Agroforestry Comes of Age:
Putting Science into Practice

Proceedings of the 11th North American Agroforestry Conference

May 31-June 3, 2009

Columbia, Missouri

Michael A. Gold & Michelle M. Hall, Eds.

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

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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 watershdeds 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 agroforerstry 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 groforestry 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 P_2O_5, and 3.6 kg of K_2O. 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.

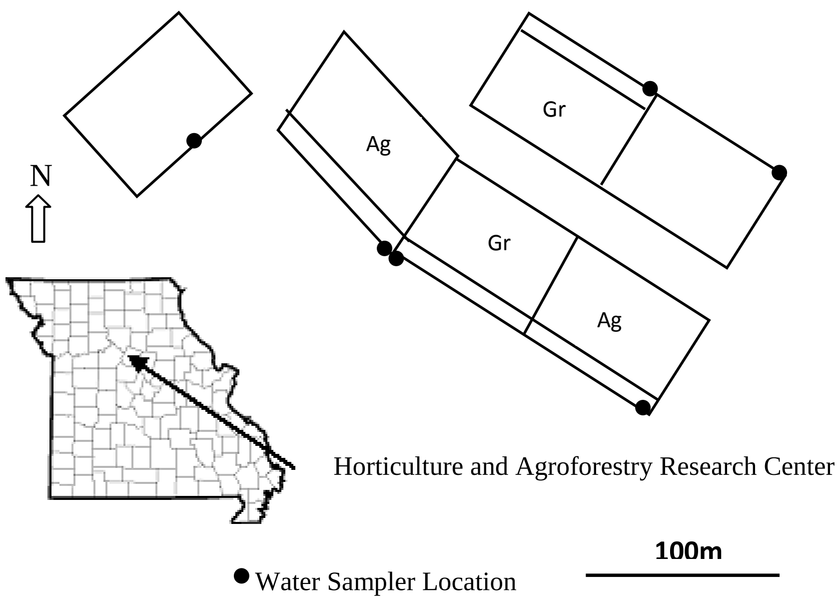

Figure 1. The six studied watersheds at Horticulture and Agroforestry Research Center (HARC), New Franklin, Howard County, Missouri. The inset map shows approximate location of the HARC Center. Narrow strips on four watersheds represent agroforestry (Ag) and grass (Gr) buffers.

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 m^3 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 perusulfate 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%

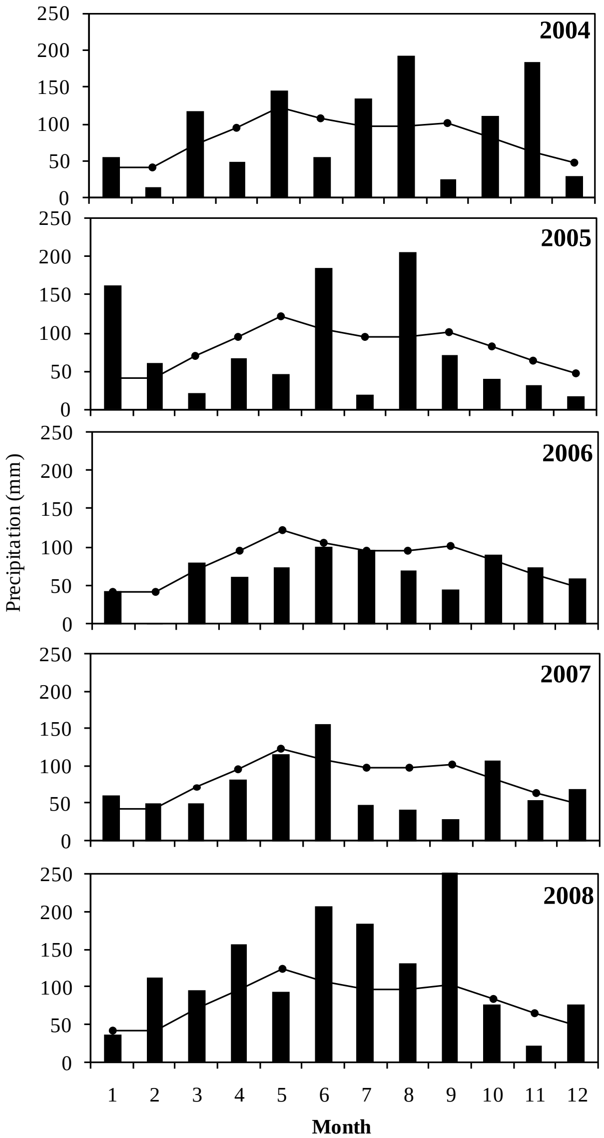

Figure 2. Monthly precipitation (bars) and long-term mean (line) for the study site from 2004 to 2008.

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 m^3 ha^{-1} yr^{-1} (2006) to 2548 m^3 ha^{-1} yr^{-1} (2004 on the control). During the study period, agroforestry, grass buffer, and control treatments produced 2655, 3067, and 5598 m^3 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.

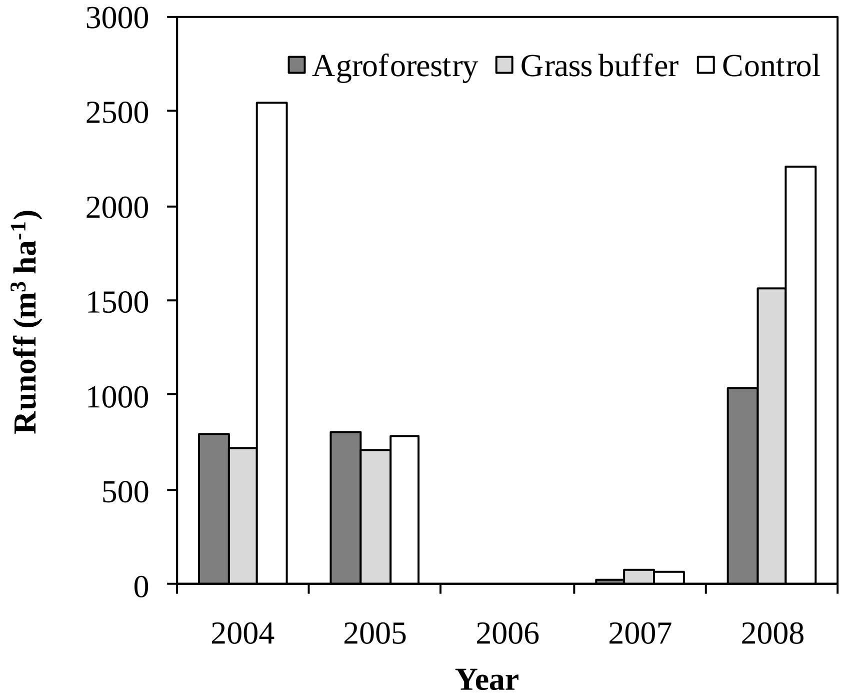

Figure 3. Annual runoff volumes by agroforestry buffer, grass buffer, and control treatments from 2004 to 2008

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.

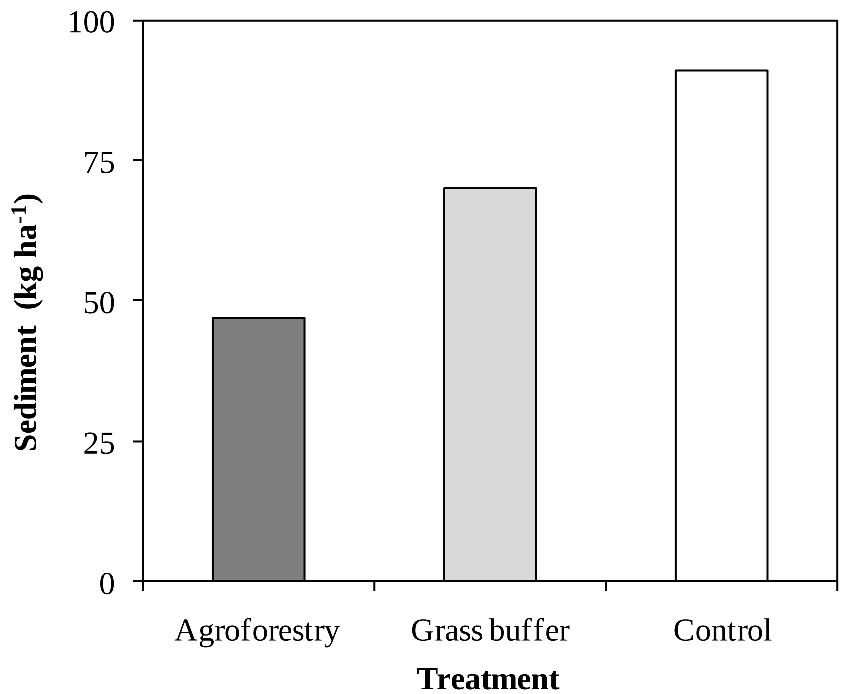

Figure 4. Total soil loss on agroforestry buffer, grass buffer, and control treatment watersheds from 2004 to 2008.

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 significanty 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 were significantly reduce losses in runoff from grazed pasture. Cattle are allowed graze near the sample collection unit and flume approach area as compared to watersheds with buffers. As cattle walk near the flume during wet period more soil and nutrient loss cannot be reduced. This implies the important of no-access buffer strip 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.

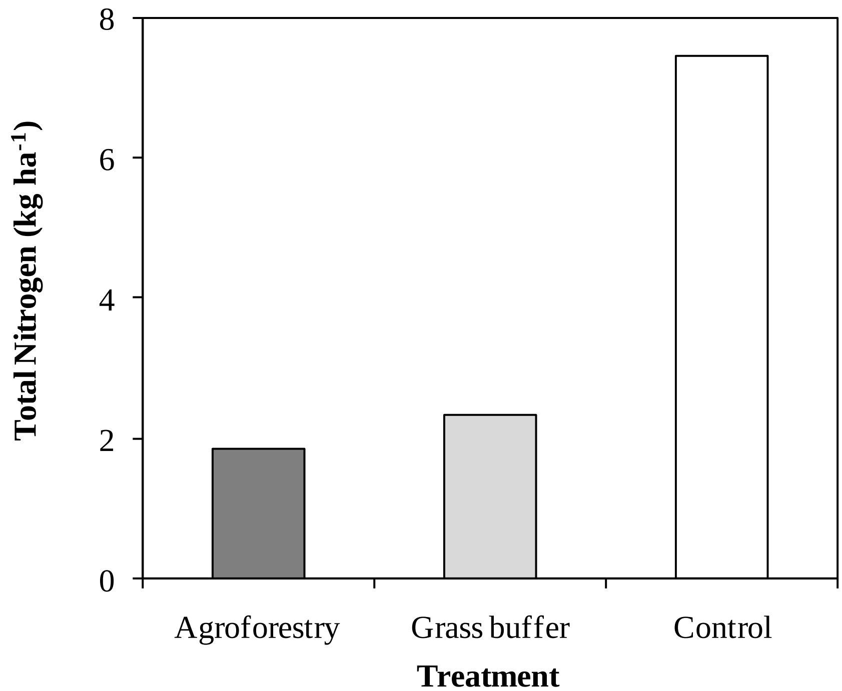

Figure 5. Total nitrogen loss on agroforestry buffer, grass buffer, and control treatment watersheds from 2004 to 2008.

Acknowledgements: This work was funded through the University of Missouri Center for Agroforestry under cooperative agreements with the USDA-ARS Dale Bumpers Small Farm Research Center, Booneville, AR. The authors thank Kenny Bader and Brandom Adamson for their assistance in field and laboratory procedures.

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