ESTABLISHMENT OF A SILVOPASTORAL SYSTEM INTO A MISSOURI HARDWOOD FOREST

A Thesis presented to the Faculty of the Graduate School
University of Missouri-Columbia

In Partial Fulfillment of the Requirements for the Degree

Master of Science

By

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December 2010

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A candidate for the degree of Master of Science

And hereby certify that, in their opinion, it is worthy of acceptance.

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DEDICATION

To my wife, Trish Ladyman and to my parents, Dave and Diann Ladyman.

For all the encouragement and support they have given me.

ACKNOWLEDGEMENTS

I would like to take this time to say thanks for all the help and opportunities that I was given during my time at the University of Missouri.

I would first like to thank Dr. Kerley and Dr. Garrett for giving me the opportunity to come to the University of Missouri to work on my Master's degree. I am grateful to have had the opportunity to be part of this program. I would also like to thank the members of my committee; Dr. Garrett, Dr. Kerley, Dr. Cutter, and Dr. Kallenbach for their guidance and assistance throughout the course of my program.

A big thanks to Jim Porter for all the help, knowledge, and laughs we had over the years. Thank you to all my fellow graduate students in Lab 111; Joe Golden, Deke Alkire, Bill Kolath, Chris Willis, Erin Venable, Andy Mueller, and Chunjiang Fu for all their help and the fun we had.

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CHAPTER 1

INTRODUCTION

Silvopasture is a form of agroforestry designed specifically for the management of trees and/or tree products, livestock, and forages. Silvopasture is the deliberate introduction of forage species into a timber production system or the introduction of trees into a forage production system where they are managed as one unit. Silvopastoral systems are designed to provide a long-term income from the timber and a short-term cash flow from the livestock or forage crop.

It is hypothesized that the inherent genetic variability in forages is great enough that some species are shade tolerant. Identifying shade tolerant forages would allow creation of conducive silvopastoral management. Concluded from the literature is the potential to select forage species that have the ability to adapt or thrive in an environment where available sunlight is reduced.

The goal of this research project was to develop a multi-cropping system of timber and forage that was dependent upon improved timber management. The purpose of this research was first to identify different forage species that can either maintain or increase dry matter production under reduced sun light. After shade-tolerant forage species were identified, selection of a subset was made to study in a production environment. The objective of this research was to determine if an existing stand of hard-wood forest could be thinned to allow approximately 50% sunlight and then have a forage stand established for grazing by cattle. This would allow a productive timber crop to be maintained while using a forage crop (pasture) for grazing. We further hypothesized that certain forages grown under reduced sunlight would produce higher quality and quantity forage compared to forages grown in full sunlight.

CHAPTER 2

Review of Literature

Silvopasture is an agroforestry practice that intentionally integrates trees, forages, and livestock forming a structural system of mutually beneficial interactions. Unlike forest range grazing, silvopasture management practices focus on interactions among components rather than the individual components. “The combination of pine, pastures, and cattle, an example of silvopasture, can help decrease financial risk and increase farm receipts through commodity diversification and the simultaneous production of food and fiber” (Clason and Sharrow, 2000). Silvopastures can be developed either by planting trees into an established pasture or by establishing forages into an existing forest. A silvopastoral system is neither a timber nor a livestock production system. It is a land-use management system that simultaneously maintains production continuity of commercial timber and livestock enterprises (Clason, 1995). The objective of employing silvopastoral practices is to integrate the production agriculture components of trees, forages, and grazing herbivores for a production benefit. The benefit supposed is that the tripartite sum is greater than the value of any component individually (Garrett et al., 2004). Relatively few landowners in the US employ silvopastoral practices because there is poor understanding of the economics, marketing, and cost efficiencies involved with the production and sale of agroforestry products (Pearson et al., 1995).

Shade and forage quality interactions

Photosynthesis is the primary mechanism for increasing useable energy on this planet. With forage plants, we have a manageable process for capturing solar energy and converting it to useful products, primarily through ruminants that depend on forages to meet their nutrient requirements. While photosynthesis is critical, it is often not the most important factor in determining yield, quality, or persistence of a grass or legume (Nelson, 1988). The plant is a highly integrated organism with a wide range of interconnected activities. Thus, photosynthesis should not be considered alone but as one component in carbon metabolism, which also includes photorespiration, respiration, partitioning, storage, and growth rates.

All plants respond differently both physiologically and morphologically to shade and vary considerably in regard to their shade tolerance (Bjorkman, 1966; Boardman, 1977). Grasses in general respond to shade by increasing their leaf-area and shoot-to-root ratio to increase their surface area, while decreasing their specific leaf weight, leaf blade thickness and shoot dry weight (Cooper and Tainton, 1968; Allard et al., 1991; Kephart et al., 1992). In a study conducted by Allard et al. (1991), it was demonstrated that shaded plants allocated relatively more carbon to production of leaf area and less to roots than did plants grown in full sun. In absolute terms, shoot dry weight was significantly lower in the shade, but leaf blade dry weight was similar over treatments, indicating that shading reduced dry weight of leaf sheath and stem base tissues. The production of fewer leaves, but each with a relatively larger blade area, alters partitioning to favor light interception and reduces the amount of dry weight used for sheath material. In Allard et al. work, production of leaf blade dry weight was fairly constant across all treatments, thus the leaf area ratio was increased 30% in the shade. Lin et al., (1999) reported that leaves of grasses grown at 50% shade had a blade area that was 13 to 126% larger than leaves grown in full sun. As the shade level increased to 80%, the blade area of most grasses was 19 to 220% greater than for plants grown under full sun.

The effect shade stress has upon forage quality also varies. Kephart and Buxton (1993) illustrated that reduction of ambient sunlight to 37 and 70% of full intensity resulted in increased nitrogen concentration, decreased neutral detergent fiber (NDF) and enhanced in vitro dry matter digestibility. A study conducted by Ladyman et al. (2003) reported an increase in nitrogen content in nineteen forage species grown under reduced sunlight. These results agreed with research conducted by Denium et al. (1996) who reported increased nitrogen content at lower light levels. The Ladyman et al. (2003) study also showed an unexpected increase in the amount of neutral detergent fiber (NDF) and acid detergent fiber (ADF) content as light intensity decreased. However, even with the higher NDF concentration, there was an increase in NDF digestibility. Lin et al., (1999) tested a variety of forage species and their responses to 0, 50, and 80% shade. The response for yield, percentage NDF, ADF and crude protein (CP) were measured in this study to identify species that could be recommended for incorporation into an agroforestry system. They further reported that the response to shade varies with different shade levels, species, and growing season. Six of the eight cool season grasses had no significant reductions in dry weight yield under 50% shade. In addition, the mean dry weight of smooth bromegrass and ‘KY31’ tall fescue at 50% shade was greater than in full sun, although only smooth bromegrass showed a statistically significant difference. Data for legumes revealed that dry matter yield of most tended to decline when shade level increased. However, there were two native *Desmodium* species that displayed shade tolerance and had significantly greater dry matter at both 50 and 80% shade than in full sun. There were two cool season legumes ('Cody' alfalfa and white clover) and one warm season legume (striate lespedeza) that showed no significant reduction in dry weight under 50% shade. It is important that species and cultivars be identified that can withstand shade and grazing pressure for use in a silvopasture program. Results from Lin et al. (1999) suggest that several forage species are sufficiently shade tolerant to be considered for use in an agroforestry practice. Kentucky bluegrass, orchardgrass (Justus and Benchmark), ryegrass, smooth bromegrass, tall fescue ('KY31' and Martin), timothy, alfalfa (Cody), white clover, striate lespedeza, *Desmodium canescens* and *Desmodim paniculatum* were shown to have the greatest growth potential under either 50 or 80% shade during the summer to fall (July to October) test period. Lin et al. also reported that almost all of the warm-season grasses (C_4) tested performed poorly under the shade, regardless of the growing season. Halls and Suman (1954) provided important insight on forage production in southern pine stands. Their research indicated that white clover (*Trifolium repens*) under trees grew later into the summer than clover in the open. This response was not limited to clover alone as they concluded that existing plants under trees continued growth longer into the summer than did those in full sunlight. This demonstrates the role silvopastoral systems can play in cattle production for increasing forage productivity. Sharrow et al. (1996) demonstrated that productivity of forages in a silvopastoral system utilizing Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in the Pacific Northwest can be high enough to support animal production. Their work revealed that production of a fescue-subterranean clover mix pasture produced 5,080 to 6,260 kg/ha following establishment. Production gradually decreased when trees obtained five years of age to 2,268 to 3,992 kg/ha. This research demonstrated that forage yield was equal to that of an open pasture for the first four years following establishment. Lastly, they revealed that tall fescue production was similar for all systems (pasture, silvopasture, and forest) and ranged from 2,000 to 2,600 kg/ha refuting the commonly held opinion that forage will not be productive under a canopy of trees.

Tree-forage relationships are important in determining forest grazing potential. The overstory tree density or canopy cover greatly influences forage yields (Gaines et al., 1954; Halls and Schuster, 1965). Forage yields generally decrease as tree overstory increases. In 13 to 17 year-old longleaf (Pinus palustris Mill.) and slash (Pinus elliottii Englm.) pine stands, forage yield decreases of about 15 lb per acre were observed for every ft^2 of increased tree basal area (Wolters, 1973). In a thinned 35 to 40 year-old longleaf pine stand, yields decreased about 7 lb per acre for every ft^2 increase in tree basal area (Grelen and Enghardt, 1973; Grelen and Lohrey, 1978). Forage yields can be optimized by controlling the shade level of the forage micro-environment. This can be accomplished by conducting appropriately timed thinnings which will be influenced by the age of the stand and the canopy cover.

As with all things, the key to success of silvopasture is management. However, the art with silvopasture is managing three entities as one. If managed correctly, the three entities can benefit from one another while providing long- and short-term income on the same land.

Tree growth-animal grazing interactions

Trees, like all other plants, capture the suns energy through photosynthesis to produce carbohydrates. Some of this energy is used for respiration to meet basic metabolic needs, while the remaining energy is used for growth. The silviculturist attempts to harness this energy to influence the size and shape of each tree in an effort to achieve the desired stand structure and value. The amount of growing space available to a tree will regulate the amount of growth, and the genetic makeup of a tree will dictate how the growth is allocated to different parts. One of the difficulties that a silviculturist faces is that rapid growth is almost always accompanied by large lower branches whose knots reduce the timber value of the tree. However, through good management (pruning the lower branches) timber value can be maintained and even enhanced (Smith et al., 1997).

Silvicultural practices that reduce timber stand density, such as thinning to accommodate silvopastoral management, can have both positive and negative effects on residual trees. From a technical or an engineering perspective, quality depends on how well the physical and chemical characteristics of wood in a tree meet the specifications and expectations of different end products and uses. Foresters often view quality as the measurable condition of a product or opportunity in its existing state, while awaiting some future use. In most forestry situations, price does not necessarily reflect what the seller considers valuable or even how a seller rates quality. Rather it represents the buyer's judgment about how well logs or forested areas will satisfy some anticipated use or provide some value of interest. With logs or trees, it depends on how much of a particular kind of lumber can eventually be cut. Any physical characteristic that limits the use of a tree for an intended product reduces its potential dollar value. Thus, for saw logs, any feature that will degrade or reduce the usefulness of boards sawn represents a grading defect. Generally, the most valuable trees have large diameters and straight logs, as well as a minimum number of knots and other physical defects that might reduce the usefulness of wood in them. Wood strength, consistency, and other engineering characteristics based on density and annual ring width also affect wood quality for some purposes. But in most cases, buyers tend to correlate value with size. Tree utilization is broad and may include products such as lumber and nuts, or services provided to society, such as filtering water and air.

There are several studies that have been conducted over the years that show that if livestock are managed properly, there is little to no damage done to the trees in a silvopastoral system. The trees do need to be protected or livestock removed during the period of tree establishment. If not, animals will browse the terminal bud on the trees. The use of rotational grazing also needs to be utilized to minimize the amount of stress the livestock inflict upon the forages and trees as a result of soil compaction.

In a study conducted by Pearson et al. (1990), survival and height of slash and loblolly pine seedlings were significantly less in a grazed treatment compared to a limited grazing and ungrazed treatment. Average survival of both the slash and loblolly pines on the grazed treatments was 88, 84, and 82% after the first, second, and third growing seasons while the limited grazing and ungrazed treatments averaged 97, 94, and 92% during the same period, respectively. The limited-grazing and ungrazed treatment pine heights, while not significantly different from each other at the end of the second year, averaged 1.03 m, which was greater than that of the grazed treatment pine height

(0.94 m), regardless of species. However, at the end of the third year, slash pine heights were not different for any of the treatments (1.98 m). For loblolly pine, the limited-grazing treatment had taller trees (1.91 m) than the grazed treatment (1.78 m), but heights were not significantly different from the ungrazed treatment (1.81 m).

In a study conducted by Clason (1997), the mean five year merchantable, sawtimber, and lumber volume growth for forage crop treatments exceeded that of a control treatment (no forage crop) mean growth by 11, 11, and 7 m^3 ha^{-1}, respectively. By 1995, mean pine basal area differed significantly between forage crop treatments and the control treatment, averaging 1,200 and 1,060 cm^2, respectively. Similarly, significant treatment differences were detected for mean pine merchantable sawtimber, and lumber volume growth.

In a study conducted by Lewis et al. (1983), they looked at the integration of pines, pastures and cattle and examined the response of slash pines for 20 years and the production of beef during the last 15 years under trees planted on 3.7 x 3.7 m, 6.1 x 6.1 m spacings, and no pines in pastures of coastal bermudagrass, dallisgrass, and Pensacola bahiagrass. Initial survival of slash pine was good. In the third year, a severe attack by southern pine coneworm and southern fusiform rust occurred on the boles of these fast growing trees. This combined attack lasted for several years and resulted in heavy mortality. Trees grown in fertilized pastures grew more rapidly, both in height (18.0 vs. 15.8 m) and diameter (31.8 vs. 21.3 cm), than those planted in native vegetation. Even with much lower survival, the pasture-grown trees produced about 30% more wood (136.0 vs. 104.5 m^3/ha) than did plantations in native vegetation. Wood yields from the densely planted 3.7 x 3.7 m plantations (746 trees/ha) were at least twice (181.4 vs. 90.7

m^3/ha) that of the 6.1 x 6.1 m plantations (269 trees/ha). There was little difference in wood yields as related to species of pasture grass. During the 15 years of grazing, treeless pastures produced slightly over 3,900 kg of liveweight beef gains per hectare, which was about 1.7 and 2.6 times the gain from pastures planted with slash pine at 6.1 x 6.1 m and 3.7 x 3.7 m, respectively.

Cutter et al. (1999) reported on the tree and wood quality of a slash pine plantation that had been grazed long-term. The tree and wood quality study of 56 paired grazed and ungrazed slash pine trees showed no difference between treatments for any of the variables measured: total tree height, tree diameter, tree grade, growth rate, and percentage of latewood, specific gravity or tracheid length. The stand of trees in south-central Louisiana had been grazed by cattle for nearly 30 years under controlled conditions; the number of cattle per acre was regulated in accordance with the forage production under the trees.

In a study conducted by Pearson et al. (1971), survival of planted pines was unaffected by light or moderate grazing. By age five, plots grazed at these intensities averaged 682 trees per acre and their controls averaged 736; the difference was not significant (0.05 level). At age five, planted pines on control plots were 0.9 feet taller than those on grazed plots in all range units; heights averaged 10.4 feet for controls and 9.5 feet for grazed plots. However, the difference was significant only for the moderately grazed range treatment. In this experiment, grazing had no clear cut influence on growth of seeded or planted pines at age five. Neither light nor moderate grazing affected pine survival. From the information in the studies previously described, trees will survive and grow if livestock are allowed limited access (i.e. rotational grazing) to a silvopasture area.

CHAPTER 3

EFFECT OF SHADE ON THE NUTRITIVE VALUE OF POTENTIAL SILVOPASTORAL FORAGE SPECIES

Abstract

Nineteen forage species were used in this study, including six C_4 grasses, seven C_3 grasses and six legumes. Forage species studied were grown from April to October, 1999 in a greenhouse located at the University of Missouri Horticulture and Agroforestry Research Center, near New Franklin, Missouri (longitude 92° 46’ W; latitude 39° 01’ N). The seeds were sown in germination flats with one species per flat. Seedlings were transplanted to 7.6 cm pots in a greenhouse between May 10 and May 26. On June 18, three plants of each entry were transplanted outside into 7.5 L black pots. The treatments began on June 18 and there were three levels of sunlight: 100%, 45% and 20% full sunlight. Differing levels of sunlight were created by placing polypropylene fabric over rectangular frames (5-m wide x 15-m long x 2.5-m high) set on light-colored gravel. Forages were harvested during August (cutting 1) starting with the phenologically most mature species and again in October (cutting 2). Forages were harvested by clipping all material to leave a 5 cm stubble above soil level. All forages were analyzed for their content of nitrogen (N), neutral detergent fiber (NDF), acid detergent fiber (ADF), and

neutral detergent fiber in situ digestibility (NDFIS). Eight of the 19 forages produced significantly ($P < 0.05$) more above ground dry weight at 45% full sunlight than under full sunlight. The C_3 grasses produced more yield under increased shade than the C_4 grasses (38% vs. 12% respectively). Nine of the 19 forages tested produced significantly ($P < 0.05$) less above ground dry weight when grown under 20% full sunlight than when grown under full sunlight. The N content of all forage species studied increased significantly ($P < 0.05$) as sunlight intensity decreased. Sixteen of the forage species studied had increased ($P < 0.05$) neutral detergent fiber (NDF) content when grown under reduced sunlight. Sixteen of the forages studied had greater ($P < 0.05$) acid detergent fiber concentrations when grown under reduced sunlight than when grown under full sunlight. The conclusion reached was that sunlight restriction does not negatively impact forage fiber digestibility, and may even enhance forage digestibility in certain species.

INTRODUCTION

Agroforestry is used as a collective name for practices that combine woody perennials with herbaceous plants and/or livestock. Agroforestry practices can be stable and sustainable. The planting of crops that differ in light requirements, root development, and height, allows for more efficient use of solar radiation, soil moisture, and nutrients, especially with tree and forage combinations.

Silvopasture is one of the five recognized agroforestry practices (Garrett et al., 2000). In silvopastures, the relationship between the overstory trees and the understory forage species must be compatible for optimum production (Clason and Sharrow, 2000). Forage grasses respond to shade by increasing leaf-area and shoot-to-root ratio and by decreasing specific leaf weight, leaf blade thickness and shoot dry weight (Cooper and Tainton, 1968; Allard et al., 1991; Kephart et al., 1992). Furthermore, shade stress causes grasses to concentrate nitrogenous compounds (Kephart and Buxton, 1993; Deinum et al., 1996). Shade may also result in cells with thinner walls resulting in less indigestible fiber and increased forage quality, defined as susceptible to digestion by herbivorous animals (Kephart and Buxton, 1993).

Warm-season (C_4) and cool-season (C_3) grasses respond differently to shade stress. Ford et al. (1979) observed that increases in temperature led to increased cell wall concentration in C_3 grasses, but the opposite was found in C_4 grasses. Kephart and Buxton (1993) noticed that neutral detergent fiber (NDF) concentration was higher in C_4

grasses than in C_3 grasses when grown under shade. Dry matter digestibility was higher in C_3 grasses, which agrees with previous research by Wilson et al., 1982. By understanding how forage quality of different plant species responds to sunlight intensity (shade), we can more effectively use forage species under tree canopies in an agroforestry practice. This experiment examined the effects of sunlight intensity on candidate silvopastoral forage species for biomass production and nutritional quality.

Materials and Methods

Nineteen forage species were used in this study, including six C_4 grasses, seven C_3 grasses and six legumes (Table 3.1). Forage species studied were grown from April through October, 1999.

The forages were germinated during the first three weeks in April, 1999, in a greenhouse located at the University of Missouri Horticulture and Agroforestry Research Center, near New Franklin, Missouri (longitude 92° 46' W; latitude 39° 01' N). The seeds were sown in germination flats with one species per flat. Seedlings were transplanted to 7.6 cm pots in a greenhouse between May 10 and May 26. The growth medium was Scott's Metro-Mix 360 consisting of 35-45% specially processed coconut coir, 10-20% horticultural grade vermiculite, 15-25% processed bark ash, and 20-30% Canadian sphagnum peat moss. Pots were provided with a water soluble fertilizer (20-20-20) using a hose siphon at 113 mg per L of water. On June 18, three plants of each entry were transplanted outside into a single 7.5 L black pot containing a mix of composted pine bark, medium grade vermiculite, Canadian sphagnum peat moss, horticulture perlite, sand, starter nutrient charge, and a wetting agent. Each entry was planted into six pots, and complete slow-release fertilizer was applied to all forages.

Water was supplied twice per day by a trickle irrigation system controlled by an electronic timer. The treatments were three levels of sunlight: 100%, 45%, and 20% of full sunlight. Differing levels of sunlight were created by placing polypropylene fabric over rectangular frames (5-m wide x 15-m long x 2.5-m high) set on light-colored gravel. Each sunlight treatment was randomly assigned to three of nine frames. Six pots of each plant species were placed in each frame (i.e., three replications of each light treatment). The pots were placed 50 cm apart within each row and 75 cm between rows. Following harvest, forage from the six pots was combined for one composite sample before dry weight determination.

Forages were harvested during August (cutting 1) starting with the phenologically most mature species and again in October (cutting 2). Forages were harvested by clipping all material to leave a 5 cm stubble above soil level. Clipped material was then dried at 45°C in a forced air oven for a minimum of 72 hours. Dried forage samples were ground through a 2-mm screen. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined (Goering and Van Soest, 1970) by weighing a 0.5 to 1.0 g sub-sample into a 600 mL Berzelius beaker. One hundred mL of neutral detergent fiber or acid detergent fiber solution was added and refluxed for one hour. After refluxing, the samples were filtered, dried overnight in a 105°C oven and reweighed. Nitrogen (N) was determined by weighing 0.05 to 0.1 g sub-samples into a foil pouch and then analyzing using a LECO Model FP-248 Nitrogen Determinator. NDFIS was determined by weighing out 5.0 g of sample into Dacron mesh bags. The bags were incubated in the rumen of forage-fed cows for 48 hours. The bags were removed, rinsed, and dried overnight in a 55°C oven and reweighed. The NDF procedure was then conducted on the dried residue.

The data were analyzed as a split plot in space (frame) and time (cutting) as outlined by Steele et al. (1997). Mean differences were determined using the Scott-Knot procedure (Gates and Bilbro, 1978). This is a procedure suggested for using the non-central F distribution to determine the number of replications and samples needed per experimental unit. The method requires the specification of the treatment effects to be detected, the probability of type I and type II errors, and an estimate of population variance. All data were analyzed using SAS software (1999).

Results

Forage Dry Weight Production

Under full sunlight, total dry weight production for three plants per pot ranged from 24 g for Kentucky bluegrass to almost 120 g for bermudagrass (Table 3.2). The C_4 grasses on average produced over twice as much dry weight (81 g per pot) as the C_3 grasses (39 g) or the legumes (40 g), with substantial variation within the three groups. Eight of the 19 forages produced significantly ($P < 0.05$) more above ground dry weight at 45% full sunlight than under full sunlight. To better visualize the response to shading, shade-tolerance values were calculated that compared yields under shade to full sunlight such that negative values indicate percent reduction compared to full sunlight and positive values indicate percent increase compared to full sunlight (Table 3.2). As a group, the legumes had the greatest shade tolerance value (68%) while the C_4 grasses had the least shade tolerance value (12%) to 45% sunlight, which would be comparable to the shading encountered under many agroforestry practices. The C_3 grasses were more tolerant of shade than the C_4 grasses (38% vs. 12%, respectively). These results are consistent with the general observation that C_4 grasses are less tolerant of shading than are the C_3 grasses (Kephart et al., 1992; Lin et al., 1999).

Nine of the 19 forages tested produced significantly ($P < 0.05$) less above ground dry weight when grown under 20% full sunlight than when grown under full sunlight. Hoary tick clover, paniculated tick clover, Kentucky blue grass, reed canarygrass, and smooth bromegrass had positive shade-tolerance values when grown under 20% full sunlight. However, none of these were statistically different ($P < 0.05$). As individual groups, the C_3 grasses and legumes were the most tolerant of low (20%) sunlight conditions with an average shade-tolerance value of 8% and 13%, respectively. The C_4 grasses were the least tolerant with an average shade-tolerance value of -33%.

Nitrogen Content

The N content of all forage species studied increased significantly ($P < 0.05$) as sunlight intensity decreased with the exception of Illinois bundleflower, strawberry clover, and 'Tifton-9 Pensacola' bahiagrass in cutting 1 and Hoary tick clover, white clover, redtop, annual ryegrass, and Illinois bundleflower in cutting 2 (Table 3.3).

The effect that sunlight intensity (45 vs. 20%) had on N content varied among forage species. In cutting 1, four of the legumes had significantly more ($P < 0.05$) N content at the lowest sunlight intensity. Three of the C_3 grasses had greater ($P < 0.05$) N content as sunlight intensity decreased, while the other four C_3 grasses had elevated ($P < 0.05$) N content only under 20% sunlight. With the exception of switchgrass and bahiagrass 'Tifton-9 Pensacola,' the C_4 grasses increased ($P < 0.05$) N content only at 20% sunlight. Switchgrass and bahiagrass 'Tifton-9 Pensacola' had similar ($P > 0.05$) N content when grown under 45% or 20% full sunlight. For cutting 2, only orchardgrass, smooth bromegrass, ‘Argentina’ bahiagrass and ‘Pensacola’ bahiagrass had greater ($P < 0.05$) N content as intensity of sunlight decreased. Thirteen of the forage species had greater ($P < 0.05$) N content only at 20% full sunlight. The only reductions in nitrogen content occurred for redtop and annual ryegrass at 45% full sunlight and Illinois bundleflower at 20% full sunlight in cutting 2. The N content of redtop and annual ryegrass at 20% full sunlight was similar ($P > 0.05$) to their N content under full sunlight. There was a general trend for the C_3 grasses and legumes to have greater N content than the C_4 grasses.

Neutral Detergent Fiber (NDF) Content

Sixteen of the forage species studied had increased ($P < 0.05$) NDF content when grown under reduced sunlight for cutting 1, whereas only six species had re-growth (cutting 2) that followed this trend (Table 3.4). Generally, the legumes tended to have the lowest NDF content and the C_4 grasses had the highest. Reduction in sunlight intensity appeared to increase the NDF content of initial forage growth, but had less effect on re-growth.

Acid Detergent Fiber (ADF) Content

The effect of reduced sunlight intensity on ADF content of forages in cutting 1 was similar to the effect on NDF content. Sixteen of the forages studied had greater ($P < 0.05$) ADF concentrations when grown under reduced sunlight than when grown under full sunlight (Table 3.5). Interestingly, unlike the NDF response in cutting 2, 14 of the forage species studied had greater ($P < 0.05$) ADF content when grown under reduced sunlight compared to full sunlight. This response was particularly evident for the C_3 and C_4 grasses. It appeared that reduced sunlight resulted in greater ADF content of initial growth forage and in re-growth of C_3 and C_4 grasses.

In Situ Neutral Detergent Fiber Digestibility (NDFIS)

The in situ neutral detergent fiber digestibility was increased ($P < 0.05$) for eight of the forage species in cutting 1, and seven forage species in cutting 2 when grown under restricted sunlight compared to full sunlight. Only strawberry clover, timothy, and switchgrass in cutting 1, red clover and prairie cordgrass in cutting 2, and 'Argentina' bahiagrass in both cuttings 1 and 2 had lower ($P < 0.05$) NDF digestibility when grown under restricted sunlight than full sunlight (Table 3.6). The conclusion reached was that sunlight restriction does not negatively impact forage fiber digestibility, and may even enhance forage digestibility in certain species.

Discussion

Lin et al. (1999) noted that C_3 grasses and some legumes displayed considerable shade tolerance, particularly in the summer-fall growing season. In this study, three of the C_3 grasses and five of the legumes had greater forage production when grown under 45% sunlight than under full sunlight. Of these eight species, only two had significant reductions in forage production when grown under 20% full sunlight. Based upon our findings, it is possible to select forage species that can produce ample forage mass in a silvopasture practice to support grazing.

The increased N content of forages when grown under shade in this study was expected. Halim et al. (1989) reported that shade stress would likely reduce availability of photosynthates used for secondary cell wall synthesis. Kephart and Buxton (1993) suggested that such stress could increase the percentage of digestible intracellular constituents, by reducing cell wall (fiber) content. However, the opposite occurred in our experiment. The increase in nitrogen content and fiber may have been an adaptive response to capture more available light by increasing photosynthetic activity (N) and adjusting leaf structure/area (NDF and ADF).

The second unexpected result was the increased NDF digestibility of plants grown in reduced sunlight. The effect of reduced sunlight must have altered the composition of the plant cell wall. One plausible explanation is that the fibrous tissue needed to support increased photosynthetic activity is tissue that is readily susceptible to enzymatic hydrolysis and fermentation by rumen microflora. Therefore, the fiber present in plants grown under reduced sunlight would be more digestible than that of plants grown in full sunlight, even though the shaded plants had greater fiber content.

Forage production has obvious importance for use in herbivore production systems. Too often the only consideration in agroforestry practices is compatibility of the woody perennial and forage plant (Van Sambeek and Garrett, 2004). This research demonstrated woody perennials can be used to enhance forage productivity, along with the probable enhancement of herbivore productivity.

We observed that many plants growing under full sunlight in our study had shorter internodes and more leaf damage than plants under shade. For this series of trials, all plants were grown in black 7.5-L plastic pots set on weed-free, light-colored gravel. In addition, individual pots were widely spaced to reduce side shading from adjacent plants and to assure good airflow between pots. In spite of these precautions, high summer temperatures under full sunlight may have resulted in thermal inhibition of photosynthesis for the C_3 grasses and legumes as suggested by Lin et al. (1999). Also, root temperatures may have been artificially elevated within the black pots through absorption of both direct and reflected solar energy and subsequent transfer of heat into the potting medium. The results of reduced plant growth under full sunlight would be to show higher forage production under moderate shade and to bias the shade-tolerance values.

Shade-tolerant forages have potential for use in silvopastoral or alley-cropping practices for hay production. Moreover, certain forages when grown in shade environments may produce greater dry matter yields and greater forage quality than when grown under full sunlight. This can translate into equal or even greater animal carrying capacities under trees in addition to a timber crop which increases profitability for the landowner.

Table 3.1. Forage species used to study the effect of decreasing sunlight on forage quality.

Species	Scientific Name	Forage Type
Hoary tick clover	*Desmodium canescens*	Legume
Illinois bundleflower	*Desmanthus illinoensis*	Legume
Paniculated tick clover	*Desmodium paniculatum*	Legume
Red clover	*Trifolium pretense*	Legume
Strawberry clover	*Trifolium fragiferum*	Legume
White clover	*Trifolium repens*	Legume
Annual ryegrass	*Lolium multiflorum*	C_3 grass
Kentucky bluegrass	*Poa pratensis*	C_3 grass
Orchardgrass	*Dactyus glomerata*	C_3 grass
Redtop	*Agrostis alba*	C_3 grass
Reed canarygrass	*Phalaris arundinacea*	C_3 grass
Smooth bromegrass	*Bromus inermis*	C_3 grass
Timothy	*Pheum pratensis*	C_3 grass
Bahiagrass 'Argentina'	*Paspalum notatum*	C_4 grass
Bahiagrass 'Pensacola'	*Paspalum notatum*	C_4 grass
Bahiagrass 'Tifton-9 Pensacola'	*Paspalum notatum*	C_4 grass
Bermudagrass	*Cynodon dactylon*	C_4 grass
Prairie cordgrass	*Spartina pectinata*	C_4 grass
Switchgrass	*Panicum virgatum*	C_4 grass

Table 3.2. The dry matter (g) produced from nineteen different forage species grown in full sunlight and relative percentage of dry matter (compared to that in full sun) produced when grown at 45 and 20% sunlight.

Forage	% Sunlight		
	100	45	20
	g	%	%
Hoary tick clover	28.6[b]	+124[a]	+32[b]
Illinois bundleflower	32.3[b]	+38[a]	-35[c]
Paniculated tick clover	47.4[b]	+64[a]	+7[b]
Red clover	44.1[b]	+64[a]	-35[c]
Strawberry clover	34.5[b]	+95[a]	-17[b]
White clover	45.2[a]	+25[a]	-28[b]
Annual ryegrass	45.4[a]	+28[a]	-10[b]
Kentucky bluegrass	23.7[b]	+80[a]	+7[b]
Orchardgrass	39.7	+28	-3
Redtop	47.0[a]	+22[a]	-24[b]
Reed canarygrass	46.1[b]	+53[a]	+8[b]
Smooth bromegrass	33.6[b]	+28[a]	+3[b]
Timothy	34.3[a]	+29[a]	-36[b]
Bahiagrass 'Argentina'	92.0[a]	+14[a]	-24[b]
Bahiagrass 'Pensacola'	64.8	+25	-13
Bahiagrass 'Tifton-9 Pensacola'	74.0	+24	-31
Bermudagrass	119.9	+15	-14
Prairie cordgrass	36.7[a]	-1[a]	-5 9[b]
Switchgrass	96.7[a]	-8[a]	-55[b]

[1]Shade-tolerance values = 100 $(x_i - x_{fs})/x_{fs}$, where x_{fs} = aboveground dry weight in full sunlight and x_i = aboveground dry weight under 45 percent or 20 percent full sunlight.
[abc] Means in a row with unlike superscripts differ ($P < 0.05$), according to Scott-Knot separation of means procedure.

Table 3.3. Nitrogen content (%) of forage species grown under varying percentages (100, 45 and 20) of sunlight.

Forage	Cutting 1 % Sunlight			Cutting 2 % Sunlight		
	100	45	20	100	45	20
	-------------------------- % N --------------------------					
Hoary tick clover	2.02^{e}	2.18^{d}	2.60^{c}	2.16^{d}	2.23^{d}	2.25^{d}
Illinois bundleflower	2.42^{c}	2.54^{c}	2.59^{c}	2.24^{d}	2.17^{d}	1.84^{f}
Paniculated tick clover	2.04^{d}	2.32^{d}	2.52^{c}	1.96^{e}	2.14^{d}	2.15^{d}
Red clover	2.03^{e}	2.43^{c}	3.04^{b}	3.10^{b}	3.22^{a}	3.27^{a}
Strawberry clover	1.15^{g}	1.15^{g}	1.48^{g}	0.94^{h}	0.99^{h}	1.23^{g}
White clover	2.49^{c}	2.97^{b}	3.36^{a}	3.32^{a}	3.28^{a}	3.54^{a}
Annual ryegrass	3.00^{b}	3.05^{b}	3.32^{a}	3.03^{b}	2.20^{d}	3.01^{b}
Kentucky bluegrass	1.90^{e}	2.45^{c}	3.18^{a}	1.72^{f}	1.77^{f}	2.50^{c}
Orchardgrass	2.05^{e}	2.06^{e}	2.91^{b}	1.70^{f}	1.79^{e}	2.32^{d}
Redtop	1.79^{f}	1.89^{e}	2.88^{b}	2.15^{d}	1.94^{e}	2.35^{d}
Reed canarygrass	0.70^{h}	0.84^{h}	1.52^{f}	0.86^{h}	0.91^{h}	1.42^{g}
Smooth bromegrass	1.87^{e}	2.39^{c}	3.36^{a}	1.73^{f}	1.90^{e}	2.31^{d}
Timothy	1.73^{f}	1.62^{f}	2.35^{d}	1.88^{e}	1.89^{e}	2.21^{d}
Bahiagrass ‘Argentina’	0.94^{h}	1.02^{h}	1.69^{f}	1.17^{f}	1.25^{g}	1.99^{e}
Bahiagrass ‘Pensacola’	1.63^{f}	1.83^{f}	2.73^{c}	2.02^{e}	2.25^{d}	2.38^{c}
Bahiagrass ‘Tifton-9 Pensacola’	1.50^{g}	1.33^{g}	1.40^{g}	1.09^{h}	1.03^{h}	1.21^{g}
Bermudagrass	1.35^{g}	1.30^{g}	1.71^{f}	1.28^{g}	1.45^{g}	2.04^{e}
Prairie cordgrass	1.33^{g}	1.25^{g}	1.80^{f}	0.90^{h}	1.07^{h}	1.43^{g}
Switchgrass	1.93^{e}	2.44^{c}	2.46^{c}	2.92^{b}	3.19^{a}	2.88^{b}

^{a,b,c,d,e,f,g,h} Means with unlike superscripts within a row differ ($P < 0.05$), according to Scott-Knot separation of means procedure.

Table 3.4. Neutral detergent fiber (NDF) content (%) of forage species grown under varying percentages (100, 45 and 20) of sunlight.

Forage	Cutting 1 % Sunlight			Cutting 2 % Sunlight		
	100	45	20	100	45	20
	----------------------- % neutral detergent fiber --------------------					
Hoary tick clover	35.3^{i}	48.1^{g}	48.5^{g}	38.5^{h}	40.4^{h}	42.5^{h}
Illinois bundleflower	33.9^{i}	36.0^{i}	39.6^{h}	26.7^{k}	40.0^{h}	40.6^{f}
Paniculated tick clover	35.9^{i}	45.4^{g}	46.4^{g}	42.1^{h}	37.3^{i}	34.3^{i}
Red clover	32.6^{j}	39.0^{h}	48.2^{g}	31.5^{g}	27.6^{k}	35.7^{l}
Strawberry clover	63.4^{c}	63.3^{c}	65.4^{c}	46.7^{g}	60.6^{c}	59.8^{c}
White clover	27.2^{k}	27.4^{k}	27.8^{k}	24.2^{l}	20.3^{l}	22.0^{l}
Annual ryegrass	55.1^{e}	53.2^{e}	56.7^{d}	54.0^{e}	55.8^{e}	54.6^{e}
Kentucky bluegrass	47.3^{g}	50.9^{f}	51.6^{f}	45.0^{g}	47.0^{g}	48.3^{g}
Orchardgrass	50.8^{f}	51.6^{f}	53.7^{e}	46.6^{g}	44.1^{g}	46.5^{g}
Redtop	48.7^{g}	51.5^{f}	51.2^{f}	51.8^{f}	50.1^{f}	47.6^{g}
Reed canarygrass	52.6^{e}	59.5^{d}	55.5^{d}	59.9^{d}	60.2^{d}	64.2^{c}
Smooth bromegrass	46.7^{g}	51.6^{f}	50.4^{f}	45.3^{g}	43.7^{h}	46.4^{g}
Timothy	51.8^{f}	55.4^{e}	54.7^{e}	50.3^{f}	47.0^{g}	49.5^{g}
Bahiagrass ‘Argentina’	59.2^{d}	65.8^{b}	58.9^{d}	58.2^{d}	53.3^{e}	55.2^{e}
Bahiagrass ‘Pensacola’	51.0^{f}	57.1^{d}	50.0^{g}	51.2^{f}	53.7^{e}	51.2^{f}
Bahiagrass ‘Tifton-9 Pensacola’	55.7^{d}	56.0^{d}	61.0^{c}	62.8^{c}	60.5^{c}	62.6^{c}
Bermudagrass	67.5^{b}	70.2^{a}	71.7^{a}	59.1^{d}	59.9^{d}	64.6^{b}
Prairie cordgrass	58.0^{d}	60.9^{c}	63.1^{c}	65.4^{b}	64.5^{b}	61.7^{c}
Switchgrass	30.4^{j}	29.5^{j}	32.0^{j}	31.0^{j}	24.5^{l}	32.4^{j}

^{a,b,c,d,e,f,g,h,i,j,k,l}Means with unlike superscripts within a row differ ($P < 0.05$), according to Scott-Knot separation of means procedure.

Table 3.5. Acid detergent fiber (ADF) content (%) of forage species grown under varying percentages (100, 45 and 20) of sunlight.

Forage	Cutting 1 % Sunlight			Cutting 2 % Sunlight		
	100	45	20	100	45	20
	------------------------- % acid detergent fiber --------------------					
Hoary tick clover	26.5^{d}	33.5^{b}	31.6^{b}	25.8^{d}	23.4^{e}	20.6^{e}
Illinois bundleflower	19.0^{f}	20.7^{f}	26.6^{d}	16.3^{g}	19.0^{f}	26.6^{d}
Paniculated tick clover	27.1^{c}	34.2^{a}	32.9^{b}	29.2^{c}	26.3^{d}	28.2^{c}
Red clover	22.8^{e}	27.1^{c}	23.1^{e}	18.6^{g}	18.1^{g}	16.7^{g}
Strawberry clover	31.0^{c}	34.2^{a}	36.5^{a}	30.6^{c}	32.7^{b}	34.4^{b}
White clover	16.0^{c}	19.2^{f}	19.4^{f}	17.8^{g}	17.2^{g}	17.2^{g}
Annual ryegrass	27.2^{c}	29.6^{c}	29.0^{c}	25.9^{d}	30.0^{c}	33.9^{a}
Kentucky bluegrass	24.0^{e}	27.7^{c}	27.2^{c}	21.2^{e}	26.4^{d}	26.7^{d}
Orchardgrass	27.2^{c}	29.5^{c}	30.1^{c}	21.3^{f}	25.8^{d}	27.6^{c}
Redtop	23.0^{e}	28.9^{c}	29.0^{c}	24.0^{e}	28.5^{c}	27.4^{d}
Reed canarygrass	22.0^{e}	24.7^{d}	30.1^{c}	23.2^{e}	27.6^{c}	29.2^{c}
Smooth bromegrass	24.9^{d}	28.8^{c}	29.0^{c}	25.9^{d}	25.8^{d}	26.1^{d}
Timothy	26.6^{d}	27.7^{c}	32.3^{b}	24.2^{e}	26.4^{d}	25.5^{d}
Bahiagrass ‘Argentina’	29.9^{c}	34.6^{a}	31.7^{b}	22.6^{e}	27.9^{c}	24.8^{d}
Bahiagrass ‘Pensacola’	30.1^{c}	34.0^{a}	31.6^{b}	25.2^{d}	28.8^{c}	27.5^{c}
Bahiagrass ‘Tifton-9 Pensacola’	29.7^{c}	31.9^{b}	36.8^{a}	30.4^{c}	32.1^{b}	32.8^{b}
Bermudagrass	32.2^{b}	35.8^{a}	36.8^{a}	26.4^{d}	29.9^{c}	29.7^{c}
Prairie cordgrass	29.0^{c}	33.2^{b}	35.5^{a}	30.8^{c}	34.5^{a}	31.5^{b}
Switchgrass	22.9^{e}	23.3^{e}	22.9^{e}	21.4^{f}	23.0^{e}	20.9^{f}

^{a,b,c,d,e,f,g,} Means with unlike superscripts within a row differ ($P < 0.05$), according to Scott-Knot separation of means procedure.

Table 3.6. Neutral detergent fiber (NDF) digestibility (%) of forage species grown under varying percentages (100, 45 and 20) of sunlight.

Forage	Cutting 1 % Sunlight			Cutting 2 % Sunlight		
	100	45	20	100	45	20
	-------------- % neutral detergent fiber digestibility ------------					
Hoary tick clover	69.0^{b}	76.5^{a}	77.1^{a}	71.4^{b}	69.3^{b}	73.1^{b}
Illinois bundleflower	61.7^{d}	67.0^{c}	72.6^{b}	64.9^{c}	63.0^{c}	74.2^{b}
Paniculated tick clover	69.0^{b}	77.0^{a}	75.6^{a}	75.5^{a}	76.0^{a}	75.6^{a}
Red clover	76.3^{a}	79.5^{a}	76.8^{a}	75.9^{a}	69.7^{b}	70.5^{b}
Strawberry clover	76.1^{a}	76.3^{a}	72.2^{b}	79.1^{a}	78.3^{a}	74.4^{a}
White clover	72.1^{b}	70.9^{b}	71.5^{b}	69.0^{b}	68.7^{b}	71.9^{b}
Annual ryegrass	71.4^{b}	71.5^{b}	72.5^{a}	66.7^{b}	66.7^{b}	71.8^{b}
Kentucky bluegrass	72.6^{b}	77.8^{a}	73.8^{a}	66.5^{b}	72.0^{b}	74.8^{a}
Orchardgrass	74.5^{a}	76.8^{a}	77.9^{a}	72.7^{b}	73.3^{a}	77.4^{a}
Redtop	70.6^{b}	74.0^{a}	74.0^{a}	66.0^{c}	64.2^{c}	71.5^{b}
Reed canarygrass	77.2^{a}	79.6^{a}	74.7^{a}	78.3^{a}	76.9^{a}	74.5^{a}
Smooth bromegrass	70.5^{b}	75.2^{a}	77.7^{a}	69.6^{b}	72.5^{b}	74.5^{a}
Timothy	78.1^{a}	70.4^{b}	77.4^{a}	76.7^{a}	73.3^{a}	74.9^{a}
Bahiagrass 'Argentina'	79.2^{a}	78.1^{a}	72.2^{b}	71.6^{b}	72.4^{b}	67.7^{c}
Bahiagrass 'Pensacola'	76.6^{a}	76.6^{a}	74.3^{a}	66.6^{c}	73.8^{b}	69.1^{b}
Bahiagrass 'Tifton-9 Pensacola'	71.1^{b}	71.1^{b}	74.2^{a}	76.2^{a}	73.5^{a}	75.8^{a}
Bermudagrass	76.9^{a}	76.6^{a}	77.1^{a}	69.4^{b}	69.8^{b}	74.6^{a}
Prairie cordgrass	74.6^{g}	72.1^{g}	74.2^{g}	75.8^{a}	73.5^{d}	74.9^{a}
Switchgrass	72.9^{b}	66.8^{c}	64.6^{c}	70.1^{a}	68.9^{a}	67.8^{a}

^{a,b,c,d} Means with unlike superscripts within a row differ ($P < 0.05$), according to Scott-Knot separation of means procedure.

CHAPTER 4

QUALITY AND QUANTITY EVALUATIONS OF SHADE-GROWN LEGUME FORAGES

Abstract

Seven legumes were grown during the summer-fall of 2000, at the Horticulture and Agroforestry Research Center (39' 01 ' N, 92' 46' W) near New Franklin, MO. The forages were grown in 7.5 L white pots placed on light-colored gravel either under full sunlight, 45% sunlight, or 20% sunlight created by a shade cloth over a rectangular frame. Drip irrigation was applied once a day. Forages were grown in a well-drained potting medium with a complete slow-release fertilizer. Forages were sown and germinated in the greenhouse between May 18 and June 14 and put outside into the shade study area between June 21 and June 30. Forages were harvested in August and October. All forages were analyzed for their content of nitrogen (N), neutral detergent fiber (NDF), acid detergent fiber (ADF), and neutral detergent fiber in situ (NDFIS) digestibility. Three of the legume species had greater ($P < 0.05$) forage production at 45% sunlight than at full sunlight. As the percentage sunlight was decreased, most forage species studied had greater ($P < 0.05$) concentrations of nitrogen and fiber. Fiber digestibility was higher ($P < 0.05$) or unchanged ($P < 0.05$) for most forage species as

sunlight intensity was decreased. Several legume species have the potential to be used in a silvopastoral practice to improve forage productivity and quality as compared to an open pasture environment.

INTRODUCTION

Agroforestry is a collective name given to a land-use system that incorporates woody perennials, herbaceous plants, and/or livestock together. Both ecological and economic benefits are obtained from this kind of system. Agroforestry systems are both stable and sustainable. While agroforestry has been practiced for thousands of years in the tropics, only recently has it been accepted as a science in the temperate zone. The use of trees in an agoforestry system may result in more efficient use of sunlight, moisture, and plant nutrients. A well-designed system should satisfy three basic criteria: productivity, sustainability, and adaptability. Silvopasture is an agroforestry practice used to intensively manage the production of livestock, forages, and trees in a structured practice of planned interactions. These interactions are managed for simultaneous production of wood products, high quality forage, and livestock on an environmentally sustainable basis. Silvopasture can be used to maximize the growth potential from a hectare of land by more fully utilizing the horizontal and vertical growing space.

Photosynthesis is a primary mechanism for increasing useable energy in biological systems. With forage plants, we have a manageable process for capturing solar energy and converting it into useful products, mainly through ruminants which are dependent on forages to meet their nutrient needs (Nelson, 1988). Research performed by Garrett and Kurtz (1983) and Lin (1999) demonstrated an improvement in yield of some forages when grown in shade as compared to full sunlight. Plants respond differently both physiologically and morphologically to shade and vary considerably in regard to their shade tolerance (Bjorkman, 1966; Boardman, 1977). Grasses in general respond to shade by increasing their leaf-area and shoot-to-root ratio to increase light interception (Cooper and Tainton, 1968; Allard et al., 1991; Kephart et al., 1992). Lin et al. (1999) reported that leaves of grasses grown at 50% shade had a leaf blade area that was 13 to 126% larger than leaves grown in full sun. As the shade level increased to 80%, the leaf blade area of most grasses was 19 to 220% greater than for plants grown under full sun.

The effect of shade stress on forage quality also varies. Kephart and Buxton (1993) illustrated that reduction of ambient sunlight to 37 and 70% of full intensity resulted in increased nitrogen concentration, decreased NDF and enhanced in vitro dry matter digestibility, while cell-wall composition remained constant. By knowing how forage quality changes in response to different shade intensity, we can more effectively use and manage forage species in an agroforestry practice. This experiment examined the effects of shade on various legume species to determine biomass production and nutritional quality.

Materials and Methods

Seven legume species were used in this shade study (Table 4.1). Forage species were grown from April to October, 2000. The forages were germinated during the first week in May, 2000, in a greenhouse at the University of Missouri Horticulture and Agroforestry Research Center, New Franklin, Missouri (longitude 92" 46' W; latitude 39" 01' N). Seeds were sown in germination flats filled with Scott's Metro Mix 380 as a soil medium, with one forage species per flat. A water soluble fertilizer (20-20-20) was added, using a hose siphon at 1.72 grams per 15.1 L of water. Seedlings were transplanted to 7.6 cm pots in a greenhouse between May 10 and May 26. On June 21 to June 30, three plants each were transplanted outside into 7.5 L white pots and placed on white gravel. A growth medium (containing a horticulture mix of composted pine bark, medium grade vermiculite, Canadian sphagnum peat moss, horticulture perlite, starter nutrient charge and wetting agent) was used. Water was supplied once per day by a trickle irrigation system controlled by an electronic timer. Forages were harvested on August 7 (cutting 1) and October 17 (cutting 2).

The treatments consisted of three levels of sunlight: 100%, 45% and 20% full sunlight. Differing levels of sunlight were created by placing polypropylene fabric over rectangular frames (5-m wide x 15-m long x 2.5-m high). Three each of the sunlight treatments were randomly assigned to nine frames. Six pots of each plant species were placed in each frame. The pots were placed 50 cm apart between each row. Forages from the six pots were combined for one composite sample before dry weight determination.

Forages were harvested by clipping all material 5 cm above soil level. Clipped material was then dried at 45°C in a forced air oven for a minimum of 72 hours. Dried forage samples were ground in a Wiley mill through a 2-mm screen. Neutral detergent fiber and acid detergent fiber were determined (Goering and Van Soest, 1970) by weighing out a 0.5 to 1.0 g sample into a 600 mL Berzelius beaker. One hundred mL of NDF or ADF solution was added and refluxed for one hour. After refluxing, the samples were filtered, dried overnight in a 105°C oven and reweighed.

Nitrogen (N) was determined by weighing out a 0.05 to 0.1 g sample into a foil pouch and then analyzed using a LECO Model FP-248 Nitrogen Determinator. Neutral detergent fiber in situ digestibility (NDFIS) was determined by weighing out 5.0 g of sample into Dacron mesh bags. The bags were incubated in the rumen of forage-fed cows for 48 hours. The bags were removed, rinsed and dried overnight at 55°C and reweighed. The NDF procedure was then conducted on the dried residue to determine digestibility. The experiment was conducted as a randomized complete block design where shade was used as the main plots and forage species as subplots. Analysis of variance was performed using the general linear model of the Statistical Analysis System. The least significant difference (LSD) program was conducted using a split plot LSD testing for significant differences at the ($P \leq 0.05$) level.

Results

Forage Dry Weight Production

Forage dry weight production was determined as an average weight per pot in grams (g) (Table 4.2). Only one legume species (Korean lespedeza) showed significant decreases ($P<0.05$) in late summer (cutting 2) production between 100% and 45% sunlight. Three legume species (crimson clover, birdsfoot trefoil, and rhizomatous birdsfoot trefoil) increased ($P<0.05$) late summer production when grown in 45% sunlight as compared to full sun. All species produced significantly less ($P<0.05$) biomass when grown at 20% light compared to 45% or full sunlight.

Nitrogen Concentration (N)

Most of the legumes studied had increased nitrogen concentration as a trend when grown under shaded conditions as compared to full sun (Table 4.3). However, not all were statistically significant. Two species (birdsfoot trefoil, (R) birdsfoot trefoil) produced significantly higher ($P<0.05$) levels of N at 45% sun as compared to full sun.

Neutral Detergent Fiber (NDF)

Only two species (alfalfa and crimson clover) showed a significant increase ($P<0.05$) in NDF content when grown under 100% light as compared to 45% light for cutting 1 (Table 4.4). For cutting 2, only birdsfoot trefoil 'Norcen' and crimson clover showed an increase in neutral detergent fiber.

Acid Detergent Fiber (ADF)

Acid detergent fiber (ADF) followed the same pattern as NDF except for Alsike clover which had a significant increase ($P<0.05$) when grown at 100% light as compared to 45% light (Table 4.5).

Neutral Detergent Fiber in situ Digestibility (NDFIS)

For cutting 1, only alfalfa had an increase ($P<0.05$) in NDFIS when grown under 45% light as compared to full sun (Table 4.6). Alsike clover for cutting 1 showed a decrease ($P<0.0.5$) in NDFIS from 45% to full sun. For cutting 2, only birdsfoot trefoil 'Norcen' showed a significant change ($P<0.05$) in NDFIS digestibility from 45% to full sun.

Discussion

Due to the significant ($P<0.05$) decrease in dry matter production at the 20% light level, comparisons for NDF, ADF, and NDFIS were only made between the 100% and 45% light levels. The 45% light level is the light intensity that most closely resembles the available light potential of a well managed silvopasture system. Forage nitrogen content generally increased while changes in NDF, ADF, and NDFIS digestibility were less predictable under shade. Halim et al. (1989) reported that stressful conditions such as drought and shade likely reduces availability of photosynthesis for secondary cell wall development, and stress may increase the percentage of digestible intracellular constituents by reducing cell wall (fiber) content as suggested by Kephart and Buxton (1993). However, this study showed that digestibility over all remained constant with a few legumes having a slight increase or decrease in digestibility as the light level changed. The nitrogen concentration increased overall as the light levels decreased which agrees with previous research by Kephart and Buxton (1993). The overall percent NDF and ADF remained constant as the light levels were changed. Based upon the findings from this study, certain legume species appear to have the potential to be very beneficial in a silvopasture system by providing high quality forage while serving as a source for nitrogen fixation.

Table 4.1. Forage legumes used in 2000 shade study

Species	Scientific Name
Creeping Alfalfa	*Medicago sativa L.*
Alfalfa	*Medicago sativa L.*
Birdsfoot trefoil 'Norcen'	*Lotus corniculatus L.*
Rhizomatous (R) birdsfoot trefoil	*Lotus corniculatus L.*
Alsike clover	*Trifolium hybridum L.*
Korean lespedeza	*Kummerowia stipulacea [Maxim]*.
Crimson clover	*Trifolium incarnatum L.*

Table 4.2. Above ground dry weight of legumes harvested in late spring (cutting 1) and again in late summer (cutting 2) under three light intensities.

Forage Species	Cutting 1 % sunlight			Cutting 2 % sunlight		
	100	45	20	100	45	20
Creeping Alfalfa	9.7[a]	11.5[a]	3.4[b]	11.7[a]	14.8[a]	4.3[b]
Alfalfa	10.3[a]	12.6[a]	3.1[b]	14.5[a]	16.7[a]	4.7[b]
Birdsfoot trefoil 'Norcen'	7.8[a]	7.4[a]	3.7[b]	11.7[b]	23.9[a]	7.2[c]
Rhizomatous (R) birdsfoot trefoil	8.7[a]	6.0[a]	2.7[b]	8.3[b]	13.1[a]	5.3[c]
Alsike clover	14.7[a]	16.0[a]	3.3[b]	16.9[a]	18.8[a]	5.0[b]
Korean lespedeza	24.3[a]	21.0[a]	7.1[b]	25.3[a]	7.8[b]	2.7[c]
Crimson clover	5.0[b]	8.6[a]	2.0[c]	6.5[b]	14.2[a]	1.1[c]

[a,b,c] Means within a row and cutting with unlike superscripts are significantly different ($P < 0.05$). Comparisons were made within cuttings and not between cuttings.

Table 4.3. Nitrogen (%) for legume species grown in 2000 shade study for two cuttings and three light intensities.

Forage Species	Cutting 1 % sunlight			Cutting 2 % sunlight		
	100	45	20	100	45	20
Creeping Alfalfa	3.06[b]	3.67[a]	3.33[a,b]	2.36[a]	2.72[a]	-
Alfalfa	3.31[a]	3.45[a]	3.75[a]	-	-	3.39[a]
Birdsfoot trefoil 'Norcen'	1.61[b]	2.25[a,b]	3.04[a]	3.43[a]	3.55[a]	3.04[a]
Rhizomatous (R) birdsfoot trefoil	1.87[b]	2.25[a,b]	2.98[a]	3.35[a]	3.35[a]	3.14[a]
Alsike clover	3.42[a]	3.38[a]	3.46[a]	-	-	-
Korean lespedeza	2.23[a]	2.61[a]	3.03[a]	3.40[a]	3.61[a]	2.78[a]
Crimson clover	2.66[a]	3.41[a]	3.31[a]	-	-	-

[a,b,c] Means within a row and cutting with unlike superscripts are significantly different ($P < 0.05$). Comparisons were made within cuttings and not between cuttings.

Table 4.4. Neutral detergent fiber (%) for legume species grown in 2000 shade study for two cuttings and three light intensities.

Forage Species	Cutting 1 % sunlight			Cutting 2 % sunlight		
	100	45	20	100	45	20
Creeping Alfalfa	29.6[a]	35.2[a]	35.0[a]	50.3[a]	47.6[a]	41.6[b]
Alfalfa	28.0[b]	36.9[a]	38.0[a]	30.7[a]	32.5[a]	30.7[a]
Birdsfoot trefoil 'Norcen'	32.7[b]	39.6[a,b]	43.3[a]	25.3[b]	37.0[a]	36.2[a]
Rhizomatous (R) birdsfoot trefoil	36.0[a]	39.2[a]	38.3[a]	29.7[a]	31.3[a]	34.9[a]
Alsike clover	27.0[a]	32.2[a]	31.2[a]	-	-	-
Korean lespedeza	38.1[b]	41.0[b]	47.9[a]	48.3[a]	48.7[a]	48.8[a]
Crimson clover	31.8[b]	43.7[a]	40.3[a]	43.0[b]	48.5[a]	50.2[a]

[a,b,c] Means within a row and cutting with unlike superscripts are significantly different ($P < 0.05$). Comparisons were made within cuttings and not between cuttings.

Table 4.5. Acid detergent fiber (%) for legume species grown in 2000 shade study for two cuttings and three light intensities.

Forage Species	Cutting 1 % sunlight			Cutting 2 % sunlight		
	100	45	20	100	45	20
Creeping Alfalfa	22.0[a]	24.0[a]	25.7[a]	36.1[a]	36.6[a]	31.2[b]
Alfalfa	20.7[b]	26.9[a]	28.7[a]	21.1[a]	23.2[a]	24.0[a]
Birdsfoot trefoil ‘Norcen’	24.8[b]	27.0[a,b]	33.0[a]	17.3[b]	25.4[a]	25.4[a]
Rhizomatous (R) birdsfoot trefoil	27.4[a]	30.7[a]	30.4[a]	20.8[a]	22.2[a,b]	24.6[a]
Alsike clover	19.8[b]	23.4[a]	24.3[a]	-	-	-
Korean lespedeza	29.0[b]	30.6[b]	42.7[a]	35.1[a]	36.9[a]	37.8[a]
Crimson clover	19.4[b]	25.8[a]	27.4[a]	29.9[b]	34.9[a]	35.5[a]

[a,b,c] Means within a row and cutting with unlike superscripts are significantly different ($P < 0.05$). Comparisons were made within cuttings and not between cuttings.

Table 4.6. Neutral detergent fiber in situ (%) for legume species grown in 2000 shade study for two cuttings and three light intensities.

Forage Species	Cutting 1 % sunlight			Cutting 2 % sunlight		
	100	45	20	100	45	20
Creeping Alfalfa	80.8[a]	73.3[a,b]	60.8[b]	53.3[b]	56.6[b]	65.1[a]
Alfalfa	60.8[b]	82.7[a]	76.1[a,b]	78.7[a]	80.4[a]	79.7[a]
Birdsfoot trefoil 'Norcen'	76.4[a]	75.3[a]	70.7[a]	85.1[a]	70.0[b]	72.5[b]
Rhizomatous (R) birdsfoot trefoil	72.5[a]	69.3[a]	73.4[a]	77.8[a]	78.1[a]	75.8[a]
Alsike clover	90.6[a]	77.8[b]	78.0[b]	-	-	-
Korean lespedeza	62.7[a]	66.4[a]	61.5[a]	58.7[a]	56.7[a]	-
Crimson clover	80.0[a]	74.1[a]	73.9[a]	56.8[b]	50.7[a]	56.1[a]

[a,b,c] Means within a row and cutting with unlike superscripts are significantly different ($P < 0.05$). Comparisons were made within cuttings and not between cuttings.

CHAPTER 5

ESTABLISHMENT OF A SILVOPASTORAL SYSTEM IN A MISSOURI HARDWOOD FOREST

Abstract

This research was conducted at the University of Missouri Hugo Wurdack Farm located near Cook Station, MO (Crawford County, Section 36, Township 36N, Range 5W). Plots were located on north- or north-east facing slopes. Grazing plots were 132.9 meters on the contour of the slope and 70.1 meters from base of the slope. The experiment was designed as a randomized complete block with five treatments, and five replications of each treatment. The five treatments were: (1) 1.01 hectares thinned forest, planted with selected forages and grazed, (2) 0.51 hectares thinned forest, planted with selected forages and not grazed, (3) 0.51 hectares thinned forest only, with no forage planting and not grazed, (4) 0.51 hectares control forest (no applied management), and (5) 1.01 hectares open pasture. Forage treatments were established on April 4 and 5, 2003, using Kentucky 31 Tall Fescue (*Lolium arundinacea* Schreb.). Red clover (*Trifolium pretense* L.) and 'Marion' lespedeza (*Kummerowia striata* Thunb.) were sown on April 9, 2003. Pelletized lime was applied at the rate of 4,536 kg per hectare for silvopasture plots and 363 kg per hectare for open plots. All treatments received 154 kg per hectare of 0-150-75 fertilizer. The forest thinning that was conducted was a

shelterwood cut. The timber removed was mostly small diameter white oak and post oak with scattered larger diameter black and red oak. The number of trees left per ha following thinning averaged 165. Forages were harvested May 3, 2004 (cutting 1) and again on May 28, 2004 (cutting 2). All forages were analyzed for their content of nitrogen (N), neutral detergent fiber (NDF), and acid detergent fiber (ADF). The silvopasture had a lower NDF and ADF for the May 28 cutting compared to the open pastures.

INTRODUCTION

The state of Missouri has over 5.7 million ha of timber, of which less than 5% is under timber management (personal communication, H.E. Garrett, University of Missouri, Forestry Department). In a Missouri Department of Conservation survey of four rural Missouri counties, it was found that 68% of the woodlands were grazed (Hershey, 1991). Unmanaged forest grazing is destructive to the forest and contributes little forage for grazing animal consumption. This research was designed to evaluate a management system with timber as a long-term investment, and forage production for grazing livestock as a short-term investment. This silvopastoral practice uses Missouri's position as third in the nation in cow-calf production to drive interest in managing timber stands for the simultaneous production of wood products and forage to provide more grazable land and higher quality timber. National projections suggest that land area available for grazing is likely to be reduced due to conversion to other uses, and use of forages for grazing will decrease by 32% (Van Tassell et al., 2001). Thus, new ways are needed to create or better utilize available grazing land. The goal of this project is to develop the technology to better utilize forest resources, especially forages, by incorporating them into a multi-cropping system that is dependent upon improved timber management.

Materials and Methods

Site

This research was conducted at the University of Missouri Hugo Wurdack Farm located near Cook Station, MO (Crawford County, Section 36, Township 36N, Range 5W) and consists of a rolling topography with shallow clay soils. Average annual rainfall is approximately 96 cm. Plots were located on north or north-east facing slopes. The grazing plots were 132.9 meters on the contour of the slope and 70.1 meters from the base of the slope. Plots were established into an existing upland hardwood forest located on the research farm's property. A randomized block design was used with five treatments, and five replications (blocks). The five treatments were: (1) 1.01 hectares thinned forest, planted with select forages and grazed, (2) 0.51 hectares thinned forest, planted with select forages and not grazed, (3) 0.51 hectares thinned forest only, with no forage planting and not grazed, (4) 0.51 hectares control forest (no applied management), and (5) 1.01 hectares open pasture. On silvopasture plots, leaf matter was removed with a prescribed burn to help facilitate sprouting of sown seed.

Trees

The forest thinning that was conducted was a shelterwood cut. The timber removed was mostly small diameter white oak and post oak with scattered larger diameter black and red oak. The average pre-harvest diameters of the white oak and post oak were approximately 20 cm, dominant and co-dominant white oak ranged from 18 to 43 cm; post oak ranged from 18 to 31 cm. The red and black oak averaged 33 cm with the dominant and co-dominant red oak ranging from 23 to 58 cm, and the black oak from

20 to 53 cm. Timber harvesting was conducted as a whole-tree operation, having log and top (crown) removed from the research site. Pre-thin basal area averaged 25.7 m^2ha^{-1} while the residual basal area following thinning was 10.3 m^2ha^{-1}. This residual basal area represented trees left onsite resulting from a crop tree thinning, i.e., dominant and co-dominant trees. The trees that were left as crop trees were mainly pole-size white oaks with a few red oaks, black oaks and walnut.

Soil

Soil samples were taken and tested in the fall of 2002. The average pH of the silvopasture plots was 4.1 and the open plots were 6.0. Based upon these tests, pelletized lime was applied at the rate of 4,536 kg per hectare for the silvopasture plots and 363 kg per hectare for the open plots. Pelletized lime was used because of its faster activation time and higher effect neutralizing material (ENM). All treatments received 154 kg per hectare of 0-150-75 fertilizer. Lime and fertilizer were applied the first two weeks of March 2003 with a pull type fertilizer buggy.

Forages

Treatments with forages were established on April 4 and 5, 2003, using Kentucky 31 Tall Fescue (*Lolium arundinacea* Schreb.) sown at the rate of 36 kg of PLS per hectare. Red clover (*Trifolium pretense* L.) and 'Marion' lespedeza (*Kummerowia striata* Thunb.) were sown on April 9, 2003. Red clover was sown at the rate of 4.5 kg of PLS per hectare, and 'Marion' lespedeza at the rate of 9 kg of PLS per hectare. All seed was sown with a Vicon spreader.

Forage Collection and Processing

Forages were harvested May 3, 2004 (cutting 1) and again on May 28, 2004 (cutting 2). Forages were harvested with a flail chopper, with a cutting strip 76 cm wide by 4.6 m long, clipping all material 5 cm above soil level. A total of 10 strips per plot were taken. Clipped material was then dried at 45°C in a forced air oven for a minimum of 72 hours. Dried forage samples were ground through a Wiley mill using a 2-mm screen. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) content were determined using an Ankom 200 Fiber Analyzer (Ankom Technology, Fairport, NY). Nitrogen (N) was determined by weighing a 0.05 to 0.1 g sub-sample into a foil pouch and then analyzing using a LECO Model FP-248 Nitrogen Determinator.

Results

Nitrogen Concentration

The N content was only significantly ($P<0.05$) higher for the open pasture compared to the silvopasture for the May 3 cutting. This was most likely due to cattle being wintered in this pasture causing a build-up of manure and subsequently greater soil nitrogen levels. The silvopasture plots averaged 1.99% N for the May 3 cutting and 2.09% for the May 28 cutting while the open pastures averaged 2.72% for May 3 and 2.04% for the May 28 cutting.

Neutral Detergent Fiber (NDF)

There was no significant ($P < 0.05$) difference for NDF content between the silvopasture and open pasture for the May 3 cutting. However, for the May 28 cutting, the silvopasture had a significantly ($P < 0.05$) lower NDF than open pastures. The silvopasture plots averaged 51.67% NDF for the May 3 cutting and 56.39% for the May 28 cutting while the open pastures averaged 51.35% for May 3 and 58.56% for the May 28 cutting.

Acid Detergent Fiber (ADF)

There was a significant ($P < 0.05$) difference between silvopasture and open pasture for ADF content with open pasture having less acid detergent fiber for the May 3 cutting. However, for the May 28 cutting the results were the opposite with silvopasture having a lower ADF than the open pasture. The silvopasture plots averaged 32.16% ADF for the May 3 cutting and 36.04% for the May 28 cutting while the open pastures averaged 28.99% for May 3 and 38.51% for the May 28 cutting.

Forage Visual observations

Forage was not harvested the first year, however based upon visual observations, the forage sown under the tree canopy was well established in almost all areas. It was also observed that forage under the tree canopy remained vegetative and growing during the mid- and late-summer whereas the forage in the open pasture became dormant.

Discussion

Silvopasture could be a valuable management tool for cattle producers with wooded acres on their land. With no negative effect on forage quality, silvopasture could allow producers to have summer grazing in a shaded environment, helping to increase grazing time in the heat of summer. Our research found increased nitrogen levels for the May 3 open pasture with all other readings being similar. However, this spike in nitrogen in the open pasture is likely due to the management of the pasture the winter prior.

Silvopasture forages were equal to or greater in nutritional value than open pastures based upon NDF and ADF data. Visual observation led to concluding that silvopasture would make possible extending the grazing time into the summer months for cool season grasses. It also would allow the producer to have long- and short-term income from the same parcel of land.

Table 5.1 Quality analysis of forages from Silvopasture Project at Wurdack Farm, 2004

	Date	%N	%Neutral Detergent Fiber	%Acid Detergent Fiber
Silvopasture	3-May	1.99[b]	51.67[c]	32.16[c]
Silvopasture	28-May	2.09[b]	56.39[b]	36.04[b]
Open	3-May	2.72[a]	51.35[c]	28.99[d]
Open	28-May	2.04[b]	58.56[a]	38.51[a]

CHAPTER 6

Summary and Conclusions

Silvopasture uses Missouri's position as third in the nation in cow-calf production to drive interest in managing timber stands for the simultaneous production of wood products and forage to provide more grazable land. National projections suggest that land area available for grazing is likely to be reduced due to conversion to other uses, and use of forages for grazing will decrease by 32% (Van Tassell et al., 2001). Missouri currently has around 14 million acres of forested land with less than 5% of this forested area under some kind of management. Thus, new ways are needed to create or better use available grazing land. With such a large industry, most cattle operations are unprofitable. The average cattle operation has a net operating margin of -$23.75 per head/year (Short, 2001). The introduction of a well-planned forestry system has been demonstrated to be beneficial to both the pasture and cattle, and improves the bottom line by also increasing the value of the timber grown. Also, the diversification of multiple incomes from the same parcel of land serves as an excellent risk hedge. Some landowners who have established a silvopasture practice have received a pasture rental rate that is as much as 33% higher than for open pasture (Godsey, et al. 2006). Also, for producers raising grass-fed beef, there is an additional benefit to a silvopasture system. Kallenbach (2009) demonstrated that steers finished in a silvopasture had a greater average daily gain and larger ribeye area as compared to steers finished on open pastures.

Kallenbach (2008) showed that cows grazing on silvopasture during the winter months lost approximately 10% less weight, which in turn reduced the amount of feed supplement needed by each cow by 12%. Most of the benefits are likely due to the windbreak effect of the trees, providing a more comfortable environment by reducing the amount of energy needed by the cow to stay warm. Kallenbach also saw two benefits from silvopasture during the summer months. First, there was a 12% decrease in calving difficulty and heavier weaning weights of calves were observed. Second, there was a 15% increase in the amount of forage production of cool-season grasses during the months of July and August in the silvopastures compared to the open pastures.

The research presented in this thesis has identified forage species that have the ability to produce (yield) at comparable levels under reduced light as compared to open conditions, making them excellent candidates for incorporation into a silvopasture system. Furthermore, by incorporating shade tolerant forages into a well designed silvopasture system, multiple crops can be produced, risk is reduced, and increased production can be realized which could be the difference between profit and loss for family farms with small cattle operations in times of weak economies.

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