDA, 2009). This region, which includes Missouri, Kentucky, Tennessee, Kansas, Arkansas, and Oklahoma use more than 62.9 million acres of private grasslands and engage more than 312,000 farm families in its beef operations (Vesterby and Krupa, 2001). Despite the enormity of this industry, most beef operations in the lower Midwest are unprofitable. The average beef producer has a net operating margin of $-\$23.75 \text{ head}^{-1} \text{ year}^{-1}$ (Short, 2001).

Planned forestry might provide better economic returns than pastures in the lower Midwest. Economic analyses conducted by Kurtz et al. (1984), Dwyer et al. (1990), Campbell et al. (1991), and Kurtz (2000) have demonstrated that well-planned forestry systems can provide an above-average long-term return on investment. Even though the conversion of pastures to planned forestry systems could have long-term economic benefits for producers, many landowners feel that it is economically difficult for them to make the change. This is because

most landowners need some income from their land during the 10 to 60+ years necessary to sell marketable forest products.

One feasible way to introduce forestry to producers in the lower Midwest is through silvopasture, one of the five recognized agroforestry practices. Typically in silvopasture practice, perennial grasses and/or grass-legume mixes are planted between rows of trees for livestock pasture (Clason and Sharrow, 2000). The trees not only provide a long-term investment, but also provide the animals shade in the summer and a windbreak in the winter (Clason and Sharrow, 2000). In turn, the forage base provides feed for beef cattle which ultimately provides livestock sales for short-term income.

Prior research has demonstrated that grazing forage within tree stands can be a viable production practice (Pearson and Whitaker, 1974; Clason and Sharrow, 2000; Kallenbach et al., 2006). Most research to date has compared a single or series of silvopasture practices to systems where livestock have no access to silvopastures. However, at the farm level, it is unlikely that current livestock producers would convert their entire pasture acreage to silvopasture practice. Rather, a more likely scenario is that a portion of the farm would be converted to silvopasture practice and much of the rest of pasture acreage used as it has been in the past. Little research, where silvopasture practice has been integrated into a larger grazing system has been conducted. Our objective was to determine the impact of introducing silvopasture as part of an integrated whole-farm forage-livestock system.

MATERIALS AND METHODS

Experimental site

This study was conducted at the Horticulture and Agroforestry Research Center near New Franklin, MO, USA (latitude 39° 01' N, longitude 92° 44' W). The soil type at this location is a Menfro silt loam (Fine-silty, mixed, superactive, mesic Typic Hapludalfs). Average annual precipitation is 943 mm and the mean annual temperature is 12.3°C.

Treatments

This experiment had two treatments: i) cow-calf pairs that were maintained in a traditional “open” pasture system and ii) cow-calf pairs that had access to silvopastures at strategic times in winter, early spring, during heat stress periods in summer and at calving. The animals with access to silvopastures spent approximately 25% of the year in pastures with trees. For the purposes of this manuscript the treatments will be referred to as the “traditional” and “integrated” treatments hereafter. In the integrated treatment, the silvopastures included a 10 to 12-year old pine-walnut plantation and a 6-year old mixed hardwood plantation. Each treatment was replicated three times. The pasture species used for both treatments were a mixture of tall fescue (*Lolium arundinaceum* (Schreb.) S.J. Darbyshire = *Schedonorus phoenix* (Scop.) Holub), alfalfa (*Medicago sativa* L.) and red clover (*Trifolium pretense*, L.) established in 2001. All treatments were fertilized with 84 kg ha⁻¹ of N as ammonium nitrate in mid-August each year to stimulate fall growth. Fertilization rates for P, K, secondary and microelements were based on the results of soil analysis from the University of Missouri Soil Testing Laboratory. The experiment was conducted from September 2005 through September 2007 (2 years).

Animals and Grazing Management

The animals used in this project were Angus crossed fall-calving cows and their calves. The average calving date was 10 September each year and calves remained on cows until weaning in June. After weaning calves were sold. Water and salt blocks were provided to animals throughout the duration of the experiment.

Each of the six (2 treatments x 3 replications) grazing units was 4.8 ha, divided into 8 equally (\pm 0.05 ha) sized paddocks. In the integrated treatment there were 1.2 ha (two paddocks) of silvopasture and 3.6 ha (six paddocks) of open pasture. The paddocks were rotationally stocked, except during winter when hay was fed. Six cow-calf pairs were stocked in each 4.8 ha unit for a total of 36 cow-calf pairs (6 cow-calf pairs x 2 treatments x 3 replications). Except when hay was fed in winter, animals remained in their respective pasture areas during the entire 2-year experiment. During the grazing season, animals were moved to a new paddock within each unit every 3 to 7 days based on forage availability and expected forage growth. Paddocks were stocked to remove forage down to an 8- to 10-cm stubble height, before moving to the next paddock. In spring, when forage growth rates exceeded the ability of animals to graze it in a timely manner, excess forage was harvested and stored as round bale silage, and then fed back to animals in winter.

Forage Mass Determinations

Forage mass was determined weekly from each paddock by taking 50 rising plate meter readings (Earle and McGowan, 1979). The rising plate meter was calibrated every 3 to 4 weeks during the experiment by clipping six strips, from the most recently grazed and next-to-be-grazed paddock within each unit. The strips were cut to a 1-cm stubble height using a flail-type harvester. The forage mass values from the harvested strips were used in a multiple regression equation to estimate forage mass on a weekly basis using rising plate meter values ($R^2=0.87$).

Performance Measurement Indices

Cow body condition (nine-point scale) and weights were collected at breeding, at weaning, and in mid-summer. Cows were palpated annually and conception rates calculated. Calf weights were measured at birth and at weaning. Cumulative forage production was calculated for each paddock using the following formula:

Cumulative forage production = (Pre-grazing forage mass at T1) + (Pre-grazing forage mass at T2 – post-grazing forage mass at T1) + (Pre-grazing forage mass at T3 – post-grazing forage mass at T2) ++ (Pre grazing forage mass at Tn – post grazing forage mass at Tn-1). In this formula T = time sample was collected and n = the number of times a paddock was sampled.

Experimental Design

Each treatment was replicated three times in a randomized complete block design (three traditional units and three integrated units) in a split-split plot arrangement. In this analysis, treatments were considered main plots, years as sub-plots, and sampling dates as sub-sub-plots

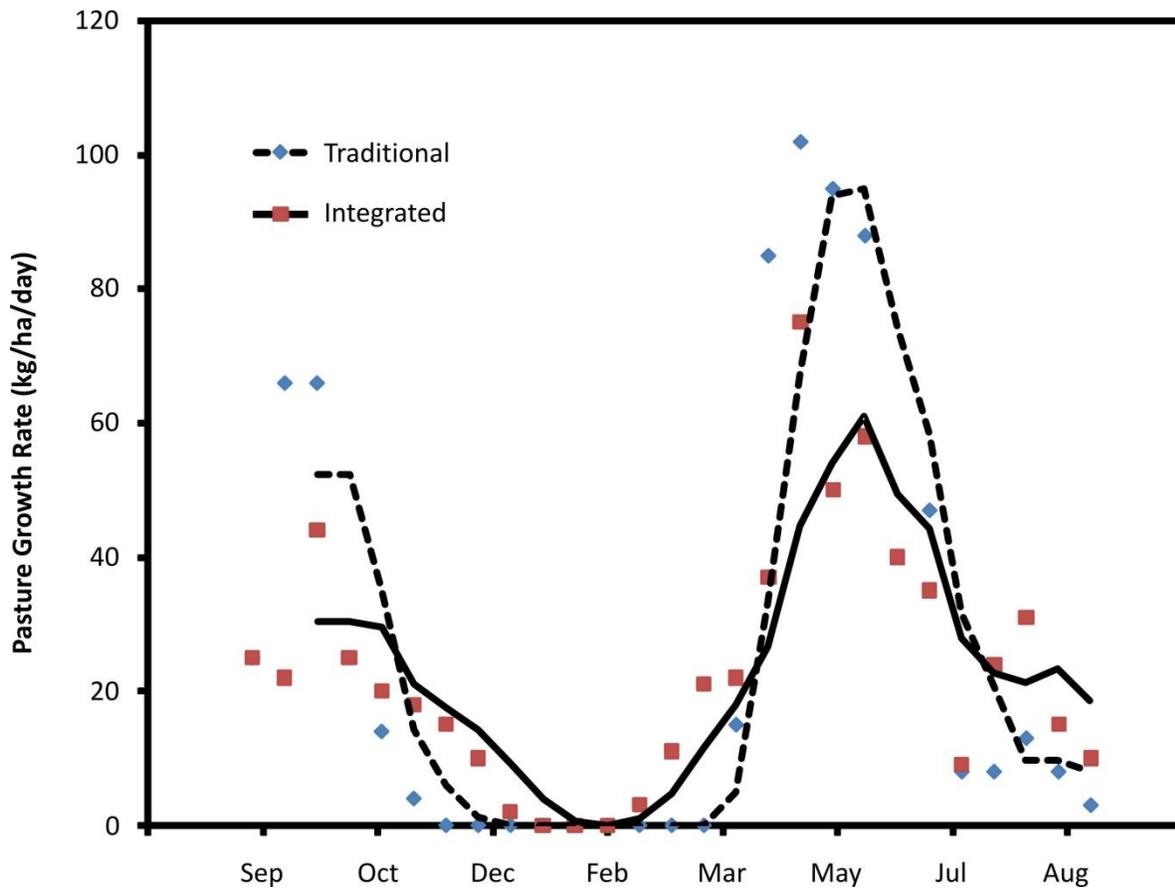
(Steel and Torrie, 1980). Sampling dates were analyzed as repeated measures. Analysis of variance was conducted on treatments, years, and sampling dates (forage measurements only), and all possible interactions using the model outlined by Steel and Torrie (1980). Main effects and all interactions were considered significant when $P < 0.05$.

RESULTS AND DISCUSSION

Cumulative Forage Production

Cumulative forage production did not have an interaction between years, so data were pooled over both years. Cumulative forage production on an annual basis was greater ($P=0.02$) for the traditional treatment at 9,625 kg/ha compared to only 8,409 kg/ha for the integrated treatment. If we stopped there, however, we would only have a portion of the story. Most of the extra forage produced by the traditional treatment was in spring, when forage in both systems was in excess of what the animals could reasonably consume by grazing alone (Fig. 1). Thus, the amount of silage that had to be made in the traditional treatment was nearly twice that required by the integrated treatment (data not shown). Additionally, forage growth began earlier in the spring and continued longer in the summer and late autumn in the integrated treatment. Most of this extended growth for the integrated treatment was produced in the silvopasture portion. This would have real benefits to cow-calf producers because it would allow more days of direct harvesting by grazing animals and reduce the need to make and feed stored forage.

Fig. 1. Pasture growth rates in the traditional and integrated pasture systems at the Horticulture and Agroforestry Research Center near New Franklin, MO. Data are averaged over two years. Trend lines are the 3-week moving average.



Several researchers have reported that cumulative forage production in silvopastures is often lower when compared to open pastures, especially as trees develop a dense canopy (Pearson and Whitaker, 1974; Clary, 1979; Sibbald et al., 1991; Silva-Pando et al., 2002). Similar to our findings, Silva-Pando et al. (2002) reported that the variation in seasonal forage production was greater from open pastures than from silvopastures in Spain. They concluded that the presence of trees in a pasture provided a microclimate that produced fewer fluctuations in light transmission, air temperatures and photosynthetically active radiation. Although we did not take these environmental measurements in our study, it is probable that the trees provided some insulation from the cold temperatures in spring and autumn. In addition, Frost and McDougald (1989) found that shade in silvopastures can reduce evapotranspiration from herbage and thus allow forage plants to avoid drought stress. So during the summer of both years, it is possible that forage in the integrated treatment was able to avoid short-term drought stress better than forage traditional treatment and this led to a greater rate of forage accumulation during this period.

Animal Performance

Cow body weight loss over winter, calving difficulty, and calf weaning weight did not show an interaction between treatments and years, and thus the data were pooled over both years. Cows in silvopastures lost approximately 10% less weight over winter, reducing the need for supplementation by about 12% (Table 1). Additionally, cows that gave birth in the integrated treatment were 12% less likely to experience calving difficulty. McArthur (1991) suggested that the trees in silvopastures can protect animals from wind and extremes in temperatures. This likely provided cows a more comfortable environment and reduced the need for them to use metabolic energy to maintain body temperatures during cold weather in winter and reduced animal stress in summer.

At weaning, calves in the integrated treatment weighed 295 kg which was 25 kg more ($P < 0.01$) than calves in the traditional treatment. This additional weight is likely a result of less stress on cows during stressful periods and additional forage produced in early spring. In all, the additional calf weight would be worth approximately \$50/head on an annual basis.

Table 1. Performance of cow-calf pairs in a traditional “open” pasture system compared to those in an integrated system where both open and silvopastures were used.

Treatment	Cow body weight loss in winter (kg)	Calving difficulty (%)	Calf weaning weight (kg)
Traditional	105	15	270
Integrated	93	3	295
P value	0.02	0.04	<0.01

CONCLUSIONS

1. Cumulative forage production in the integrated system was about 13% less than in a traditionally managed system. However, the growth patterns in the integrated system required less forage to be harvested during the spring and less forage to be fed in mid-summer and winter.
2. Cow-calf pairs in the integrated system lost approximately 10% less weight over winter, had less stress at calving time and weaned heavier calves compared to those in the traditional system. These are tangible benefits that cattle producers could use to improve farm income in the short-term.

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HYBRID POPLAR MEASUREMENT PROGRAM IN SASKATCHEWAN

Brittiany Letwinetz

ForestFirst, 101-1061 Central Avenue, Prince Albert, Saskatchewan, Canada S6V 4V4

Contact: bletwinetz@forestfirst.ca

Abstract: Agroforestry in Saskatchewan is an industry on the verge of unprecedented expansion. Biomass production, using short rotation woody crops (SRWC) is, considered to be a viable source of fibre for the emerging biofuel industry. The ForestFirst Agroforestry Demonstration Network is intended to show the growers of Saskatchewan how to grow these crops. The Network continues to expand throughout Saskatchewan.

The Demonstration Network is made up of sites from three programs. The ForestFirst demonstration sites were established using funding from the Forest Development Fund (FDF) to broaden the network all over Saskatchewan. ForestFirst and the Canadian Forest Service (CFS) worked in partnership to establish Forest 2020 sites throughout Saskatchewan, based on a federally funded program. Saskatchewan Ministry of Environment was one of the first providers of hybrid poplar to landowners to establish small scale agroforestry sites. The University of Saskatchewan developed sites through working with a variety of agencies; for example, ForestFirst, CFS and Agriculture and Agri-Food Canada-Prairie Farm Rehabilitation Administration (AAFC-PFRA) to help advance research trials with hybrid poplar and willow.

The Hybrid Poplar Measurement Program was initiated in 2007 by ForestFirst to determine the growth and yields of the different clones in each site. There are 45 sites established across Saskatchewan on farm land with eight different clones of hybrid poplar, totaling 444 hectares (1097 acres). The sites were measured in the summer of 2007 and data collected included height, diameter at breast height (dbh) and root collar diameter (rcd). Data was entered into a database to make calculations that would enable the comparison of clones, sites, site preparation, vegetation management, and establishment methods. The poster will provide an overview of ForestFirst activities to date on the Measurement Program and its plan for future uses for the program.

Key Words: Agroforestry, SRWC, hybrid poplar, measurement program, growth & yield

EARLY PRODUCTION AND VALUE OF GRAFTED BLACK WALNUTS IN MISSOURI

Andrew L. Thomas¹, Jordan T. Prindle², and Jay S. Chism³

¹ University of Missouri, Southwest Research Center, Mt. Vernon, MO

² Hammons Products Company, Stockton, MO

³ University of Missouri, Cooperative Extension Service, Lamar, MO

Contact: ThomasAL@missouri.edu

Abstract: Black walnut (*Juglans nigra* L.) shows excellent promise as a nut-bearing tree component in temperate agroforestry systems, but meaningful production and economic data are lacking. A large orchard of grafted black walnuts was established at the University of Missouri's Southwest Research Center in 1993. Trees were field grafted to the cultivars 'Sparrow', 'Emma K', 'Football', 'Kwik-Krop', and 'Tomboy'. Significant nut production began in 2005. By 2008, the earliest grafted trees in the study were 12 years post-grafting. After evaluation, the harvested nuts are sold annually to a commercial processor in Missouri (Hammons Products Company, Stockton, MO) at established market rates. Sufficient early production and market data (2005 – 2008) are now available from this study to begin determining and projecting yield and value potential of these black walnut cultivars. The cultivar Sparrow has been the most reliable and consistent producer at this site, and has not exhibited the alternate (bi-annual) nut-bearing pattern of most cultivars and wild trees. Emma K has, on average, produced the highest-value nuts at \$1.519 kg⁻¹, followed by Kwik-Krop (\$1.512 kg⁻¹), Sparrow (\$1.448 kg⁻¹), Football (\$1.437 kg⁻¹), and Tomboy (\$1.129 kg⁻¹). The highest amount paid was \$1.806 kg⁻¹ for Emma K nuts in 2006. Linear yield-by-year correlations at this early stage of production were good for Sparrow ($r^2 = 0.563$) and Football ($r^2 = 0.548$), but poor for Emma K ($r^2 = 0.244$), and no correlations were determinable for Kwik-Krop and Tomboy. Assuming that a linear (and not exponential) increase in yield continues for the near term, Sparrow, Football, and Emma K can be predicted to yield approximately 29.2, 17.7, and 16.6 kg tree⁻¹ at age 20 post-grafting, respectively. At current prices and mean percent fancy kernel yields (28.3%, 30.5%, and 31.3%), gross income of \$42.24, \$25.51, and \$25.18 per tree may be expected from Sparrow, Football, and Emma K trees, respectively, at that age.

SECTION 12

Cultural and Social Dimensions

ALBERTA WOODLOT EXTENSION PROGRAM

Doug Macaulay¹ and Toso Bozic²

¹Alberta Woodlot Extension Program, Alberta Agriculture and Rural Development, Main Floor, Airdrie Agriculture Centre, 97 East Lake Ramp NE, Airdrie, AB, Canada, T4A 0C3.

²Alberta Woodlot Extension Program, Alberta Agriculture and Rural Development, Main Floor, Administration Building (CDC North), 17507 Fort RD NW, Edmonton, AB, Canada, T5Y 6H3.

Contact: doug.macaulay@gov.ab.ca

Abstract: The Woodlot Extension Program operated in Alberta for the past eight years and currently employs two extension specialists who work with landowners all across the province. The program is administered by the Alberta Government and supported by a partnership of industry, all levels of government and conservation organizations. The program aims at quality woodlot and agroforestry stewardship, the adoption of beneficial management practices of private forested land and sustainable landscape management in Alberta.

WEP has three goals. The first goal is to increase awareness of economic, social and environmental implications of agricultural area forest management. The management of forests, woodlots and agroforestry systems on the agricultural landbase has long-term implications for the environmental integrity and economic stability of rural areas. When these areas are managed individually and on a landscape basis it has implications for water quality, water supply, soil sustainability, wildlife and biological diversity. The second goal is to increase landowner participation in sustainable woodlot and agroforestry management. Only a small portion of the agriculture area in Alberta's agroforestry systems and woodlots are being managed. Therefore landowners must actively manage these areas in a sustainable fashion to protect the resource and achieve their land use objectives. The third goal is to promote integrated community land use planning by working with communities developed with regard to landscape values and in cooperation with a variety of resources.

Key Words: extension, woodlot management, agroforestry

INTRODUCTION

The premise of the Alberta Woodlot Extension Program (WEP) is to encourage the sustainable management of more than 1.5 million hectares of privately owned forestlands in Alberta's agricultural areas (white zone) as a means to yield important social, economic and environmental benefits. WEP is a provincial based extension program that offers agroforestry awareness to landowners across Alberta with emphasis on Peace River, Southwestern and Central Alberta Regions.

Core funding for WEP is provided by a diverse group of partners from the federal government, provincial government, industry, and conservation organizations. Governance of WEP is provided through an Executive Committee comprised of a subset of the Partners. The Partners that have

signed a Memorandum of Understanding that outlines their funding and in-kind contributions to the program through to March 31st 2011 demonstrate testimony of commitment.

PARTNERS OF THE WOODLOT EXTENSION PROGRAM

- Ainsworth Engineered Canada LP.
- Alberta Agriculture and Rural Development
- Alberta Pacific Forest Industries Inc.
- Alberta Sustainable Resource Development
- Alberta Conservation Association
- Canadian Forest Service
- Daishowa-Marubeni International Ltd.
- Ducks Unlimited Canada
- Millar Western Forest Products Ltd.
- Prairie Farm Rehabilitation Administration (Agriculture and Agri-Food Canada)
- The Land Stewardship Centre of Canada
- Vanderwell Contractors (1971) Ltd.
- West Fraser Mills Ltd.
- Woodlot Association of Alberta
- Weyerhaeuser Canada Ltd.

MISSION, VISION AND GOALS

Mission

To achieve sustainable woodlot management by providing support to landowners, land managers and others who influence land use practices in Alberta.

Vision

A permanent woodlot extension program is administered by the Alberta Government and supported by a partnership of industry, all levels of government and conservation organizations. The program aims at quality woodlot stewardship, the adoption of best management practices on private forested land and sustainable landscape management in Alberta.

Goals

Goal #1: Increased awareness of economic, social and environmental implications of agricultural area forest management. Management of forests and woodlots in the agricultural area of Alberta has long-term implications for the environmental integrity and economic stability of rural areas. Increased awareness of the range of values and opportunities associated with sustained forest management will lead to balanced decision making by land owners and policy makers concerning issues related to forested land.

Goal #2: Increase landowner participation in agroforestry, afforestation and sustainable woodlot management. Landowners must actively manage the private forested areas in Alberta in a sustainable fashion to protect the resource and achieve land use goals.

Goal #3: Encourage integrated community land use planning than acknowledges the values of forest resources. Managers and landowners within the rural communities have to commit to sustainable forestland development at a landscape level to address wildlife, habitat, economic, social and other values. Integrated community land use planning will be developed with regard to landscape values, and in cooperation with a variety of resources at that scale. WEP will promote sustainable ecosystem management and long term land and forest management at the community and the landscape levels.

ACTIVITIES SUMMARY

The following is a summary of the main Directives provided by WEP's Executive / Steering Committee; the primary Activities performed by WEP staff and volunteers; and relevant Occurrences affecting WEP.

Activities

- 1) Woodlot Management Plans – Based on the Environmental Farm Planning process, the Woodlot Extension Program facilitates the completion of woodlot management plans among landowners and woodlot owners. Woodlot extension staff instructs and facilitate the completion of management plans through one-on-one visits and group planning processes.
- 2) Prairie Shelterbelt Program - We are an effective resource who is helping PFRA deliver the PSP in Alberta. Many of the current activities are complementary as we both deal with similar clients. WEP runs province wide and on average has at least 100 extension activities every year. These range from woodlot and agroforestry beneficial management practice workshops, demonstrations, to on-site consultations. WEP is also involved with two landscape planning projects and hopes to incorporate the PSP into them.
- 3) Mountain Pine Beetle Awareness - WEP works directly with landowners and municipalities on awareness and education on how to recognize and manage for Mountain Pine Beetle and other forest pests. We work closely with ASRD forest health staff, municipalities and other organizations on the endeavour of educating rural landowners on how landowners can identify and manage pests such as MPB. Our priorities areas will be to work with landowners who own land in the white zone of the Peace River region, eastern slopes and bordering areas particularly those regions known as the Leading-edge and Holding Zones.

The goal of the extension efforts will be to build awareness in rural communities and among landowners about how they can help in the containment of pests such as MPB and prevent their spread into more eastern boreal forest stands such as Jack Pine. MPB issues surrounding its threat to timber resources, forest ecology and watersheds will also be highlighted. We will focus our effort on areas that have received little to know awareness such as Slave Lake, Athabasca, Manning, Barrhead and others that are in the Leading-edge and Holding Zones.

4) Weberville Community Forest Project - Numerous organizations are trying to promote sustainable land management through the implementation of Private Land Management Plans in which different options are listed to achieve the landowners' goals and objectives. However, today the need for management plans is not limited to the individual's needs. These plans are of increasing importance, as forest industries engage in certification programs and the implementation of Environmental Management Systems that call for wood fibre from sustainable or managed wood fibre sources. Many companies depend heavily on wood fibre from private land sources. One of the problems with the currently used individual plans is that they are only designed for small properties and small scale operations. This makes the realization of some of the goals and objectives such as harvesting, timber marketing, reforestation, biodiversity considerations, etc. very hard as they often depend on larger volumes or larger areas. Many of these individual plans therefore do not shift into the implementation stage. Also, the current number of landowners throughout Alberta having or implementing a Woodlot/Private land management Plan is still extremely low. The projects purpose is to help residents and local stakeholders understand the opportunities of working together to develop a Landscape Level Management Plan. This document will identify common goals and objectives that the majority of the community residents and other stakeholders have.

5) Beaverlodge River Riparian Reforestation Project – Phase one of last year's project we successfully planted 23 000 trees on 50 acres with five landowners in the Beaverlodge River watershed. All plantings with cattle were fenced to control their access to planted sites. Some landowners also invested in offsite watering systems that further enhanced the project. These projects were supported by a number of agencies such as ACA, Alberta Fish and Wildlife and the Peace Country Flyfishers Association. This also included local landowners who were thrilled to see this kind of restoration work occurring in their community. In 2009 we plan to begin phase two of this three-year project so we can continue inspiring more landowners in the community to reforest more riparian uplands in this watershed. The goal is to plant another 23 000 trees on 50 more acres of land.

6) Beaverhill Landscape Project - The BHI is an extensively treed landscape east of Edmonton that is aspen-dominated with some patches pine and white spruce. The last large forest fire in BHI area happened in the mid-1930's and has created many old and overmature stands. This region is under significant development pressures as the city expands and more acreage is added to the landscape each year. Our goal is to help the municipality and its landowners understand the values of these forested lands so they can be managed sustainably for future demonstrations. We hope to work directly with residents and land managers to develop a series of sustainable woodlot management plans that can then be used in the development of community landscape plan.

7) Agroforestry Projects –Regional demonstrations are great tools to help educate landowners about agroforestry systems. WEP works with innovative landowners who are looking to try something new and showcases their projects to local and provincial landowners. During the past eight or so years since WEP began, we have setup a variety of agroforestry demonstrations such as the Murdoch Lake Agroforestry Projects near Manning, Alberta. This has helped inspire a number of landowners to incorporate trees into their farming operations.

8) Bioenergy – We are currently working with Alberta Agriculture and Rural Development to educate industry and municipalities on the adoption of Bioenergy/Biomass systems to heat and power their facilities. In particular, the Community Wood Energy Demonstration Project aim to overcome a major barrier to the wider development of biomass heating in Alberta namely the lack of good quality and strategically placed exemplar biomass heating projects. This barrier has been identified through dialogue with local authorities and the Energy from Wood Biomass Combustion in Rural Alberta Applications report. The report has highlighted barriers to be overcome if biomass installations are to become commonplace in public buildings. Some of the most critical issues that will be addressed by this project are:

Alberta needs exemplar biomass heating installations to demonstrate the technology

The absence of a coordinated reliable local wood-fuel supply chain undermines confidence in the technology. In many cases local authority decision makers do not believe biomass heating presents a credible alternative to fossil fuelled plant. The goal is to identify at least one site that has the potential to stand out as an exemplar project.

9) Carbon Offset Market Development for Privately Owned Afforested Lands - This project is designed to help landowners, aggregators and industry develop a better understanding of the carbon market's potential through afforestation. It is an Agri-Business and Product Development project for tree crops. This project is to focus on the development of a carbon offset market for private landowners who either have or those who would like to afforest acres on their farms. We would work directly with these individuals on the development of a system to measure the offsets they produce and help them understand how it relates to the Alberta Afforestation Protocol. We will work with producers to setup their tree planting so they can position themselves to either sell directly to industrial emitters or aggregators.

The project will provide the following short and long-term benefits to rural communities:

- Support economic growth by providing long-term annual income for rural Albertans by helping them diversify and develop new tree-based businesses
- Encourage landowners to develop long term sustainable business plans for their tree businesses
- Learn and develop new skills regarding a tree-fuelled industry
- Industry and aggregators will be educated and consulted about this developing market

OPPORTUNITIES & FUTURE DIRECTION

- Continuing promotion of BioEnergy/Biomass systems to communities and industry
- Continuing to work with communities on integrated land use planning
- Exploration of how agroforestry and afforestation systems relate to the newly emerging carbon market
- Continue to build awareness regarding Mountain Pine Beetle to landowners.

RECREATIONAL MULTIFUNCTIONALITY AND ITS IMPLICATIONS FOR AGROFORESTRY

Carla Barbieri¹ and Corinne Valdivia²

¹ Dept. of Parks, Recreation & Tourism, University of Missouri
105 Anheuser Busch Natural Resources Building, Columbia, MO 65211

² Dept. of Agricultural Economics, University of Missouri
214 D Mumford Hall, Columbia, MO 65211

Contact: BarbieriC@missouri.edu

Abstract: Multifunctionality occurs when farms provide different services along with food production including recreation and agroforestry. Multifunctional farms simultaneously offer several services suggesting synergies among them that are not yet understood. This study aims to fill this gap, examining the relationships between recreational multifunctionality and agroforestry. In 2006, 353 randomly selected landowners from four Missouri counties were interviewed about their farm characteristics, recreational services and agroforestry perceptions. Statistical tests include cluster analysis followed by ANOVA and chi-square tests.

Responding landowners are preponderantly middle age and male. The majority provide at least one recreational service and on average more than four. The most frequently provided services are hunting, gathering wild edibles and nature contemplation, showing a blend of consumptive/ extractive and non-consumptive recreational uses. Cluster analysis performed over the recreational services revealed two groups of recreational multifunctionals: Farming Lifestyle Landowners - FLL (n=122) and Rural Lifestyle Landowners - RLL (n=199).

Both types of recreational multifunctionals differ in their engagement in agricultural production, types and amount of recreational services provided, socio-demographic and farming attributes. Overall, FLL are not as multifunctional and their farm has a production function. RLL are highly multifunctional and mainly non-farmers who appear to own a farm for non-extractive values. Clusters also differ in their understanding of agroforestry. RLL are more knowledgeable and interested in most agroforestry practices than FLL. Differences between groups on their awareness and perceptions of agroforestry suggest that different strategies should be applied to inform them about the values of agroforestry.

Keywords: Recreation, Multifunctionality, Agroforestry, Agritourism, Cluster Analysis.

INTRODUCTION

The vast majority (91.2%) of farms in the U.S. have annual sales lower than US\$250,000, representing a small share (27%) of the national agriculture production (Hoppe et al. 2007). These farms, labeled as small family farms, control a large proportion (72%) of agriculture productive assets including farmland (Hoppe et al. 2007), which has important implications for rural well-being. Small family farms help mitigate the negative environmental effects from

agricultural production, provide landscape beautification and control for residential sprawl, and foster native and wildlife conservation (Hoppe et al. 2007; Lambert et al. 2006; Valdivia 2007).

The current agriculture context is posing economic challenges to small family farms, which are experiencing a significant reduction of their agriculture income (Hoppe et al. 2007). In response, family farms are adopting several strategies to remain in business or retain their lands. These strategies include revenues diversification through off-farm employment (Hoppe 2001), development of on-farm enterprises and crops diversification among others (Barbieri et al. 2008; Hoppe 2001; Knutson et al. 1998). The economic challenges affecting small family farms demands a holistic approach to better understand the many values, especially those non-economic, which these firms provide to rural societies. Multifunctionality can serve this purpose as it approaches the different functions that farms provide along with food and fiber production, including rural heritage preservation, land conservation and maintenance of agri-biological diversity, among others (Dobbs and Pretty 2004; Marsden and Sonnino 2008).

In this study we use the multifunctionality approach to examine a set of recreational services (i.e., recreational multifunctionality) that small family farms in Missouri provide, because of the myriad of benefits associated with recreation participation in rural settings. These benefits include the increase of farm revenues, revitalization of local economies, preservation of agriculture heritage and natural resources among others (Hegarty and Przezbórska 2005; Wicks and Merrett 2003). Given that farms can concurrently provide different functions (Barbieri et al. 2008; Ploeg et al. 2000), this study further examines associations between recreation and agroforestry. A simultaneous concurrence of on-farm recreation and agroforestry can amplify the positive impacts on farms, local communities and society as agroforestry brings a wide range of benefits including revenues generation, reduction of livestock stress and mortality, decrease of runoff and non-point source pollution, creation of aquatic and terrestrial habitats, carbon sequestration, and scenic beauty among others (Gold and Garret *in press*; Valdivia and Poulos 2009; Williams et al. 1997).

LITERATURE REVIEW

Agriculture is multifunctional as it provides many functions (i.e., services) to society along with food and fiber production (Ploeg et al. 2000). Multifunctionality is frequently approached to holistically assess the many values of farming outputs, including environmental amenities, agritourism opportunities, food quality, landscape management, preservation of biodiversity, and others (Marsden and Sonnino 2008). Agriculture multifunctionality is synergetic as on-farm functions and enterprises do not operate in isolation but there is interaction among them (Barbieri et al. 2008; Ploeg et al. 2000). Moreover, on-farm recreation appears to be more synergistic than other functions, which can amplify the values within the farm household as it assists in promoting and encouraging the sales of other farm specialties, or value-added products and services (Barbieri *in press*).

On-farm recreation is a type of agriculture multifunctionality because it provides multiple benefits to: 1) the business unit, such as cross marketing of farm products and revenues generation; 2) the landowner in their accomplishment of entrepreneurial intrinsic goals; and 3) to society in the preservation of the agriculture landscape and heritage among others (Barbieri and

Mshenga 2008; Hegarty and Przezbórska 2005; Wicks and Merrett 2003). It is important to stress that the concept of recreational multifunctionality developed in this study differs from the term agritourism. The latter is commonly placed within the enterprise diversification grand scheme, thus defined as one type of on-farm entrepreneurial endeavor with the purpose of attracting visitors to increase farm revenues or value (Barbieri and Mshenga 2008; Hegarty and Przezbórska 2005). Common activities typified as agritourism include orchard tours, self-recreational harvests, programmed hunting, festivals and special events as they have the capability to capture visitors' fees directly (e.g., activity-based fee) or indirectly (e.g., direct sale of farm value-added products). However, for the purpose of this study, recreational multifunctionality includes eight activities that can commonly occur within the farmland regardless of the landowner economic goals: hunting, fishing, gathering of wild edibles (e.g., berries, mushrooms), wildlife observation or nature contemplation; walking or hiking, use of off-road recreational vehicles, horseback riding and camping.

Agroforestry is defined as an intensive land-use management practice, where trees and/or shrubs are incorporated into the agricultural landscape (Gold and Garrett *in press*). The various physical, biological, ecological, economic and social benefits produced by the biophysical interactions between the trees/shrubs and crops/livestock makes agroforestry multifunctional (Dobbs and Pretty 2004; Gold and Garrett *in press*). The economic benefits include the increase of farms' revenues, the maximization of land production and reduction of production costs (Gold and Garrett *in press*; Gold et al. 2009). Agroforestry also produces important environmental benefits including control of wind erosion, reduction of run-off and non-point source pollution, stabilization of stream banks, improvements of internal drainage and enhance infiltration, and enhancement of aquatic and terrestrial habitats and connective travel corridors, among others (Gold and Garrett *in press*).

DATA AND METHODS

This study explores the extent of recreational multifunctionality among landowners in Missouri and examines possible associations with agroforestry. Specific objectives are: (1) to investigate the occurrence of recreational functionality in terms of types of recreational services provided by landowners; (2) to cluster landowners based on their levels of recreational multifunctionality engagement; and (3) to identify associations between recreational multifunctionals and several agroforestry indicators.

The valid sample frame included 728 landowners, excluding those that the enumerators were unable to contact or reach. This sample was randomly drawn with an automatic number generator with replacement from four counties Tax Assessor's Lists in Missouri. The survey was conducted in 2006 and produced 353 completed surveys (48.5% response rate). In addition, 49.4% landowners refused to participate. The final questionnaire comprised 93 questions inquiring about involvement with farming, land resources and use, participation in programs and contact with organizations, experience and attitudes towards trees, marketing, environmental problems, sources of information, social networks, perceptions of farming, non farm land use questions, agroforestry practices, attitudes, knowledge and adoption, and personal background information.

Analysis for this study was performed in three stages to address the study objectives. First, descriptive statistics were used to examine the extent of recreational functionality among respondents. Second, a hierarchical cluster analysis was performed over the recreational services to classify respondents. Third, chi-square and ANOVA tests were conducted to determine differences between clusters regarding various agroforestry indicators, including current adoption, knowledge perception and willingness to adopt agroforestry practices.

RESULTS

Profile of Responding Landowners and their Farmland

The majority of responding landowners are male (72.3%) and at least 50 years old (62.7%). Respondents in the sample show strong ties with their farm as the majority (51.7%) occupied their farm for more than 20 years (mean=33.7 years). About a quarter (25.3%) estimated their assets in less than \$200,000 while a third (33.1%) reported over \$500,000 assets, confirming the high level of agriculture assets controlled by family farms (Hoppe et al. 2007).

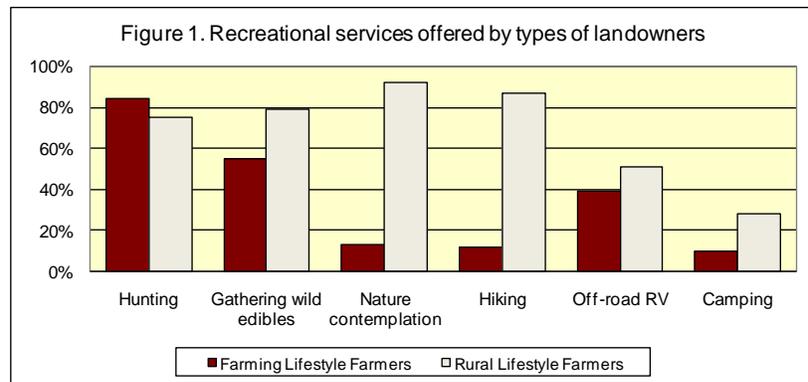
Responding farms are similarly located in urban (50.1%) and rural (49.1%) counties, equally representing both countryside and proximity to urban areas. Average land size was 184 acres, with about half (47.8%) of participants with farms smaller than 50 acres. Given the nature of the sample and the small farm size reported, it is not surprising that most landowners (72.4%) received less than \$1,000 in sales from their agriculture production in 2005 (mean=US\$17,928). On average, about half (48.4%) of the farmland is woodland, either for timber production or non-consumptive purposes (e.g., shade for livestock), followed by hay land and non-wooded pastures (37.7%), with an even distribution between forest and non-forest agriculture production.

There is a low incidence of agroforestry adoption among respondents. Less than a third (30.9%) of respondents are employing at least one of the six agroforestry practices most frequently adopted in the U.S. (i.e., alley cropping; windbreaks; riparian/stream bank plantings; forest farming, trees planting in front of levees, and silvopasture). The agroforestry practices most frequently adopted are windbreaks (17.3%) closely followed by riparian or stream bank plantings (15.9%). Adoption of other practices was very limited. On average, those engaged in agroforestry (30.9%, n=109) are adopting more than one practice at the time (mean=1.31 practice).

Recreational Multifunctionality

The vast majority of participants (92.4%) provides at least one recreational service (i.e., function) to household members and outsiders. On average, they are simultaneously offering more than four of these services (mean=4.16 services). The services provided most frequently include hunting (78.5%), gathering of mushrooms, berries or other wild edibles (70.1%), wildlife observation or nature contemplation (61.7%) and walking or hiking (58.6%), showing a blend of consumptive and non-consumptive recreational uses.

A hierarchical cluster analysis with the recreational services provided by respondents revealed two groups that differ significantly in the types and amount of recreational services provided. First, the *Farming Lifestyle Landowners* – FLL (38.0%; n=122) are not very multifunctional in terms of number of recreational



services (mean=2.99 services), and are mostly associated with recreation linked to the farming lifestyle, such as fishing, hunting and horse-back riding. Second, the *Rural Lifestyle Landowners* – RLL (62.0%, n=199) are highly multifunctional (mean=4.87 recreational services), offering significantly more ($p < 0.05$) recreational services associated with the rural life-style, such as walking or hiking and wildlife and nature contemplation (figure 1). There are no significant differences regarding fishing and horse-back riding between groups.

Recreational clusters also differ in their socio-demographic and their production unit attributes. FLL are predominantly full and part-time farmers (47.1%) for whom the farm is a production unit. On the other hand RLL are mainly non-farmers (72.5%) who appear to own a farm for non-economic values such as nature escapism or recreation ($\chi^2 = 24.76$, $p < .001$) as shown in table 1. Although the majority of respondents reported having off-farm jobs, the proportion was statistically higher among RLL (71.7%) compared to their counterparts (53.8%) ($\chi^2 = 6.56$, $p = .010$). Given the differences found between clusters in labor efforts invested on the farm, it was not surprising that the proportion of revenues derived from agriculture during the last three years was significantly higher among the FLL (26.9%) than the RLL (9.7%) ($F = 26.62$, $p < .001$).

Few significant differences regarding the farm characteristics were found between clusters. A greater proportion of FLL reported having decreased the number of acres farmed in the past five years compared to the other cluster ($\chi^2 = 6.07$, $p = .048$), which is consistent with the farming exodus and the increased off-farm pluriactivity widely reported in the literature (Hoppe and Banker 2006; Gardner 2000). Interestingly, more RLL have increased their farmed acreage in the same period of time, suggesting that these landowners may be shifting to a steadier farming mode, either as hobbyists or connoisseur farmers. As it would be expected, FLL hired more farming labor in 2005 (36.3%) than RLL (21.5%). No significance differences were found between clusters regarding the location (rural/urban) of the farm and the gross revenues from agriculture production.

Table 1: A comparison of farm household and farm characteristics between recreation multifunctionality clusters.

Landowner and Farm Descriptors	FLL (n=122)	RLL (n=199)	<i>Sig.</i>
Type of Landowner			$\chi^2=24.76, p<.001$
Full-time farmer	16.0%	3.1%	
Part-time farmers	31.1%	24.5%	
Non-farmers living on the farm	36.9%	59.6%	
Non-farmers living away the farm	16.0%	12.8%	
Landowner Off-farm Pluriactivity			$\chi^2=6.56, p=.010$
Currently working off-farm	53.8%	71.7%	
Do not work off-farm	46.2%	29.3%	
Household Farming Income (Last 3 years)			$F=26.62, p<.001$
Income from farming (in percent)	26.9%	9.7%	
Farmed Acres Change - Last 5 years (in percent)			$\chi^2=6.07, p=.048$
Farmed acreage increased	16.1%	20.0%	
Farmed acreage remained the same	62.5%	74.5%	
Farmed acreage decreased	21.4%	5.5%	
Hired labor in 2005			$\chi^2=4.96, p=.026$
Farms with hired labor	36.3%	21.5%	
Farms without hired labor	63.7%	78.5%	

Agroforestry Perceptions among Recreational Clusters

Statistical tests were conducted to explore the implications of recreational multifunctionality on agroforestry in terms of current adoption, perceived knowledge and willingness to adopt in the future. Landowners' perceived knowledge regarding agroforestry practices was examined using a five-point Likert type scale ranging from one (very low knowledge) to five (very high knowledge), while willingness to adopt them was measured using a four-point Likert type scale anchoring in one (not interested at all) and four (very interested).

Analysis didn't yield any significant differences between recreational clusters on their level of current engagement in any of the five agroforestry practices included in this study, which is not surprising taking into account the small incidence of agroforestry among respondents. However, ANOVA tests show that there are significant differences between clusters in the understanding and willingness to adopt most agroforestry practices (table 2). Overall, RLL perceive themselves as more knowledgeable about most agroforestry practices than FLL ($p<0.05$), with the exception of silvopasture. Greater differences were found with windbreaks ($F=12.88, p<.001$), alley cropping ($F=9.33, p=.002$), and forest farming ($F=8.18, p=.005$). Worth noting is that clusters rank their knowledge of certain agroforestry practices differently. For example, silvopasture is the third most known agroforestry practice for FLL (mean=1.73), while the least known for RLL (mean=1.78).

Results show a very low (mean<2.0) interest in adopting agroforestry practices in the future (i.e., less than “slightly interested”). Consistent with the perceived knowledge results, RLL are overall more willing to adopt agroforestry practices than their counterparts ($p<0.05$) except in the case of silvopasture. Once more, there is not consistency between clusters in the practices more willing to be adopted. For example, the practices most willing to be adopted are riparian/stream bank plantings (mean=1.55) for FLL, and forest farming for RLL (mean=1.99). In turn, planting trees in front of levees (mean=1.15), and alley cropping (mean=1.45) are the practices least willing to be adopted by FLL and RLL respectively. Further, results show that there is not a complete correspondence between knowledge and willingness to adopt agroforestry practices. For example, while windbreaks is the most known practice (mean=2.91) by rural lifestyle landowners, it is not the preferred one to be adopted (mean=1.76). Conversely, rural lifestyle landowners are more willing to adopt forest farming (mean=1.99), while their knowledge of it is low (mean=2.01).

Table 2: A comparison of knowledge perceptions and willingness to adopt agroforestry practices between recreation multifunctionality clusters.

Agroforestry Indicators	FLL (n=122)	RLL (n=199)	Sig.
Landowner’s Knowledge Perception¹			
Alley cropping	1.58	1.92	$F=9.33, p=.002$
Windbreaks	2.41	2.91	$F=12.88, p<.001$
Riparian/stream bank plantings	2.07	2.39	$F=5.64, p=.018$
Forest farming	1.67	2.01	$F=8.18, p=.005$
Trees planting in front of levees	1.51	1.84	$F=6.75, p=.010$
Silvopasture	1.73	1.78	<i>Not Sig.</i>
Landowner’s Adoption Willingness²			
Alley cropping	1.17	1.45	$F=7.92, p=.005$
Windbreaks	1.51	1.76	$F=4.15, p=.042$
Riparian/stream bank plantings	1.55	1.92	$F=7.44, p=.007$
Forest farming	1.44	1.99	$F=19.48, p<.001$
Trees planting in front of levees	1.15	1.50	$F=6.87, p=.010$
Silvopasture	1.41	1.57	<i>Not Sig.</i>

¹ Measured using a 5-point *Likert*-type scale defined as: (1)=very low; (2)=low; (3)=medium; (4)=high; and (5)=Very high knowledge

² Measured using a 4-point *Likert*-type scale defined as: (1)=Not interested at all; (2)=slightly interested; (3)=moderately interested; and (4)=very interested

CONCLUSIONS

This study adds to the existing knowledge of agriculture multifunctionality, exploring the recreational functions among Missouri landowners. According to the profile developed, the majority of landowners provide several consumptive and non-consumptive recreational services to household members and outsiders, being the most frequently observed hunting, gathering wild edibles and nature contemplation. A recreation-based cluster analysis revealed two groups of

landowners who differ significantly in the types and amount of recreational services provided, their demographic and farmland attributes, and their attitudes towards agroforestry.

The first cluster, *Farming Lifestyle Landowners* – FLL (38.0%), is mainly composed by full and part-time farmers (47.1%) for whom the farm is a production unit. They provide few recreational services, mostly associated with recreation linked to the farming lifestyle, such as fishing, hunting and horse-back riding. The second cluster, *Rural Lifestyle Landowners* – RLL (62.0%), is mostly composed of non-farmers (72.5%) who appear to own a farm for non-economic values. They offer several recreational services on their land, mostly associated with the rural life-style, such as walking or hiking and wildlife and nature contemplation. Although clusters do not differ on the extent of current involvement in agroforestry, tests show that RLL have a greater understanding of these practices, and more willing to adopt these practices compared to the FLL.

The associations found in this study between recreational multifunctionality and agroforestry have various extension and academic implications. Results suggest that different strategies should be applied in the diffusion efforts of agroforestry, recognizing both types of landowners. For example, communications intended for RLL should emphasize the intrinsic benefits of agroforestry as this cluster is already more knowledgeable and willing to adopt these practices and not constrained by the economic utility of their farmland. In turn, greater efforts are needed to inform FLL about the several economic benefits of agroforestry such as the generation of direct revenues and maximizing returns to the land with additional alternatives.

The recreation-agroforestry associations found in this study also raise questions that need further examination. First, future studies need to closely examine the benefits produced by the concurrent presence of different farm functions (e.g., recreation and agroforestry), as these can expand our holistic understanding of the value of small family farms. Second, this study needs to be replicated, expanding its scope to also include agritourism, which includes recreational activities for entrepreneurial purposes. Finally, inconsistencies found between and within recreational clusters on their knowledge perception and willingness to adopt agroforestry practices suggest further exploration regarding presence of synergies between recreation and agroforestry functions in terms of perceived benefits and barriers associated with the adoption of agroforestry.

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THE ROLE OF AGROFORESTRY PRACTICES IN A HEALTHY FARM

James R. Brandle¹, Ron. J. Johnson², and John E. Quinn¹

¹School of Natural Resources, University of Nebraska Lincoln, Lincoln, NE.

²Department of Forestry & Natural Resources, Clemson University, Clemson, SC.

Contact: jbrandle1@unl.edu

Abstract: The University of Nebraska-Lincoln is developing a Healthy Farm Index that reflects a vision of sustainable farming. The index uses multiple indicators within ecological, environmental, and socio-economic categories to assess production, biodiversity, and ecosystem services provided by sustainable farm systems. The value of various agroforestry practices is reflected in these indicators as a component that improves farm profitability, conserves biological diversity, and enhances ecosystem services to and from agroecosystems.

Agricultural systems are typically managed to maximize the provision of food and fiber. In contrast, proponents of sustainable agricultural systems seek to optimize long-term outcomes that include multiple components of agroecosystems and rewards for farmers who use sustainable practices. Understanding how shape, arrangement, and management of agroforestry landscape features affect different components of the farm system is important, as is recognizing tradeoffs. Understanding tradeoffs requires whole farm analysis and management. Management objectives help plan the shape and arrangement of landscape features.

In this paper we will discuss how the use and arrangement of woody landscape features will be included in the Healthy Farm Index. Four participating organic farms in eastern Nebraska provide examples of the influence of woody land cover on the index scores. The structure of the index allows for the integration of current and future components. The index will be a mechanism for communicating interdisciplinary data toward farm practices and policy that optimize food production, biodiversity, and ecosystem services.

Key Words: Farm Assessment, Ecosystem Services

INTRODUCTION

Integration of agroforestry practices into long-term farm management plans can provide important benefits to organic and sustainable farmers. Potential components include windbreaks, woodlots, and riparian forest buffers. These landscape features provide essential ecosystem services and improve the health of the farm (Santelmann et al. 2004, Mize et al. 2008). Because agroforestry management occurs over a longer time scale, the consequences of decisions may not be known for many years. As such, new decision making tools are needed.

Momentum to include ecosystem services in management and economic decisions is growing. A greater understanding of the beneficial outputs, i.e., ecosystem services, that sustainable farm systems provide has created a call for new assessment tools. Tenets of agroforestry include intensification, integration, and interaction; actions that optimize multiple ecosystem services.

Building on past tools, the University of Nebraska Lincoln has designed a new assessment tool, the Healthy Farm Index (Quinn et al. 2009), that encompasses the multi-functional nature of sustainable farm systems. Different agroforestry practices are represented in the different components (Fig. 1) of the Healthy Farm Index.

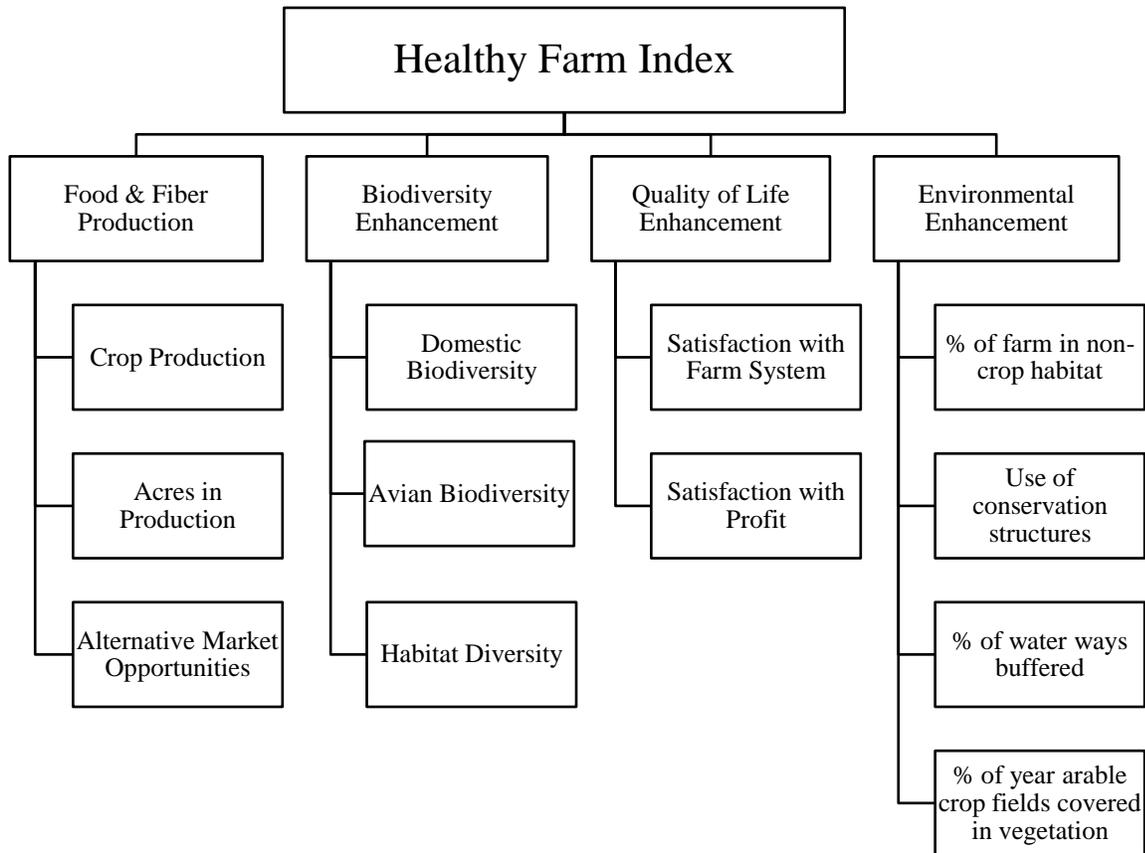


Figure 1. Components and Indicators of the Healthy Farm Index

Developing an applicable index requires relevant and measurable indicators that can be readily quantified and communicated. A broadly applicable index of farm health needs to be flexible enough to fit the location of the farm and the resources and labor that are available (Karr and Chu 1997, Dale and Haeuber 2001). To ensure a holistic view of the farm not typically provided by other content based frameworks (Van Cauwenbergh et al. 2007), we selected indicators from multiple categories of ecosystem services to and from agroecosystems. The difficulty in placing an economic value on many parameters of a healthy farm necessitates a form of non-market valuation or multiple criteria analysis (Hajkowicz 2008). To provide a measurable goal for farmers, target values (Table 1) have been set based on data collected from working farms.

Category	Indicator	Target Values	Weight w/in category	Weight w/in index	Final Score
Food Production	Alternative Market Opportunities	3	0.1	0.25	HFI Score
	Crop Production	100	0.9		
Biodiversity	Domestic biodiversity	6 species	0.3	0.25	
	Wild Biodiversity I (Indicator Bird Species)	3 sp/habitat	0.25		
	Wild Biodiversity II (Avian Diversity)	1	0.2		
	Habitat Diversity	1	0.25		
Environmental Enhancement	% in non-crop habitat	15%	0.25	0.25	
	% of year arable land covered in crops or cover crops	100	0.25		
	% of waterways buffered	100	0.25		
	% of farm fields protected with soil conservation structures	100	0.25		
Quality of Life	Satisfaction with profit	100	0.5	0.25	
	Satisfaction with farm system	100	0.5		

Table 1. Target values and weights of the Healthy Farm Index

Providing a tool to predict and model effects of decisions on multiple components would prove valuable to farmers, consumers, land-owners, and policy makers. The Healthy Farm Index deals with ecological, economic, and social components over which the farmer or land-owner has control. Understanding the driving forces and relationships at field and farm scales will improve the effectiveness of farm decisions.

HFI Categories

The production category addresses the primary purpose of agricultural land, the production of food, fiber, and fuel (Zhang et al. 2007). Alley cropping, windbreaks, and other agroforestry practices optimize production from a unit of land (Kort 1988, Brandle et al. 2004, Mize et al. 2008). Production includes alternate market opportunities. Farm management that includes woody florals, fruits and nuts, or timber diversifies farm revenue.

Wild and agricultural biodiversity are an essential part of a healthy farm system (MA 2005). Increased heterogeneity on a farm makes the farm ecosystem more resistant and resilient to fluctuations and disturbances (Tilman et al. 2006). Inclusion of woody vegetation diversifies a farm landscape. Increased woody land cover increases the diversity of many bird species (Perkins et al. 2003) and other natural enemies of insect pests (Dix et al. 1995; Matson et al. 1997).

Agroforestry practices can reduce the environmental impacts of farm operations and enhance ecosystem services. Tree plantings sequester carbon. Windbreaks reduce the need for inputs and irrigation, decrease fuel usage, and contain the drift of soils, chemicals, and odors into the surrounding environment (Brandle et al. 2004; Mize et al. 2008). Riparian forest buffers filter

runoff, contain sediment, and enhance stream quality. Carefully managed they can provide sources of revenue through timber, woody florals, and fruits and nuts. By regulating the flow of soil and contaminants, these beneficial landscape features limit water and wind erosion and reduce negative impacts on the surrounding region. They also constrain the impacts of detrimental land use practices on current and future generations.

U.S. Farm Service Agency color digital imagery was used to assess land use and land cover patterns on participating farms. It is interesting to note that all participating farms include either planned or associated woody land cover features with windbreaks being the most frequent planned land-cover. Perimeter windbreaks were found on half of the farms while interior windbreaks were found only on $\frac{1}{4}$ suggesting that there is potential to improve the use of windbreaks in organic farm systems. Riparian forest buffers were part of nineteen farm systems. Four farms are presented here to demonstrate how the Healthy Farm Index incorporates the benefits provided by woody land cover.



Figure 2. Farm 1



Figure 3. Farm 2



Figure 4. Farm 3



Figure 3. Farm 4

Farm 1 has an extensive windbreak system around and within the farm system. Thirty-eight acres are committed to woody land cover. The value of windbreaks is reflected in the production

component through increased yields. In the biodiversity component increased habitat heterogeneity provided by windbreaks and coupled with increased bird diversity would result in a higher score. Environmental quality is increased as a result of the reduced impact that is a result of the windbreak system. The non-crop habitat between the windbreaks improves the environmental quality score.

Woody land cover makes up 10 acres of Farm 2. This farm also has a large windbreak system protecting the same amount of area as Farm 1. The production score will be improved by both the windbreak system and the inclusion of fruit and nut trees recently planted between fields. A diversity of woodland and birds will be attracted to the woody land cover. Like Farm 1, an increased environmental quality score will reflect with benefits provided by the windbreak.

Farm 3 has minimal woody vegetation. A small number of trees are located near the water pool. However they provide limited protection to crops and soil. The sparse trees do provide habitat for birds, though not to the extent of the previous farms.

While Farm 4 lacks the extensive windbreak systems of Farms 1 and 2, woody land cover makes up almost 70 acres of Farm 4. The large riparian area that buffers much of the stream running through the middle of the farm would increase the farm's score. The diversity of bird species using the riparian area would improve the farm score. The wooded area may also serve as an important carbon sink. This farmer is considering adding nature tours to the operation, taking advantage of the abundant wildlife found throughout the farm.

DISCUSSION

Mixed farming methods that include windbreaks, riparian forest buffers, pasture, crop rotations, and grass are important to help ensure that farms remain a source of diverse ecosystem services. Model landscapes assessed with the Healthy Farm Index (Quinn et al. 2009) demonstrate the value of agroforestry practices, particularly windbreaks. Many organic and sustainable farmers are using agroforestry practices, however as we show here, there are still many improvements that can be made. The Healthy Farm Index will provide a means for farmers and other decision makers to understand the multi-functional benefits of a diversified farm system.

Understanding these benefits will improve the decision making ability of farmers and other stakeholders, such as governmental (e.g., farm bill) or organizational incentive program leaders. The multiple goals of farmers and society include food production, ecosystem services, biodiversity conservation, and a high quality of life now and in the future. The HFI seeks to improve how decisions are made by providing a full range of outcomes from farm decisions; not just how yield or profit will change.

Further research is needed to quantify the trade offs among goals for production, biodiversity, ecosystem services, and rural quality of life. Understanding the full range of outcomes of farm management decisions can ensure resiliency in farm systems. Optimizing multiple outputs requires new tools that recognize and reward organic and sustainable farm systems for the provisioning, supporting, cultural, and regulating services they provide (Daily and Matson 2008). Ultimately we foresee the Healthy Farm Index as a potential means to bring about payments for

ecosystem services. In order for these programs to succeed, new tools must assign appropriate value to biodiversity and functioning ecosystem services within agricultural landscapes. The lack of an integrated assessment and decision making tool limits farmers and other stakeholder's ability to obtain multiple goals. The Healthy Farm Index will offer a tool to better assess multiple goals, including the role of agroforestry practices on farms.

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FREQUENCY OF CONSUMPTION AND PREFERENCES FOR CHESTNUTS IN MISSOURI

Francisco X. Aguilar¹, Mihaela Cernusca², Michael Gold² and Carla Barbieri³

¹ Department of Forestry, University of Missouri,
203 Anheuser-Busch Natural Resources Building, Columbia, MO 65211

² Center for Agroforestry, University of Missouri
203 Anheuser-Busch Natural Resources Building, Columbia, MO 65211

³ Dept. of Parks, Recreation & Tourism, University of Missouri
105 Anheuser-Busch Natural Resources Building, Columbia, MO 65211

Contact: aguilarf@missouri.edu

Abstract: A longitudinal study of consumers' preferences for chestnuts (*Castanea* spp.) was conducted from 2003 to 2008. Information was collected during the annual Missouri Chestnut Roast festival at the Horticulture and Agroforestry Research Center, New Franklin, MO. The objective of this research was to track changes in the preferences for chestnuts in mid-Missouri. It also elicited salient chestnut characteristics influencing consumers' purchasing decisions. Results from a conjoint analysis conducted in 2008 are reported. The conjoint analysis used a choice-based model to investigate responses from pair-wise product profile comparisons. The attributes investigated include price per pound, production process, and origin. Our findings indicate that consumer frequency of chestnut consumption is increasing. Results suggest a strong preference for locally and U.S. grown chestnuts. Growers that provide the market with chestnuts that are certified to be pesticide-free or organically grown could exercise competitive advantages.

Keywords: Consumer preferences, chestnuts (*Castanea* spp.), conjoint analysis, Missouri.

INTRODUCTION

In the United States, chestnut cultivation can be an attractive enterprise due to high product demand, favorable prices, and relatively low initial investment requirements (Gold et al., 2006). However, commercial chestnut production is still in its infancy with the majority of producers in business for less than 10 years and just beginning to produce at a commercial scale (Gold et al., 2006). Recent research performed in Missouri (production, market and consumer research) and Michigan (production and value added opportunities) contribute to the creation of a thriving national chestnut industry.

Consumers across Europe, Australia, New Zealand, and the United States manifest an increasing interest in chestnuts (Kelley and Behe, 2002, Cernusca et al., 2008). Current demand for chestnuts in the United States exceeds national production, which is offset by imports. According to the U.S. Department of Agriculture (USDA), chestnut imports have grown steadily in value between 2003 and 2006 reaching \$11.6 million in 2006. In 2008 the value of imports was \$10.26 million (USDA, 2009). According to the USDA (2009), chestnuts were mostly imported from Europe (52%) and Asia (48%) in 2008.

Over the last two decades there have been a limited number of studies focusing on improving understanding of chestnut markets (Gold et al., 2004, 2006). A study by Wahl (2002) assessed the interest of upscale restaurant chefs in value-added chestnut products and found that product freshness and quality were the main attributes that influenced consumers' and chefs' interest in purchasing food products and ingredients. Wahl (2002) recommended that growers should promote chestnuts on the basis of quality, uniqueness, and local production. Another study developed by the Midwest Nut Producers Council and Michigan State University identified marketing opportunities for chestnuts in upscale restaurants in Michigan (Kelley and Behe, 2002; Smith et al., 2002). Chefs that participated in the study preferred peeled chestnuts and incorporated them in a variety of dishes. Gold et al. (2004, 2005) also reported that U.S. consumers prefer to buy chestnuts from grocery stores or farmers markets and that organic, brand name, and cultivar chestnuts can help capture price premiums. Research at the consumer side revealed that in regions where activities directed to promote chestnuts are performed, consumers' familiarity with chestnuts, and knowledge and frequency of consumption is increasing (Cernusca et al., 2008). This situation represents a market opportunity for expansion of chestnut production in the United States that demands a better understanding of consumer preferences. In an exploratory study of consumers' preferences Aguilar et al. (2009) report that Mid-Missourians prefer locally organic-grown chestnuts of medium size.

This study was designed to advance current knowledge related to consumers' preferences for chestnuts. Specifically, this research aimed to 1) track changes regarding familiarity with chestnuts in Mid-Missouri, 2) identify how much attributes such as size, price, quality, locally grown, and nutrition-diet-health, influence consumers' decisions to purchase chestnuts, 3) determine salient product characteristics that chestnut producers should evaluate and adopt for effective marketing purposes. This project is a continuation of past efforts in the University of Missouri Center for Agroforestry in the study of specialty agricultural produce markets.

RESEARCH SITE AND METHODS

Information was gathered during the Missouri Chestnut Roast, a festival that has been held annually at the University of Missouri's Horticulture and Agroforestry Research Center (HARC) in New Franklin, Missouri. This one day event provides the opportunity to introduce participants to a variety of specialty products including chestnuts. The Missouri Chestnut Roast includes chestnut roasting demonstration and free samples of roasted chestnuts, vendors offering a diversity of Missouri agricultural products (e.g., fresh chestnuts, cheese, wine, honey and other nuts); informational booths providing resources of agricultural products and strategies to diversify farm revenues; guided tours to various agroforestry-related research projects; and a combination of entertainment offerings including cooking demonstrations with chestnuts, music, food, and children's activities.

To track changes in consumers' preferences for chestnuts (i.e., familiarity with chestnuts and influence of chestnuts attributes on purchase decisions), a longitudinal study has been performed. At the beginning of the study in 2003 (the first year of the festival), a questionnaire was administered to festival participants to obtain baseline information about participants' familiarity with chestnuts, pecans, and eastern black walnuts. For each nut species, survey questions covered frequency of consumption, familiarity with cooking and attributes that influence

purchase decisions. The survey was repeated in 2004, 2006, 2007 and 2008 with focus exclusively on chestnuts.

Questionnaires were constructed and administered following Dillman's (2000) recommendations. Familiarity with chestnuts in general was assessed using a three-item Likert-type scale: frequency of consumption, familiarity with roasting, and familiarity with preparing chestnuts.

The influence of various chestnut attributes on purchase decisions (i.e., price, quality, locally grown, and nutrition-diet-health) was evaluated on a five-point Likert-type scale ranging from "not at all" (1) to "very strongly" (5). Interviewers randomly selected festival attendees, explained the purpose of the study, and asked for their participation. Those who agreed to participate completed the survey on site. The sample generated by this method is representative for festival participants but implies caution in generalizing the results to the whole population of consumers in Missouri. Each participant took between 5 to 10 minutes to complete the questionnaire. No incentive in the form of monetary or in-kind reward was offered to study participants.

Conjoint analysis (CA) was used to understand the relative importance that consumers place on particular chestnut characteristics (including price, production method and label of origin). CA involves the measurement of consumer preferences by studying the joint effects of multiple product attributes on product choice (Green and Srinivasan, 1978, 1990). Price (\$3, \$5, and \$7 per pound), label of origin (produced in Missouri, produced in the United States, and imported), and production process (conventional, pesticide free and organic) were chosen as attributes and corresponding levels.

Production process and origin label were defined on the survey as follows:

- Conventional: Chestnuts produced using conventional methods to fertilize and chemical control of weeds and/or pests.
- Pesticide free: Chestnuts produced with minimal use of chemicals in the form of herbicides, pesticides and hormones.
- Organic certified: Chestnuts produced using methods that maintain and replenish soil fertility without the use of toxic and persistent pesticides and fertilizers, according to strict uniform standards that are verified by independent state or private organizations.
- Origin label: Label indicating whether chestnuts were grown in Missouri, in the United States, or imported.

The profiles of hypothetical products for CA were generated using the Bretton-Clark designer program following a fractional design. This program produces a subset of hypothetical profiles based on the attribute levels provided by the researcher. Eighteen profiles for a total of nine comparisons were produced and included in the survey questionnaire. Respondents were asked to review pairs of hypothetical chestnut products and to select one product (A or B) that they would be most likely to purchase (Fig. 1) in a traditional choice-based model (McFadden, 1986). An option (neither) was introduced in the study to represent what is commonly known as the status quo or opt-out option. In this case it represented a chestnut priced at \$5 per pound produced in the U.S. with conventional methods. Demographic information gathered in the study included age, gender, marital status, education, household income, and ethnic group. Each questionnaire

was pre-tested before administration. Data was analyzed using a conditional logit model in Stata 10. Details of the model and data entry are available in Aguilar et al. (2009).

Figure 1: Example of the conjoint analysis pair-wise instrument used to gather consumer preferences for chestnuts' attributes in 2008.

<i>Box 1.</i>	<i>A</i>	<i>B</i>	
Price per pound	\$5	\$3	
Production process	Conventional	Pesticide free	
Origin label	U.S.A.	Imported	
<i>Please check your preferred choice →</i>	<input type="checkbox"/> A	<input type="checkbox"/> B	<input type="checkbox"/> Neither

RESULTS

Profile of Respondents

Table 1 summarizes information collected since 2003 and presents the distribution of respondents according to their reported demographic information (age, household income, gender, marital status and level of education). The low number of responses collected in 2007 was due to adverse weather conditions. No survey was conducted in 2005.

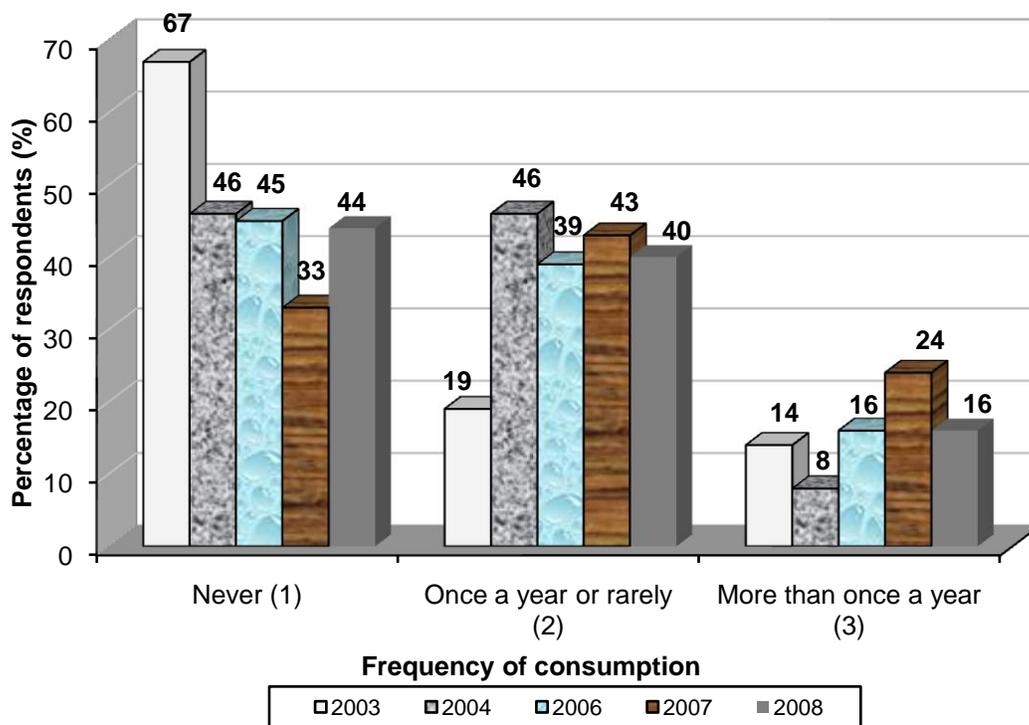
Table 1: Demographic characteristics of festival participants

	2003	2004	2006	2007	2008
<i>n</i>	232	217	487	132	524
Age	Percent of respondents (%)				
under 25	9	6	4	5	10
26-35	8	19	13	9	19
36-45	13	18	14	11	15
46-55	23	23	27	28	20
56-65	24	16	20	27	20
over 65	23	18	22	20	16
Household income	%				
Less than \$35,000	- *	26	31	21	26
\$35,000-\$50,000	- *	27	14	14	18
\$50,000-\$75,000	- *	27	31	30	25
\$75,000-\$100,000	- *	16	14	11	13
>\$100,000	- *	4	10	24	18
Gender	%				
Male	40	- *	38	46	40
Female	60	- *	62	54	60
Marital status	%				
Married	77	- *	74	81	69
Unmarried	23	- *	26	19	31
Education	%				
High school	25	16	25	21	16
Technical school	7	8	7	8	4
College	52	61	34	41	37
Graduate	- *	- *	30	29	37
Other	16	15	3	1	6
* Question was not offered in survey					

Frequency of Consumption

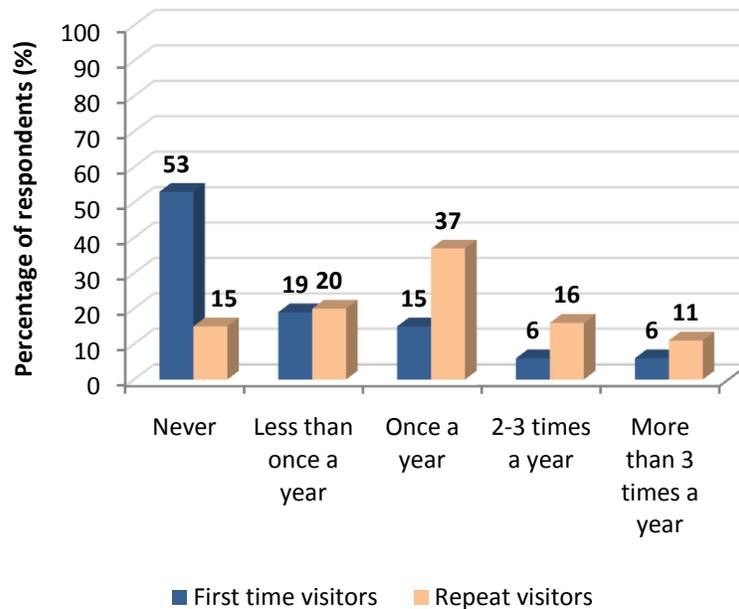
Results of the longitudinal survey indicate an increase in chestnut consumption among festival participants from 2003 to 2008. The percentage of participants that have never tasted a chestnut decreased while the percentage of people that consume chestnuts more often increased (Fig.2). It is worth a word of caution on the 2007 data as it might be biased towards individuals who consume chestnuts more frequently. This situation is stemmed from the circumstance that inclement weather may have had a selective effect toward people who had a strong interest in chestnuts and for whom rain was not an impediment to their participation in the Festival. Notice that 2007 is the year with the highest percentage of “More than once a year” responses and the lowest with “Never” answers.

Figure 2: Frequency of chestnut consumption between 2003 and 2008



Although in 2008 frequency of consumption seems to be lower than in 2007, comparing first-time Missouri Chestnut Roast visitors to repeat visitors revealed an important difference in frequency of chestnut consumption (Fig. 3). Fifty-three percent of first-time visitors had never eaten chestnuts compared to 15% of repeat visitors. Only 15% of first-time visitors consumed chestnuts once a year compared to 37% of repeat visitors. From these results we can infer that increased exposure to chestnuts (the festival in itself and information about chestnuts received during the event) persuaded participants to seek out chestnuts and consume them more frequently.

Figure 3: Frequency of Consumption in 2008: First-Time ($n= 390$) Versus Repeat Visitors ($n=123$)

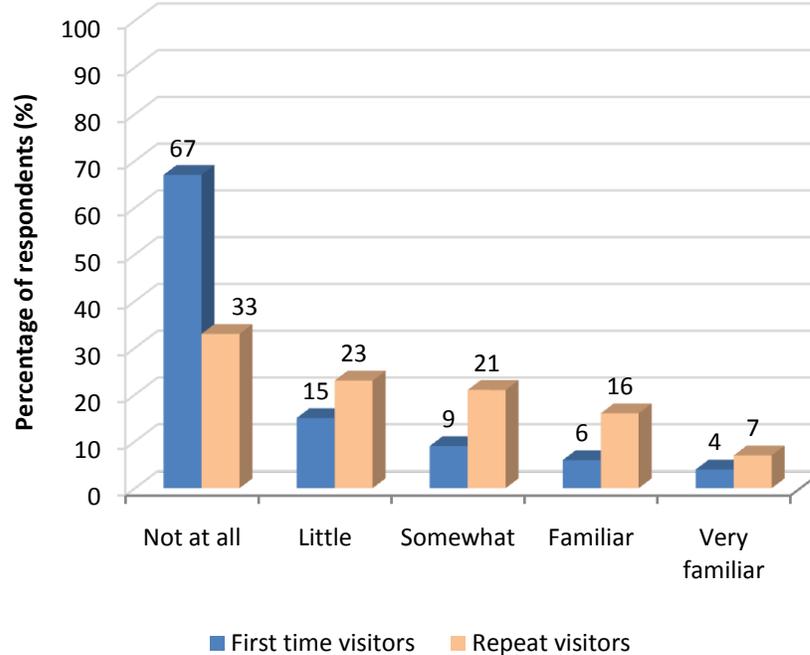


Familiarity with Cooking Chestnuts

In 2003, familiarity with cooking or preparing chestnuts was very low (74% not at all familiar). In 2004 and 2006-2008, two questions addressed this subject: familiarity with roasting chestnuts and familiarity with cooking chestnuts using recipes. Results indicated that in 2004 and after, the overall familiarity with cooking remained low, but people became more familiar with roasting (~70% not at all familiar with cooking compared with ~60% not at all familiar with roasting).

Based on 2008 data, return visitors were more familiar with roasting chestnuts than first-time visitors (Figure 4). Sixty-seven percent of first-time participants were not at all familiar with roasting chestnuts, compared with 33% of return visitors. Ten percent of first-time visitors were familiar and very familiar with roasting chestnuts, compared to 23% of return visitors. The results are not surprising considering that we provided free samples of roasted chestnuts during the festival along with information and demonstrations on how to roast chestnuts.

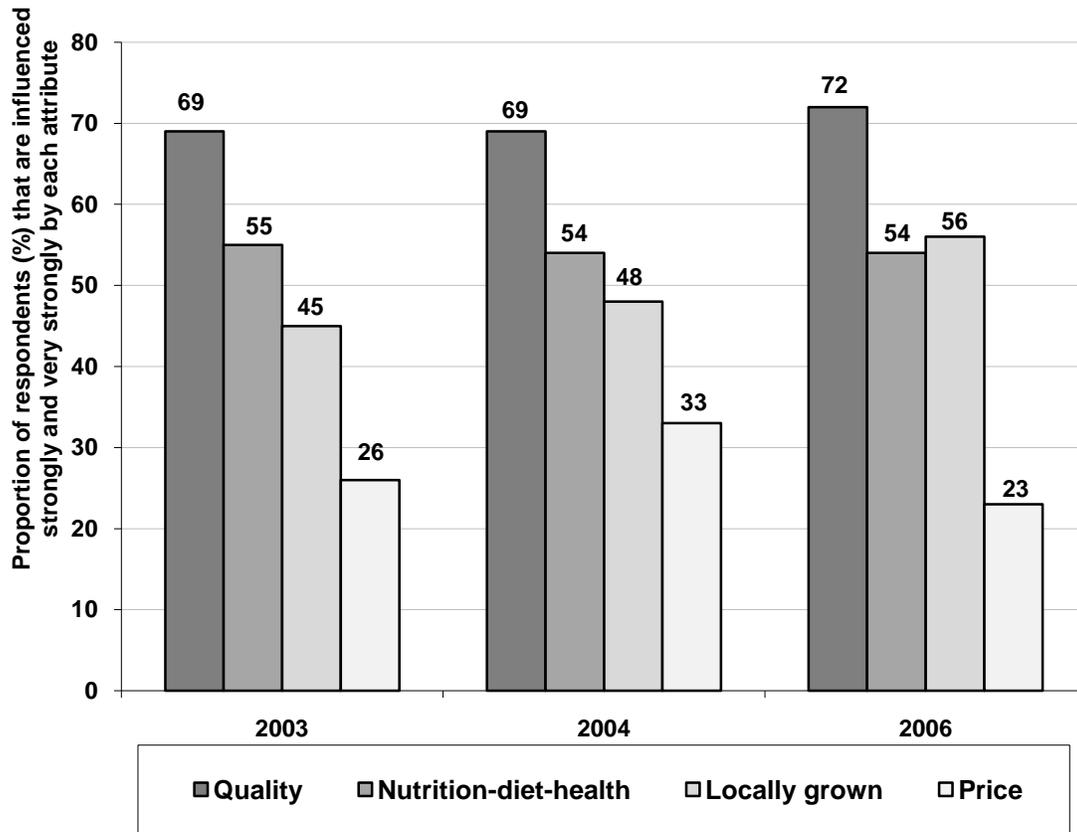
Figure 4: Familiarity with Roasting Chestnuts in 2008: First-Time ($n=390$) Versus Repeat Visitors ($n=123$)



Characteristics that influence purchasing decisions

In 2003, quality (69% of respondents were strongly and very strongly influenced by quality in their decision to buy chestnuts) and nutrition-diet-health (55%) were the most important attributes mentioned. Price was listed as the least important attribute by 26% of respondents (Gold et al., 2004). Similar results were obtained from the 2004 data (Gold et al., 2005). In 2006, an increase was noted in the preference for locally grown chestnuts. As shown in Fig. 5, quality remained the top attribute (72% of respondents were strongly and very strongly influenced by quality in their decision to purchase chestnuts), followed by locally grown (56%), nutrition-diet-health (54%), and price (23%). Some of these results are in accordance with those reported by Brown (2003). Brown found that quality and freshness were the most important concerns when shopping for fresh fruits and/or vegetable for 82% of consumers in southeast Missouri, while price was important for only 8%.

Figure 5: Chestnut attributes that influence purchase decisions (2003, 2004, 2006)



Conjoint Analysis

The estimated attribute partworth coefficients of the conditional logit models, along with P values and odds ratios, are presented in Table 2. Odds ratios were obtained by exponentiating the β coefficient and can be interpreted as changes in the odds of a consumer choosing a product with a given category over the base level. An odds ratio of 1, then, indicates that there is no difference in consumer preference between that attribute and the base level, while an odds ratio of 5 suggests that consumers like a given attribute five times better than the base level.

Results of the conditional logit model show that all product attributes were statistically significant at the $\alpha=0.05$ level (Table 2). Based on the odd ratio calculations, consumers were 4.280 times more likely to select chestnuts that are organically certified compared with conventionally produced chestnuts. A similar result suggests the pesticide-free chestnuts are 3.888 times more likely to be chosen by consumers than chestnuts produced with conventional methods. The most salient product attribute was the label of origin. Information collected indicates that consumers were over 20 times more likely to choose chestnuts grown in Missouri, and 4.257 times more likely to select chestnuts grown in the United States compared with imported nuts. These results reflect the support for locally grown products reported by Darby et al. (2006) in Ohio, Gallons et al. (1997) in Delaware, Jekanowski et al. (2000) in Indiana, and Patterson et al. (1999) in Arizona. In a study conducted in New England, Giraud et al. (2005)

found that favorable attitudes toward local goods are positively correlated with the probability of purchasing the local good.

As it would be expected, the model suggests that as price increases, the likelihood of purchasing chestnuts decreases. However, the relative influence of price on consumer choice is much smaller than that of the other attributes (0.73) for a single dollar. However, an increase in price per pound of \$5 would cause a decline in the likelihood of purchasing preferences equal to 3.68 times.

Table 2: Conditional logit partworth estimates of chestnut product attributes for fixed-effects conditional models derived from CA in 2008.

Attributes	β Coefficient (std. error)	$P > z$	Odds ratio
Produced in Missouri ^a	3.032 (0.083)	<0.001	20.731
Produced in the U.S. ^a	1.449 (0.073)	<0.001	4.257
Organic production ^b	1.454 (0.089)	<0.001	4.280
Pesticide-free production ^b	1.358 (0.062)	<0.001	3.888
Price	-0.307 (0.020)	<0.001	0.736

^a Base level value for comparison: Imported chestnuts.

^b Base level value for comparison: Conventional production process.

CONCLUSIONS

A longitudinal analysis indicates that frequency of consumption has increased among the pool of study participants since the Missouri Chestnut Roast festival was launched in 2003. Similarly, familiarity with cooking recipes using chestnuts has increased over the last five years. When asked as individual product attributes, respondents report that the most important chestnut characteristics include quality, nutrition and locally grown. Consumers seem to be less sensitive to price changes. A conjoint analysis of price, label with place of origin and production process suggest that chestnuts grown in Missouri using organic methods are the most likely to be preferred by consumers. Further, the high value of coefficients on these attributes (Missouri, organic) and the lower level of coefficient on prices suggest that producers may be able to exercise important premiums over prices prevalent in the market for imported or non certified chestnuts.

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ATTENDANCE MOTIVATIONS BEHIND THE MISSOURI CHESTNUT ROAST FESTIVAL

Carla Barbieri¹, Mihaela Cernusca², Michael Gold² and Francisco X. Aguilar³

¹ Dept. of Parks, Recreation & Tourism, University of Missouri
105 Anheuser-Busch Natural Resources Building, Columbia, MO 65211

² Center for Agroforestry, University of Missouri
203 Anheuser-Busch Natural Resources Building, Columbia, MO 65211

³ Department of Forestry, University of Missouri
203 Anheuser-Busch Natural Resources Building, Columbia, MO 65211

Contact: BarbieriC@missouri.edu

Abstract: Festivals attract visitors with different types of motivations which are associated with a festival's theme. The Missouri Chestnut Roast festival combines recreational and educational activities to promote agroforestry, chestnuts and other agricultural specialty products. The objective of this study was to identify the motivations behind attendance at the Missouri Chestnut Roast festival given its unique theme. It also identified different socio-economic attributes, levels of chestnut consumption and event behavior associated with different motivations. Intercept interviews were carried out on-site. The survey queried 12 attendance motivations, levels of chestnut awareness (i.e., consumption, cooking), festival behavior, and socio-demographics. A total of 524 responses were collected. Statistical tests included principal component factor analysis with varimax rotation and multiple linear regressions.

The most important motivations drawing attendance to the Chestnut Roast festival were: enjoying a day out; the uniqueness of the festival; and tasting chestnuts and other Missouri specialty products. Factor analysis of the attendance motivations produced three motivational dimensions: (D1) *Fun and Entertainment* related to the types and variety of recreation and entertainment activities offered at Chestnut Roast; (D2) *Theme Identity* associated with the chestnut thematic; and (D3) *Educational Experience* associated with the educational offerings of this festival. Multiple linear regressions show that demographic characteristics and festival behavior are associated with the three motivational dimensions identified (D1; D2; and D3). However, frequency of chestnut consumption is not associated with any motivational dimension.

Study results suggest important implications for Chestnut Roast festival organizers. Advertising efforts (e.g., promotional material) and festival offerings (e.g., recreational activities; educational sessions) should consider all three identified motivational dimensions to ensure that the Chestnut Roast festival attracts a diverse set of visitors driven by different motivations.

Keywords: Festivals, Motivations, Factor Analysis

INTRODUCTION

The University of Missouri Center for Agroforestry (UMCA) is working to establish a viable chestnut industry, focusing its efforts on three key areas: testing and identifying the best chestnut

cultivars and production techniques, conducting national market research, and working toward an increase in consumer awareness and demand. The long-term goal is to develop a thriving domestic chestnut industry in Midwest. In support of its long-term goal, in 2003 UMCA created the Missouri Chestnut Roast festival, a unique event that blends entertainment and educational activities to inform, promote and increase awareness and recognition of agroforestry, chestnuts and other Missouri agricultural specialty products.

The Missouri Chestnut Roast is held annually at the University of Missouri's Horticulture and Agroforestry Research Center (HARC), a 660-acre research farm located in the Missouri River Hills adjacent to New Franklin, Missouri. The festival is a free event for vendors and visitors. This one day event is an outstanding opportunity to introduce participants to the broad range of possibilities and benefits that can result from implementing agroforestry practices or consuming specialty products. The Missouri Chestnut Roast includes vendors offering a diversity of Missouri agricultural products (e.g., cheese, wine, honey and nuts); informational booths providing resources of agricultural products and strategies to diversify farm revenues; guided tours to various agroforestry-related research projects; and a combination of entertainment offerings including music, food, cooking demonstrations and children's activities, among others.

The Missouri Chestnut Roast has steadily increased in popularity among chestnut consumers and non-consumers. The first event (2003) attracted around 1,000 people, most of whom tasted roasted chestnuts for the first time while, the last one (2008) pulled about 4,000 visitors. The consistent growth of the number of Chestnut Roast visitors is very important for the UMCA purposes as it exposes more people to chestnuts, agroforestry practices and their benefits. As a case in point, the proportion of attendees who had never consumed a chestnut before attending the festival has consistently decreased over years, dropping from 67% in 2003 to 44% in 2008.

LITERATURE REVIEW

Festivals are a popular form of tourism and many destinations employ them in their development strategies as they can attract a wide range of visitors in terms of number and characteristics (Getz 2007; Kim et al. 2007). Festivals bring several benefits, including the development and maintenance of cultural resources and traditions, enhancement of local economies, and improvement of the destination image, among others (Crompton and McKay 1997; Formica and Uysal 1998; Getz 1997). Many characteristics shape the uniqueness and novelty of festivals, including their theme (e.g., arts, agriculture); offerings and attractions (e.g., recreational activities; informative resources), duration (e.g., one-day, weekend); purpose (e.g., product awareness, fundraising), and others.

A key element of festivals and event research relates to motivations as these drive people to the venue. Research on festival motivations is not new, yet not settled (Getz 2008). Overall, studies conclude that festivals attract people with different motivations (Crompton and McKay 1997). Studies are also conclusive regarding some motivations that are consistently found to drive festival attendance, such as escapism, gregariousness, socialization, and family/personal-related motives (Backman et al. 1995; McDonnell et al. 1999). However, more recent studies suggest that there are other motivations that are associated with the uniqueness and novelty of festivals

that are still not fully understood (Nicholson and Pearce 2001; Schofield and Thompson 2007; Yuan et al. 2005).

Inconclusive findings regarding the set of motivations associated with the unique attributes of festivals demand further inquiry. This is especially pertinent for agriculture festivals as they have received little attention in the literature. Understanding these motives is important for festival marketing and programming in future years because they provide information that can help tailor the festival offerings to their target market addressing visitors' needs and expectations, thus strengthening their satisfaction levels (Fondness 1994; Lee et al. 2004).

DATA AND METHODS

This study examines the demographic characteristics, behavior and attendance motivations of visitors to the Chestnut Roast Festival in New Franklin, Missouri. Specific objectives are: (1) to identify the motivations behind festival attendance, and (2) to identify attendees' characteristics and their levels of chestnut awareness associated with motivational dimensions. Festival attendees were intercepted and surveyed on-site in October 2008. Trained interviewers randomly selected festival attendees, explained the purpose of the study and asked for their participation. Those who agreed to participate completed the survey on site. A total of 524 responses were obtained; a very small proportion (less than 5%) refused to participate. The survey queried twelve attendance motivations, levels of chestnut awareness (i.e., frequency of consumption, familiarity with cooking), festival behavior, and socio-demographics.

Three types of analysis were conducted in this study. First, descriptive statistics were used to profile respondents regarding their socio-economic characteristics, festival behavior and level of chestnut awareness. Second, an exploratory factor analysis with varimax rotation was performed to reduce attendance motivations to fewer dimensions. Listwise, pairwise and mean imputation methods were tested to handle missing values. The pairwise method was finally used because it yielded a stronger model as compared to the other ones. Chronbach's alpha was used to assess the overall and internal factors reliability. Finally, a multiple linear regression was used to identify associations between respondents' attributes (i.e., socio-demographics and event behavior) and attendance motivational dimensions.

RESULTS

Profile and Festival Behavior of Respondents

Respondents are preponderantly female (59.5%) and over 45 years old (56.1%). They are also highly educated, having the vast majority (74.0%) at least a college degree and over a third (37.2%) a graduate degree. Over two-thirds of respondents are married or living with a partner (68.5%). The majority of respondents live with at least one other person at home (83.6%). From these, a relatively small proportion live with children younger than 7 years old (12.8%), between 7 and 12 years old (14.4%) or between 13 and 17 years old (11.9%) showing a late stage on respondents' family life-cycle. The majority of respondents (56.9%) reported over \$50,000 household income and about a third (31.4%) over \$75,000 which may be associated with respondents' age and their family life-cycle stage.

Although the Chestnut Roast Festival attracts a high proportion of first time attendees (76.7%), results suggest that the festival is also building a group of loyal visitors. Taking into account the repeated customers (23.3%, n=121), about half attended this festival in 2007 (49.6%), in 2006 (57.0%) and in 2005 (49.6%). The festival mostly attracts a very local and urban clientele. The majority of respondents traveled less than 30 miles to the festival (56.8%) and live in an urbanized area with a population of at least 50,000 (50.8%). Importantly, the vast majority of respondents spent at least one hour at the event (95.2%) and over a third (39.0%) at least three hours suggesting good event entertainment programs. On average, party size was composed by four people (mean=4.2); a very small proportion (8.0%) attended the festival alone.

Overall, festival attendees have little familiarity with chestnuts in terms of consumption, past purchase and cooking knowledge. Although about a third (35.4%) of respondents have purchased chestnuts in the past, regular consumption is not evident. About half of respondents (44.2%) do not consume chestnuts at all and over three quarters (84.2%) consume them once a year or less. Interesting though, a relatively large proportion of respondents are at least a little familiar with cooking with chestnuts, either roasting (41.3%) or preparing them using recipes (30.4%), suggesting some interest in chestnuts as a culinary specialty product.

Table 1: Motivations driving attendance to the Chestnut Roast Festival.

Motivations (n=415)	Mean ^a	S.D.
To enjoy a day out	4.36	0.97
The uniqueness of the Missouri Chestnut Roast festival	4.03	1.06
Taste chestnuts and other Missouri specialty products	4.03	1.19
I like to attend festivals	3.82	1.17
Learn about other Missouri specialty products	3.71	1.13
Learn about chestnuts	3.69	1.20
The variety of entertainment and activities offered	3.47	1.22
Buy other Missouri specialty products	3.39	1.22
Learn about agroforestry	3.25	1.23
Buy chestnuts	2.87	1.38
Visit the Hickman House	2.77	1.37
The activities for children	2.57	1.61

^a Measured in a five-point Likert type scale where (1) not important; (2) somewhat important; (3) moderately important; (4) fairly important; and (5) very important.

Attendance Motivations to the Chestnut Roast Festival

Results show that visitors attend the festival driven by a complex set of motivations. The most important motivations, measured using a five-point Likert-type scale anchored in one (not important) and five (very important), are: enjoying a day out (mean=4.36); the uniqueness of the festival (mean=4.03); and tasting chestnuts and other Missouri specialty products (mean=4.03), exemplifying a blend of leisure, festival and product –chestnut- related motives (table 1). Visiting the historic Hickman House (mean=2.77) and the activities for children (mean=2.57) are the least important attendance motivations, which is surprising as they are related to major and highly visited attractions.

Attendance motivations were reduced to fewer dimensions to facilitate their application in marketing strategies (e.g., advertising, positioning) and planning activities. An exploratory factor analysis used for this purpose produced three motivational dimensions with eigenvalues greater than one and accounting for 62.2% of variance (table 2). A loading higher than 0.50 was the threshold for including an attendance motivation as part of a motivational dimension. “To buy other Missouri specialty products” did not load in any dimensions and it was removed from further analysis. Results show very high overall ($\alpha=.824$) and internal alpha reliability coefficients ($\alpha \geq .71$).

Table 2: Rotated factor matrix of the attendance motivations to Chestnut Roast Festival.

Factors and Motivations	Factor Loadings	Explained Variance (%)	Eigenvalue
Fun and Entertainment – D1 ($\alpha=.752$)¹		37.08	4.08
I like to attend festivals	.836		
The variety of entertainment and activities offered	.769		
To enjoy a day out	.726		
The activities for children	.548		
Theme Identity – D2 ($\alpha=.730$)		15.44	1.69
Taste chestnuts and other Missouri specialty products	.801		
Learn about chestnuts	.714		
Buy chestnuts	.638		
The uniqueness of the Missouri Chestnut Roast festival	.521		
Educational Experience – D3 ($\alpha=.705$)		9.65	1.06
Learn about agroforestry	.768		
Visit the Hickman House	.678		
Learn about other Missouri specialty products	.608		
Total Variance Explained		62.17	

¹ Cronbach’s alpha reliability coefficients for domains. Overall reliability ($\alpha=.824$)

The three dimensions obtained were labeled based on the common characteristics of their loaded motivations as follows. Four motivations related to the types and variety of recreation and entertainment activities offered at the festival loaded on the *Fun and Entertainment* dimension (D1). This dimension explained 37.1% of variance in the data and had an eigenvalue greater than four. The second dimension, *Theme Identity* (D2), is associated with motivations defining the chestnut thematic and uniqueness of the festival. It explained 15.4 of variance and had an eigenvalue of 1.7. The last dimension was labeled *Educational Experience* (D3) as it comprised motivations related to the educational offerings of this festival (eigenvalue=1.1; explained variance=9.7%).

Attributes Associated with Attendance Motivational Dimensions

Multiple linear regressions performed on the three motivational dimensions (D1; D2; and D3) produced three significant models suggesting that socio-economic attributes (i.e., age, education level; residence location) and event behavior (i.e., party size, travel distance and hours of stay) are associated with different motivations driving festival attendance (table 3). Product

recognition, measured in terms of chestnut consumption, is not associated with any motivational dimension, maybe due to the still low recognition of chestnuts in the U.S.

Table 3. Multiple linear regressions of socio-economic attributes, event behavior and levels of chestnut consumption on the attendance motivational dimensions.

Independent Variables	DV – Attendance Motivational Dimensions ^a (Standardized β and Significance)		
	D1	D2	D3
Visitor's age	-.211***	.238***	.080
Visitor's level of education	-.053	.184**	.073
Residence distance from an urbanized area	.065	.011	.200**
Frequency of chestnut consumption	-.011	.084	-.111
Distance travelled to the festival	-.115	-.015	-.119*
Hours staying at the festival	.068	.035	.240***
Party size	.141*	-.116*	.146**
p value	.001	.000	.000
R^2	.085	.130	.140

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

^a (D1) Fun and Entertainment; (D2) Theme Identity; and (D3) Educational Experience

The first statistically significant model shows that age ($\beta = -.211$, $p < .001$) and number of people in the party ($\beta = .141$, $p = .015$) are related to the motivations loading on the *Fun and Entertainment* dimension – D1 ($R^2 = .085$, $p = .001$). The second model shows that age ($\beta = .238$, $p < .001$), level of education ($\beta = .184$, $p = .002$), and number of people in the party ($\beta = .116$, $p = .041$) are related to the motivations loading on the *Theme Identity* dimension ($R^2 = .130$, $p = .001$). The final model shows that residence proximity to an urbanized area ($\beta = .200$, $p < .001$), distance traveled to the festival ($\beta = -.119$, $p = .048$), number of hours staying at the festival ($\beta = .240$, $p < .001$), and number of people in the party ($\beta = .146$, $p = .010$) are related to the motivations loading on the *Educational Experience* dimension ($R^2 = .140$, $p = .001$).

Findings regarding age distribution and party size are not surprising. The older the participants, the less interested they may be in traditional forms of entertainment (D1) being more selective in choosing new and unique leisure experiences such as those defining the Chestnut Roast Festival (D2). In turn, larger parties seek for a greater variety of entertainment and recreational offerings (D1) and educational offerings (D3) as they need to satisfy the needs of their various members that may include different age compositions (e.g., young children, teenagers, and middle-age adults). The findings regarding residence location and distance travelled to the festival are surprising and need further examination. The farther respondents live from an urban area, the more associated with the educational-related motivations (D3) which is opposing to the romanticism of rural America usually included as an important tourism driver of agritourism and agriculture events among urban residents.

CONCLUSIONS

This study confirms that festivals attract people with different motivations, including those frequently suggested in the literature (i.e., seeking entertainment) and those associated with the festival uniqueness (i.e., educational opportunities and theme identity). Specifically, results show

that the most important motivations driving people to the Missouri Chestnut Roast are enjoying a day out, the uniqueness of the festival and tasting chestnuts and other Missouri specialty products, showing a mixture of leisure, festival and chestnut related motives. The twelve motivations tested in this study resulted in three motivational dimensions using an exploratory factor analysis: *Fun and Entertainment* (D1) related to the types and variety of recreation and entertainment activities offered at the festival; *Theme Identity* (D2) associated with motivations defining the chestnut thematic and uniqueness of the festival; *Educational Experience* (D3) comprising motivations related to the educational offerings of this festival. These results have important marketing implications as festival organizers need to convey the three motivational dimensions found in this study in their promotion and advertising efforts to capture their diverse clientele.

Further, this study adds to the existing knowledge of festival research, identifying socio-economic attributes and different event behaviors associated with the motivational dimensions obtained, including visitor's age, party size, residence location and distance travelled to the Missouri Chestnut Roast. These results have important marketing and programming implications for the festival organizers in future years, especially taking into account the socio-demographic and group composition of festival attendees. For example, the older the visitors the less interested in entertainment activities but the most motivated by agroforestry and chestnut related opportunities. Taking into account that the majority of visitors were at least 45 years old, these results suggest that organizers need to keep offering and strengthening their chestnut thematic activities (e.g., demonstrations of cooking with chestnuts; sampling and tasting of chestnuts and other Missouri specialty products). But at the same time, festival organizers need to provide a broad variety of educational and entertainment activities, as these appear to attract large groups most likely composed of individuals with different age distribution, thus interests.

This study also brings two questions in need of further exploration. Results show that the farther respondents live from an urbanized area the more driven they are by the festival educational component. This may be suggesting an opposing direction related to the romanticism image of agriculture as a driver of agritourism among urban residents. This finding needs a closer examination taking into consideration that the Missouri Chestnut Roast predominantly attracts a local and urban market. In addition, the diversity of motivations and socio-demographic attributes found in this study suggest testing a motivation-based segmentation of Missouri Chestnut Roast visitors. This segmentation can assist in better attracting different groups of visitors using tailored marketing channels and messages, which is important as previous studies found that visitation increases chestnut recognition and consumption which is a critical goal of UMCA (Cernusca et al. 2008).

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COMPARING ATTENDANCE MOTIVATIONS FOR FIRST TIME AND REPEAT VISITORS AT THE MISSOURI CHESTNUT ROAST FESTIVAL

Mihaela Cernusca¹, Michael Gold¹, Carla Barbieri², and Francisco X. Aguilar³

¹ Center for Agroforestry, University of Missouri
203 Anheuser-Busch Natural Resources Building, Columbia, MO 65211

²Dept. of Parks, Recreation & Tourism, University of Missouri
105 Anheuser-Busch Natural Resources Building, Columbia, MO 65211

³Department of Forestry, University of Missouri
203 Anheuser-Busch Natural Resources Building, Columbia, MO 65211

Contact: cernuscam@missouri.edu

Abstract: Repeat purchase is perceived as a positive attitude towards a product. Repeat attendance to recurrent festivals is desired as it reinforces the effect of word-of-mouth marketing which is a very important informational source. Although the Chestnut Roast Festival attracts a high proportion of first time attendees, the festival is also building a group of loyal visitors. The event organizers aim to increase the number of first time visitors to expose more people to chestnuts, other nuts and their benefits while encourage repeat attendance year after year. This research focuses on understanding differences in attendance motivations between first timers and repeat visitors to directly market the festival to both groups.

The survey evaluated 12 attendance motivations, festival behavior, and socio-demographics. A total of 524 responses were collected. Statistical tests included MANOVA, discriminant analysis and multiple linear regressions.

Results show that the most important motivations driving people to the Missouri Chestnut Roast are: “Enjoying a day out”, “The uniqueness of the festival”, and “Tasting chestnuts and other Missouri specialty products”. Differences between groups suggest that “Uniqueness of the Missouri Chestnut Roast festival” is a stronger driver for repeat visitors, while “Learn about chestnuts”, “Buy chestnuts”, and “I like to attend festivals” are more important motivators for first timers.

Study results have important marketing implications. The festival brand “Missouri Chestnut Roast - A Festival of Culture and Agriculture” with its unique theme on chestnuts needs to be reinforced in all promotional efforts, especially to attract repeat visitors. In addition, marketing and programming efforts need to emphasize the festival as an entertainment venue to learn about chestnuts to attract new visitors.

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