Forage Production and Nutritive Value in a Temperate Appalachian Silvopasture

by

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Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Crop and Soil Environmental Sciences

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Date of Defense: May 10, 2004
Blacksburg, VA

Key Words: Silvopasture, Microclimate, Tall fescue, Honey locust, and Black walnut

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(ABSTRACT)

Integrating trees into pasture may be an effective management tool to improve water, nutrient, and light allocation and increase total system productivity in Appalachia. We tested this hypothesis in a silvopasture near Blacksburg, VA. In 1995, black walnut and honey locust trees were planted within plots (r=3) of predominantly tall fescue pasture. Across a 12% slope, trees were planted to create treatments of low, medium, and high tree densities at shoulder, mid, and toe slope positions within plots of honey locust and black walnut. Sampling sites (n=54) under tree density and slope position combinations were harvested May to October at 35-d intervals in 2002 and 2003 for determination of yield and nutritive value characteristics. Soil surface temperature, forage canopy temperature, soil moisture, and photosynthetically active radiation were measured to determine forage responses to field treatments as functions of resource allocation.

Tree density had the greatest effect on forage production and nutritive value. Across both years, yields were 16% greater ($P=0.0006$) at medium density (6130 kg/ha) compared to forage mass at low (5280 kg/ha)) and high density (4970 kg/ha, SE=130). Increasing tree density did not affect ($P\geq 0.2$) ADF, CP, P, K, and Mg levels, but reduced ($P<0.001$) NDF and TNC, and increased ($P<0.0001$) ADL and Ca. Elevated soil surface and forage canopy temperatures limited forage production and nutritive value at low density, while low light levels were the limiting factor at high density. Moderating forage microclimate with appropriately spaced trees is an effective way to improve forage production in temperate pastures.

ACKNOWLEDGEMENTS

The author expresses sincere gratitude and appreciation to all those who have shared their time, thoughts, and energy to help make this project a success.

Many thanks are first extended to committee members John H. Fike, Jim R. Mckenna, Jim A. Burger, Charlie M. Feldhake, and Chris D. Teutsch.

Many many thanks to Dr. Fike for all his patience, guidance, and good humor -- and especially for the many hours spent editing and reviewing this thesis. Special thanks go to Dr. Burger for his sound advice, awesome politics, and for making science inspiring again. For assistance with microclimate measurements and PAR data, much thanks is due to Dr. Feldhake. And of course, the author is most grateful to Dr. Mckenna for his continued support and encouragement despite the author's lack of fashion sense.

Mountains of thank yous go to the Kentland Farm Crew: Jon Wooge, Tommy Sowers, Brooks Saville, Chad Keith, and Forrest Davis. Not only did they make this project possible and largely contribute to its success, but they made every day in the field the best ever, and they let the author drive tractors and happily fixed everything she broke.

For crucial assistance with NIRS and TNC, many thanks go to Bob Arnold and Jim Fedders at USDA ARS in Beaver, WV.

For lab and field assistance, hugs and thanks go to Chandra Bowden and Amanda Beier who also tolerated the author's daily diatribes on pop culture that lasted the duration of the truck ride to and from the field. Special appreciation goes to Amanda Shuck, without whose lab work and grinding of samples the author would not have stayed sane. And thank you to Dave Mitchem for lab assistance and for measuring all the trees.

For being strong and keeping everyone organized and in-line, special thanks are due to Cathy Atkinson.

If it is possible to thank a plant, the author would like to recognize yerba maté (*Ilex paraguariensi)* as the greatest tea on earth.

The author’s family, Mom, Dad, Julia, and Greg, deserves many thanks, kicks to the head (the good kind), and all the love in the world for being crazy, strong, hilarious, and unbelievably amazing.

Thanks a billion times and more to Dave Guyot. He knows why.

DEDICATION

For my sister, Julia

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction and Overall Objectives

Introduction

As demand for food and fiber increases, today's farms must deal with diminishing energy reserves, soil loss in excess of regeneration, and low farm income resulting from depressed commodity prices and government subsidies as a result of the overproduction of monocultures (Lockeretz, 1998; Olson et al., 2000). Farms must increase production without increasing costs in order to survive in today's unreliable, erratic market. To meet this goal, agricultural research institutes continue to strive for higher and higher productivity levels by developing and improving agricultural technology including genetics, machinery, fertilization, and pesticides (Heitschmidt et al., 1996; Heitschmidt et al., 2001). However, such solutions may not address the needs for long-term productivity or sustainability of our production systems (Krueger, 1981; Cameron et al., 1991, Burger, 1994) and in some cases may mask or even contribute to environmental contamination and degradation resulting from agrochemical pollution, soil erosion, pest problems, and loss of biological diversity (Dangerfield and Harwell, 1990; Workman et al., 2003). In short, the primary means of increased productivity often comes with high environmental cost and may not be sustainable (Olson et al., 2000).

Sustainable systems should be managed to optimize positive biological interactions between crop components and emphasize species diversity rather than only crop yield (Matson et al., 1997). Incorporating trees into agricultural systems helps those systems fulfill the criteria for sustainability while simultaneously reducing both on- and off-site degradation (Schaefer, 1989; Rietveld and Francis, 2000). Agroforestry does exactly that -- it combines trees, crops, and livestock to create sustainable food and fiber production systems.

Agroforests are basically planned, managed agro-ecosystems (Sharrow, 1997). More specifically, agroforestry is a land use practice of intensive management that optimizes the benefits (physical, biological, ecological, economic, and social) from the biophysical interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock (MacDicken and Vergara, 1990; Garrett et al., 1991; Leakey, 1996). A principal aim of agroforestry is to create interactions between woody perennials, herbaceous crops or pastures, and their biotic and abiotic environments which increase the overall productivity and efficiency of the land use system and its sustainability (Schroth, 1995). Unlike conventional agriculture or forestry, the focus of agroforestry is on the interactions among components rather than on each individual component (Sharrow, 1997). Essentially, agroforestry uses specific structural and functional characteristics of natural ecosystems to create a truly sustainable agro-ecosystem (Winterbottom and Hazlewood, 1987; Vandermeer, 1995). Agroforestry mimics the large patch scale dynamics and successional progression of a natural ecosystem (Ong and Leakey, 1999). Hence, agroforestry “follows nature” and is a sustainable way to manage and protect our land resources.

In the southern United States, 20 million acres of row crop production are on marginal land (Dangerfield and Harwell, 1990). Marginal land has low profit potential when row cropped and is highly erosive. This marginal land can be protected when converted to pasture or forests (Dangerfield and Harwell, 1990). However, the most efficient and economical production schemes on marginal land in the southern United States are tree-pasture combinations, also known as silvopastures (Zinkhan and Mercer, 1997).

Silvopastoralism intentionally integrates trees, forage crops, and livestock into a structural practice of planned interactions (Clason and Sharrow, 2000). It offers farmers and pastoralists the advantage of crop diversification, fuelwood and fodder production, erosion control, and increased soil fertility (Belsky et al., 1993). Additionally, silvopastures protect biodiversity, create wildlife habitat, improve soil and water quality, and sequester high amounts of carbon (McGregor et al., 1999). Hence, silvopasture systems can successfully utilize marginal lands while both protecting environmental resources and generating income for producers. Silvopastures can be highly productive but are complex to design and manage. Although, many researchers have found positive forage production responses to trees or shade (Smith, 1942; Garrett and Kurtz, 1983; Gyenge et al., 2001; Burner and Brauer, 2003), very little research has been conducted in the Appalachian Region. Because design and management of silvopasture systems will vary by location, it is important to test these systems on a regional scale before making widespread recommendations to farmers.

Therefore, we designed a study to accomplish the following objectives.

Objectives

Our hypothesis is that incorporating trees into pasture benefits resource capture for cool season forage production and nutritive value in a temperate Appalachian silvopasture. The objectives used to test this hypothesis are:

1) To determine what is “known” and “unknown” with regard to silvopasture systems, especially within the temperate zones
2) To determine what research is needed to fill gaps in our current knowledge
3) To measure cool-season forage production and nutritive value response to field treatments: tree species, tree density, and slope position
4) To measure microclimate responses to field treatments: tree species, tree density, and slope position
5) To determine the relationships between microclimate modification and forage production
6) To determine the relationships between microclimate modification and nutritive value
7) To relate field treatments to forage production and nutritive value as a function of specific microclimatic factors
8) To describe the management implications of the data

Chapter 2: Review of Literature

Objectives

1) To establish what is "known" and "unknown" with regard to forage production, nutritive value, and management of silvopasture systems, especially within the temperate zones;
2) Determine what research is needed to fill the "gap" in our current knowledge.

Follow Nature

> One of the lessons of history is the fact that whenever civilization mines its soil to enjoy short-term prosperity, that civilization suffers long-term famine and poverty (Kirschenmann, 1988, p. 45).

Agriculture faces a crisis. As demand for food and fiber increases, today's farms must deal with diminishing energy reserves, soil loss in excess of regeneration, and low farm income resulting from depressed commodity prices and government subsidies as a result of the overproduction of monocultures (Lockeretz, 1998; Olson et al., 2000). Farms must increase production without increasing costs in order to survive in today's unreliable, erratic market. To meet this goal, agricultural research institutes continue to strive for higher and higher productivity levels by developing and improving agricultural technology including genetics, machinery, fertilization, and pesticides (Heitschmidt et al., 1996; Heitschmidt et al., 2001). However, such solutions may not address the needs for long-term productivity or sustainability of our production systems (Krueger, 1981; Cameron et al., 1991, Burger, 1994) and in some cases may mask or even contribute to environmental contamination and degradation resulting from agrochemical pollution, soil erosion, pest problems, and loss of biological diversity (Dangerfield and Harwell, 1990; Workman et al., 2003). In short, the primary means of increased productivity often comes with high environmental cost and may not be sustainable (Olson et al., 2000).

To address this situation, the 2002 Farm Bill places emphasis on increasing the United State's food security by maintaining sufficient yields in sustainable production systems (Workman et al., 2003). In an agricultural context, a sustainable system is:

> One that, over the long term, enhances environmental quality and the resource base on which agriculture depends: provides for basic human food and fiber needs, is economically viable; and enhances the quality of life for farmers and society as a whole (American Society of Agronomy, 1989).

In other words, Sustainability = Production + Conservation (Young, 1990). General strategies for designing sustainable agricultural systems include (Hodges, 1982; Harwood, 1985; Francis et al, 1986; Madden, 1987; Francis and King, 1988; Schaefer, 1989; Crews et al., 1991; Lockeretz, 1998):

1) Diversification of plant species to enhance farm biological and economic stability
2) Use of plants/animals well suited to farm soil and climate
3) Preference for farm-generated resources over purchased-goods
4) Tightening of nutrient cycles
5) Management of livestock at low densities; herd size appropriately scaled to farm size
6) Soil conservation and improvement practices including cover crops and living mulches
7) Rotations that include deep-rooted plants to utilize nutrients deep in the soil profile
8) Enhancement of conditions for controlling weeds, pests, and diseases; chemical application used as a very last resort
9) Controlled use of livestock manure/legumes to replenish nutrient losses
10) Creation of an overall net-positive effect on the environment (McDonough and Braungart, 2002).

These strategies, based on naturally occurring ecosystems, are economically viable, socially acceptable, and biologically sound (Wood, 1990). However, sustainable agriculture is considered to be more of a management philosophy than a method of operation (Heitschmidt et al., 1996). Ideally, sustainable systems should be managed to optimize positive biological interactions between crop components and emphasize species diversity rather than only crop yield (Matson et al., 1997). Incorporating trees into agricultural systems helps those systems fulfill the criteria for sustainability while simultaneously reducing both on- and off-site degradation (Schaefer, 1989; Rietveld and Francis, 2000). Agroforestry does exactly that -- it combines trees, crops, and livestock to create sustainable food and fiber production systems.

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The five main agroforestry practices include riparian buffer strips, windbreaks, alley cropping, forest farming, and silvopasture. Riparian buffer strips are zones along waterways (i.e. streams, creeks, rivers, lakes, wetlands), made up of permanent vegetation including trees, shrubs, and grasses (Gold et al., 2000) that slow water flow, reduce erosion, and filter out nutrients and contaminants. Windbreaks are permanent areas or rows of trees and shrubs that are managed, as part of a livestock or crop production system, to reduce wind speed and prevent wind damage from soil erosion or crop lodging (Gold et al., 2000). With alley cropping systems, crops such as grains, cotton, or forage are grown between rows of trees (Gold et al., 2000), while forest farming utilizes the forest floor for production of high-value crops such as gensing, shiitake, and goldenseal (Gold et al., 2000). Silvopasture systems are even more complex, combining livestock, forage, and tree crops on the same unit of land (Gold et al., 2000). In each system, trees can be used and managed for both their protective and productive purposes.

Agroforestry: An Ancient Practice

Agroforestry has been practiced for thousands of years across the globe (Casey, 1983; Coomes, 1991). Evidence of the use of agroforestry practices dates back to ancient China and the practice was common throughout the Mediterranean and South America (Nair, 1993). Agroforestry played a prominent role in subsistence farming, and continues to do so throughout tropical, temperate, and arid climates. The ability for agroforestry systems to provide food and fiber, while simultaneously protecting the resource base, may be the reason for its continued use throughout history.

Agroforestry is also part of North American history. Native Americans managed both their forests and their pastures to encourage specific, complex tree-crop-animal interactions

(King, 1987). They grazed their buffalo on fire-managed oak savannas and grew food crops under the forest canopy. When Europeans arrived on North American soil, they too practiced agroforestry, allowing their cattle to graze the native vegetation of the forests within a silvopastoral context (Russell, 1982; Clason, 1995).

Despite the historical use of trees in temperate agricultural systems, agroforestry practices are most widely utilized throughout the tropics today (Peñaloza et al., 1985; Nair, 1990). This discrepancy is most likely explained by the poorer soils and harsher climates of the tropics that demand more conservation-oriented agricultural practices. As land degradation continues in developed, temperate-climate countries, agroforestry adoption will most likely increase in those areas (Cameron et al., 1991: Nair, 1993; Garrett et al., 1994; Sanchez, 1995; Kass et al., 1999). Common tropical agroforestry practices of the past and of the present include shifting cultivation, improved fallows, multilayer tree gardens, intercropping systems, taungya (cultivation of food crops between tree seedlings planted as a timber plantation), silvopastoral systems, windbreaks, and the use of multipurpose trees on farmland for fuel or fodder (Nair, 1990).

Today, agroforestry combines traditional, indigenous knowledge with modern agricultural knowledge to create sustainable ways to not only manage degraded lands, but all lands under production-oriented management (Sanchez 1995; Matson et al., 1997; Eibl et al., 2000). Compared to monocultural cropping systems, agroforestry systems patterned after natural ecosystems have the potential to (Young, 1989; Cameron et al., 1991; Johnson 1995; Sanchez, 1995; Schroth, 1995; McGregor et al., 1999; Huang et al. 2002; Santoso et al 2001; Clason and Sharrow 2000):

(a) Increase total system productivity;
(b) Increase efficiency in use of solar radiation;

(c) Increase soil organic matter;
(d) Increase biodiversity in agricultural landscapes;
(e) Decrease agriculturally derived contaminants in riparian zones;
(f) Reduce soil erosion;
(g) Increase nutrient retention via greater exploitation of soil profiles;
(h) Improve economic efficiency;
(i) Increase utilization of both above- and below-ground resources;
(j) Improve recycling of nutrients and organic matter
(k) Improve soil chemical, physical, and biological characteristics, reducing use of chemical fertilizers;
(l) Improve infiltration of rainfall;
(m) Decrease weed competition;
(n) Enhance biological regulation of major insect problems;
(o) Increase carbon storage and sequestration;
(p) Improve microclimate conditions;
(q) Rehabilitate degraded land;

These characteristics make agroforestry systems appropriate for areas affected by or prone to environmental degradation.

Combining trees with traditional cropping practices can increase biological diversity and may improve system sustainability by integrating both protective and productive land use practices (Lin et al. 1999; Schroth 1995; Stoney and Bratamihardja, 1990; Leakey, 1998). Although specific design and management of agroforestry systems differ across climatic regions, soil types, and socio-cultural beliefs, history has shown they have potential on a global scale.

Resource Sharing Concepts in Agroforestry Systems

An aim of agroforestry is enhancement of plant capture of soil moisture, solar radiation, and nutrients (Yunusa et al., 1995). The biological interactions between the crop components (i.e. trees, crops, and livestock) are of primary importance within agroforestry systems, and require challenging, yet highly rewarding management strategies not currently employed in traditional monoculture systems (Lin et al., 1999).

Agroforestry systems differ across the globe, but they are universally driven by the general concepts of multi-dimensional (above- and below-ground) resource sharing and utilization among and between crop components (Buck 1986; Ong et al. 1991). Temporal and spatial complementarity of resource capture by trees and crops in an agroforestry system is a major determinant of the ability of the system to improve crop yields and overall productivity (Cannell et al., 1996; Ong and Black, 1995).

The production relationships existing between crop components can be competitive, supplementary, and complementary (Buck, 1986; Kurtz, 2000). These relationships result from competitive partitioning, competitive exclusion, and facilitation (Ong et al. 1991; Nair, 1993). Researchers agree that integrating trees with cropping systems is beneficial only when the trees acquire resources of water, light, and nutrients that the crops otherwise would not (Cannell et al., 1996; Sharrow, 1997; Samra et al., 1999). In general, competitive partitioning is the basis for overyielding which results in production per land area above that of a monoculture (Willey, 1995; Kurtz, 2000).

Sustainability in any agroforestry system, regardless of the level of complementarity, can only be achieved if the combined rate of resource uptake by trees and crops does not exceed the rate of resource supply (Livesley et al., 2002). Hence, the greatest opportunity for agroforestry practices is where resources are currently under-utilized (Ong and Leakey, 1999).

Silvopasture

In the southern United States, 20 million acres of row crop production are on marginal land (Dangerfield and Harwell, 1990). Marginal land has low profit potential when row cropped, and is highly erosive. The Soil Conservation Service states that non-forest marginal land can be protected when converted to pasture or forests (Dangerfield and Harwell, 1990). Grassland and pasture-based livestock production account for about one-quarter of the land use and most of the agricultural acreage in the Appalachian Region (Humphreys, 1997). However, the most efficient and economical production schemes on marginal land in the southern United States are tree-crop and tree-pasture combinations, also known as silvopastures (Zinkhan and Mercer, 1997).

Silvopasture is the most prevalent form of agroforestry practiced in the temperate United States and Canada (Clason and Sharrow, 2000). Approximately 25 percent of all US forest land, primarily in the western states, is grazed by livestock (Sharrow, 1997). Silvopastoralism intentionally integrates trees, forage crops, and livestock into a structural practice of planned interactions (Clason and Sharrow, 2000). It offers farmers and pastoralists the advantage of crop diversification, fuelwood and fodder production, erosion control, and increased soil fertility (Belsky et al., 1993). Additionally, silvopastures protect biodiversity, create wildlife habitat, improve soil and water quality, and sequester high amounts of carbon (McGregor et al., 1999; Clason and Sharrow, 2000). Hence, silvopasture systems can successfully utilize marginal lands while both protecting environmental resources and generating income for producers.

The Appalachian region, where preliminary research shows great potential for silvopasture systems (Buergler et al., 2003), contains the headwaters of most major rivers of the Eastern USA, making this area particularly appropriate for implementing soil and water conservation practices in the form of silvopasture (Feldhake and Edwards, 1992; Zinkhan and Mercer, 1997).

Silvopastures can be highly productive but are complex to design and manage due to the dynamics of the tree-forage-animal interface. The fundamental purpose for establishing silvopastoral systems is to maximize productivity by enhancing positive interactions between plants while avoiding plant-to-plant competition (Mou et al., 1997). Development of guidelines for managing animal, forage, and tree crops will require greater knowledge regarding three-way interactions. Because design and management of silvopasture systems will vary by location, it is important to test these systems on a regional scale before making widespread recommendations to farmers.

Influence of Trees and Shade on Forage Production

Forage production responses under trees are highly dependent on many variables including climate, site productivity, management practices, and the dynamics of above- and below-ground competition (Krueger, 1981).

Trees have been found to increase, rather than decrease, understory production in temperate, tropical, and arid climates (Tiedemann and Klemmedson, 1977; Wilson et al., 1986; Stuart-Hill et al., 1987). A large body of literature details the influence of trees, shade, or both on forage production. Reported forage production responses to trees or shade are positive (Smith, 1942; Holland, 1980; Garrett and Kurtz, 1983a; Frost and McDougald, 1989; Ratliff, 1991; Belsky et al., 1993; Wild et al., 1993; Wilson, 1998, Gyenge et al., 2001; Burner and Brauer, 2003), neutral (Hart et al., 1970; Mills 1998; Lin et al. 1999; Platis and Papanastasis 2003), or negative (Lewis et al., 1983; Kephart et al., 1992; Wall et al., 1997; Lin et al. 1999; Devkota et al., 2000).

Many researchers and farmers have observed improved herbaceous production under moderate shade. In the United States, Neel (1939) reported increased Kentucky bluegrass (Poa pratensis) yield under black walnut (Juglans nigra L.) in a Tennessee pasture. In southeast Ohio, Smith (1942) found increased forage yield under mature black walnut and black locust (Robinia pseudoacacia L.) trees when compared to adjacent treeless areas in low-producing pastures. The study began in 1939 with below average rainfall, and concluded in 1940. In 1939, forage yields were 41% greater under black walnut (1820 vs. 1290 kg/ha) and 24% greater under black locust compared to treeless check plots (1410 vs. 1150 kg/ha). In 1940, forage yields were 33% greater under black walnut (1920 vs. 1450 kg/ha) and only 2% greater under black locust compared to check plots (1960 vs. 1930 kg/ha).

Forty years later, Garrett and Kurtz (1983a) found one-third greater production of tall fescue (*Festuca arundinacea*) under black walnut trees compared to open pasture in Missouri. In Texas, Blair et al. (1983), while examining the effects of shade on deer browse (*Cornus florida, Ilex vomitoria, Lonicera japonica*), observed that all species of plants in moderate shade were more vigorous than those in deep shade or full sunlight.

In central California, annual herbaceous production was 15-100% greater under scattered oaks than in the open grasslands of the Sierra Nevada foothills. Forage production was 1000 kg/ha greater beneath blue oak (*Quercus douglassi*) and interior live oak (*Quercus wislizenii*) canopies than in the open grassland; and 500 kg/ha greater beneath digger pine (*Pinus sabiniana*) canopies (Holland, 1980; Frost and McDougald, 1989). A later study concurred that blue oaks could increase peak standing crops, and that forage species of later successional stages are more common under trees (Ratliff et al., 1991).

Improved production under trees in the Sierra Nevada foothills can be attributed to the more favorable, moderated soil temperatures and improved soil moisture conservation in the shade. In this region, death or removal of trees has resulted in a gradual decline in annual herbaceous production and led to herbage production comparable to that in the less productive open grassland (Holland, 1980). Similarly in Chile, several studies reported decreased herbage production when tree cover of *Acacia caven* was partially or totally reduced (Ovalle et al., 1989).

Even single trees may also improve understory productivity (Holland 1980; Weltzin and Coughenour, 1990). On a Kenyan savanna, aboveground net primary productivity (ANPP) was greater inside canopy zones of *Acacia totilis* (leguminous) and *Adansonia digitata* (Baobab) when compared to the open grassland (Belsky et al., 1989; 1993).

If shade reduces production, that reduction is generally more profound for C4 grasses compared to C3 grasses even though morphological responses to shade are similar in both species (Kephart et al., 1992). However, forage response to shade or trees varies depending on environmental and management factors, and many researchers have found improved forage production of C4 grasses under shade or trees. In Australia, pasture quality measured as percent green leaf and percent of N in herbage of green panic (*Panicum maximum* var. trichoglume) tended to be higher in the tree plots, especially under *Eucalyptus argophloia*, than in the open pasture (Wilson, 1998). Wilson et al. (1990) found a 35% increase in accumulated dry matter of bahia grass (*Paspalum notatum*) pasture under trees compared with open pasture in south Queensland. Similarly, Wild et al. (1993) found that dry matter and nitrogen yields of bahia grass increased by about 40% under the 55% light intensity from the canopy of an 8-year old plantation of *E.grandis* in the humid coastal strip of subtropical south-east Queensland.

In the tropics, herbage yield often declines as pastures age. This process is commonly referred to as “rundown” or “ageing,” and results from low nutrient availability, decreased soil nitrogen levels, reduced nitrogen mineralization, and loss of organic matter. However, aging green panic pastures have shown positive productivity responses to partial shading (Myers and Robbins, 1991). Moderate shade improved forage production on N deficient sites in Hawaii

(Eriksen and Whitney, 1981). In India, planting *Bauhinia purpurea* and *Albizia lebbek* increased pasture biomass on marginal lands in the Doon Valley (Vishwanatham et al., 1999). In Australia, buffalo grass (Stenotaphrum secundatum), carpet grass (Axonopus compressus), and kikuyu grass (*Pennisetum clandestinum*), grown in pots, had higher yields under shade cloth than in full sun (Samarakoon et al., 1990). Buffalo and mat grass had increased yields with up to 68% shading and kikuyu grass increased in yield up to 42% shading.

In the southeastern United States, Johnson et al. (1994) examined the effects of increasing shade on rhizome peanut (*Arachis glabrata* Benth.), a warm season legume. Rhizoma peanut was grown at 54, 78, and 100% photosynthetic photon flux density. In two of three seasons, shaded plants maintained yields greater than 70 and 90% of those in unshaded controls. The authors concluded that rhizome peanut could provide quality pasture in moderately shaded environments characteristic of pine plantations (Johnson et al., 1994).

One goal of researchers is to select suitable forage species adapted to shaded environments. Failure of tropical grasses to persist in shaded environments has often been associated with their growth habit. Wong and Stur (1996) investigated the hypothesis that a prostrate growth habit confers better adaptive responses to shading than an erect growth habit. Paspalum wettsteinii (prostrate) and Paspalum malacophyllum (erect), two shade tolerant grasses, were grown in simulated swards at light levels of 100, 50, and 20% full sunlight. Unexpectedly, P.wettsteinii allocated high amounts of resources to root growth and failed to persist. These results suggest that growth habit (prostrate vs. erect) is not a reliable criterion for forage selection for shaded environments. The authors reported that morphophysiological adaptation to defoliation in shade is critical when selecting for persistence in shaded environments.

Many studies have used shade cloth and/or sward boxes to examine the effects of shade on forages. Such studies do not account for below-ground root and water interactions and natural sunflecking dynamics of irradiance under tree canopies. However, these studies can be useful for testing morphological and physiological responses to shade, or for screening forage species for field studies. Lin et al. (1999) used shade cloth to create treatments of 0, 50, and 80% shade in order to select shade-adapted warm- and cool-season species. Lower irradiance negatively affected forage production of warm-season species. Under 50% shade, yields of warm season grasses were reduced by 35% or more, while yields of cool season grasses, including Kentucky bluegrass (Poa pratensis), orchardgrass (Dactylis glomerata), and tall fescue (Festuca arundinacea), were not affected.

Influence of Trees and Shade on Forage Nutritive Value

Nutritive value can be influenced by the presence of trees in silvopastures via morphological and physiological adaptations (Eriksen and Whitney, 1981; Allard et al., 1991, Kephart et al., 1992; Kephart and Buxton, 1993; Sharrow, 1999), in addition to changes in botanical composition (Brooks, 1951; Burner and Brauer, 2003) in response to environmental conditions. Increased nutritive value or digestibility in response to trees and/or shade has been reported for both cool- (Krueger, 1981; Garrett and Kurtz, 1983a) and warm-season species (Eriksen and Whitney, 1981).

As with most environmental responses, shade may have a neutral effect on nutritive value. Dry matter partitioning of tall fescue growing in pots under three photosynthetic photon flux density (PPFD) treatments showed that shoot:root ratio and leaf area ratio were higher under low irradiance (midday PPFD 600 micromoles*m^{-2}*s^{-1}) (Allard et al., 1991). This study concluded that the leaf blade ratio (leaf area per plant dry weight) increases under shade with no influence on forage nutritive value.

Overall, any reductions in silvopasture productivity are often balanced with an increase in nutritive value (Kephart and Buxton, 1993; Burner and Brauer, 2003).

Digestibility and Fibers

Increases in forage fiber constituents and concomitant decrease in digestibility with increases in temperature are well documented in greenhouse and growth chamber studies (Masuda, 1977; Wilson and Minson, 1980; Akin and Burdick, 1981; Fales, 1986; Akin et al., 1987). Several studies have also examined the effects of shade on nutritive value; however it is important to note they are usually confounded because shade typically decreases temperatures.

Shade and shading effects (i.e. reduced forage canopy temperatures) may improve forage digestibility (Sharrow, 1999). In Missouri, spring-growth of tall fescue under black walnut was 11% more digestible than tall fescue grown in the open pasture (Garrett and Kurtz, 1983a). Samarakoon et al. (1990) found dry matter digestibility was greater in warm season grasses under shade cloth compared to full sun.

High temperatures can increase fiber concentration in forages. In a greenhouse experiment, NDF concentrations increased and digestibility decreased with increasing temperatures (Fales, 1986). Shading, however, can decrease fiber concentration in both C3 and C4 grasses, most likely as a result of temperature modification (Kephart and Buxton, 1993).

In silvopastures, differences in botanical composition (higher amount of warm season species under low shade vs. higher amount of cool season species in high shade) may account for differences in fiber concentrations among shade treatments in some cases. Kephart and Buxton

(1993) found that C4 species had 18% greater NDF concentrations in leaf blades and in total herbage than did the C3 species, probably due to differences associated with kranz anatomy. Brooks (1951) reported that under black walnut the presence of grasses of superior nutritive value increased compared to adjacent open pastures. Additionally, Brooks observed that under black walnut there was a decrease in common “poor land” grasses such as broomsedge (*Andropogon virginicus* L.) and poverty grass (*Danthonian spicata* L.) compared to adjacent open pastures.

Lignin and ash

Lignin is well known to limit forage digestibility (Akin et al, 1987; Ball et al., 2002). However, it is not always a good predictor of digestibility (Ford et al., 1978; Fales, 1986). Lewis et al. (1983) found a slight increase in lignin in warm season forages grown under slash pine. Cell-wall lignin increased in tall fescue grown under shade, but was unaffected in the C4 species under shade (Kephart and Buxton, 1993). Samarakoon et al. (1990) found an increase in lignin for warm season grasses grown under varying levels of shade cloth. Ash was higher in shaded forages compared to the open meadow (McEwen and Dietz, 1965).

TNC

When temperature, nitrogen, or moisture limit forage growth, soluble carbohydrate concentrations may increase (Blaser et al., 1966). The effects of trees (and their shade) on soil and air temperature play a vital role in forage production because the photosynthesis-respiration relationship depends largely on ambient temperature and influences the accumulation of carbohydrates and plant persistence (Menezes et al., 2002). Additionally, not only the amount of light, but the quality of light reaching the understory influences plant morphology and carbohydrate partitioning (Frank and Hoffman, 1994). Samarakoon et al. (1990) and Belesky et al. (personal communication, 2004) found that TNC decreased consistently with shade. These findings support earlier findings of an increase in carbohydrates as light intensity increased (Alberda, 1965).

Crude Protein

Crude protein is frequently greater in shaded plants (Smith, 1942; Eriksen and Whitney; 1981; Wolters, 1973; Krueger, 1981; Blair, et al., 1983; Samarakoon et al., 1990; Kephart and Buxton, 1993; Wilson, 1995; Wilson, 1996), although neutral effects of shade on protein have been reported (Clason, 1995; 1999).

A study in the Midwestern USA found crude protein to be higher in pastures with trees compared to without (14.8 vs. 13.8%; Lehmkuler et al., 2003). In southern Georgia, crude protein increased in warm season grasses under slash pine compared to treeless pastures (Lewis et al., 1983). And in an Arkansas silvopasture of loblolly pine with tall fescue pasture, crude protein increased as tree planting density increased (Burner and Brauer, 2003).

Forage N levels of tropical grasses grown in Hawaii were significantly higher at 27% daylight than under more intense light. In Australia, shade increased N concentrations in warm season grasses (Samarakoon et al., 1990). In Australia, shade increased N uptake in warm season pasture (Wilson et al., 1986; 1990).

Shade may have a positive influence on availability of soil nitrogen (Wong and Wilson, 1980; Wilson, 1998). Also, soil type can affect crude protein concentrations in forages grown with trees (McEwen and Dietz, 1965). For example, McEwen and Dietz (1965) found higher concentrations of crude protein on sites with limestone soils compared to metamorphic.

With temperate grasses, the increase in N may be attributed to morphological changes (Kephart and Buxton, 1993), while with tropical grasses it most likely is due to increased microbial action, increasing soil nitrogen availability (Wilson, 1996).

Minerals

Forages grown in moderate shade are usually higher in minerals than those grown under full sun. Moderate shading may play a role in improving nutrient uptake, including minerals, especially P and Ca (Eriksen and Whitney, 1981; Krueger, 1981; Wilson et al., 1990; Myers and Robbins, 1991). Smith (1942) suggested shade may play a role in improving phosphorus uptake in forage grasses. In Brazil, deeply rooted trees may promote the distribution of mycorhizzal fungi at deeper soil layers and change the dynamics of the nutrient cycle, especially with regards to phosphorus (Cardoso et al., 2003). Although shade may have a neutral effect on mineral concentration (Wilson et al., 1990; Clason, 1995; 1999), the majority of reports suggest shade increases mineral concentration in forage plants.

Pine-shaded forage (*Poa pratensis*) in the Black Hills of South Dakota contained more calcium and phosphorus than forage in the open meadow (McEwen and Dietz, 1965). In Louisiana, a cover of young longleaf or slash pines increased phosphorus content in herbage on range dominated by Pinehill (*Andropogen divergens*) and slender bluestem (*A. tener*) (Wolters, 1973). And in Georgia, calcium in warm season forages doubled under planted slash pines (Lewis et al., 1983). In Texas, deer browse leaves grown in deep shade were significantly higher in calcium and phosphorus than those in full sunlight (Blair et al., 1983). These differences in chemical composition were caused primarily by light reduction and not by differences in the stage of morphological development as is often hypothesized (Blair et al., 1983). In Arkansas, calcium and phosphorus concentrations decreased with increasing tree planting density of loblolly pine, while Mg did not respond to density treatments. Additionally, P levels were higher in the second half of the growing season, most likely due to a shift in botanical composition from cool- to warm-season forages (Burner and Brauer, 2003).

Trees and shading clearly influence nutritive value constituents and will ultimately play an enormous role in determining silvopasture design and management success. However, as shown above, there are gaps in our knowledge regarding the impacts on forage nutritive value in silvopastures. More research is needed to determine forage nutritive value responses to silvopasture situations in regionally appropriate field studies.

The Influence of Trees and Shade on the Forage Microclimate

> The effect of trees on pastures is a complex phenomenon that cannot
> be explained on the basis of any single factor (Smith, 1942, p. 397).

The microclimate consists of a complex combination of above- and below-ground interactions. Above-ground interactions include changes in shading, temperature, wind speed, and humidity; below-ground interactions include plant root competition for water and nutrients (Ong et al. 1991). Many factors play a role in determining which interactions dominate a particular system, and whether the effect is negative or positive. For example, in drier climates, below-ground competitive partitioning for water may largely determine total system productivity (Braziotis and Papanastasis, 1995); and in wetter climates, the dominant interaction may be above-ground temporal partitioning for light (Osei-Bonsu et al., 2002). In the semi-arid tropics where nutrients and water are the most limiting factors, Ong et al. (1991) found that below-ground competition for water was the most critical factor determining total system compatibility and production. And in Oregon, where water is usually not limiting, light and temperature may be the controlling factors (Krueger, 1981).

Increased productivity of forage grasses in silvopasture systems compared to traditional pasture practices has been primarily attributed to improved microclimate environment including 1) improved soil fertility and structure, 2) moderated soil temperatures, 3) and improved plant-water relationships (Gustafson, 1935; Radwanski and Wickens, 1967; Belsky et al., 1989; Holland, 1980; Ratliff, 1981; Campbell et al., 1994; Belsky et al., 1994, Menezes et al., 2002).

Soil Fertility and Structure

Grass roots constitute 70-95% of the pasture biomass, and form a huge nutrient sink in the soil (Partridge, 1996). When comparing a silvopasture with an open pasture, the top 1-2cm of the soil surface is cooler and remains moister longer after a rain, favoring soil fauna and microorganisms that can work to quickly break down the litter and organic layers (Wilson, 1998). In short, the rates of litter and soil organic matter mineralization and nutrient availability to plants may be greater under trees, due to higher litter inputs, higher soil moisture levels, and lower soil and air temperatures (Menezes et al., 2002).

In the neotropical savannas of Belize, soil enrichment by native trees was attributed to increased capture of precipitation inputs as the major source of mineral-nutrients (Kellman, 1979). Mineralizable N and microbial biomass were significantly higher in soils under *A. tortilis* and *A. digitata* canopies in Kenya (Belsky et al., 1989). Additionally, soil bulk density may be lower under tree canopies (Belsky et al., 1993; Buergler et al., 2004).

Tree roots enrich soil with organic matter, feed soil biota, reduce nutrient leaching, recycle nutrients from the subsoil below the crop rooting zone, and improve soil physical properties (Schroth, 1995; 1999; Buresh, 1998). Establishing beneficial shade trees is an important management option that may increase productivity and longevity by increasing N supply (Myers and Robbins 1991).

Soil Surface Temperature

Production of cool season forages declines at soil surface temperatures exceeding 24°C (Sprague, 1943). Shading by trees can reduce daily temperature extremes for forage grasses, thus reducing metabolic cost of adaptation to extreme conditions (Feldhake, 2001).

In Hawaii, soil temperatures under 27% daylight, created by shade cloth in the field, were between 0.8^{o}C (in the winter) and 2.0 ^{o}C (in the summer) lower than full daylight (Eriksen and Whitney, 1981). In Kenya, soil temperatures were 5-12°C lower under *A. tortilis* and *A. digitata* canopies (Belsky et al. 1989; Belsky et al., 1993). In Appalachia, soil temperatures were 8-12°C less under shade compared to the open pasture (Feldhake, 2001). In Brazil, daily minimum soil surface temperatures were similar under trees and in the open, while daily maximum soil surface temperatures were higher (an average of 16^{o}C higher) in the open than under *Zizphus joazeiro* (Menezes et al., 2002). In Spain, minimum soil temperatures during the night were tempered under a pine canopy, and maximum soil temperatures during the day were lower than in plots without trees (Silva-pando et al., 2002). Also, higher minimum soil temperatures below the trees at the start and end of the growing season may determine a higher understory herbage production than in the stand without trees (Silva-pando et al., 2002).

Soil surface temperature is not only important for its value in helping to determine the coupling of the soil to the atmosphere, but also for its effect on physiological processes of many forage species (Feldhake et al., 1996). Soil surface temperature can influence forage growth rates and persistence (Feldhake et al., 1996).

Soil Moisture

Despite much concern regarding reduced soil moisture levels as a result of tree-forage competition, many studies have found no negative effects on soil moisture (Gustafson, 1935; Belsky et al., 1989; Belsky et al., 1993; Feldhake, 2001; Menezes et al., 2002; Buergler et al., 2004). Many researchers have observed improved soil moisture in silvopastures compared to open pasture (Smith, 1942; Ovalle et al., 1989). Smith (1942) found that the surface 3 inches of soil under black walnut trees averaged higher in moisture compared to open sites. He also observed that the black walnut roots were absent from the top soil where the forage gets most of its water. Under Acacia caven, soil water availability increased because of moderated extreme temperatures and reduced evaporation (Ovalle et al., 1989). Similarly, a Missouri study showed that black walnut extracted most of its water from soil depths of 20 and 40 cm, and did not compete with the forage crop for water resources (Dey et al., 1987).

In Patagonia, silvopastoral systems were found to be more productive than traditional pastures due to more exhaustive use of water resources (Gyenge et al., 2002). Leaf water potential was greater in grasses growing under tree canopies compared with grasses growing in open pastures (Gyenge et al., 2002). Shallow rooted grasses exploited small rainfall events while the deep rooted trees exploited reserves of water not available to grasses, showing no reaction to small rainfall events (Gyenge et al., 2001). The authors concluded that silvopastoral systems use water resources that otherwise are lost from the system. Their work supports the resource sharing theory of competitive partitioning. Similar effects on water relations were reported for a southern African savanna, in which the grass layer obtained most of its water from the topsoil (Knoop and Walker, 1985; Ong and Leakey 1999).

Solar Radiation

Naturally, the presence of trees in the pasture will alter the light environment for the forage crop. Cool season forages are light saturated at 50% sunlight, (Gardner et al., 1985) so shading, within limits, is unlikely to reduce photosynthetic activity. Moreover, shaded forages may still receive considerable amounts of photosynthetically active radiation via diffuse radiation (Feldhake, 2001), and radiation use efficiency is much greater for diffuse than direct radiation (Healey et al., 1998). Thus, trees can increase radiation use efficiency by creating a more diffuse light environment (Feldhake, 2001). Even if light levels are periodically less than optimum, forage plants may benefit by not using resources to adapt to levels that are higher than optimum (Feldhake, 2001). Basically, light intensity is of minimal importance for production of cool-season plants until the tree canopy becomes very dense (Krueger, 1981).

Ovalle et al. (1989) found that the canopy of *Acacia caven* reduced incident radiation to the forage crop, but not enough to suppress plant growth. In Kenya, Belsky and her colleagues compared the open, treeless grassland with the microenvironment under acacia (*Acacia tortilis*) and baobab (*Adansonia digitata*) tree canopies. Compared to the open grassland, acacia and baobab trees reduced solar radiation by 45-65% Belsky et al., 1989). In Brazil, *Zizphus joazeiro* intercepted 65-70% of total solar radiation from 10am-2pm, while *Prosopis juliflora* only intercepted 20-30% of total solar radiation (Brazil) (Menezes et al., 2002).

Trees in Silvopastures

Desireable characteristics for trees in silvopasture systems are 1) marketable timber; 2) high quality; 3) fast growing; 4) deep-rooted; 5) drought tolerant; 6) production of additional products such as nuts or fodder; 7) and provide environmental conservation services (Buck, 1986; Schroth, 1995).

Black walnut (*Juglans nigra* L.) has received a lot of research attention in temperate zone silvopastures and multi-cropping systems mainly because of its high value wood and nut production. Its foliage characteristics of late spring leafing and early fall release allow penetration of sufficient light to support plant growth in the understory (Garrett and Kurtz, 1983b; Garrett et al., 1991). Honey locust (*Gleditsia triacanthos* L.) is also an excellent species for temperate silvopastures. The Millwood cultivar produces a high energy fall fodder crop that can serve as a valuable source of livestock feed (Wilson, 1991) and the pulpy pods contain up to 35% sugar and have yields similar to an equivalent acreage of oats (Smith, 1950). A third species, black locust (*Robinia pseudoacacia* L.), also has potential as a multi-use, nitrogen fixing tree for temperate silvopasture. The species has been found to improve bluegrass production by improving soil fertility and soil moisture, while reducing microclimate temperatures (Gustafson, 1935; cited by Smith, 1942).

Historically, there was concern regarding negative allelopathic effects of forage species on tree growth because tall fescue leachate has been found to negatively affect sweet gum growth (Walters and Gilmore, 1976). However, a later study examining the effect of tall fescue leachate, fertilizer, and moisture stress on black walnut, found that moisture stress overshadowed the effects of the leachate or fertilizer (Rink and Sambeek, 1985). As described earlier, tall fescue-black walnut multi-cropping regimes have been thoroughly researched and demonstrate that there are no negative allelopathic effects on black walnut growth. Actually, slope appears to have the greatest effect of black walnut growth (Pham 1978).

Many timber producers are concerned that grazing livestock will damage forest stands, reducing timber production and quality. This may occur on overgrazed, poorly managed lands. However, Cutter et al. (1999a) reported that grazing cattle for over 30 years had no effect on total height, diameter grade, growth rate, percentage of latewood, specific gravity, or tracheid length of slash pine trees in a silvopasture. Other studies suggest well-managed tree-forage intercropping can actually improve timber production (Jaindl and Sharrow 1988; Clason 1995; 1996; 1999). Jaindl and Sharrow (1988) tested the effect of grazing on tree growth in newly established conifer plantations in Oregon. The authors reported increased tree height and diameter growth in grazed conifer plantations, and this effect carried over to years well after grazing ceased. Dangerfield and Harwell (1990) reported 9% more total wood flow from loblolly pine trees in silvpastures compared with traditional timber management.

Several explanations for increased tree growth have been given. Dangerfield and Harwell (1990) indicated increased tree production occurred with capture of fertilizer applied to the forage grasses. Also, grazing of the understory vegetation may also reduce exposure of trees to water stress, fire hazard, and competition for soil nutrients (Haney, 1980; Sharrow, 1997). Even without a boost in tree production, under good management, total system productivity necessarily increases with the production of additional crops (i.e. livestock, nuts, fodder, and pine straw; Carlson et al., 1994; Mills, 1998).

From a nutrient-cycling perspective, an ideal tree should possess a deep root system with limited lateral extension in the topsoil. Such root architecture allows for nutrient recycling from the subsoil, creates a “safety net” against nutrient leaching below the forage rooting zone, and has limited interference with root systems in the topsoil (Schroth, 1995). In addition to downward displacement of their root systems to minimize tree-grass root competition, desirable trees also display temporal differences between the root activity when compared with grasses (Schroth, 1999), allowing for greater resource sharing.

Paired with trees, livestock also play an integral role in maintaining closed nutrient cycles, helping increase nutrient use efficiency and sustainability of silvopastoral systems (Pell, 1999). Only 10-20% of nitrogen harvested by grazing animals is actually retained, thus the other 80-90% of the nitrogen is cycled back into the system (Pell, 1999); large herbivores shorten the cycle, increasing the rate of N cycling and availability (Russelle, 1992). This “recycled” nitrogen combined with biological nitrogen fixation can maintain soil organic matter and nitrogen at levels capable of sustaining forage crop yields (Pell, 1999).

Animals

Pasture productivity is usually the single most important factor affecting livestock carrying capacity (Fernández et al., 2002). As explained above, incorporating trees into pastures can increase forage productivity, and as a result, animal performance. Shade can also decrease heat stress, increase milk yield, and increase conception rates (Cameron et al., 1991). Shelter provided by trees may benefit livestock output as well (Kellas et al., 1995). However, the presence of trees may negatively affect animal performance as a result of reduced TNC and CP, as mentioned before.

In Tennessee, Neel (1939) observed a 20% increase in steer days per acre, and a 22% increase in steer gain per acre on a black walnut-bluegrass silvopasture. In West Texas, shade improved daily gain and carcass quality, and decreased respiration rate of feedlot heifers, suggesting that shade can improve animal well-being and performance (Mitlöhner et al., 2002). Although these animals were not on pasture, the results of this study clearly demonstrate benefits of shade for animals subject to heat stress.

When given options of high, medium, and low shade (2500, 1750, and 1000 tree/ha), animals preferred to graze under moderate shade (Braziotis and Papanastasis, 1995). Cameron et al. (1991) reported that cattle grazed for greater proportions of the day and made greater weight gains in shaded paddocks compared to unshaded paddocks. These benefits, coupled with increased nutritive value, can result in an overall increase in animal performance, and improve total system productivity.

Silvopasture System Design and Management

Understanding the ecological interactions within agroforestry systems is essential for proper management. Every design for an agroforestry system must appropriately consider the sharing of resource pools: light, water, and nutrients. Farmers can manipulate and control the light climate through specific silvicultural treatments. Management options will differ greatly as a result of the wide possible range of environmental, social, and economic variables (Buck, 1986). In the United States, agroforestry research has primarily been localized to the South, Northwest, and Midwest. Despite the great potential for silvopasture production in the Eastern and Northeastern States, very little research has been conducted in the region.

In Louisiana, loblolly pine densities as high as 4451 trees/ha did not significantly decrease herbage yields during the first 10 years following tree planting (Pearson et al., 1995). A study on sites with poor soil fertility in Arkansas compared forage production under loblolly pine plantings. Alley widths between tree rows ranged from 2.4 to 14.6 m wide. When trees were 6 years old and approximately 4.9 m tall, herbage yield approached its maximum at row widths ≥4.9m (Burner and Brauer, 2003). The authors recommended a 4.9 m spacing as a reasonable first-approximation for an initial agroforestry system design.

In Kerala, India, a grass-tree association study examined the effects of four multi-purpose trees (MPTs) on production of hybrid napier (*Pennisetum purpureum* Schumach.), guinea grass (*Panicum maximum* Jacq.), and congo signal (*Brachiaria ruziziensis* Germain and Everad.). The MPTs studied were *Acacia auriculiformis, Ailanthus triphysa, Casuarina equisetifolia*, and *Leucaena leucocephala*. Forage production increased during the first three years in all tree-grass combinations, but declined after that due to tree crown expansion (Kumar et al., 2001). Pruning was suggested as a management tool to extend the period of time where forage production is enhanced by the presence of trees.

Lin et al. (1999) suggested using species with slight shade tolerance for silvopasture establishment. These species include Kentucky bluegrass (*Poa pratensis*), orchardgrass (*Dactylis glomerata*), ryegrass (*Lolium perenne*), tall fescue (*Festuca arundinacea*), timothy (*Phleum pratense*), smooth bromegrass (*B. inermis*), and legumes such as hog peanut (*Amphicarpaea bracteata* L.). Selection of forages for established tree stands will depend on the level of shading provided by the trees and the potential to manage the trees with pruning (Kumar et al., 2001). Conversely, selection and establishment (planting density) of trees in existing pastures will need to account for response of existing forage species to shade. Essentially, Lin et al. (1999) suggests that yield can be optimized by controlling the shade level of the microenvironment. Another factor to consider is that side-lighting effect increased yields;

therefore skilled management of tree canopy cover can play a key role in shifting forage productivity towards strategic periods by reducing seasonality (Silva-pando et al 2002).

Sibbald et al. (1994) found that relative pasture yield (the ratio of growth below a canopy to open pasture growth) was linearly related to green crown length (sum of the heights of the green crowns of individual trees, per meter, per hectare) in the case of ryegrass growing under *Pinus radiata*. Forage production decreased linearly with increasing green crown area. The authors concluded that crown area was the best predictor of relative pasture yield in the temperate zones of the Northern hemisphere. However, herbage yield was measured by harvesting ryegrass (*Lolium perenne*) growing in sward boxes. The boxes were subsequently transported from the greenhouse to the experimental area during the growing season. The researchers used the sward boxes in this way to control any unwanted random variation. This method assumes that shade alone is the only factor influencing forage production, failing to account for any below-ground tree-grass facilitative interactions or competitive partitioning that clearly play a large role in determining how forage production is affected by the presence of trees.

Establishment of trees in pasture requires appropriate management strategies, including species selection, tree shelters, grass control, mulch, and fertilization (Bendfeldt et al., 2001; Schroth 1995; Addlestone et al., 1999). In general, trees are more easily established into an existing pasture as opposed to planting pasture within a growing timber crop (Isaacson, 1998). Establishing tree seedlings within cool season pastures did not hinder performance of beef cattle in Wisconsin (Lehmkuhler et al., 2003). Weight gains were similar for cattle that grazed in paddocks containing seedlings versus those grazing in open pastures. Regardless of age or production phase (lactating cows, nursing calves, and yearling heifers), all animals were in positive energy balance measured by the positive body weight gain in the silvopasture systems (Lehmkuhler et al., 2003).

Tree shelters can protect seedlings from deer or livestock damage. Transitioning from conventional pastures to silvopastures can be accelerated utilizing electrified fencing to prevent cattle damage, which is most prominent during the first two years of tree establishment (Lehmkuhler et al. 2003).

Grasses, especially tall fescue, can be highly competitive with tree seedlings for resources (Alley et al, 1999). Many producers utilize herbicide treatments and mulching to ensure strong seedling establishment. Generally, once trees are established, tree growth rates improve over monoculture plantations as a result of the routine fertilization of the pasture (Dangerfield and Harwell, 1990).

Planting trees in rows, rather than on a grid or in clusters, is optimum (Sharrow, 1997). This arrangement provides open spaces for pasture, supports high forage production, and facilitates agricultural operations and animal herding. For a black walnut silvopasture, Garrett and Kurtz (1983b) recommend an initial tree spacing of 3.04 x 12.2 m (about 267 trees/ha). This allows for tree selection early in the rotation. An ultimate spacing of 12.2 x 12.2 m for a final tree harvest of 67 trees per hectare was suggested as ideal. This spacing, designed specifically for Missouri,is appropriate in most temperate zones (Garrett et al., 1991). This spacing was created to minimize limitations on crop production, while the additional trees, early in the rotation, “train” the final crop trees to grow straight and tall. Many silvopasture systems are characterized by intensified management practices and require corrective pruning to further increase the timber value (Garrett and Kurtz, 1983b).

The literature clearly shows that forage production in silvopasture systems is dynamic and changes over time as the trees mature (Pearson et al., 1995; Lin et al. 1999). Management of these systems needs to focus on maintenance of ideal tree density, to maximize the benefits of the tree-grass association and minimize the negative effects of competition between the two components. More research is needed to provide information on selection of tree, forage, and livestock components, and how to manage competition for light, water, and nutrients (Rietveld and Francis, 2000).

Economics of Silvopasture Systems

Agroforestry systems are more economically viable than traditional agriculture and forestry (Benjamin et al, 2000) because they naturally diversify the product base while maintaining long-term land productivity (Stoney and Bratimihardja, 1990; Gordon and Williams, 1991; Clason, 1996).

In the southeast where silvopasture research focuses on warm-season forages under pine, Clason (1995) determined that establishing a hybrid Coastal bermudagrass silvopasture in a maturing loblolly pine plantation can provide investment income, high quality forage, enhanced timber production, and improved soil fertility – resulting in an economically viable land management plan.

In southern Georgia, limited land resources are forcing farmers to better manage their resources and produce more than one crop (Lewis et al., 1983). Silvopasture systems were more economically viable than monocultures because it offers multiple-product yields, especially for farmers with small land holdings (Lewis et al., 1983).

Silvopasture systems generate substantially more rural employment per hectare than do pastures (Yamada and Gholz, 2002a). In the southern United States, the net present value (NPV) of silvopasture production is 71% greater than traditional forestry production (Dangerfield and Harwell, 1990). In this case, the increase of the NPV is mainly due to the annual income generated by the livestock, and as a result of agroforestry incentive programs. Haney (1980) also found that cattle-timber production systems in the South were highly profitable and recommended the system to farmers as an excellent investment over that of traditional cattle production.

Agroforestry systems incorporating black walnut have been shown to be more profitable than conventional farming (Garrett et al, 1991; Godsey, 2001). In Missouri, a black walnut-steer-tall fescue multicropping system yielding more than 6-fold greater NPV than the comparable system in open pastures (Garrett and Kurtz, 1983a).

In Mississippi, cattle grazing of improved forage in commercially productive loblolly (Pinus taeda) stands can relieve annual cash flow problems inherent in tree production (Grado et al., 2001). On average, there was a 100% increase in cash flow on a per hectare per year basis for silvopasture systems compared to monocultural pine forest plantations (Grado et al., 2001). Silvopasture practices are both economically and environmentally sound, because they can increase incomes levels while simultaneously preventing environmental degradation (Peñaloza et al., 1985). Additionally, the hilly topography of areas such as Appalachia does not support intensive crop agriculture, but is ideal for grazing livestock as short-term income on lands producing long-term forest crops (Carlson et al., 1994).

Many states, including Maryland and Virginia, have legislation pertaining directly to agroforestry and provide some type of cost-sharing for implementing and maintaining specific agroforestry practices such as silvopastures (Cutter et al., 1999b). These programs facilitate silvopasture adoption by supplementing farm income and reducing the initial risk of silvopasture establishment (i.e. planting and protecting trees). Additionally, these programs help make an enterprise that is already economically viable, even more so. More states need to pass legislation supporting agroforestry adoption. Legislation usually follows university-led research and outreach-extension efforts (Cutter et al., 1999b).

I have a dream
I have a dream that the forests will return;
that the farmers will plant trees;
that the land will be healed.
(Mead 1995)

Chapter 3: Materials and Methods

Objectives

1) Site description;
2) Describe material and methods that are appropriate for all chapters, while specific procedures are detailed within each chapter.

Materials and Methods

This research was conducted at Virginia Tech's Kentland Farm near Blacksburg, Virginia. Site elevation is approximately 540 m (1772 ft) above sea level, 37° 11' N latitude and 80° 35' W longitude. Moderately cold winters and relatively cool summers characterize this area. The nearby Appalachian and Blue Ridge Mountains produce various steering, blocking, and modifying effects on storms and air masses. As a result, this area is somewhat protected from the weather extremes of winter and summer. Prevailing winds are generally westerly with a more northerly component in the winter and a more southerly component in the summer. Monthly minimum, maximum, and average temperatures at Kentland Farm for the 2001 to 2003 growing seasons are shown in Table 3.1. Additionally, ambient air temperatures were higher in 2002 than 2003 (Figure 3.2).

Long-term average annual precipitation in Virginia is 109 cm (43 inches) (Virginia State Climatology Office, http://climate.virginia.edu/description.htm) and is generally evenly distributed throughout the year (Figure 3.3). The latter two years of the study were characterized by extremes of precipitation, with sustained drought in 2002 and unusually high rainfall during summer of 2003.

Soils on the site are classified as clayey, mixed mesic Typic Hapludults. They are well drained, with moderately steep slopes (10-25%). These acidic soils are generally found on stream terraces and characterized by moderate permeability, rapid surface runoff, low fertility, low organic matter, and moderate available water capacity. Water table depth is generally more than 2 m (6.5 ft). Cultivated crops are poorly suited for this site due to limitations of slope, soil fertility, cobbles, and severe erosion hazard. Forage-livestock or tree production systems are well suited for these soils, which are used mostly for pasture and woodlots.

In 1995, black walnut (*Juglans nigra*) and honey locust (*Gleditsia triacanthos*) trees were planted in existing pastures. Each replicate (n = 3) contained both a black walnut (BW) and a honey locust (HL) plot with plots arranged in a split-split plot design. Within each tree plot, four rows of trees were planted down the face of the 12% slope with 1.8, 3.7, 7.3, and 14.6 m (6, 12, 24, and 48 feet) within the rows and 3.7, 7.3, and 14.6 m (12, 24, and 48 feet) between rows (Figure 3.1). Spacings were designed to establish an increasing shade gradient both across and up the slope.

Pastures were predominantly tall fescue (*Festuca arundinacea*), but contained orchardgrass (*Dactylis glomerata*), bluegrass (*Poa pratensis*), redtop (*Agrostis gigantea*) and quackgrass (*Elytrigia repens*) among others. Pastures were maintained by infrequent clipping from time of tree establishment until the start of the study in May 2002.

The site was recently fertilized in late fall of 2001 and 2002. In October 2001, 39.2 kg/ha of nitrogen as urea was applied to the site. In October 2002, a blend of nitrogen, phosphorus, and potassium fertilizer was applied at a rate of 44.8, 78.4, and 22.4 kg/ha, respectively, in addition to 3.4 Mg/ha of lime. On 18 December 1998, 15 November 1999, and 16 November 1997, the site was fertilized with 45 kg/ha of nitrogen, phosphorus, and potassium. In October of

1995, fertilizer was first applied at a rate of 56, 134, and 84 kg/ha for nitrogen, phosphorus, and potassium, respectively.

To examine the interactions of slope and shading environment on forage production, sampling sites were located at points across the combination of tree density and slope gradients. At shoulder-, mid- and toe-slope positions, three permanent sites were created within low-, medium- and high-shade environments for a total of nine sampling sites within each tree plot (n = 18 sites/replicate). Sampling site locations were selected based on tree densities that created three shade classes: 1) full to partial shading all day; high shade environment or high tree density; 2) morning sun exposure with shading events after solar noon; medium shade environment or medium tree density; and 3) full exposure to sunlight; low shade environment or low tree density. The sampling sites were 0.53 m X 2.44 m (1.75 ft. X 8.0 ft) and ran parallel to the tree rows. At each site, corners were marked with painted metal plates held to the ground with nail stakes. A flag marked each metal plate for ease of location during rapid forage growth.

Tree Growth:

Tree growth measurements (diameter at breast height and tree height) were taken on April 1, 2003 in order to relate tree size to microclimate and forage responses.

Soil nutrients:

Soil samples were taken to a depth of 20 cm (8 in) with a 5-cm (2-in) auger on 4 June 2002. Three cores were extracted along the left side of each sampling site, composited, and mixed in a plastic tub. Representative samples were collected, placed in a forced draft oven at

60 °C (140 °F) for 24 hours, removed, and allowed to air equilibrate. Samples were sifted sequentially through #10 and #2 sieves to remove rocks and organic matter.

Soil samples were analyzed for carbon (C), nitrogen (N), and phosphorous (P). Soil C and N concentrations were measured with a CNS Analyzer (vario Max CNS analyzer, Elementar Americas, Inc., Mt. Laurel, NJ, USA). Results were used to calculate total N, and percent soil organic matter. Available soil P was determined using the Mehlich I method outlined in Methods of Soil Analysis (1982).

Soil Physical Properties:

Soil cores were collected from directly alongside each sampling site 15 June 2002 for determination of bulk density. In addition, Time Domain Reflectometry (TDR) rods were inserted to a depth of 15 cm (6 in) at the bottom edge of each sampling site and left in place for the duration of the study. The TDR measures gave instantaneous determination of the volumetric water content of the soil. Measurements were taken each month during harvesting season in 2002. In 2003, soil moisture measurements were taken about every two weeks beginning 12 April and ending just before the last harvest on 29 October 2003.

Botanical composition:

Botanical composition of each site was determined just prior to harvests in spring, summer and fall of each year. Two quadrats (0.3 m X 0.5 m) were randomly placed within each sampling site. Herbage within the quadrats was clipped to 7.5 cm and separated into the following components: tall fescue, other cool season grasses, warm season grasses, legumes, broadleaf weeds, and dead material. Separated herbage was dried at 60 °C (140 °F) for 48 hours and weighed. Botanical composition at each site was calculated as a component's percent of the total sample. Weights of botanical composition components were summed and added to herbage mass values from their respective plots, but these samples were not used for determination of moisture or nutritive value.

Botanical composition samples were collected 25 July and 22 September during 2001. During 2002, samples were collected 9 May, 17 July, and 11 November. September sampling was postponed to November due to drought. In 2003, samples were collected on 6 May, 16 July, and 24 September. Visual assessment of percent clover cover was also taken on 10 June 2003.

Microclimate Measures:

In 2002, forage canopy and soil surface temperatures were recorded at 3-h intervals from 0600 h for a 12- (16 July) or 24-h period (15-16 August). Based on results from 2002, some modifications in measurement procedure were made in 2003.

No differences in temperature at 0600 were observed in 2002, thus that sampling time was eliminated in 2003. Forage canopy and soil surface temperatures were recorded from April through October in 2003 to more fully characterize microclimate responses over the growing season. Measurement dates were 12 and 27 April, 20 May, 10 June, 8, 11, and 18 July, 29 August, 12 September, and 3 and 30 October.

Forage canopy temperatures were measured with an infrared thermometer (Everest Interscience Inc., Tustin, CA) to for potential relationship to plant-water status (Feldhake and Edwards, 1992). Soil surface temperatures were measured with an HI 9063 microcomputer K-thermocouple thermometer (HANNA Instruments, Lisbon, Portugal). In addition to thermocouple readings, StowAway TidbiT® temperature dataloggers were installed at each sampling site in the top 5cm of soil, just below the organic (Ao) horizon in 2003. These data loggers measured soil surface temperature every 3 h-from 1200 h on 22 May until 1200 h on 25 October. Before field installation, TidbiT®s were placed in a dryer at 38 °C to check for uniformity of temperature measurement. One TidbiT® was lost from one plot due to mole (*Scalopus aquaticus* L.) activity.

Photosynthetically active radiation (PAR) was measured in the third replicate at shoulder- and toe-slope positions using LI-COR LI-191-SB line quantum sensors (Sunfleck Ceptometers, Decagon Devices Inc., Pullman, WA) mounted parallel to tree rows about 25 cm above the ground to prevent shading by forages. Data from the sensors were collected using Campbell Scientific 21X data loggers with measurements made every 10 seconds and averaged hourly.

Measurements of PAR with light meters could only be taken at one slope X shading intensity for each species combination at a time. Three sensors were placed adjacent to the sampling site under high shade, two under medium shade, and one under low shade. Measurements at toe position for both species were taken 4-10 September 2002 and 5-13 August 2003. Measurements of PAR at shoulder position for both species were taken 23 August through 4 September 2002, and 5-13 August 2003.

Statistical Analysis:

Data were analyzed as a split-split plot using the General Linear Model procedure of SAS (2001). Field replicate, slope position, tree species, and shade intensity (i.e. tree stand density) were the whole-, main-, sub-, and sub-sub-plots, respectively. All main effects and interactions were tested across both growing seasons, by year, and by harvest date. Treatments were considered different at P levels < 0.05 and trends are reported, where appropriate, for $P < 0.10$.

Correlation procedure of SAS (2001) was used to determine the relationship among response and regressor variables for linear regressions. The Reg Procedure was used for multiple linear regression analysis. Stepwise selection (%=0.05) was used to determined variable significance for building the regression equations.

Table 3.1. Monthly minimum (Min), maximum (Max), and mean air temperatures at the Kentland Farm research site, Blacksburg, VA, during the 2002 and 2003 growing seasons.

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
	°C							
2002								
Min	-13.76	-8.30	-1.67	6.38	11.79	7.83	5.00	1.87
Max	24.03	29.74	29.81	32.40	31.44	32.83	32.49	27.31
Mean	5.92	12.27	14.90	20.47	22.22	21.60	19.25	12.57
2003								
Min	-6.49	-3.60	4.77	6.43	12.17	14.87	3.21	-2.81
Max	23.29	26.34	28.40	31.19	31.40	31.31	29.33	26.59
Mean	7.64	11.22	15.28	18.85	21.29	21.93	16.93	10.83
LTA*								
Min	1.20	5.90	11.20	15.70	17.90	17.30	13.90	7.20
Max	13.80	19.50	24.30	28.30	30.10	29.20	26.20	20.70
Mean	7.50	12.70	17.80	21.90	24.00	23.30	20.10	13.90

*Virginia Long-Term Average (1895-1998)

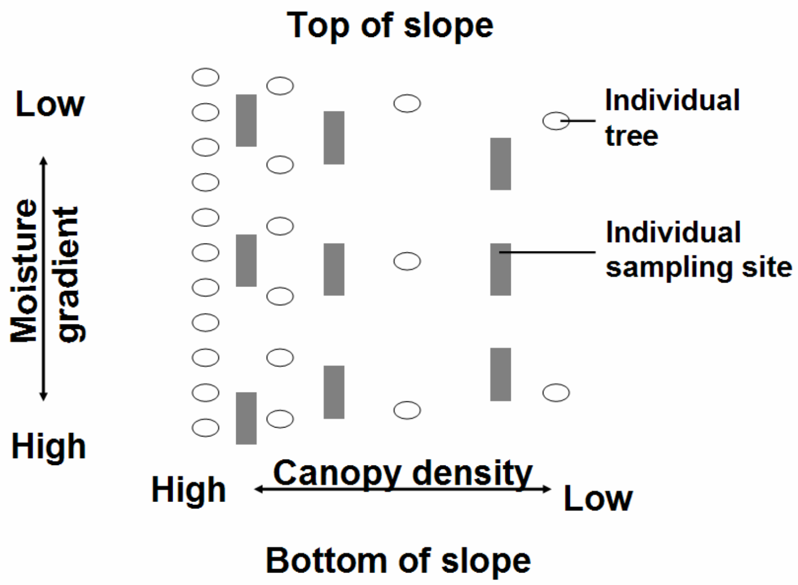


Figure 3.1. Layout of one plot depicting tree placement, moisture and tree canopy gradients, and forage sampling sites.

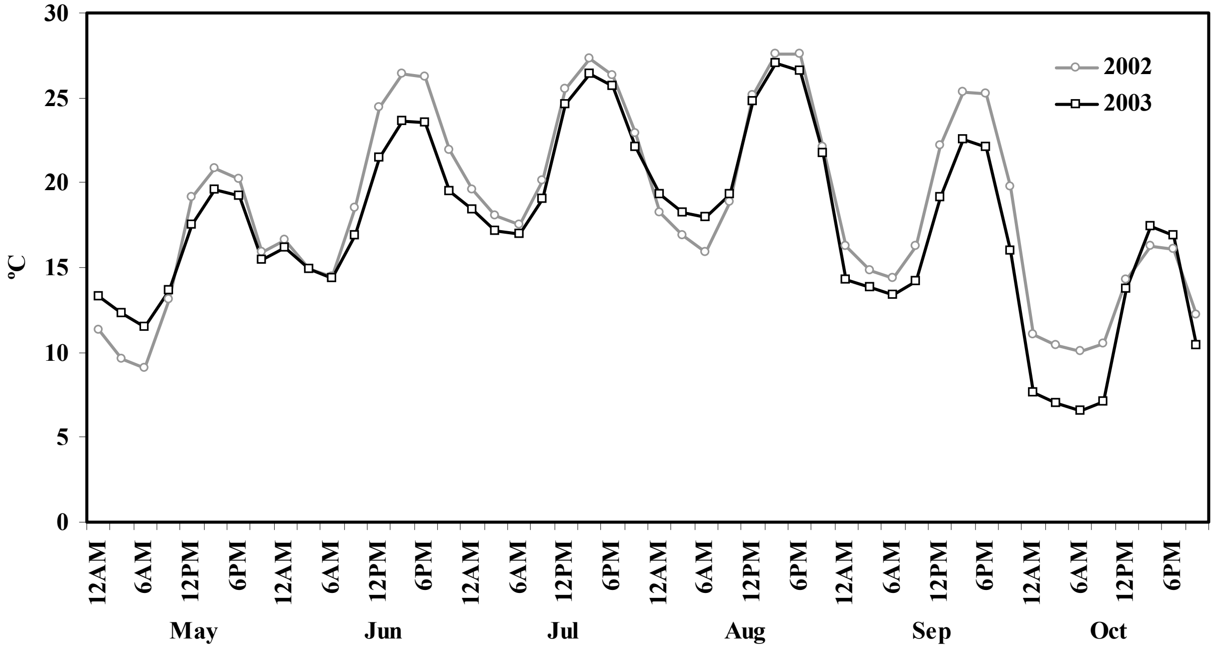


Figure 3.2. Ambient air temperatures at the Kentland Farm research site, Blacksburg, VA, during the 2002 and 2003 growing seasons.

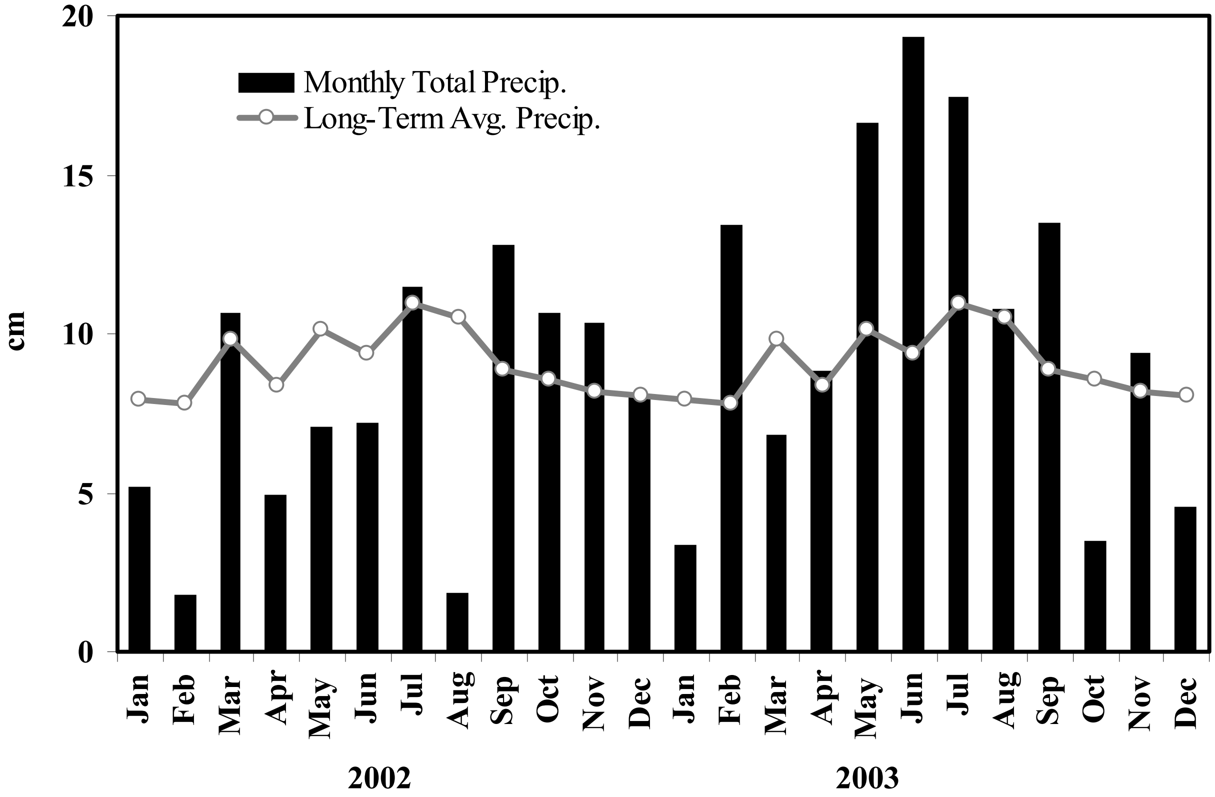


Figure 3.3. Monthly total and long-term average rainfall data at the Kentland Farm research site, Blacksburg, VA, during the 2002 and 2003 growing seasons.

Chapter 4: Cool-Season Forage Production in a Temperate Silvopasture

Abstract

Integrating trees into pasture may be an effective management tool to improve resource allocation (i.e. temperature, water, and light) and increase total system productivity in temperate Appalachia. In 1995, black walnut and honey locust trees were planted within plots (r=3) of predominantly tall fescue pasture. In each plot, four rows of each tree species were planted down a 12% slope with spacings of 1.8, 3.7, and 14.6 m within rows and 3.7, 7.3, and 14.6 m between rows. Spacings created field treatments of low, medium, and high tree densities at shoulder, mid, and toe slope positions within plots of honey locust and black walnut trees. Forage sampling sites (n=54) under field treatment combinations were harvested May to October at 35-d intervals in 2002 and 2003. Soil surface temperature (SST), forage canopy temperature (FCT), soil moisture, and photosynthetically active radiation (PAR) levels were measured at field treatment combinations. The objective of this study was to determine and describe forage responses to the field treatments as functions of resource allocation.

Across both years, forage mass at low, medium, and high tree densities were 5280, 6130, and 4970 kg/ha, with greater (P=0.0006) production under medium density trees. Yields under black walnut were 12% greater (P=0.02) than under honey locust trees (5790 vs. 5130 kg/ha). Slope had no overall effect on forage mass in neither dry nor wet years.

Both SST and FCT were higher (P<0.02) at sites under low and medium density trees. Soil moisture concentrations were greater (P<0.001) under honey locust. Levels of PAR decreased (P=0.0003) with increasing tree density. Elevated SST and FCT limited forage growth at low density while low PAR limited forage growth at high density sites. At medium density, FCT and SST were moderated while PAR reduction did not limit forage production. Medium

tree density is an effective way to moderate microclimatic parameters for optimum forage production in a temperate silvopasture.

Hypothesis

Incorporating trees into pasture benefits resource capture for cool-season forage production in a temperate Appalachian silvopasture.

Objectives

1) To measure forage production in response to tree species, tree density, and slope position in a temperate pasture;
2) To measure effects of tree species, tree density, and slope on microclimate responses;
3) To determine the relationships between microclimate modifications and forage production;
4) To relate field treatments to forage production as a function of specific microclimatic factors.

Materials and Methods

During each season, herbage sampling began when average canopy height was about 25 cm (10 in) tall. Harvests in 2002 and 2003 were scheduled at approximately 35-d intervals. In 2002, harvests occurred 9-10 May, 12 June, 17-20 July, 21 August, and 11-13 November. Due to drought, the planned September harvest was postponed. During 2003, sites were harvested on 7 May, 10 June, 16 July, 20 August, 24 September, and 29 October.

Herbage within each 1.3 m^2 sampling site was cut to a height of 7.5 cm (3 in) with a Honda push mower (American Honda Motor Co., Inc. Alpharetta, GA) with bag attachment. Immediately after cutting, samples were weighed so that moisture concentration could be determined. Samples were dried at 60 °C (140 °F) for 48 hours, then weighed for determination of dry matter (DM) and estimates of yield per unit land area (kg/ha). Sites were harvested in the afternoon (after 1500 h) to limit differences in nutritive value due to diurnal variation. In 2003, sampling sites for rep 2 and 3 of black walnut at both high and medium tree densities on mid and shoulder slope were appropriately relocated before the May 7th harvest due to groundhog (*Marmot marmax*) damage and tree death.

Results

FORAGE MASS RESPONSE TO FIELD TREATMENTS

Forage Mass Response to Tree Species

Forage production was lower (P<0.0001) in 2002 compared to 2003 (4660 vs. 6260 kg/ha) across all treatments. Over both years, forage production was about 13% greater (P=0.02) under black walnut compared to honey locust trees (5790 vs. 5130 kg/ha; SE=130) (Table 4.1). However, species had no effect (P=0.2) on yield in 2003, resulting in a significant species X year interaction (P=0.02)

In 2002, seasonal forage yield was greater (P=0.007) under black walnut compared to honey locust (5100 vs. 4200 kg/ha; SE=130). Yields tended (P≤0.08) to be lower under honey locust at spring harvests (May and June) and were significantly reduced ($P \leq 0.03$) at summer and fall harvests (July, August, and November). The magnitude of these differences influenced the observed species X date interaction ($P<0.0001$). Additionally, the yield reduction due to high density plantings was greater under honey locust than black walnut trees (species X density interaction; $P = 0.01$) (Figure 4.2).

In 2003, tree species did not affect ($P=0.2$) forage yield across the season. However, yields were lower ($P \leq 0.01$) under honey locust at August and October harvests (species X date interaction; $P<0.0001$).

Forage Mass Response to Tree Density

Forage mass was 16% greater ($P=0.0006$) under medium tree density in both years ($P \geq 0.002$) (Figure 4.1). Across both years, yields under low, medium, and high tree densities were 5280, 6130, and 4970 kg/ha respectively (SE=130). Monthly herbage yields were greater ($P \leq 0.04$) at medium density sites in May and November of 2002, and in June, September, and October of 2003 (density X date interaction; $P \leq 0.04$).

Herbage yield was lower ($P=0.01$) under high density sites in June 2002 compared with low and medium density sites. This response to tree density was observed in July ($P=0.01$) and August ($P=0.001$) of 2003 (density X date interaction; $P=0.003$).

Forage Mass Response to Slope Position

In 2002, slope had no effect ($P=1.0$) on seasonal forage yield, although yields in August were greater ($P=0.04$) at toe slope (470 kg/ha) compared to mid (400 kg/ha) and shoulder slope (300 kg/ha) positions (SE=20; slope X date interaction; $P=0.0004$) (Table 4.2 and 4.3). Seasonal forage production in 2003 was lower ($P=0.05$) at mid slope (6000 kg/ha) compared to shoulder (6400 kg/ha) and toe slope (6400 kg/ha) positions (SE=80).

TREE GROWTH RESPONSE TO FIELD TREATMENTS

Diameter at breast height was greater (P=0.002) for honey locust (5.6 cm) compared to black walnut (4.0 cm; SE=0.18). Honey locust trees were also taller (P=0.0002) than black walnut trees (5.1 vs. 3.2 m).

Tree Response to Tree Density

With these 10 yr old trees, neither diameter at breast height nor tree height was affected (P≥0.2) by current treatment densities.

Tree Response to Slope Position

Diameter at breast height was greatest (P=0.04) at toe slope (5.8 cm) compared to mid (4.3 cm) and shoulder slope position (4.4 cm; SE=0.18). Similarly, tree height tended to be greater (P=0.07) at toe slope (4.7 m) compared to mid (3.9 m) and shoulder slope (3.8 m; SE=0.15).

SOIL AND MICROCLIMATE RESPONSE TO FIELD TREATMENTS

Soil Nutrients and Bulk Density

Treatments had no effect on soil nitrogen and phosphorus levels, percent organic matter, or bulk density.

Soil Surface Temperature

Soil surface temperatures (SST) within 3-hr measurement intervals (0900-1500 h) were averaged over the year for each sampling site. The SST were higher (P<0.0001) in 2002 compared to 2003 (30.2 vs. 22.6°C; SE=0.06) due to greater ambient air temperatures and lower rainfall.

SST Response to Tree Species

Overall, tree species did not significantly effect SST in 2002 ($P=0.09$) or 2003 ($P=0.2$) (Figure 4.3).

SST Response to Tree Density

Although SST data for 2002 were measured with a thermocouple and 2003 temperatures were measured with TidbiT® dataloggers, there were no density X year interactions. Thus, data for responses to tree density are presented for the combined years.

As expected, soil surface temperatures were generally higher at low density sites compared to temperatures at medium and high density sites throughout the 2002 (Table 4.5) and 2003 growing season (Figure 4.4). Across both years, SST were higher ($P<0.0001$) under low density stands (27.6 °C) compared to medium (25.7 °C) and high density stands (25.6 °C) (Figure 4.5). At ambient air temperatures between 5 and 15 °C, SST were lower at low density sites compared to medium and high density sites ($R^2=0.9$; $P<0.0001$) (Figure 4.6). Conversely, SST were highest at low density sites when ambient air temperatures were between 15 and 27 °C.

In 2003, TidbiT® dataloggers measured soil surface temperature every 3 hours from mid May to October, gathering 1400 measurements per sampling site. These data were used to determine the effect of field treatment on the number of recorded measurements in excess of 24 °C, the upper critical temperature for optimum tall fescue growth. The total number of measurements exceeding 24 °C decreased ($P<0.0001$) with increasing tree density (314, 250, and 234 for low, medium and high density sites; SE=3).

These data suggest that temperature extremes are better moderated by medium and high density plantings, most likely due to the insulating effects of the tree canopy.

SST Response to Slope Position

Across 2002 and 2003, soil was warmer (P=0.02) at mid slope (27.2 °C) compared to toe slope (25.6 °C) but not different from shoulder slope positions (26.4°C; SE=0.2) (Figure 4.7). With the greater ambient air temperatures of 2002, SST were warmer (P=0.03) at both mid (31.1 °C) and shoulder slope positions (30.4°C; SE=0.3) than at the toe slope (29.0 °C). Under the lower ambient temperatures of 2003, SST were warmer (P=0.02) only at mid slope (23.3 °C vs. 22.1 and 22.4 °C for toe and shoulder slope positions; SE=0.1).

For both species, SST were numerically greater at mid slope. However, in 2002, soils at mid slope under honey locust were warmer (P=0.05; 31.2 °C) than soils at both shoulder (30.1 °C) and toe slope (29.7 °C) positions. Soils under black walnut trees were warmer (P=0.02) at both mid (31.0 °C) and shoulder (30.7 °C) slope relative to toe slope (28.2 °C) positions (species X slope interaction; P=0.02) (Figure 4.8).

In 2003, SST were highest (P=0.005) at mid slope (23.6 °C), and lowest at toe slope under black walnut (21.8 °C), but no differences (P=0.1) due to slope were observed under honey locust (22.5, 23.0, and 22.1 °C for toe, mid and shoulder positions; species X slope interaction; P=0.03).

Forage Canopy Temperature

Forage canopy temperatures (FCT) were measured at 1200 and 1500 h at each site and averaged across months within years prior to statistical analysis. The FCT were higher (P<0.0001) in 2002 compared to 2003 (33.0 vs. 23.7°C; SE=0.2).

FCT Responses to Tree Species

Tree species had no effect (P=0.6) on FCT (Figure 4.3).

FCT Responses to Tree Density

Across years, FCT were higher (P<0.0001) at low density sites (30.0 vs. 27.7 and 27.6 °C for medium and high density sites; SE=0.2) (Figure 4.5). Forage canopy temperatures were 34.8, 32.2, and 32.1°C (P=0.003; SE=0.4) in 2002 and 25.1, 23.2, and 22.9°C (P<0.0001; SE=0.1) for low, medium, and high density sites, respectively.

Forage Canopy Temperature Responses to Slope Position

Across both years, FCT were cooler (P=0.003) at toe slope positions (26.9 °C) compared with mid (29.2 °C) and shoulder (29.2 °C) positions (SE=0.2) (Figure 4.7). In 2002, FCT were lower (P=0.001) at toe slope positions (T=30.6, M=34.2, S=34.2°C; SE=0.4), but in 2003, FCT at all three slope positions were significantly different (P=0.05) from each other, with lowest temperatures at the toe slope (23.2 °C) and the highest temperatures at mid slope (24.3 °C; SE = 0.1; slope X year interaction, P=0.003) (Figure 4.7).

Soil Moisture

Soil moisture data were averaged by year for each sampling site. Soil moisture levels were lower (P<0.0001) in 2002 compared to 2003 (18.5 vs. 27.3%; SE=0.2) because of the differences in rainfall.

Soil Moisture Response to Tree Species

Across both years, soil moisture levels were 11% higher (P=0.009) under honey locust (24.1 vs. 21.7%; SE=0.4) than under black walnut trees (Figure 4.3). Interestingly, this difference was consistent both in dry (2002; 19.5 vs. 17.5%; P=0.05; SE=0.5) and wet (2003; 28.7 vs. 25.8%; P=0.01; SE=0.5) growing seasons. Also, this pattern seems to reflect the differences in yield; there was less soil moisture under black walnut where greater forage production was measured, suggesting that the soil moisture measurements represented the greater water usage needed for greater forage production.

Soil Moisture Response to Tree Density

Averaged over both years, tree density did not significantly affect (P=0.2) soil moisture levels (Figure 4.5). However, in the drier year, 2002, soil moisture levels were lower (P=0.05) at medium density (17.4%) compared to low (20.0%) density sites (SE=0.7). Tree density had no effect (P=0.8) on soil moisture during the wetter year, 2003.

Soil Moisture Response to Slope Position

Surprisingly, slope position alone had no effect (P=0.2) on soil moisture (Figure 4.7). However, soil moisture levels at toe slope positions were numerically greater than those at mid and shoulder slope positions in 2002 (20.3, 17.5, 17.7%; SE=0.9) and 2003 (28.4, 26.4, 27.1%; SE=0.1).

Photosynthetically Active Radiation

Measurements of PAR were not replicated within years, thus results were reported across both years, using year as a replicate. Although we cannot test for a year effect, it is useful to look at the numerical differences between the years to note how tree species (Figure 4.9), tree density (Figure 4.10), and slope position (Figure 4.11) affected PAR levels during the experiment.

Photosynthetically Active Radiation Response to Tree Species

Levels of PAR did not differ (P=0.1) between honey locust (2100000 micromoles m^{-2} hr^{-1}) and black walnut (1800000 micromoles m^{-2} hr^{-1}) (Figure 4.12), although PAR was numerically greater under honey locust compared to black walnut in 2002 (Figure 4.9). Additionally, PAR levels at toe slope positions were higher under honey locust than under black walnut, but lower under honey locust at shoulder slope positions (species X slope interaction; P=0.05) (Figure 4.13). The magnitude of the difference was greater at toe slope.

Photosynthetically Active Radiation Response to Tree Density

As planned, PAR decreased (P=0.0003) with increasing tree density (Figure 4.12). Low, medium, and high tree density sites had PAR levels of 2700000, 1800000, and 1500000 micromoles m^{-2} hr^{-1}, respectively (SE=11000). This pattern was numerically consistent in 2002 and 2003 (Figure 4.10).

Photosynthetically Active Radiation Response to Slope Position

Slope position had no overall effect (P=0.6) on PAR levels. In 2002, PAR levels at the toe slope position were numerically higher at all daylight hours, but the effect of slope position was variable and of a lesser magnitude in 2003 (Figure 4.11). Additionally, PAR levels were greater ($P \leq 0.06$) under medium and high density stands at the toe slope under honey locust compared to black walnut (slope X species X density interaction; P=0.003).

General Forage Mass Response to Microclimate Measurements: Regression

Simple linear regression analysis showed forage mass was not well correlated with soil moisture alone ($R^2=0.12$). However, strong negative correlations ($P \leq 0.0003$) were observed for forage mass and both elevated soil surface ($R^2=0.40$) and forage canopy temperatures ($R^2=0.36$) (Figure 4.14). A negative correlation between elevated soil surface temperatures and forage mass was observed in the data for low ($R^2=0.59$; $P<0.0001$), medium ($R^2=0.58$; $P<0.0001$), and high tree densities ($R^2=0.32$, P=0.0004) (Figure 4.15). Additionally, soil surface and forage canopy temperatures were highly correlated (Table 4.6), most likely because they are largely controlled by the same environmental factors. Thus, for multiple linear regression forage canopy temperature was removed from the model to prevent colinearity, and forage mass response to soil surface temperatures were applied to forage canopy temperature. Figure 4.15 shows the predicted response of forage mass to soil surface temperature and soil moisture parameters. Forage mass was not well correlated with PAR levels (R^2=0.06; P=0.9).

Discussion

Across both years, forage mass at low, medium, and high tree densities were 5280, 6130, and 4970 kg/ha, with greater (P=0.0006) production under medium density trees. Yields under black walnut were 12% greater (P=0.02) than under honey locust trees (5790 vs. 5130 kg/ha). Slope had no overall effect on forage mass in neither dry nor wet years.

Forage yield increased where soil surface temperatures and soil moisture levels were lower than the mean. These data show that forage mass was lower where soil surface and forage canopy temperatures were elevated. Furthermore, because forage mass was greater where soil moisture levels were lower than the mean, these data suggest that soil moisture measurements reflected higher levels of water usage as a result of increased forage production.

Forage mass was not well correlated with PAR levels (R^2=0.06; P=0.9), even though greatest yield was measured under medium tree density with mid PAR levels. Despite this poor statistical relationship, density significantly reduced PAR but had no effect on FCT, SST, and soil moisture from medium to high density sites. Taken in combination with lower forage mass at high density sites, these data indicate that lower yields were caused by reduced PAR levels.

FORAGE MASS RELATIONSHIP TO SOIL SURFACE TEMPERATURE

Effect of Tree Density

Forage production was greatest at medium tree density where soil surface temperatures were well moderated. Furthermore, our data show that elevated soil surface temperatures at low tree density limited forage production. Soil surface temperatures >24 °C limit cool-season forage growth (Sprague, 1943), but soil surface temperatures under medium and high tree densities were moderated. Even though soil surface temperatures at all tree densities reached levels greater than 24 °C (Table 4.4), soil surface temperatures at low tree density spent longer periods of time above 24 °C (Figure 4.4). Shading attenuates daily temperature extremes for forage grasses, and thus reduces metabolic cost of adaptation to extreme conditions (Feldhake, 2001). Because soil temperatures under high tree density were similar to those under medium density, forage production was not reduced by elevated soil surface temperatures, but most likely was limited by lower PAR levels. This is further supported by regression analysis showing that more variability in forage mass was explained by soil surface temperature for low and medium density sites than for high density sites (Figure 4.16).

Our results agree with previous studies that found greater forage production under tree canopies due to the reduction of soil surface temperatures (Eriksen and Whitney, 1981; Belsky et al., 1989; Belsky et al., 1993; Menezes et al., 2002; Silva-pando et al., 2002).

Effect of Tree Species

Tree species had very little effect on soil surface temperature. Thus, forage production differences between honey locust and black walnut were most likely due to other microenvironmental factors.

There are very few studies comparing the different effects tree species on forage production as a function of soil surface temperature. One study compared the different effects of *A. tortilis* and *A. digitata* on soil surface temperature and found that both species moderated the soil surface temperature, and that the magnitude of that moderation was similar between the two species (Belsky et al., 1993). Although our data agree with this previous study, root architecture, canopy structure, nutrient and water needs, leaf litter composition and decomposition rates, and effects on soil fertility and physical properties differ among tree species. Thus, more research is needed to examine the influence of different tree species on forage production and the microclimate.

Effect of Slope Position

Slope had no significant effect on forage production in 2002, but forage production was lower at mid slope positions in 2003. Soil surface temperatures were highest at mid slope sites during both years, but the low levels of precipitation in 2002 may have limited the expression of production differences by slope in that year. Soil moisture levels were numerically lower at mid slope positions in both seasons. The combination of lower moisture and elevated temperature due to direct interception of incident light appear to be major factors limiting forage production at these sites.

FORAGE MASS RELATIONSHIP TO FORAGE CANOPY TEMPERATURE

The relationship between forage mass and FCT is quite similar to that of forage mass and SST because both sets of temperatures were largely driven by shading (Table 4.6). However, forage production's relationship to FCT as a function of field treatments was not as strong as its relationship to SST. This may largely be a result of the inherent variability associated with the measurement. The FCT measures were highly sensitive to small changes in wind speed, ground cover, and cloud cover, and large fluctuations in values were observed within seconds.

The tightest relationship between forage mass and FCT as a function of field treatments was with tree density. Forage canopy temperatures were highest under low density trees, where forage production was reduced. Similar canopy temperatures at mid and high density sites, coupled with greater production at the mid density sites reinforce the conclusions that reduced temperatures supported greater production under medium density trees. The lower production under high tree density again suggests that reductions in temperature were offset by reductions in PAR.

Forage canopy temperatures were similar between tree species. Thus, factors other than temperature appear to drive the difference in production between the black walnut and honey locust. Possible mechanisms affecting this response include factors not measured in this experiment such as, hydraulic lift, light quality, or differences in soil ecology (Rhoades, 1997).

Although FCT were lowest at the toe slope position, the lower temperature did not appear to drive production at these sites. However, at mid slope, FCT were greater in 2003, and the elevated temperatures likely played a role in limiting forage growth at those sites.

Studies using forage canopy temperature measurements to characterize the forage microclimate are few and far between. However, due to the high correlation between forage canopy temperature and soil surface temperature, similar conclusions can be drawn relating elevated forage canopy temperature to reduced forage production.

FORAGE MASS RELATIONSHIP TO SOIL MOISTURE

No differences in soil moisture levels were found among the three tree densities in both dry (2002) and wet (2003) production seasons. Despite much concern regarding reduced soil moisture levels as a result of tree-forage competition, many studies have found no negative effects of trees on soil moisture (Gustafson, 1935; Belsky et al., 1989; Belsky et al., 1993; Feldhake, 2001; Menezes et al., 2002). Competitive partitioning may explain the apparent "lack" of competition for soil moisture between the tree crop and the forage crop (Ong et al., 1991). In this particular case, the honey locust and black walnut roots acquired water from deeper within in the soil profile, allowing the forage grasses to extract water from the upper portion of the soil. Because the trees and the grasses are extracting water from different resource pools, available resources are more efficiently utilized. Competitive partitioning for soil moisture may be responsible for the overyielding of the forage resource under medium tree density (Kurtz, 2000).

Surprisingly, slope position had no effect on soil moisture across both growing seasons. Thus, when relating soil moisture levels to forage production along the slope gradient, it appears that microenvironmental factors other than moisture are dominating forage production. This is further evident by comparing the relationship between forage mass and soil moisture (Figure 4.14). Although a positive correlation (P=0.0006) between forage mass and soil moisture was observed, soil moisture accounted for only about 10% of the variability in forage mass (R^2=0.12).

The only field treatment which influenced soil moisture levels across both growing seasons was tree species. Soil moisture levels were lower under black walnut than honey locust. However, this response was not associated with reduced forage production, but rather reflects the greater growth (and soil water use) of forage grown under black walnut trees. This is further supported by soil moisture responses to tree density in 2002, when soil moisture levels were lower at medium tree density where forage production was greatest.

FORAGE MASS RELATIONSHIP TO PHOTOSYNTHETICALLY ACTIVE RADIATION

One of the main goals of this study was to measure forage production under the three different light environments created by the three tree densities. As expected, PAR decreased with increasing tree density.

The only profound micro-environmental difference between medium and high density sites was the lower level of PAR under high density trees. This was the main factor limiting forage production at high density sites.

Levels of PAR were highest at low tree density sites, but forage production was lower. Despite adequate amounts of PAR under low tree density, elevated soil surface and forage canopy temperatures limited forage growth.

Forage production was higher at medium tree density, despite the reduction in PAR levels. Cool season forages are light saturated at 50% sunlight, (Gardner et al., 1985) so shading, within limits, is unlikely to reduce photosynthetic activity. Either the reduction in PAR was not sufficient to compromise forage production or it was offset by improvements in other microenvironmental factors. In 2002, lower PAR under black walnut (compared to honey locust) trees did not reduce forage production, further supporting this conclusion.

Summary and Conclusions

Growing trees in combination with cool-season grasses is an effective way to influence microclimate parameters to improve forage production. Our results suggest that manipulating shading with stand density (or pruning) is critical for optimizing resource capture. Although slope position did influence forage production, the response in forage growth was not well correlated with microclimate modification. Similarly, few differences in microclimate were observed between the two tree species, but results with honey locust and black walnut should not be extrapolated to other species given differences in growth and morphology.

Tree stand density had the most influence on soil surface temperature, and soil temperature appeared to be the dominant factor affecting forage production where light levels are adequate. The optimum microclimate environment for maximizing resource allocation to cool season forages occurs when tree canopies moderate soil surface and forage canopy temperatures without reducing PAR levels below that needed for cool season forage production.

Table 4.1. Forage mass response to honey locust and black walnut trees at low, medium, and high tree densities†.

	Honey Locust			Black Walnut						Species X
	Low	Med	High	Low	Med	High	SE	Species	Density	Density
	kg ha^{-1}							P value		
2002										
May	1640	2020	1430	1720	2050	1930	130	0.07	0.04	0.2
Jun	610	680	460	680	730	510	50	0.08	0.01	1.0
Jul	590	590	440	630	680	630	40	0.03	0.1	0.3
Aug	370	400	300	380	470	450	30	0.03	0.1	0.1
Nov	1110	1120	840	1320	1640	1570	60	0.02	0.04	0.01
Season	4320	4810	3470	4720	5560	5090	150	0.01	0.001	0.01
2003										
May	1500	1760	1580	1740	2140	1720	140	0.2	0.09	0.7
Jun	880	1140	880	800	920	850	50	0.1	0.01	0.2
Jul	1570	1600	1260	1360	1540	1280	80	0.3	0.01	0.4
Aug	1000	930	640	1020	1040	860	50	0.01	0.001	0.2
Sep	890	1190	870	950	1220	880	40	0.5	0.0001	0.8
Oct	150	210	150	200	470	350	30	0.01	0.005	0.04
Season	5990	6820	5380	6080	7320	5940	260	0.2	0.002	0.6
Mean	5160	5820	4420	5400	6440	5520	180	0.02	0.001	0.1

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 4.2. Forage mass response to slope position† and tree density‡ combinations.

	Toe			Mid			Shoulder						Slope X
	Low	Med	High	Low	Med	High	Low	Med	High	SE	Slope	Density	Density
	kg ha^{-1}										P value		
2002													
May	1580	1840	1480	1620	2010	1660	1840	2250	1900	150	0.3	0.04	1.0
Jun	550	620	440	690	710	490	680	780	530	60	0.3	0.01	0.9
Jul	680	680	580	600	620	540	550	610	480	50	0.6	0.1	1.0
Aug	480	480	450	360	450	380	270	370	290	40	0.04	0.1	0.7
Nov	1380	1410	1220	1170	1400	1270	1100	1320	1120	70	0.4	0.04	0.5
Season	4660	5030	4170	4460	5200	4340	4440	5340	4320	190	1.0	0.001	0.7
2003													
May	1600	1650	1490	1710	1990	1580	1550	2220	1880	170	0.2	0.09	0.4
Jun	940	1220	850	800	930	870	780	930	880	60	0.3	0.01	0.2
Jul	1570	1710	1210	1350	1370	1170	1480	1630	1420	90	0.1	0.01	0.4
Aug	1080	990	790	990	960	770	960	1020	690	60	0.7	0.001	0.6
Sep	980	1330	860	850	1110	850	940	1170	920	50	0.2	0.0001	0.2
Oct	190	410	290	150	330	270	180	260	190	40	0.2	0.005	0.5
Season	6370	7310	5490	5860	6680	5510	5880	7230	5980	320	0.05	0.002	0.6
Mean	5510	6170	4830	5160	5940	4930	5160	6280	5150	220	0.6	0.0006	0.6

† Toe = 3-5% slope at base of hill; Mid = 10-60% slope at side of hill; Shoulder = 3-5% slope at top of hill

‡ Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 4.3. Forage mass response to honey locust and black walnut trees at toe, mid, and shoulder (Sho) slope positions†.

	Honey Locust			Black Walnut						Species X Slope
	Toe	Mid	Sho	Toe	Mid	Sho	SE	Species	Slope	
	kg ha^{-1}							P value		
2002										
May	1460	1650	1990	1810	1890	2010	130	0.07	0.3	0.3
Jun	500	600	650	560	660	680	50	0.08	0.3	0.8
Jul	600	560	470	700	620	630	40	0.03	0.6	0.6
Aug	400	380	280	540	420	350	30	0.03	0.04	0.4
Nov	1080	1040	950	1590	1530	1400	60	0.02	0.4	1.0
Season	4040	4210	4340	5200	5120	5060	230	0.01	1.0	0.7
2003										
May	1700	1600	1540	1450	1920	2230	140	0.2	0.2	0.1
Jun	1120	890	880	880	840	840	50	0.1	0.3	0.3
Jul	1520	1350	1560	1470	1240	1470	80	0.3	0.1	1.0
Aug	900	880	800	1010	930	980	50	0.01	0.7	0.1
Sep	980	950	1030	1140	930	980	40	0.5	0.1	0.2
Oct	170	150	180	430	350	240	30	0.01	0.2	0.2
Season	6390	5820	5990	6390	6210	6740	330	0.2	0.05	0.6
Mean	5220	5020	5170	5790	5670	5900	220	0.02	0.6	0.9

† Toe = 3-5% slope at base of hill; Mid = 10-60% slope at side of hill; Shoulder = 3-5% slope at top of hill

Table 4.4. Average minimum (Min) and maximum (Max) soil surface temperatures for low, medium, and high densities† and average minimum and maximum air temperatures for 2002 and 2003.

		Month					
		May	Jun	Jul	Aug	Sep	Oct
	Density	°C					
2002							
Min	Low	--	--	20.5	29.1	--	--
	Medium	--	--	20.6	28.5	--	--
	High	--	--	20.5	27.2	--	--
Max	Low	--	--	31.6	38.6	--	--
	Medium	--	--	30.1	34.5	--	--
	High	--	--	30.2	35.1	--	--
Avg. Air Temp.							
Min		-1.7	6.4	11.8	7.8	5.0	1.9
Max		29.8	32.4	31.4	32.8	32.5	27.3
2003							
Min	Low	13.3	16.3	19.3	20.5	16.8	9.8
	Medium	13.7	16.5	19.5	20.6	17.2	10.7
	High	13.5	16.4	19.2	20.4	17.1	11.2
Max	Low	26.7	30.0	31.1	32.2	27.3	23.4
	Medium	22.4	27.4	28.0	28.0	24.4	21.0
	High	21.0	24.5	27.2	28.0	25.7	21.5
Avg. Air Temp.							
Min		4.8	6.4	12.2	14.9	3.2	-2.8
Max		28.4	31.2	31.4	31.3	29.3	26.6

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 4.5. Soil surface temperature response to tree densities† in July and August 2002; soil surface temperatures were higher at low density compared to medium and high density at 12PM and 3PM.

	Tree Density				
	Low	**Medium**	**High**	**SE**	**Density**
	°C				P value
July					
6AM	**20.5**	**20.6**	**20.5**	**0.2**	**0.9**
9AM	**26.2**	**26.0**	**24.6**	**0.2**	**<.0001**
12PM	**31.5**	**30.6**	**30.2**	**0.2**	**0.009**
3PM	**31.6**	**29.1**	**29.3**	**0.2**	**<.0001**
6PM	**28.4**	**27.1**	**26.8**	**0.2**	**0.0003**
August					
9AM	**29.1**	**28.5**	**27.2**	**0.2**	**0.002**
12PM	**38.6**	**34.5**	**35.1**	**0.5**	**0.001**
3PM	**35.5**	**32.4**	**31.6**	**0.5**	**0.001**

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 4.6. Pearson correlation coefficients (upper right) and significance (lower left) among response (forage mass) and regressor † variables‡.

	Variable			
Variable	**Mass**	**SST**	**FCT**	**Moisture**
Mass		**-0.6314**	**-0.6016**	**0.3484**
SST	**<.0001**		**0.9750**	**-0.7481**
FCT	**<.0001**	**<.0001**		**-0.7534**
Moisture	**0.0002**	**<.0001**	**<.0001**	

† Soil surface temperature (SST), forage canopy temperature (FCT), and soil moisture (SM)

‡ n=108

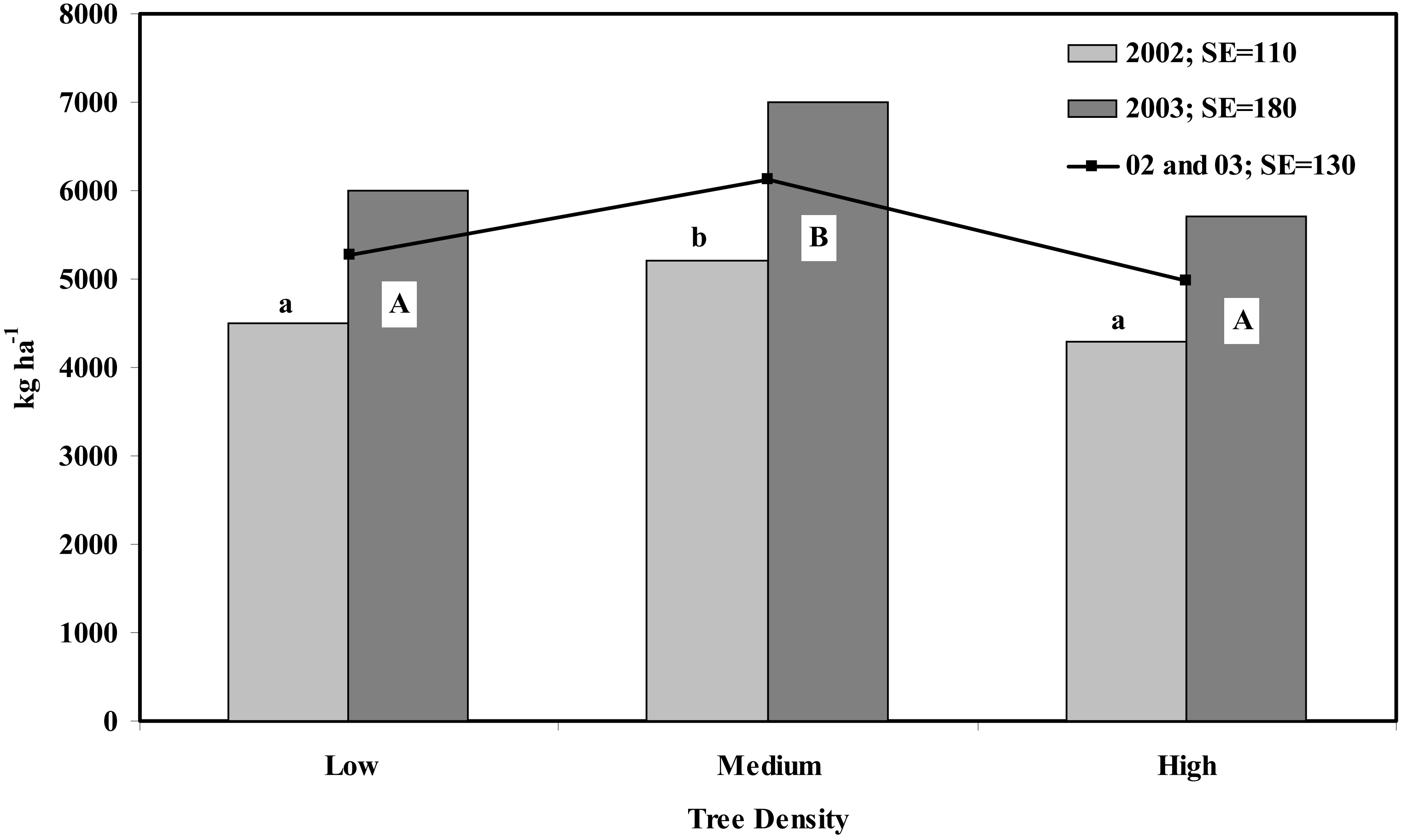


Figure 4.1. Forage mass (kg ha^{-1}) response to tree densities in 2002, 2003, and the average across both years; mean comparison within year [differentiated by lower (2002) and upper (2003) case] determined by Tukey's; means with same letter are not significantly different ($P<0.05$). Forage mass was 16% greater ($P=0.002$) at medium density in both 2002 and 2003.

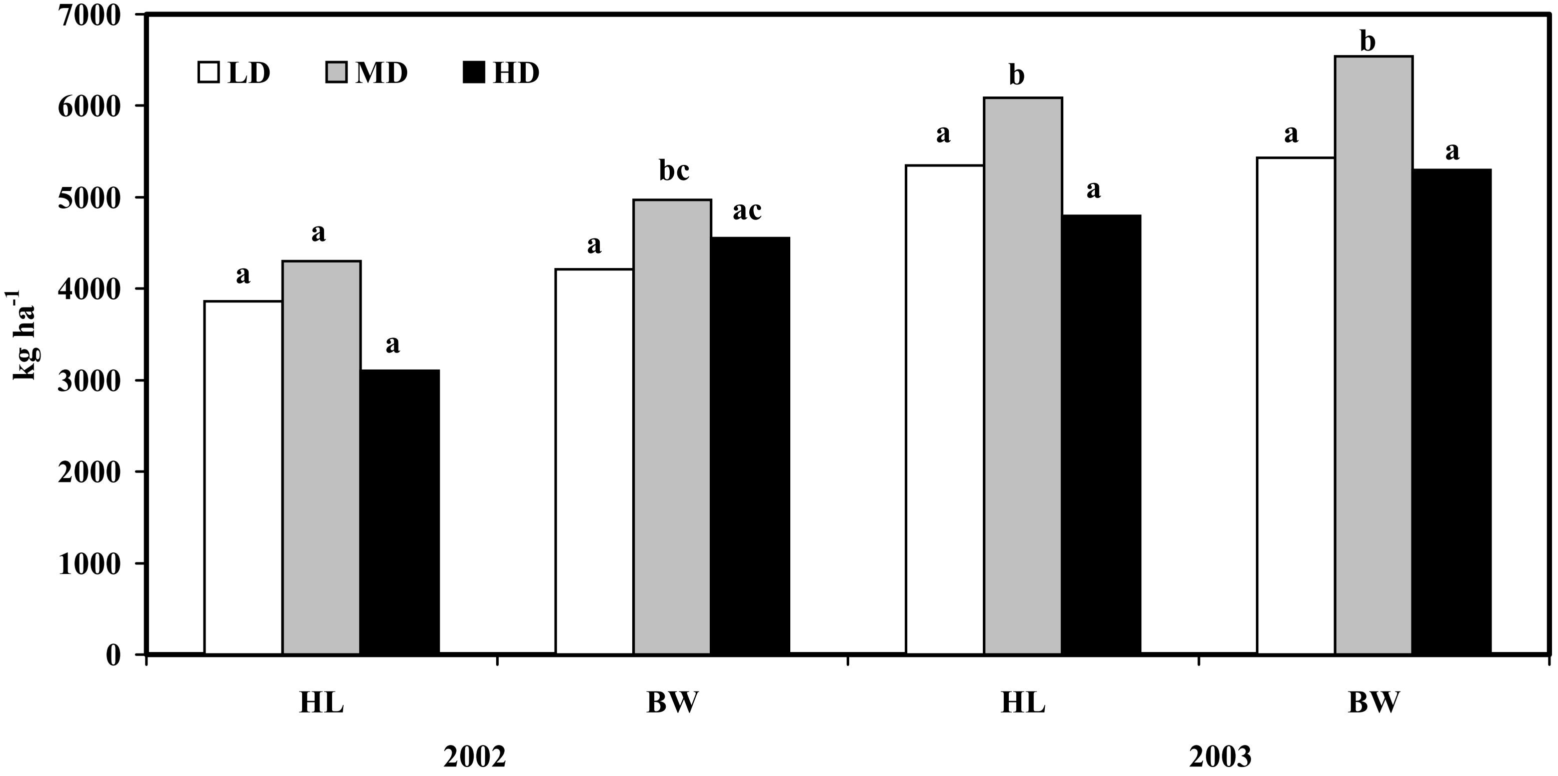


Figure 4.2. Forage mass response to honey locust (HL) and black walnut (BW) trees at low (LD), medium (MD), and high (HD) densities in 2002 and 2003; forage production was greater ($P<0.01$) under BW compared to HL in 2002 (SE=130); forage mass response varied in 2002, but was consistently greater ($P<0.02$) at medium density under both honey locust and black walnut in 2003; negative effects of high density were greater under HL compared to BW on 2002 (species X density interaction; $P =0.01$); means comparisons by species within years determined by Tukey's; means with same letter are not significantly different ($P<0.05$).

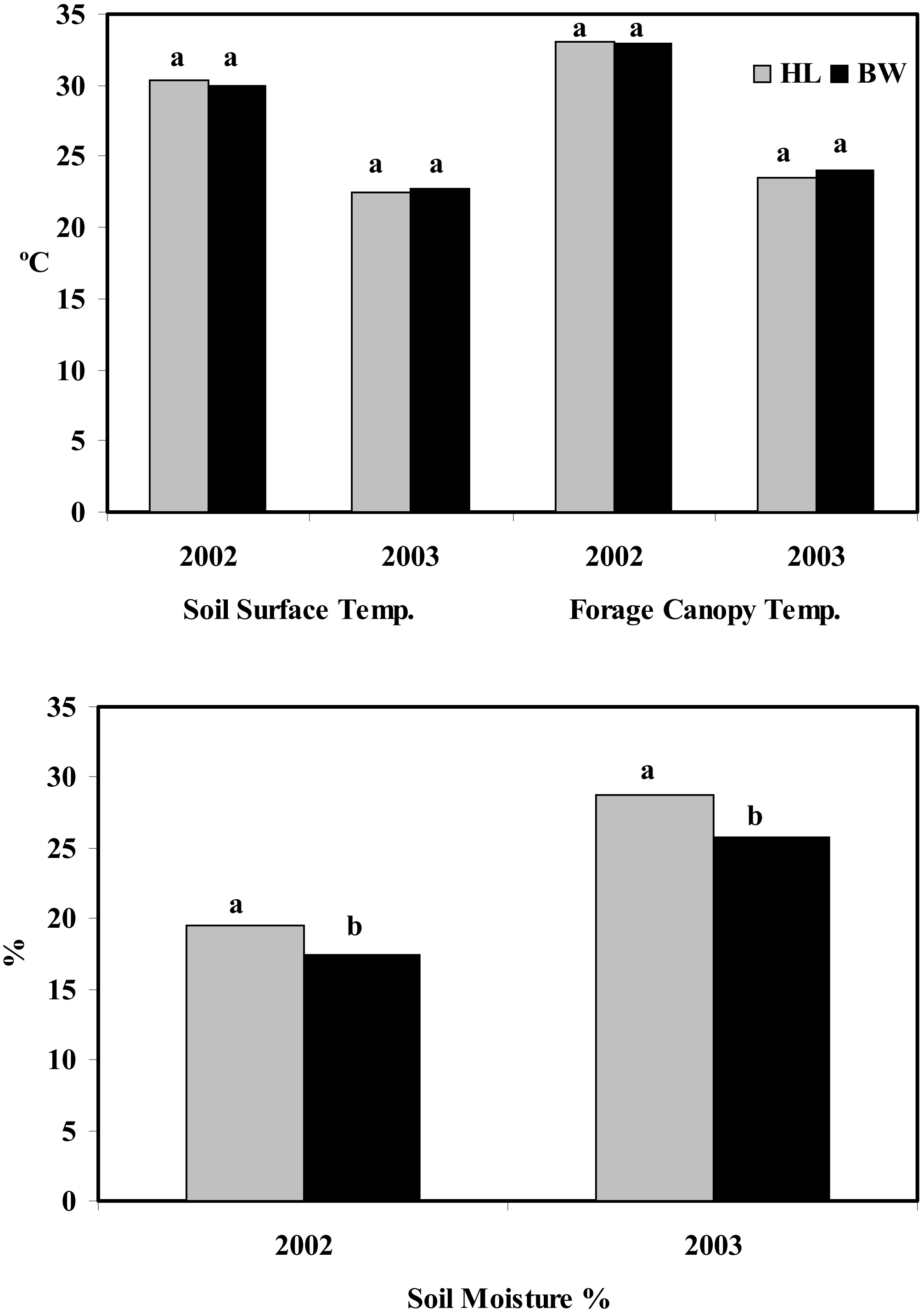


Figure 4.3. Microclimate responses to honey locust (HL) and black walnut (BW) trees in 2002 and 2003: soil surface temperature, forage canopy temperature, and soil moisture; same letters within years within each microclimate measurement are not significantly ($P<0.05$) different based on Tukey's mean separation.

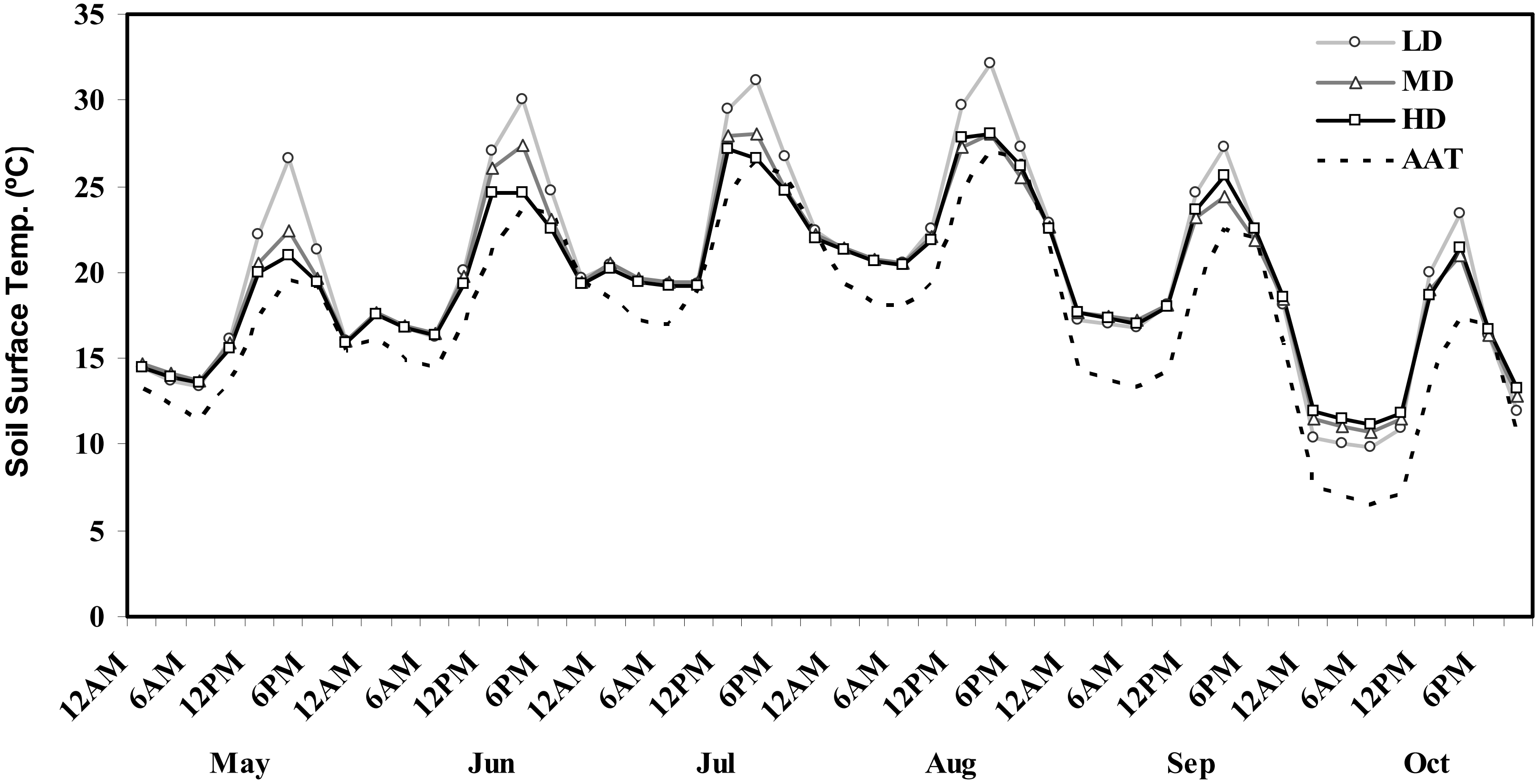


Figure 4.4. Diurnal soil surface temperatures averaged within months in response to low (LD), medium (MD), and high (HD) tree densities; measurements for each density (n=18) were taken every 3 hr. from mid May through October in 2003; AAT=ambient air temperatures; soil surface temperatures were highest (P<0.0001) at LD compared to MD and HD across the growing season.

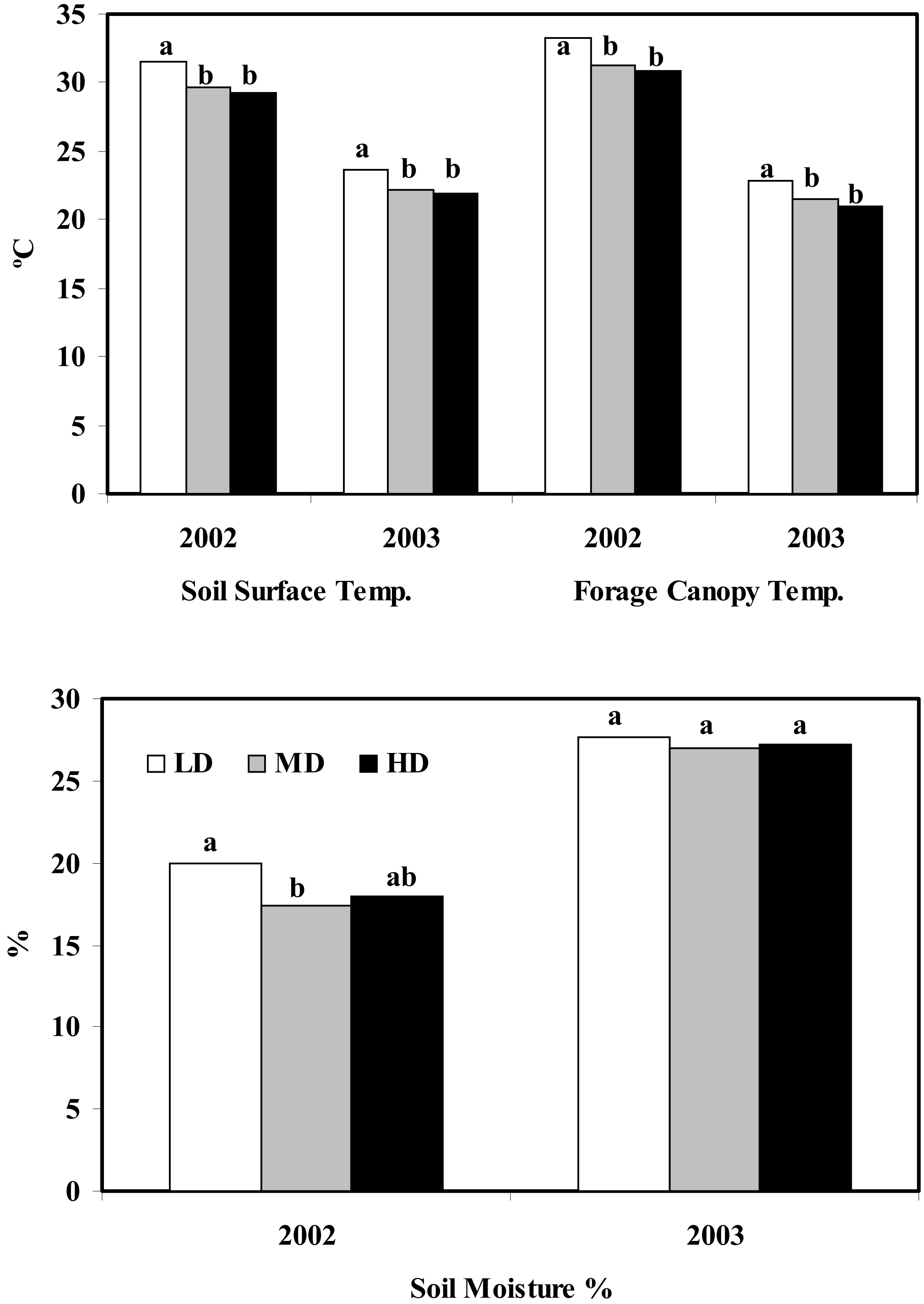


Figure 4.5. Microclimate responses to low (LD), medium (MD), and high (HD) tree densities in 2002 and 2003: soil surface temperature, forage canopy temperature, and soil moisture; same letters within years within each microclimate measurement are not significantly ($P<0.05$) different based on Tukey's mean separation.

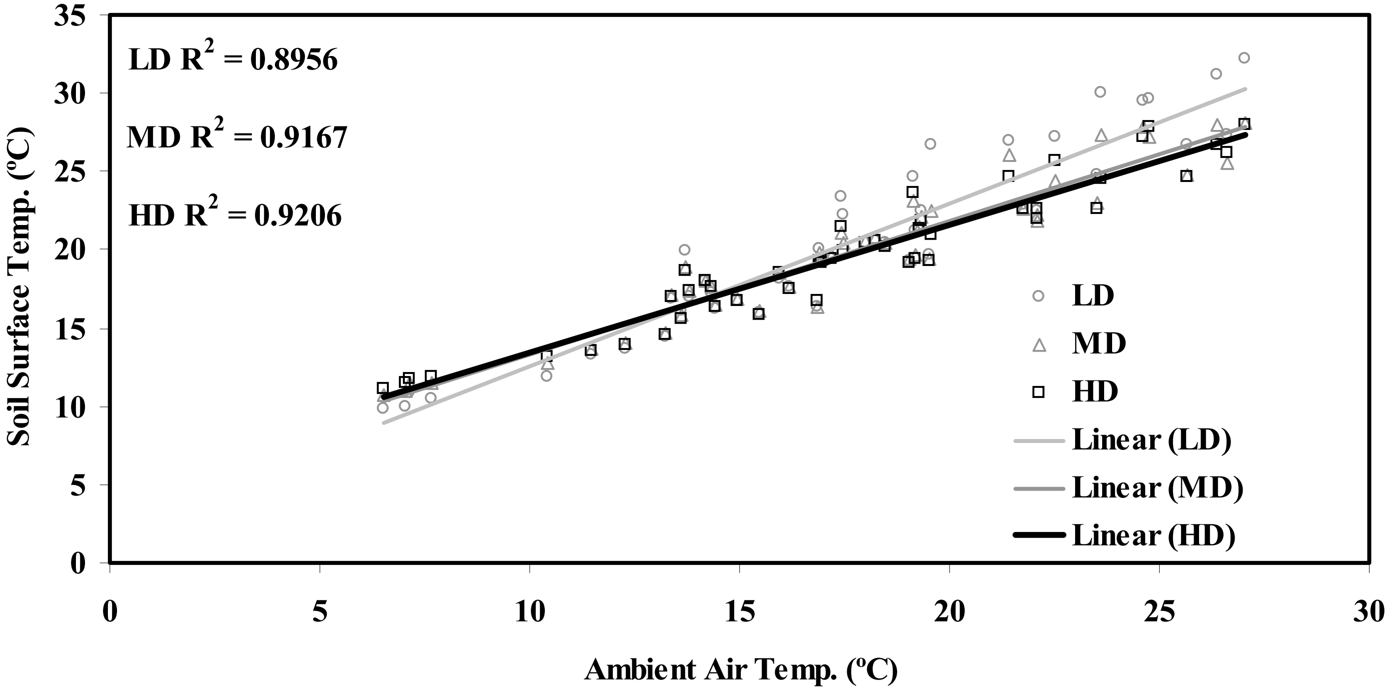
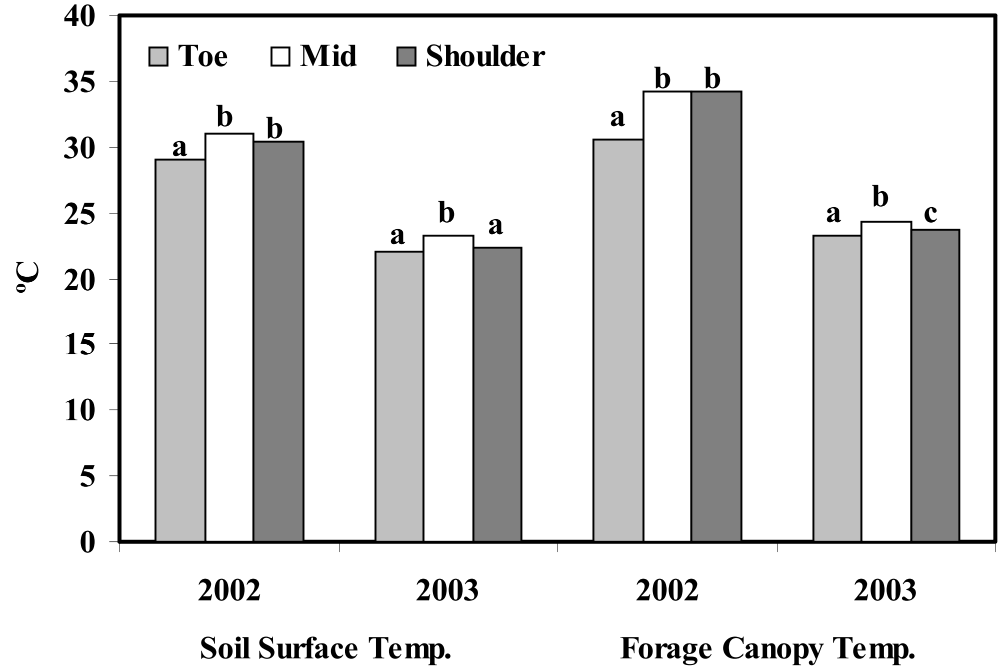


Figure 4.6. Relationship of soil surface temperature to ambient air temperature by low (LD), medium (MD), and high (HD) tree densities; R^2 values were significant ($P<0.0001$) for all densities; soil surface temperatures were better moderated at MD and HD during ambient air temperature extremes.



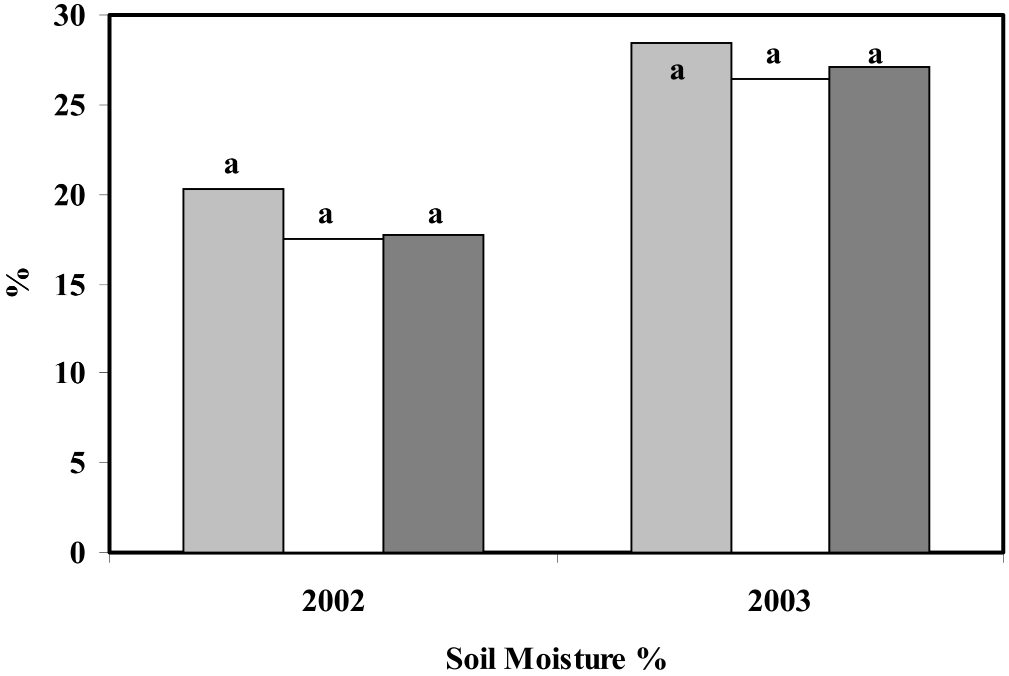


Figure 4.7. Microclimate responses to slope positions in 2002 and 2003: soil surface temperature, forage canopy temperature, and soil moisture; same letters within years within each microclimate measurement are not significantly (P<0.05) different based on Tukey's mean separation.

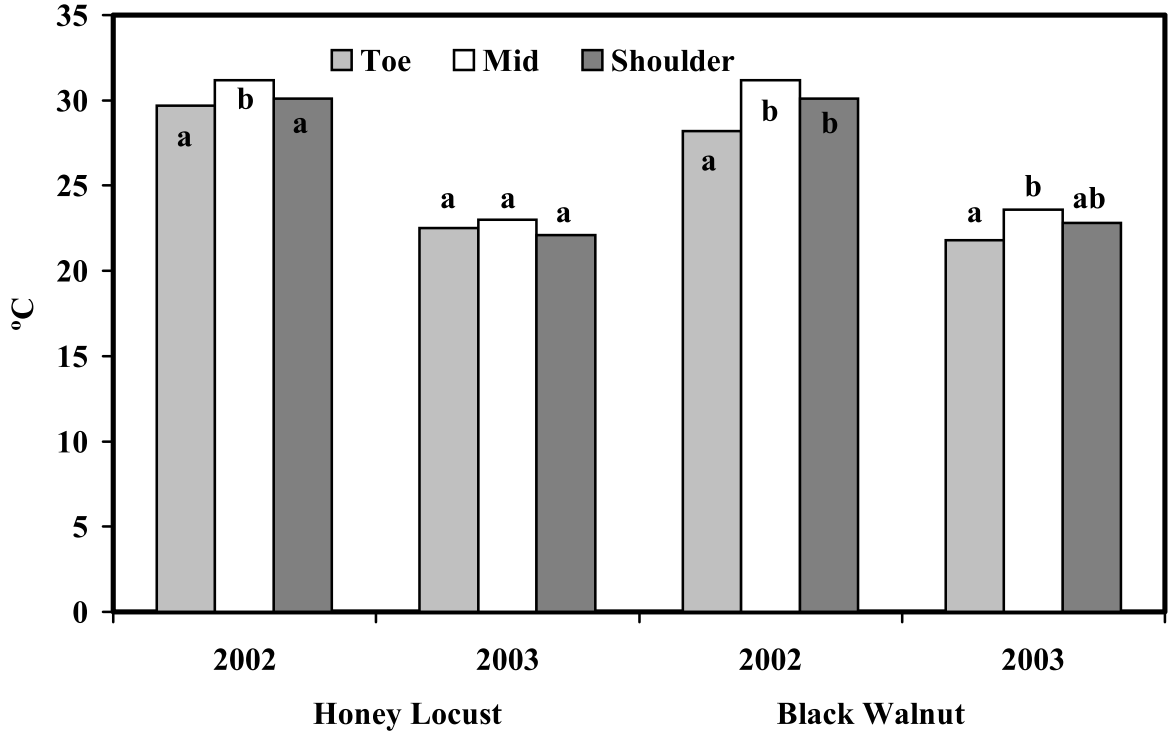


Figure 4.8. Soil surface temperature response to slope positions by tree species in 2002 and 2003; same letters within years by species are not significantly ($P<0.05$) different based on Tukey's mean separation.

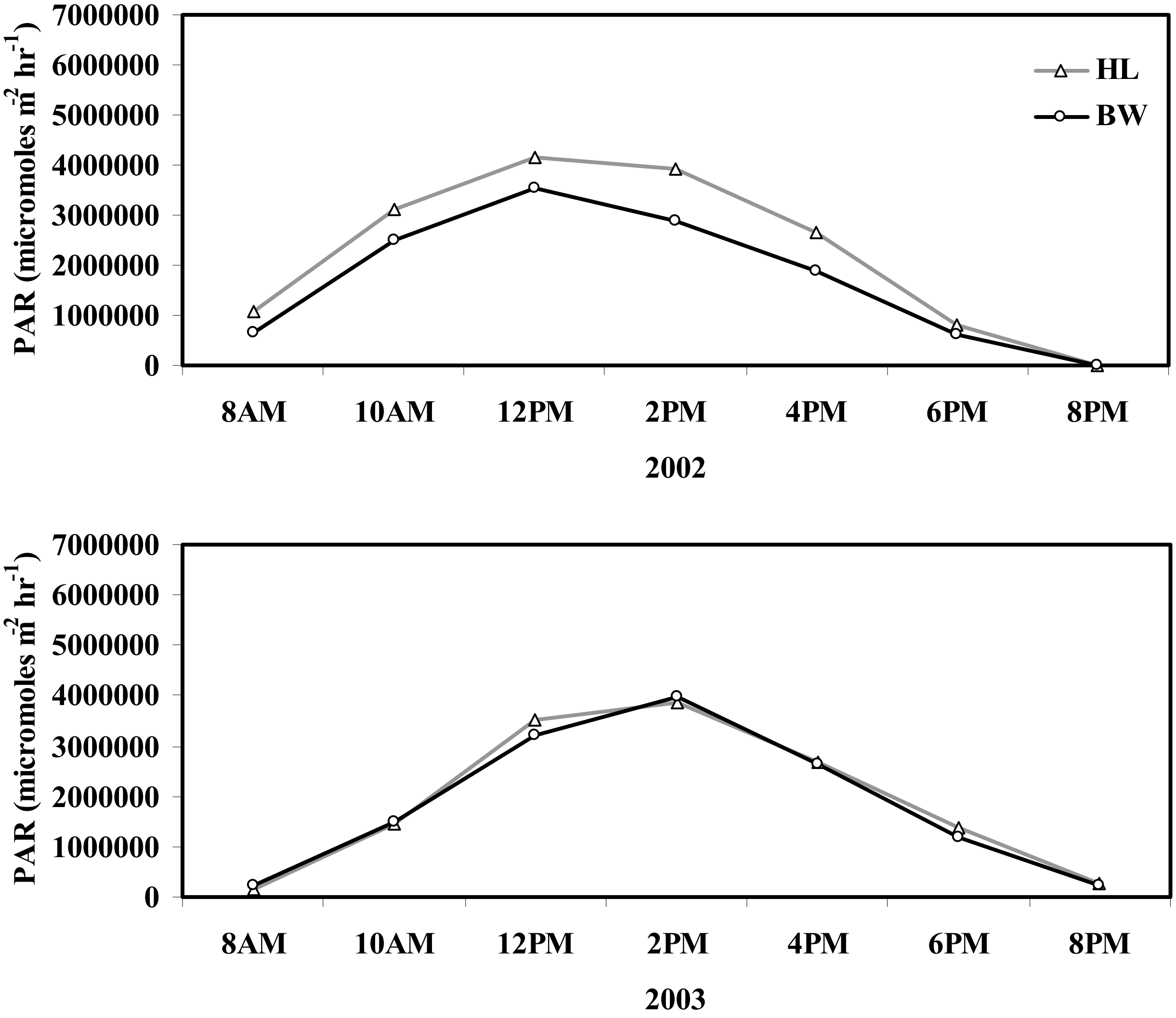


Figure 4.9. Photosynthetically active radiation (PAR) measured just above the forage canopy as affected by honey locust (HL) or black walnut (BW) trees; values averaged by time from 23-Aug through 10-Sep 2002 and 5-Aug through 21-Aug 2003.

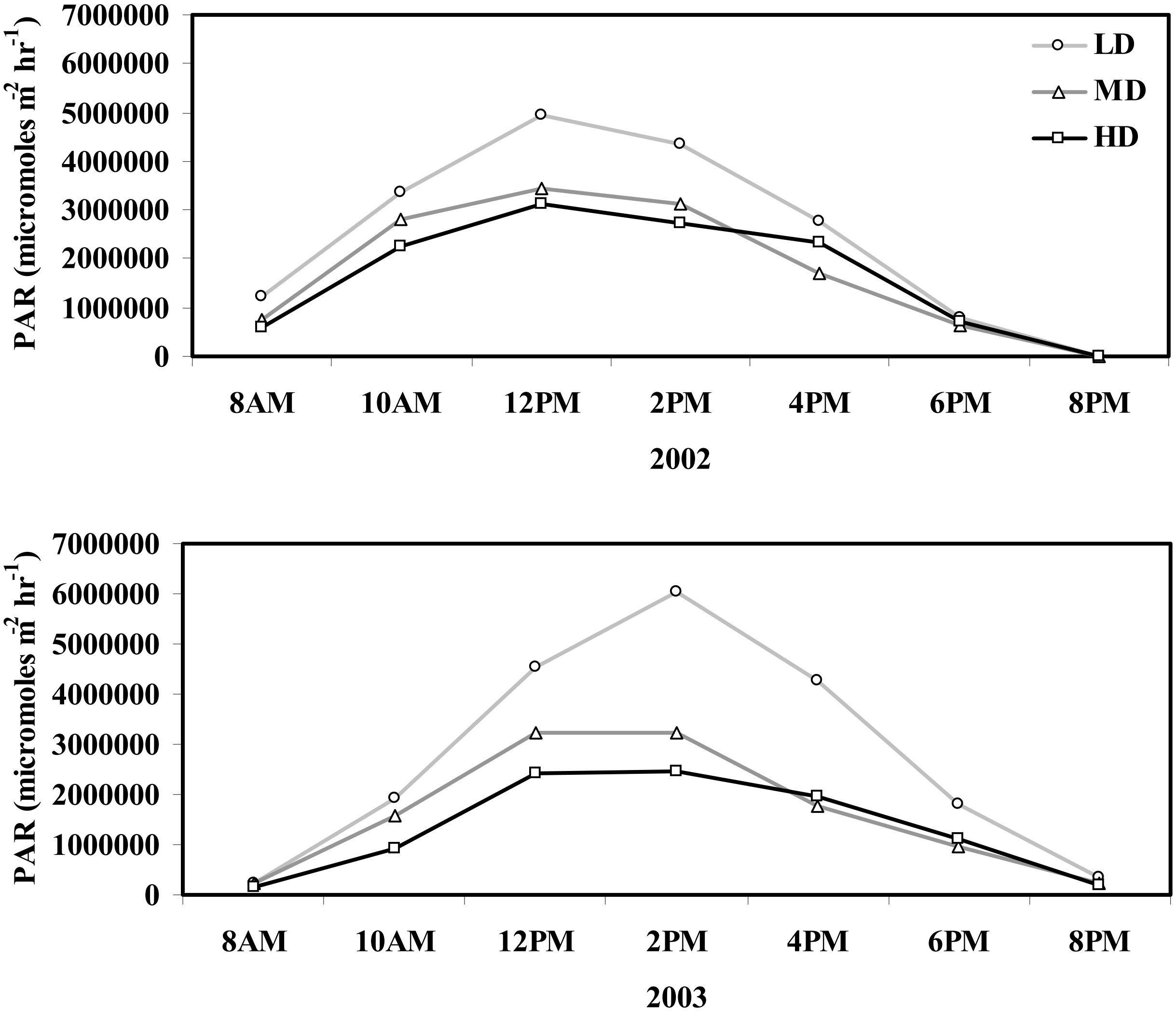


Figure 4.10. Photosynthetically active radiation (PAR) measured just above the forage canopy as affected by low (LD), medium (MD), and high (HD) tree densities; values averaged by time from 23-Aug through 10-Sep 2002 and 5-Aug through 21-Aug 2003.

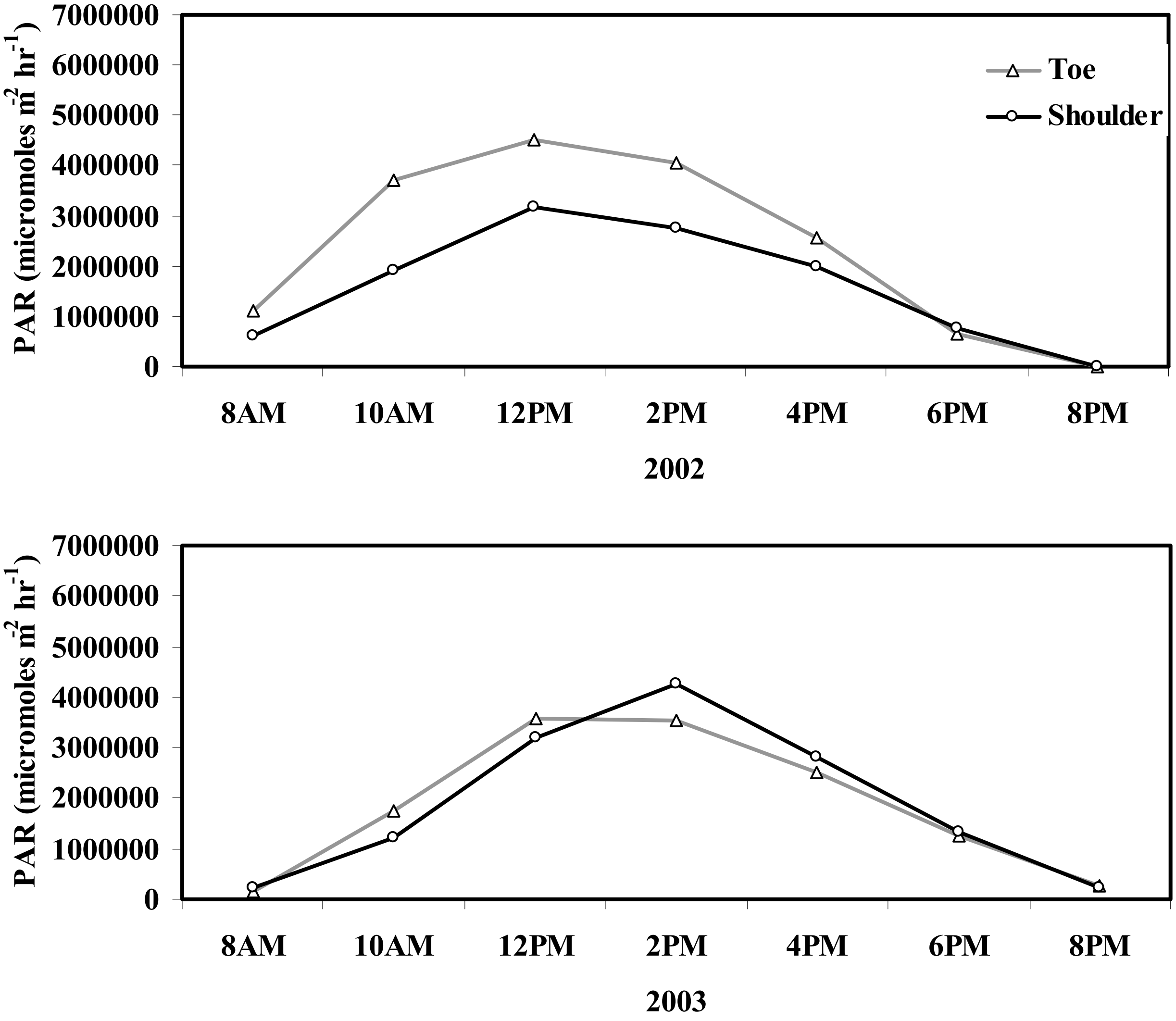


Figure 4.11. Photosynthetically active radiation (PAR) measured just above the forage canopy at to toe and shoulder slope positions; values averaged by time from 23-Aug through 10-Sep 2002 and 5-Aug through 21-Aug 2003.

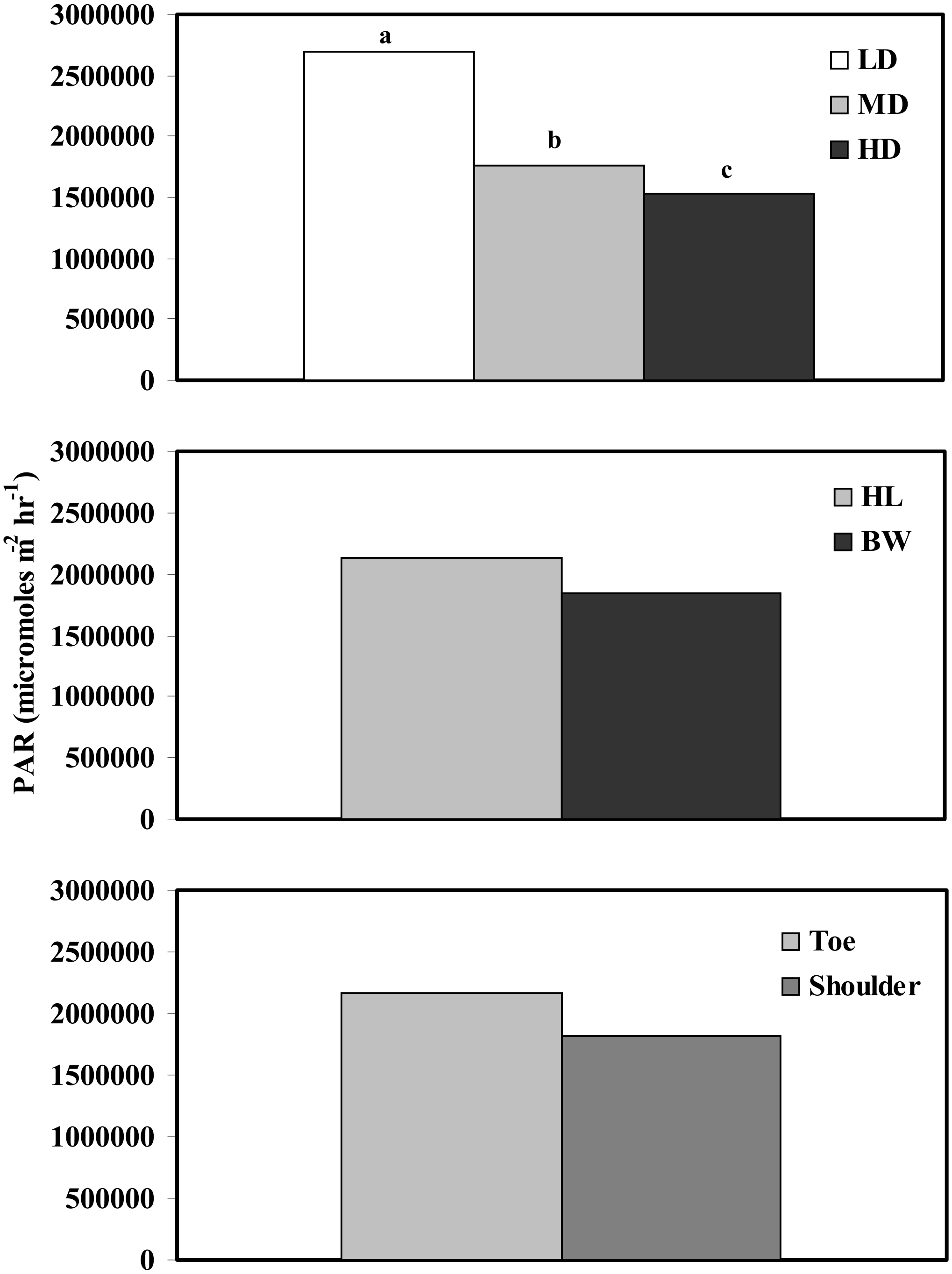


Figure 4.12. Average values of photosynthetically active radiation (PAR) in response to field treatments: low (LD), medium (MD), and high (HD) tree densities; honey locust (HL) and black walnut (BW) tree species; toe and shoulder slope positions; values with the same letter are not significantly ($P<0.05$) different based on Tukey's mean separation.

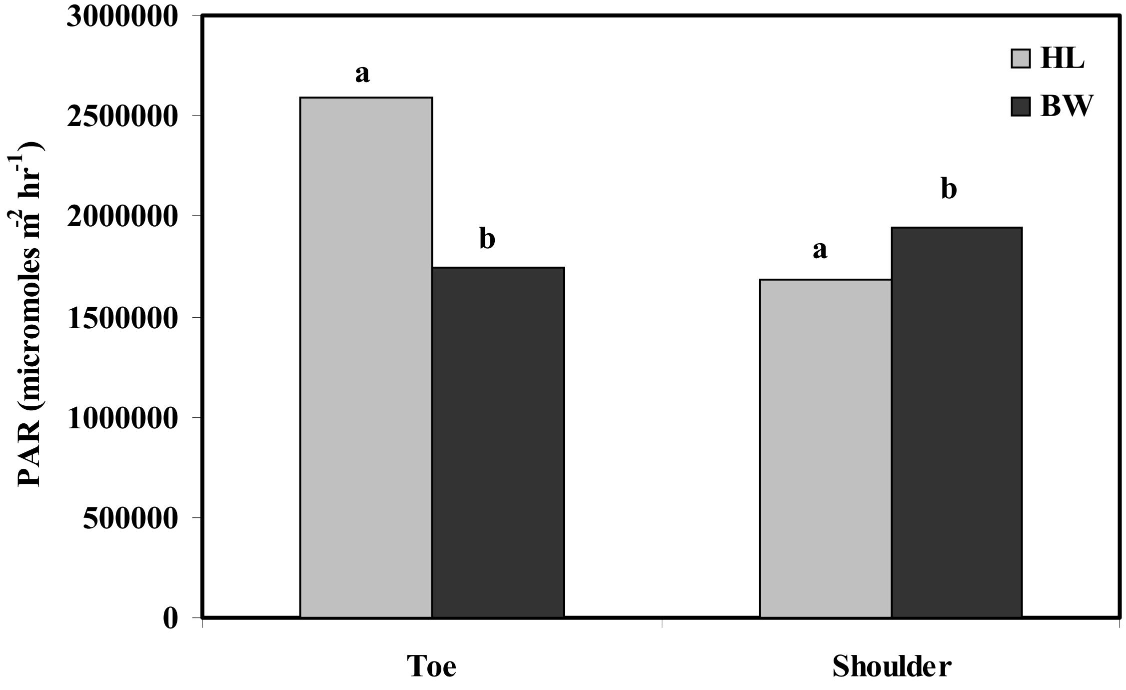
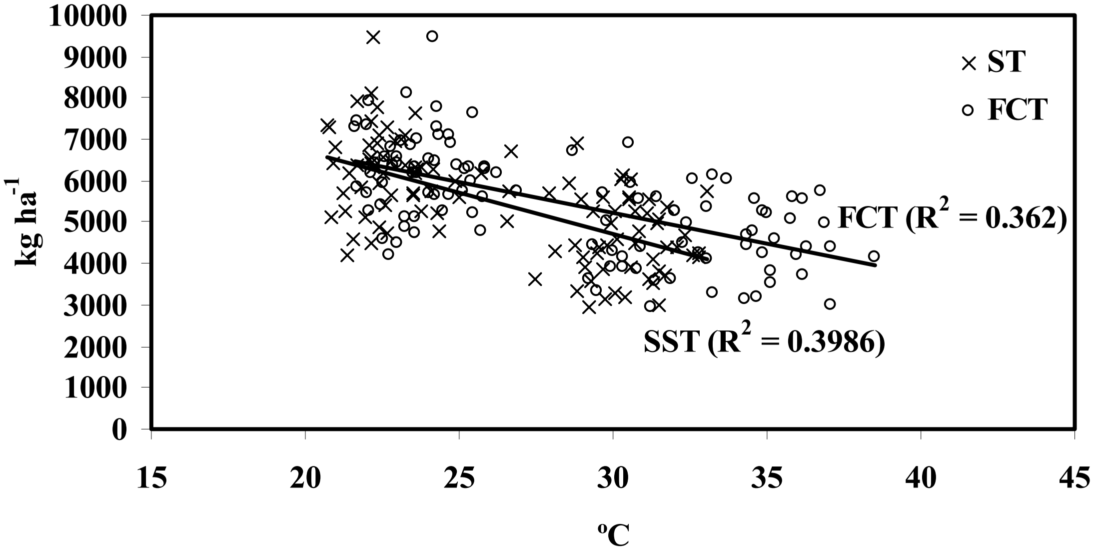


Figure 4.13. Average values of photosynthetically active radiation (PAR) in response to honey locust (HL) and black walnut (BW) trees at toe and shoulder slope positions (species X slope interaction; SE=12400); same letters within slope position are not significantly ($P<0.05$) different based on Tukey's mean separation.



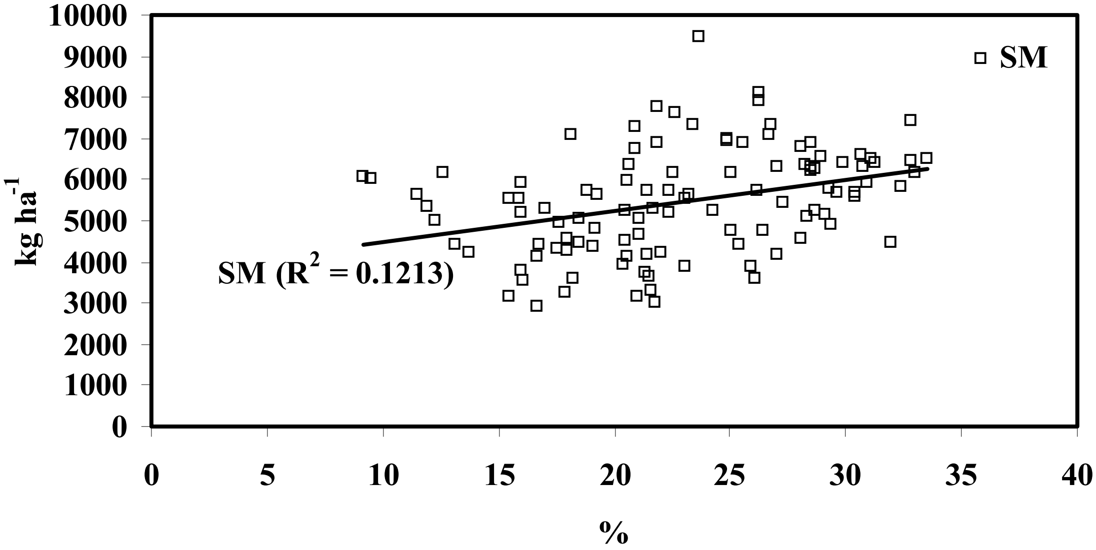


Figure 4.14. Relationship between forage mass (kg ha^{-1}) and microclimate measurements: soil surface temperatures (SST) ($P<0.0001$), forage canopy temperatures (FCT) ($P=0.0003$), and soil moisture (SM) ($P=0.0006$).

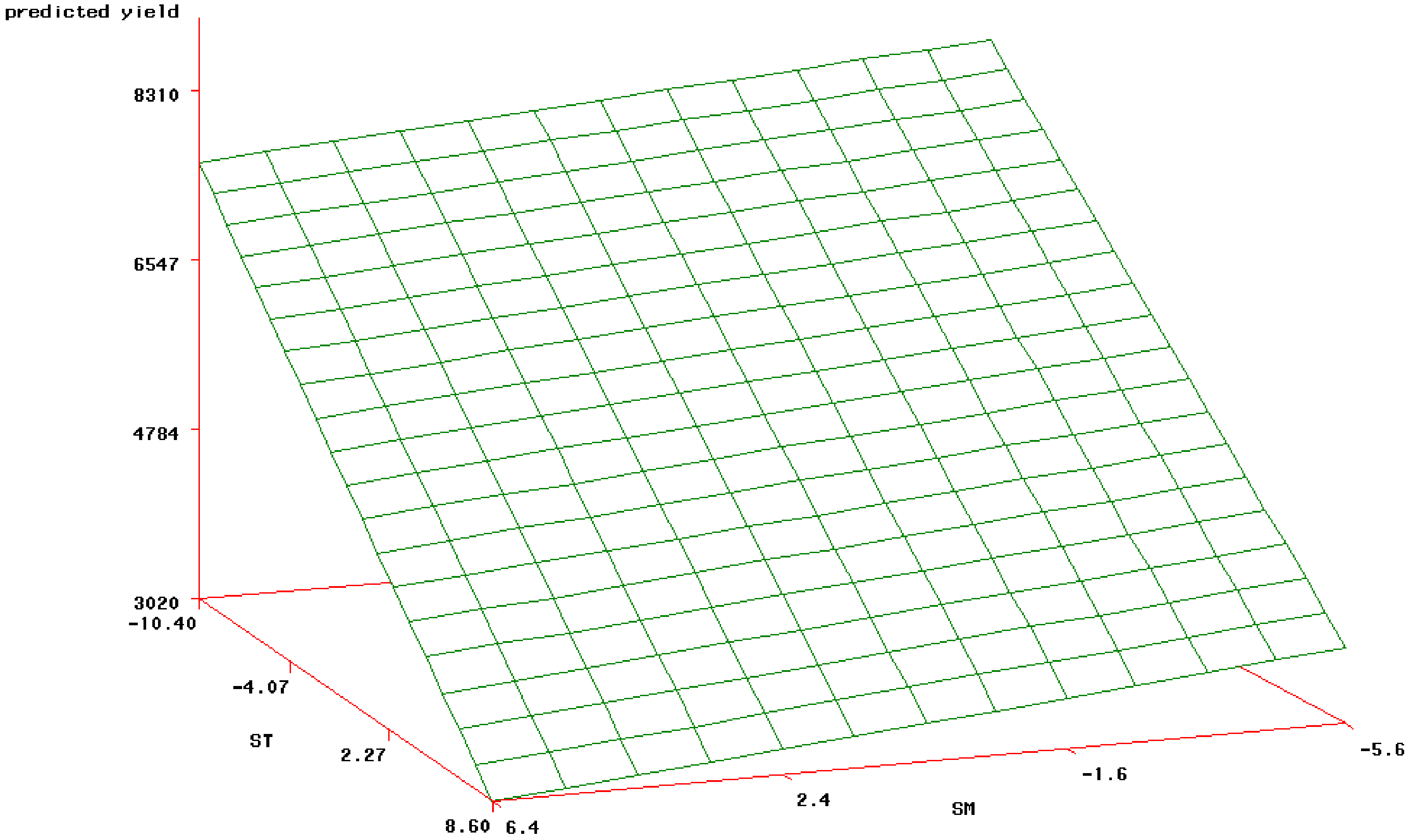


Figure 4.15. Predicted response plane for yield = 5475.15603 - 238.95763*ST - 62.44219*SM; axis 1 = soil surface temperature (ST °C); axis 2 = soil moisture (SM %); ST and SM values are centered; where ST and SM values are less than the mean (ST=26.4°C; SM=22.9%), forage yield increases.

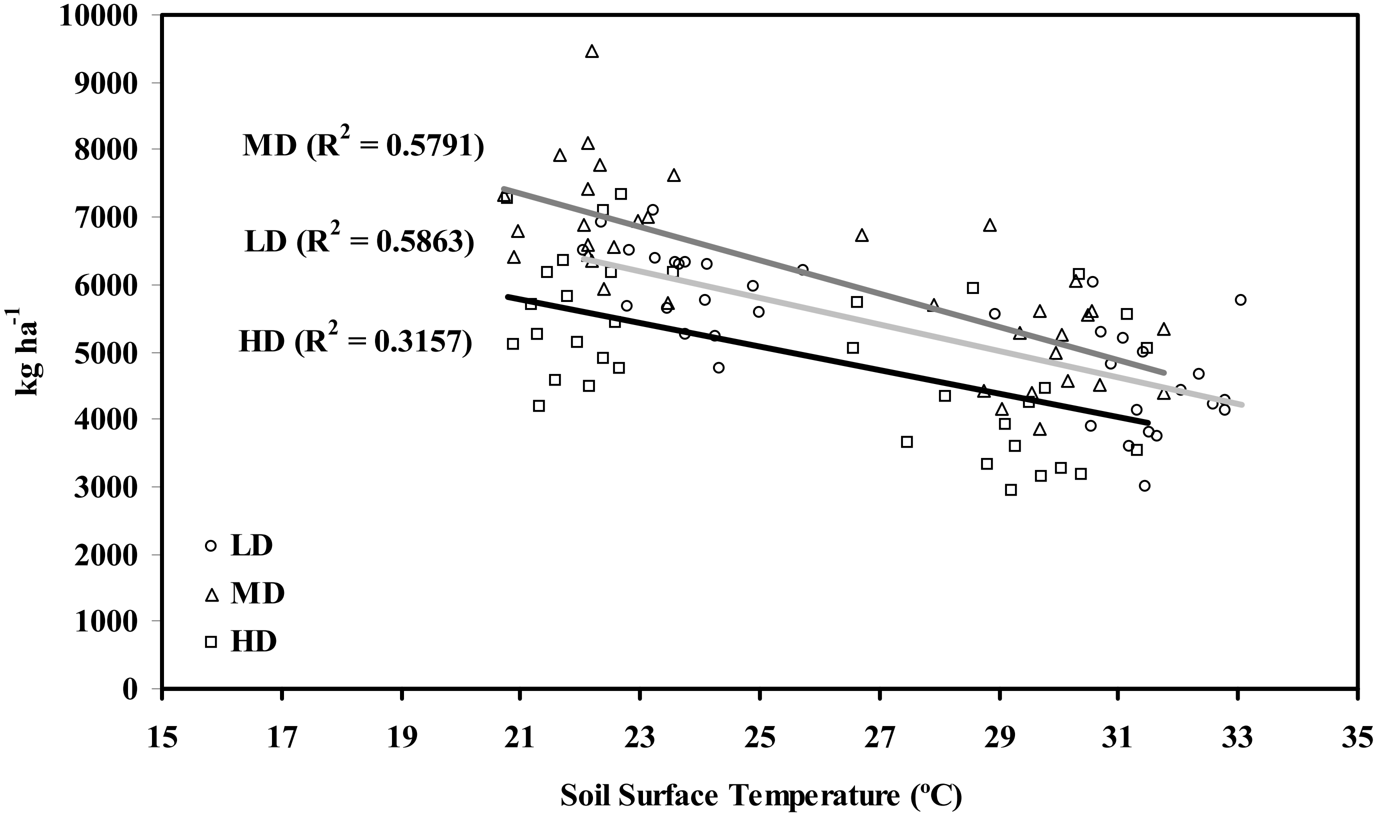


Figure 4.16. Relationship between forage mass (kg ha^{-1}) and soil surface temperatures at low (LD) ($P<0.0001$), medium (MD) ($P<0.0001$), and high (HD) ($P=0.0004$) tree densities.

Chapter 5: Cool-Season Forage Nutritive Value in a Temperate Silvopasture

Abstract

Integrating trees into pasture may be an effective management tool to improve resource allocation (i.e. temperature, water, light) and increase total system productivity in temperate Appalachia. In 1995, black walnut and honey locust trees were planted within plots (r=3) of predominantly tall fescue pasture. In each plot, four rows of each tree species were planted down a 12% slope with spacings of 1.8, 3.7, and 14.6 m within rows and 3.7, 7.3, and 14.6 m between rows. Spacings created field treatments of low, medium, and high tree densities at shoulder, mid, and toe slope positions within plots of honey locust and black walnut. Forage sampling sites (n=54) under field treatment combinations were harvested May to October at 35-d intervals in 2002 and 2003. Neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), crude protein (CP) and total non-structural carbohydrate (TNC) were determined by wet chemistry and/or near infrared reflectance spectroscopy. Soil surface temperature (SST), forage canopy temperature (FCT), soil moisture, and photosynthetically active radiation (PAR) were measured at field treatment combinations. The objective of this study was to determine forage nutritive value response to the field treatments as a function of resource allocation.

Across both years, NDF decreased (P=0.001) with increasing tree density and was lower (P=0.06) at toe slope positions. Field treatments had no overall affects on ADF and CP, but greater tree density increased (P<0.0001) ADL levels. Concentrations of TNC reflected levels of PAR. Levels of TNC decreased (P<0.0001) with increasing tree density, but were greater (P=0.04) under honey locust trees, and increased (P=0.05) from toe to shoulder slope.

Greater ($P \leq 0.02$) SST and FCT were observed under low density trees and at mid slope positions. Soil moisture levels were greater ($P < 0.001$) under honey locust trees. Levels of PAR decreased ($P = 0.0003$) with increasing tree planting density. Elevated SST and FCT may have increased NDF levels at low density sites, and at mid and shoulder slopes. Low light levels may have reduced TNC while simultaneously increasing ADL under medium and high density trees. Neutral, positive, and negative effects on forage nutritive value were mainly driven by the effects of tree density.

Hypothesis

Incorporating trees into pasture benefits resource capture for cool-season forages in a temperate Appalachian silvopasture and will thus improve forage nutritive value.

Objectives

1) To evaluate nutritive value (neutral detergent fiber, acid detergent fiber, crude protein, total nonstructural carbohydrate, and lignin) of cool-season pasture in response to field treatments: tree species, tree density, and slope;
2) To measure effects of tree species, tree density, and slope on microclimate responses ;
3) To determine the relationships between microclimate modifications and forage nutritive value;
4) To relate field treatments to nutritive value as a function of specific microclimatic factors.

Materials and Methods

Nutritive value:

Forage samples were ground to pass a 1 mm screen with a hammer mill (Christy-Norris, North Lincolnshire, U.K.). Neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), crude protein (CP) and total non-structural carbohydrate (TNC) were determined by near infrared reflectance spectroscopy (Foss NIRSystem 6500M, Silver Spring, MD, USA) (Deaville and Flinn, 2000). Samples were scanned with near infrared radiation from 1,100 to 2,500 nm, and log (1/reflectance) was recorded. A stepwise multiple regression equation was generated for each forage constituent using the program SUBSET. Optimum equations were selected based on low standard errors of calibration and validation, and high coefficients of determination for calibration (r^2) and performance (r^2). These were derived by regressing predicted data against actual data using a subset of forage samples. Samples for calibration subsets for each assay were selected by WIN ISI Winscan software version 1.5 (Infrasoft International LLC, Port Matilda, PA). The validation accuracy was evaluated with high values of one minus the variance ratio and low standard errors of cross validation (Table 5.1).

For the calibration set, a subset of samples was analyzed by wet chemistry. Concentrations of NDF, ADF, and ADL were determined sequentially with an ANKOM fiber analysis system. Samples were analyzed in duplicate and a 3% coefficient of variation between samples was the critical limit for repeating the analysis. Forage CP concentrations were determined at the Virginia Tech Forage Testing Laboratory using Kjeldahl 2400 with a Foss

Tecator (AN 300, AN 3001, Sweden). Procedures of Dension et al. (1990) were used for determination of TNC.

NIRS calibration and validation statistics for NDF, ADF, TNC, CP, and ADL are presented in Table 5.1. Prediction equations for each analyte were based on harvests over both growing seasons.

Results

NDF

Concentrations of NDF were higher ($P<0.0001$) in 2002 compared to 2003 (49.6 vs. 44.5; SE=0.2) (Figure 5.1). The 2002 growing season was warm and unusually dry, while 2003 was characterized by abundant rainfall and cool growing conditions.

NDF Response to Tree Species

Across both growing seasons, tree species did not affect ($P=0.9$) NDF levels (Table 5.2). However, there was a species X year interaction ($P=0.004$) because in 2002 forage grown under honey locust had greater ($P\leq0.05$) NDF concentrations than that grown under black walnut at May, August, and November harvests (species X date interaction; $P<0.0001$). Conversely, NDF concentrations were lower ($P\leq0.02$) in forage from under honey locust trees at harvests in June, July, and October of 2003 (species X date interaction; $P<0.0001$).

NDF Response to Tree Density

Neutral detergent fiber decreased ($P=0.001$) with increasing tree density (48.2, 47.0, and 45.9% for low, medium, and high density, respectively; SE=0.3) (Table 5.2). Under black walnut, NDF was higher ($P=0.002$) at low density (49%) compared to medium (46.8%) and high

(45.2%) density (SE=0.5; species X density interaction; P=0.02). Under honey locust, NDF was not different (P=0.4) among low (47.5%), medium (47.3%), or high (46.6%) tree densities

In August and November of 2002, NDF concentrations were greater (P≤0.03) at low density compared to medium and high density plantings (density X date interaction; P=0.005). In 2003, NDF was lower (P=0.008) at high density compared to medium and low density plantings in July, but decreased (P≤0.002) with increasing tree density in August and September (density X date interaction; P<0.0001).

NDF Response to Slope Position

Forage from toe slope positions tended (P=0.06) to have lower NDF concentrations over both years (45.0 vs. 48.0 and 48.2% for toe, mid and shoulder slope positions, respectively; SE=0.7) (Table 5.3). In 2002, this response was more pronounced (P≤0.03) at June and August harvests (slope X date interaction; P=0.001).

ADF

Concentrations of ADF were greater (P=0.04) in 2002 than in 2003 (25.6 vs. 25.3%; SE=0.08). However, this difference is too small to be of biological relevance.

ADF Response to Tree Species

Tree species did not affect (P=0.4) ADF concentrations over years. However, ADF concentrations from honey locust plots were greater (P=0.03) in 2002 but tended (P=0.10) to be lower in 2003 when compared with forage grown under black walnut (species X year interaction; P=0.0002). The greater ADF under honey locust in 2002 (26.1 vs. 25.0%; SE=0.6) primarily reflects much greater (P=0.001) ADF concentrations in forage from under honey locust plots at the August harvest (27.6 vs. 24.4%; SE=0.3) (species X date interaction; P<0.0001) when drought caused premature leaf drop for that species. In 2003, ADF concentrations were lower (P=0.007) in forage from under honey locust than black walnut trees (22.8 vs. 25.5%; SE=0.3) at the October harvest (species X date interaction; P<0.0001).

Response to species also differed with tree density. In 2002, ADF levels at both high (26.5 vs. 24.8%) and medium density plantings (26.3 vs. 24.8%) were greater in forage from under honey locust than black walnut (species X density interaction; SE=0.2; P=0.02). The percentage unit increase in forage ADF from medium and high density sites under honey locust in August was about twice that observed at other harvests (species X density X date interaction; SE=0.4). No such interactions were observed in 2003 (species X density X year interaction (P=0.05).

ADF Response to Tree Density

Tree density had no effect (P=0.5) on ADF across both years (Table 5.4). Although seasonal ADF concentrations were not affected by tree density, ADF concentrations were reduced (P=0.02) with increasing tree density at the August 2003 harvest (25.9, 25.4, 24.3% for low, medium and high density sites, respectively; SE=0.3; density X date interaction; P<0.0001). Conversely, ADF concentrations increased (P=0.001) with increasing planting density (22.3, 24.1, 26.0%; SE=0.4) at the October harvest.

ADF Response to Slope Position

Slope position had no effect (P=0.1) on ADF levels over both growing seasons (Table 5.5). In 2002, ADF levels in forages grown at the toe slope (24.7%) were lower (P=0.02) than concentrations from mid (26.0%) and shoulder slope (25.9%) positions (SE=0.2). This response was strongest at the June and July harvests, but the numeric pattern was the same for all but the November harvest (slope X date interaction; P<0.0001).

Although the numeric pattern of response was similar in 2003, changes in ADF due to slope were not significant (P=0.4). Concentrations of ADF were lower (P=0.04) at toe slope positions in May and tended (P≤0.10) to be lower in June and July (slope X date interaction; P=0.006).

CP

Crude protein concentrations were greater (P<0.0001) in 2003 compared to 2002 (12.9 vs. 15.0%; SE=0.1).

CP Response to Tree Species

Tree species had no effect (P=0.1) on CP over both growing seasons. However, in 2002, CP levels were lower (P≤0.01) under honey locust at July and August harvests, while in 2003, CP levels were consistently lower (P=0.02) under black walnut (14.5 vs. 15.5%; SE=0.2; species X year interaction; P=0.01).

In 2002, CP levels were the same under low density plantings of each species in July and August. However, CP increased with increased tree density under black walnut and decreased with density under honey locust (species X density interaction; P<0.0001) (Table 5.6). At medium and high density plantings, CP was 11 and 19% greater under black walnut trees over the two harvests. This pattern switched at the November harvest: CP concentration was greater (P=0.02) under honey locust than black walnut (14.1 vs. 13.5%; SE=0.2) and under high density plantings (14.2 vs. 12.6%; SE=0.3; species X density interaction; P=0.02).

CP Response to Tree Density

Tree density did not affect (P=0.5) CP concentrations in 2002. In May of 2003, CP levels were lower (P=0.04) in forage from low (12.4%) density sites as compared to forage from medium (13.4%) and high density sites (13.7%; SE=0.3; density X date interaction; P=0.0002) (Table 5.6).

CP Response to Slope Position

Slope had no overall effect (P=0.2) on CP across both seasons, but CP concentrations were lower (P=0.04) at mid slope (12.6%) compared to toe (13.3%) and shoulder (13.0%; SE=0.1) slope positions in 2002 (Table 5.7). Crude protein concentrations were greater (P= 0.003) at toe slope positions at the August 2002 harvest. For 2002, the pattern held for all but the November harvests, when CP was lowest at the toe slope and highest at the shoulder slope positions (13.3, 13.6, and 14.5%; SE=0.2; slope X date interaction; P<0.0001). Similar, but non-significant (P=0.2) patterns for CP in response to slope were observed in 2003.

TNC

Concentrations of TNC were lower (P=0.04) in 2002 compared to 2003 (8.5 vs. 8.8%; SE=0.1), but it is likely that the difference is of limited biological relevance (Table 5.8).

TNC Response to Tree Species

Across both years, TNC was higher (P=0.04) under honey locust compared to black walnut (9.0 vs. 8.3%; SE=0.1). Although not significant (P=0.7) in 2002, the reduction in TNC concentration with increasing tree density was less under honey locust than under black walnut in 2003 (species X density interaction; P<0.0001) and over years (species X density X year interaction; P=0.03) (Table 5.8).

Tree species did not affect (P=0.7) seasonal TNC levels (8.5%) in 2002, but TNC concentrations were greater under honey locust (9.6 vs. 8.0%; SE=0.3) across the 2003 growing season (species X year interaction; P=0.0005). Under black walnut trees, forage TNC concentrations were similar or greater than under honey locusts at May and June harvests but then typically lower through the summer and into the fall (species X date interaction; $P<0.0001$). An exception was the August 2002 harvest, when TNC concentrations were lower ($P=0.06$) for forage grown under locust trees, perhaps due to early leaf drop

In 2003, the significance in reduction of TNC with increased tree density grew stronger in forage from under black walnut trees from the July harvest (species X density X date interaction ($P<0.0001$). Decline in TNC with increased density under black walnut was particularly severe at the October harvest.

TNC Response to Tree Density

Across both years, TNC decreased ($P<0.0001$) with increasing planting density (9.9, 8.3, and 7.8% for low, medium, and high density; SE=0.07). From low to high tree density, concentrations of TNC dropped 12% (9.2 vs. 8.1%) in 2002 vs. a 29% decrease (10.6 vs. 7.5%) in 2003 (density X year interaction; $P=0.003$). The greatest decrease in TNC was typically from low to medium tree density, and frequently little difference in TNC were observed when comparing medium to high density (Table 5.8). Exceptions in which TNC concentrations were further reduced with density occurred at June 2002 and July and September 2003 harvests, resulting in density X date interactions ($P\leq0.05$) in each year.

TNC Response to Slope Position

Across the two years, TNC increased ($P=0.05$) up the slope (8.3, 8.8, and 8.9%) for toe, mid, and shoulder slope positions; SE=0.1) (Table 5.9). Concentration of TNC did not change ($P=0.8$) with slope in 2002 but increased ($P=0.005$) from toe (8%) to mid (9%) and shoulder (9.5%) positions over the 2003 growing season (SE = 0.1; slope X year interaction; $P=0.008$).

Slope position had little effect on TNC during the first three harvests of 2003. However, average TNC levels at mid and shoulder slope positions were about 25% greater than those at the toe slope during the final three harvests of 2003 (slope X date interaction; P<0.0001).

Increased (P=0.01) TNC concentrations for forage from mid and should slope positions (relative to toe slope positions) were observed with both low and mid density trees. However, under high density plantings, TNC levels were similar for toe and mid slope positions and greater at the shoulder slope (slope X density interaction; P=0.03).

ADL

Levels of ADL were lower (P<0.0001) in 2002 than in 2003 (2.4 vs. 2.9%: SE=0.04).

ADL Response to Tree Species

Tree species did not affect (P=0.1) ADL across years, but in 2002 ADL was greater (P=0.003) in forage from under honey locust than from under black walnut trees (2.8 vs. 2.1%; SE=0.07; species X year interaction; P<0.0001). Though species was not significant over the 2003 harvest season, ADL in forage from under honey locust was greater (P≤0.02) than that from under black walnut trees at the June and July harvests, but lower than that from under black walnut in October (species X date interaction; P<0.0001).

In 2002, levels of ADL increased with increased tree density to a greater degree under honey locust than under black walnut (species X density interaction; P <0.0001) (Table 5.10). The interaction was significant (P <0.0001), but the pattern was reversed in 2003 (species X density X year interaction; P=0.0004).

ADL Response to Tree Density

Across both years, ADL increased (P<0.0001) with increasing tree density (2.1, 2.7, and 3.2%; SE=0.04). In both years, the strength of this response increased further into the season (density X date interaction; P <0.00010 (Table 5.10).

ADL Response to Slope Position

Slope position had no effect (P=0.08) on ADL levels over both years, but ADL concentrations were lower at slope positions in 2003 (slope X year interaction; P=0.02). In late summer and fall, concentration of ADL typically increased from shoulder to toe slope positions.

Across both years, ADL levels were higher (P=0.02) under black walnut at toe compared to mid and shoulder slope positions at medium density, while at high density, ADL levels were lower at shoulder slope positions; while there was no difference (P=0.2) in ADL levels among slope and species under honey locust (slope X species X density interaction; P=0.03) (Table 5.11).

Botanical Composition

Due to the high variability between the two growing seasons evaluation, botanical composition was reported for each year separately (Table 5.12).

Tall Fescue

In 2002, pasture under honey locust tended (P=0.08) to have higher percentage of tall fescue than pasture under black walnut. No differences by slope position (P=0.3) or tree density (P=0.6) were observed.

No differences (P≥0.3) among treatments were observed in 2003.

Other Cool-Season Grasses

No differences (P≥0.1) among treatments were observed in 2002.

In 2003 under medium density, percentage of cool-season grasses was lower (P=0.06) under honey locust (14.2%) compared to black walnut (24.8%; SE=2.9; species X density interaction). No other differences (P≥0.2) were observed among treatments.

Weeds

No differences (P≥0.1) among treatments were observed in 2002.

In 2003, percentage of weeds was quite lower (P=0.03) at low density (9.7%) compared to medium (15.5%) and high density (17.1%; SE=1.6). No differences by tree species (P=0.9) or slope position (P=0.1) were observed.

Warm-Season Species

No differences (P≥0.3) among treatments were observed in 2002.

In 2003, percent warm season grasses decreased (P=0.01) with increasing tree density (8.9, 2.3, and 2.9% for low, medium, and high density trees; SE=1.2). Again, no effects of tree species (P=0.5) or slope position (P=0.4) were observed.

Clovers

No clovers were present in 2002.

In 2003, more (P=0.01) clovers were present under honey locust (23.2%) than under black walnut trees (13.1%; SE=1.6) No differences were found among the other field treatments (P≥0.4).

SOIL AND MICROCLIMATE RESPONSE TO FIELD TREATMENTS

Soil Nutrients and Bulk Density

Field treatments had no effect on soil nitrogen and phosphorus levels, percent organic matter, or bulk density.

Soil Surface Temperature

Soil surface temperatures (SST) within 3-hr measurement intervals (0900-1500 h) were averaged over the year for each sampling site. The SST were higher ($P<0.0001$) in 2002 compared to 2003 (30.2 vs. 22.6°C; SE=0.06), most likely due to differences in ambient air temperature and rainfall.

SST Response to Tree Species

Overall, tree species did not significantly effect SST in 2002 ($P=0.09$) or 2003 ($P=0.2$) (Figure 5.2).

SST Response to Tree Density

Although SST data for 2002 were generated using a thermocouple and 2003 data were generated by TidbiT® dataloggers, there were no density X year interactions. Thus, data for responses to tree density are presented for the combined years.

As expected SST were generally higher at low density compared to medium and high density throughout 2002 (Table 5.13) and 2003 growing season (Figure 5.3). Across 2002 and 2003, SST were higher ($P<0.0001$) under low density (27.6 °C) compared to medium (25.7 °C) and high density (25.6°C) plantings (Figure 5.4). When ambient air temperatures were cooler (5 - 15°C), SST were lower at low density compared to medium and high density ($R^2=0.9$;

P<0.0001) (Figure 5.5). Conversely, SST were highest at low density sites when ambient air temperatures were between 15 and 27°C.

In 2003, TidbiT® dataloggers measured soil surface temperature every 3 hours from mid May to October, gathering 1400 measurements per sampling site. This data was used to analyze field treatments effect on the length of time spent above 24°C based on the amount of measurements taken which exceeded 24°C. The total number of measurements exceeding 24°C decreased (P<0.0001) with increasing tree density (LD=314, MD=250, HD=234; SE=3).

These data suggest that temperature extremes are better moderated by medium and high density plantings, most likely due to the insulator effects of the tree canopy.

SST Response to Slope Position

Across 2002 and 2003, soil was warmer (P=0.02) at mid slope (27.2 °C) compared to toe slope (25.6 °C) but not different from shoulder slope positions (26.4°C; SE=0.2) (Figure 5.6). With the greater ambient air temperatures of 2002, SST were cooler (P=0.03) at toe slope positions (29.0 °C) than at mid (31.1 °C) or shoulder slope positions (30.4°C; SE=0.3). Under the lower ambient temperatures of 2003, SST were warmer (P=0.02) at mid slope (23.3 °C) than at toe (22.1 °C) or shoulder slope (22.4°C) positions (SE=0.1).

For both species, SST were numerically greater at mid slope. However, in 2002, soils at mid slope under honey locust were warmer (P=0.05; 31.2 °C) than soils at toe (29.7 °C) and shoulder slope (30.1 °C) positions, while soils at toe slope positions under black walnut were cooler (P=0.02; 28.2 °C) than soils at mid (31.0 °C) and shoulder slope (30.7 °C) positions (species X slope interaction; P=0.02) (Figure 5.7).

In 2003, SST were highest (P=0.005) at mid slope (23.6 °C), and lowest at toe slope under black walnut (21.8 °C; species X slope interaction; P=0.03). Under honey locust, there was no difference (P=0.1) among toe (22.5 °C), mid (23.0 °C), and shoulder (22.1 °C).

Forage Canopy Temperature

Forage canopy temperatures (FCT) were measured at 1200 and 1500 h at each site and averaged across months within years for statistical analysis. Forage canopy temperatures were higher (P<0.0001) in 2002 compared to 2003 (33.0 vs. 23.7°C; SE=0.2).

FCT Responses to Tree Species

Tree species had no effect (P=0.6) on forage canopy temperatures (Figure 5.2).

FCT Responses to Tree Density

Across both years, canopy temperatures were higher (P<0.0001) at low density sites (30.0, 27.7, and 27.6°C for low, medium and high density sites; SE=0.2) (Figure 5.4). Forage canopy temperatures were 34.8, 32.2, and 32.1°C (P=0.003; SE=0.4) in 2002 and 25.1, 23.2, and 22.9°C (P<0.0001; SE=0.1) for low, medium, and high density sites, respectively.

FCT Responses to Slope Position

Across both years, forage canopy temperatures were lower (P=0.003) at toe slope positions (26.9 °C) when compared with mid (29.2 °C) and shoulder (29.2°C) positions (SE=0.2) (Figure 5.6). In 2002, FCT were lower (P=0.001) at toe slope positions (T=30.6, M=34.2, S=34.2°C; SE=0.4), but in 2003, canopy temperatures at all three slope positions were significantly different (P=0.05) from each other, with lowest temperatures at the toe slope (23.2 °C) and the highest temperatures at mid slope (24.3 °C; SE = 0.1; slope X year interaction, P=0.003) (Figure 5.6).

Soil Moisture

Soil moisture data were averaged by year for each sampling site. Soil moisture levels were lower ($P<0.0001$) in 2002 compared to 2003 (18.5 vs. 27.3%; SE=0.2) because of the differences in rainfall.

Soil Moisture Response to Tree Species

Across both years, soil moisture levels were 11% higher ($P=0.009$) under honey locust (24.1 vs. 21.7%; SE=0.4) than under black walnut trees (Figure 5.2). Interestingly, this difference was consistent both in dry (2002; 19.5 vs. 17.5%; $P=0.05$; SE=0.5) and wet (2003; 28.7 vs. 25.8%; $P=0.01$; SE=0.5) growing seasons.

Soil Moisture Response to Tree Density

Averaged over both years, tree density did not significantly affect ($P=0.2$) soil moisture levels (Figure 5.4). However, in the drier year, 2002, soil moisture levels were lower ($P=0.05$) at medium density (17.4%) compared to low (20.0%) density sites (SE=0.7). Tree density had no effect ($P=0.8$) on soil moisture during the wetter year, 2003.

Soil Moisture Response to Slope Position

Surprisingly, slope position alone had no effect ($P=0.2$) on soil moisture (Figure 5.6). However, soil moisture levels at toe slope positions were numerically greater than those at mid and shoulder slope positions in 2002 (20.3, 17.5, 17.7%; SE=0.9) and 2003 (28.4, 26.4, 27.1%; SE=0.1).

PAR

Measurements of PAR were not replicated within year, thus results were reported across both years, using year as a replicate. Although we cannot test for a year effect, it is useful to look at the numerical differences between the years to note how tree species (Figure 5.8), tree density (Figure 5.9), and slope position (Figure 5.10) affected PAR levels during the experiment.

PAR Response to Tree Species

PAR levels did not differ ($P=0.1$) between honey locust (2100000 micromoles m^{-2} hr^{-1}) and black walnut (1800000 micromoles m^{-2} hr^{-1}) (Figure 5.11). PAR levels were numerically greater under honey locust compared to black walnut in 2002, but were no different in 2003 (Figure 5.8).

Additionally, at toe slope PAR levels were higher under honey locust compared to black walnut, while at shoulder slope PAR levels were lower under honey locust compared to black walnut (species X slope interaction; $P=0.05$) (Figure 5.12). The magnitude of the difference was greater at toe slope.

PAR Response to Tree Density

As planned, photosynthetically active radiation (PAR) decreased ($P=0.0003$) with increasing tree density (Figure 5.11). PAR levels for low, medium, and high tree densities were 2700000, 1800000, and 1500000 micromoles m^{-2} hr^{-1}, respectively (SE=10750). This pattern was numerically consistent in 2002 and 2003 (Figure 5.9).

PAR Response to Slope Position

Slope position had no overall effect ($P=0.6$) on PAR levels. In 2002, PAR levels were numerically higher at toe slope position, but in 2003, the effect was variable and of a lesser magnitude than in 2002 (Figure 5.10). Additionally, at the toe slope at high and medium density, PAR levels were greater (P#0.06) under honey locust compared to black walnut (slope X species X density interaction; P=0.003).

Discussion

NDF

Concentrations of NDF were lowest at medium and high tree stand densities and at toe slope positions. These data agree with those of Lin et al. (2001), who reported small (1 to 3%) reductions in NDF with increasing levels of shade in tall fescue. Growth at high ambient temperatures increases forage fiber concentrations (Fales, 1986), but shading can decrease NDF, usually as a consequence of temperature modification (Kephart and Buxton, 1993) In this study, NDF concentrations were lower at sites where soil surface and forage canopy temperature were significantly lower. This relationship between temperature and NDF is further supported by the lack of difference in NDF concentrations between the two tree species, because there were no species effects on soil or canopy temperatures.

Lower NDF levels in forage from under medium and high tree density may also have resulted from differences in botanical composition. As tree density increased, the percentage of C4 grasses in the sward decreased by 6 %. Higher fiber concentrations are a common trait of C4 species.

ADF

Concentrations of ADF were not affected by treatment across years. Our results support those of Lin et al (2001), who reported that ADF levels are commonly unaffected or slightly increased by shade.

In 2002, ADF was significantly greater (by one percentage point) under honey locust. However, this was likely a consequence of locust's premature leaf drop due to extended drought. In 2003, a year with adequate rainfall, tree species had no effect on forage ADF concentrations.

Slope position had no overall effect on ADF levels across both years. However, at harvests when the relationship to slope was significant, it was generally characterized by lower ADF at the toe slope position. These results parallel the NDF response to slope, and are most likely due to moderated soil surface and forage canopy temperature at the toe slope position.

CP

Over both growing seasons, tree stand density had no effect on forage CP concentrations. Similar response to shade has been reported by Clason (1995; 1999). However, crude protein is frequently greater in shaded plants (Smith, 1942; Eriksen and Whitney; 1981; Wolters, 1973; Krueger, 1981; Blair, et al., 1983; Samarakoon et al., 1990; Kephart and Buxton, 1993; Wilson, 1995; Wilson, 1996).

Overall, tree species also had no effect on CP, but CP levels were higher under honey locust compared to black walnut in 2003. This is may have been due to differences in botanical composition as there was a higher percentage of clover growing under honey locust.

TNC

Across both growing season, TNC decreased with increasing tree density. These data agree with studies from both tropical (Samarakoon et al., 1990) and temperate (D. Belesky, personal communication, 2004) environments. The decrease in forage TNC from low to medium density was about 3-fold greater than that from medium to high density (-20 vs. -6%). Levels of TNC were also lower at toe slope (vs. shoulder slope) positions, and under black walnut as compared with honey locust.

Within each treatment comparison, reduced TNC levels were directly related to reductions of PAR. Soluble sugars and starches are known to accumulate in leaves with increasing levels of PAR (Deinum, 1984; Gardner et al., 1985; Lin et al., 2001), thus the reduced TNC with reduced PAR was expected.

ADL

Across both years, ADL concentrations consistently increased with increasing tree density (by 0.6 to 1.1%). Similar results have been reported by others (Lewis et al., 1983; Samarakoon et al., 1990; Kephart and Buxton, 1993). As with TNC, the dominant factor in the relationship between density and ADL is tree density's effect on PAR. Morphological adaptations to low light environments generally include increased internodal length and reduced specific leaf weight (Allard et al., 1991). Typically, internodal tissues contain elevated levels of lignin. These adaptations promote interception of available light, and consequently ADL concentrations are increased.

However, based on our observations, internodal length did not appear affected by shade, most likely because the mowing frequency did not allow plants enough time to morphologically adapt. Additionally, ADL concentrations increased toward the end of the growing season, suggesting that leaf drop may have been responsible for elevated ADL levels under shade.

Summary and Conclusions

The presence of trees in the pasture has both positive and negative effects on forage nutritive value. Levels of ADF and CP were unaffected by increasing tree density, but the positive response of lower NDF concentrations may be offset by lower TNC levels. Thus, more research is needed to determine the effects of shade on grazing animals in order to better characterize forage quality and animal performance in silvopasture systems.

Table 5.1. Calibration and validation statistics for near infrared spectroscopy (NIRS) for determination of forage nutritive value†.

	Calibration				Validation	
Item	**n**	**mean**	**R^2**	**SEC‡**	**1 - VR§**	**SECV¶**
NDF	**259**	**0.4971**	**0.9594**	**0.0099**	**0.9211**	**0.0139**
ADF	**256**	**0.2556**	**0.928**	**0.0061**	**0.8749**	**0.0081**
CP	**185**	**0.1353**	**0.9584**	**0.0039**	**0.9422**	**0.0046**
TNC	**183**	**0.0795**	**0.978**	**0.0042**	**0.9718**	**0.0048**
ADL	**176**	**0.0238**	**0.8247**	**0.0056**	**0.761**	**0.0066**

† NDF = neutral detergent fiber; ADF = acid detergent fiber; CP = crude protein; TNC = total nonstructural carbohydrates; ADL = acid detergent lignin

‡ SEC = standard error of calibration

§ 1 - VR = 1 minus the variance ratio calculated in cross validation in modified partial least squares regression

¶ SECV = standard error of cross validation in modified partial least squares regression

Table 5.2. Neutral detergent fiber response to honey locust and black walnut trees at low, medium, and high tree densities†.

	Honey Locust			Black Walnut						Species X
	Low	Med	High	Low	Med	High	SE	Species	Density	Density
	%							P value		
2002										
May	51.7	52.5	50.9	50.5	49.9	49.9	0.5	0.05	0.3	0.3
Jun	52.9	52.9	51.4	55.1	52.8	53.6	0.9	0.4	0.3	0.4
Jul	51.1	52.0	52.9	52.4	51.5	51.9	0.9	1.0	0.7	0.4
Aug	51.1	50.5	49.6	51.7	45.5	43.5	1.0	0.03	0.03	0.1
Nov	44.8	44.2	44.1	44.6	42.7	40.8	0.5	0.02	0.01	0.06
Season	50.3	50.4	49.8	50.9	48.5	48.0	0.4	0.2	0.01	0.04
2003										
May	49.2	49.7	48.8	51.7	51.9	50.7	1.3	0.07	0.7	1.0
Jun	40.7	39.6	39.7	42.3	45.7	41.9	1.0	0.01	0.2	0.1
Jul	44.0	44.2	42.7	47.1	47.3	44.0	0.6	0.02	0.01	0.3
Aug	45.9	44.8	42.7	50.2	45.6	41.5	1.0	0.4	0.002	0.09
Sep	48.0	46.2	44.3	48.5	44.5	38.8	1.2	0.3	0.001	0.09
Oct	39.8	40.4	42.5	42.5	35.5	37.6	1.2	0.01	0.08	0.02
Season	44.6	44.1	43.4	47.0	45.1	42.4	0.5	0.4	0.002	0.04
Mean	47.5	47.3	46.6	49.0	46.8	45.2	0.4	0.9	0.001	0.02

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 5.3. Neutral detergent fiber response to slope position† and tree density‡ combinations.

	Toe			Mid			Shoulder						Slope X
	Low	Med	High	Low	Med	High	Low	Med	High	SE	Slope	Density	Density
	%										P value		
2002													
May	49.8	48.6	48.8	51.4	52.0	52.1	52.2	52.9	50.3	0.7	0.2	0.3	0.2
Jun	50.8	49.3	49.3	55.8	54.1	54.4	55.4	55.0	53.9	1.0	0.02	0.3	1.0
Jul	50.1	50.1	51.8	52.2	52.9	54.5	53.0	52.2	50.7	1.0	0.3	0.7	0.3
Aug	48.9	44.8	42.7	53.0	49.4	47.6	52.2	49.8	49.5	1.5	0.03	0.03	0.5
Nov	46.7	41.7	40.9	43.2	44.2	42.4	44.2	44.5	44.1	0.6	0.07	0.01	0.01
Season	49.3	46.9	46.7	51.1	50.5	50.2	51.4	50.9	49.7	0.5	0.02	0.01	0.4
2003													
May	48.4	47.7	45.7	50.8	52.4	53.1	52.3	52.1	50.6	1.6	0.04	0.7	0.6
Jun	39.6	38.8	40.5	41.9	46.5	41.6	43.0	42.6	40.4	1.0	0.2	0.2	0.1
Jul	43.1	43.7	41.8	46.1	46.3	43.8	47.5	47.2	44.4	0.8	0.1	0.01	0.8
Aug	47.1	42.6	41.4	49.6	45.8	41.4	47.4	47.3	43.5	1.3	0.5	0.002	0.4
Sep	46.7	41.4	40.1	49.8	46.2	40.6	48.3	48.4	43.9	1.4	0.2	0.001	0.3
Oct	39.4	34.8	38.3	42.1	37.7	39.6	41.9	41.3	42.3	1.5	0.2	0.08	0.6
Season	44.1	41.5	41.3	46.7	45.8	43.3	46.7	46.5	44.2	0.7	0.1	0.002	0.4
Mean	46.7	44.2	44.0	48.9	48.2	46.8	49.1	48.7	46.9	0.5	0.06	0.001	0.3

† Toe = 3-5% slope at base of hill; Mid = 10-60% slope at side of hill; Shoulder = 3-5% slope at top of hill

‡ Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 5.4. Acid detergent fiber response to honey locust and black walnut trees at low, medium, and high tree densities†.

	Honey Locust			Black Walnut						Species X
	Low	Med	High	Low	Med	High	SE	Species	Density	Density
				%					P value	
2002										
May	26.3	26.6	26.1	25.3	25.0	25.5	0.3	0.03	0.9	0.4
Jun	26.9	27.2	25.9	27.9	27.0	27.1	0.4	0.3	0.2	0.3
Jul	25.3	26.2	27.1	25.5	25.3	25.5	0.4	0.04	0.1	0.1
Aug	26.1	27.9	29.5	25.7	23.5	22.8	0.4	0.001	0.3	0.002
Nov	23.4	23.5	23.9	22.9	23.3	23.2	0.3	0.05	0.6	0.4
Season	25.6	26.3	26.5	25.4	24.8	24.8	0.2	0.03	0.8	0.02
2003										
May	27.0	27.0	27.1	26.9	27.3	27.4	0.5	0.6	0.8	0.9
Jun	23.1	22.9	22.9	22.8	24.2	23.1	0.4	0.3	0.3	0.2
Jul	25.8	26.2	25.3	25.9	26.2	25.6	0.3	0.7	0.09	0.9
Aug	25.4	25.2	24.6	26.3	25.6	24.1	0.4	0.5	0.02	0.3
Sep	26.5	26.8	26.5	26.5	25.9	25.4	0.5	0.4	0.6	0.5
Oct	21.4	22.8	24.2	23.2	25.5	27.9	0.6	0.01	0.001	0.4
Season	24.9	25.1	25.1	25.3	25.8	25.6	0.2	0.1	0.3	0.9
Mean	25.2	25.7	25.8	25.4	25.3	25.2	0.2	0.4	0.5	0.2

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 5.5. Acid detergent fiber response to slope position† and tree density‡ combinations.

	Toe			Mid			Shoulder						Slope X
	Low	Med	High	Low	Med	High	Low	Med	High	SE	Slope	Density	Density
	%										P value		
2002													
May	25.1	24.5	25.1	26.0	26.2	26.4	26.3	26.7	25.7	0.4	0.2	0.9	0.4
Jun	25.4	25.2	24.7	28.7	28.0	27.4	28.1	28.0	27.4	0.5	0.01	0.2	1.0
Jul	24.8	25.3	26.1	25.7	26.3	27.1	25.8	25.7	25.7	0.5	0.09	0.1	0.5
Aug	25.0	24.3	24.8	26.4	26.5	26.6	26.3	26.2	26.9	0.5	0.2	0.3	0.07
Nov	24.2	23.3	23.4	22.4	23.4	23.5	22.8	23.5	23.9	0.3	0.1	0.6	0.07
Season	24.9	24.5	24.8	25.9	26.1	26.2	25.9	26.0	25.9	0.3	0.02	0.8	0.7
2003													
May	25.9	26.1	25.4	27.0	27.6	28.7	28.0	27.8	27.6	0.6	0.04	0.8	0.3
Jun	22.3	22.3	22.7	22.9	25.0	23.6	23.5	23.3	22.7	0.5	0.1	0.3	0.2
Jul	24.9	25.2	24.2	26.2	26.6	25.9	26.5	26.8	26.2	0.4	0.07	0.09	1.0
Aug	26.0	24.6	24.4	26.5	25.4	24.0	25.2	26.2	24.6	0.5	0.9	0.02	0.2
Sep	26.3	24.9	26.1	27.4	26.3	25.4	25.9	27.7	26.3	0.7	0.6	0.6	0.1
Oct	22.7	24.3	26.3	22.1	23.4	26.2	22.1	24.6	25.6	0.7	0.9	0.001	0.8
Season	24.7	24.6	24.9	25.3	25.7	25.6	25.2	26.1	25.5	0.3	0.4	0.3	0.5
Mean	24.8	24.5	24.9	25.6	25.9	25.9	25.5	26.0	25.7	0.2	0.09	0.5	0.4

† Toe = 3-5% slope at base of hill; Mid = 10-60% slope at side of hill; Shoulder = 3-5% slope at top of hill

‡ Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 5.6. Crude protein response to honey locust and black walnut trees at low, medium, and high tree densities†.

	Honey Locust			Black Walnut						Species X
	Low	Med	High	Low	Med	High	SE	Species	Density	Density
	%							P value		
2002										
May	12.5	13.1	12.8	12.6	13.1	12.8	0.2	0.8	0.2	1.0
Jun	12.3	12.8	13.1	11.2	11.7	12.3	0.3	0.5	0.2	0.8
Jul	13.8	13.5	13.0	13.7	14.5	14.9	0.3	0.01	0.7	0.01
Aug	12.2	11.2	10.5	12.2	13.0	13.0	0.3	0.001	0.3	0.004
Nov	13.9	14.2	14.2	14.3	13.7	12.6	0.3	0.02	0.07	0.02
Season	12.9	12.9	12.7	12.8	13.2	13.1	0.2	0.2	0.5	0.3
2003										
May	12.9	13.9	14.4	11.9	12.9	13.0	0.4	0.06	0.04	0.9
Jun	16.1	16.6	16.9	15.2	14.6	16.4	0.5	0.01	0.1	0.4
Jul	15.6	15.7	16.1	14.7	15.0	15.4	0.3	0.06	0.2	0.9
Aug	16.5	16.8	16.7	14.9	16.1	15.4	0.3	0.02	0.1	0.4
Sep	15.4	15.7	16.0	14.6	15.4	14.2	0.5	0.07	0.6	0.4
Oct	15.1	14.3	14.2	14.0	14.5	13.4	0.3	0.07	0.08	0.1
Season	15.3	15.5	15.7	14.2	14.8	14.6	0.3	0.02	0.4	0.8
Mean	14.1	14.2	14.2	13.5	14.0	13.9	0.1	0.09	0.2	0.5

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 5.7. Crude protein response to slope position† and tree density‡ combinations.

	Toe			Mid			Shoulder						Slope X
	Low	Med	High	Low	Med	High	Low	Med	High	SE	Slope	Density	Density
	%										P value		
2002													
May	13.0	13.7	13.0	12.5	12.6	12.4	12.2	12.9	12.9	0.3	0.3	0.2	0.5
Jun	13.1	13.5	13.3	10.8	11.5	12.1	11.4	11.8	12.7	0.3	0.1	0.02	0.4
Jul	13.9	14.2	13.9	13.7	13.7	13.6	13.7	14.1	14.3	0.3	0.4	0.7	0.8
Aug	12.8	12.9	11.8	12.0	11.6	11.8	11.8	11.9	11.7	0.3	0.003	0.3	0.4
Nov	13.6	13.8	12.6	14.2	13.6	13.1	14.5	14.5	14.5	0.3	0.02	0.07	0.3
Season	13.3	13.6	12.9	12.6	12.6	12.6	12.7	13.0	13.2	0.2	0.04	0.5	0.2
2003													
May	13.3	14.9	14.2	11.6	12.5	13.5	12.4	12.9	13.4	0.5	0.2	0.04	0.6
Jun	16.8	17.1	16.8	14.9	14.6	16.9	15.3	15.0	16.2	0.6	0.2	0.1	0.4
Jul	16.4	16.4	16.5	14.3	15.0	15.3	14.8	14.8	15.5	0.4	0.2	0.2	0.8
Aug	16.4	17.3	16.0	14.9	16.1	15.9	16.0	16.0	16.4	0.4	0.4	0.1	0.2
Sep	15.4	16.7	15.1	14.6	15.0	15.0	15.1	15.0	15.2	0.7	0.5	0.6	0.7
Oct	15.0	15.1	14.5	14.0	14.1	13.2	14.7	14.0	13.7	0.4	0.2	0.08	0.8
Season	15.5	16.3	15.5	14.1	14.5	15.0	14.7	14.6	15.1	0.4	0.2	0.4	0.5
Mean	14.4	14.9	14.2	13.3	13.6	13.8	13.7	13.8	14.1	0.2	0.2	0.2	0.1

† Toe = 3-5% slope at base of hill; Mid = 10-60% slope at side of hill; Shoulder = 3-5% slope at top of hill

‡ Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 5.8. Total nonstructural carbohydrates response to honey locust and black walnut trees at low, medium, and high tree densities†.

	Honey Locust			Black Walnut						Species X
	Low	Med	High	Low	Med	High	SE	Species	Density	Density
	%							P value		
2002										
May	8.0	6.8	7.6	9.8	9.5	9.1	0.2	0.001	0.02	0.08
Jun	7.3	7.0	7.3	7.3	6.8	6.5	0.3	0.2	0.4	0.5
Jul	8.4	7.7	6.4	8.2	6.6	6.1	0.2	0.05	0.0001	0.09
Aug	8.3	6.6	5.9	8.5	7.0	7.3	0.3	0.06	0.001	0.2
Nov	13.3	13.0	13.2	13.1	10.5	11.4	0.8	0.06	0.3	0.4
Season	9.1	8.2	8.1	9.4	8.1	8.1	0.2	0.7	0.003	0.7
2003										
May	7.3	6.3	4.5	8.2	6.0	6.6	0.8	0.05	0.06	0.4
Jun	10.5	9.7	8.5	11.3	10.7	9.6	0.3	0.01	0.001	0.9
Jul	7.9	6.5	6.5	8.3	6.2	5.9	0.2	0.6	0.0001	0.1
Aug	8.1	7.4	7.9	8.6	5.9	5.4	0.3	0.03	0.001	0.01
Sep	10.3	9.1	9.0	10.1	7.2	5.5	0.3	0.03	0.0001	0.003
Oct	19.0	18.1	16.5	17.0	8.0	4.6	0.5	0.003	0.0001	0.0001
Season	10.5	9.5	8.8	10.6	7.3	6.3	0.2	0.01	0.0001	0.0001
Mean	9.8	8.9	8.4	10.0	7.7	7.2	0.1	0.05	0.0001	0.0001

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 5.9. Total nonstructural carbohydrates response to slope position† and tree density‡ combinations.

	Toe			Mid			Shoulder						Slope X
	Low	Med	High	Low	Med	High	Low	Med	High	SE	Slope	Density	Density
	%										P value		
2002													
May	9.1	8.8	8.8	8.8	8.1	8.1	8.8	7.4	8.1	0.3	0.2	0.02	0.4
Jun	8.3	7.8	7.4	6.6	6.5	6.6	6.9	6.5	6.7	0.4	0.08	0.4	0.8
Jul	8.4	7.0	5.6	8.3	7.0	6.4	8.2	7.4	6.8	0.2	0.3	0.0001	0.09
Aug	8.8	7.2	6.5	8.3	6.4	6.6	8.1	6.8	6.7	0.4	0.1	0.001	0.6
Nov	12.3	10.7	11.2	14.1	12.4	13.4	13.1	12.2	12.4	1.0	0.06	0.3	1.0
Season	9.4	8.3	7.9	9.2	8.1	8.2	9.0	8.1	8.1	0.3	0.8	0.003	0.8
2003													
May	6.5	6.0	7.3	9.7	6.3	3.9	7.0	6.1	5.4	1.0	0.9	0.06	0.09
Jun	10.2	9.5	8.8	11.3	10.1	8.5	11.2	11.0	9.9	0.4	0.08	0.001	0.4
Jul	8.0	6.3	6.6	8.3	6.3	5.9	7.9	6.6	6.0	0.3	0.9	0.0001	0.4
Aug	7.2	5.6	5.8	8.5	7.3	6.6	9.4	7.0	7.6	0.4	0.1	0.001	0.5
Sep	9.6	7.1	5.9	9.8	8.4	7.2	11.3	8.9	8.7	0.4	0.08	0.0001	0.3
Oct	16.2	10.1	8.0	19.4	14.6	10.2	18.5	14.4	13.4	0.6	0.05	0.0001	0.05
Season	9.6	7.4	7.1	11.2	8.8	7.0	10.9	9.0	8.5	0.2	0.01	0.0001	0.01
Mean	9.5	7.9	7.5	10.2	8.5	7.6	10.0	8.5	8.3	0.1	0.05	0.0001	0.03

† Toe = 3-5% slope at base of hill; Mid = 10-60% slope at side of hill; Shoulder = 3-5% slope at top of hill

‡ Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 5.10. Acid detergent lignin response to honey locust and black walnut trees at low, medium, and high tree densities†.

	Honey Locust			Black Walnut						Species X
	Low	Med	High	Low	Med	High	SE	Species	Density	Density
	%							P value		
2002										
May	1.7	1.7	1.8	1.3	1.6	1.7	0.1	0.03	0.1	0.2
Jun	2.5	2.2	2.0	2.1	2.3	2.3	0.1	1.0	0.3	0.06
Jul	2.2	2.3	3.1	1.9	1.9	1.9	0.1	0.004	0.001	0.001
Aug	2.8	5.6	7.9	2.5	2.9	2.8	0.4	0.001	0.0002	0.001
Nov	1.3	1.8	2.7	1.2	2.4	2.9	0.1	0.3	0.0001	0.07
Season	2.1	2.7	3.5	1.8	2.2	2.3	0.1	0.003	0.0001	0.002
2003										
May	1.8	1.7	1.8	1.2	1.7	1.9	0.1	0.3	0.01	0.01
Jun	2.2	2.2	2.2	1.8	1.7	2.1	0.1	0.02	0.2	0.1
Jul	3.0	3.2	3.1	2.6	2.8	3.1	0.1	0.04	0.1	0.3
Aug	2.8	3.2	3.8	2.4	3.0	3.9	0.1	0.3	0.0001	0.2
Sep	2.9	4.2	5.0	2.7	3.8	5.5	0.2	0.9	0.0001	0.04
Oct	2.1	2.7	3.3	2.4	5.4	6.4	0.3	0.01	0.0001	0.001
Season	2.5	2.9	3.2	2.2	3.1	3.8	0.1	0.3	0.0001	0.004
Mean	2.3	2.8	3.3	2.0	2.6	3.1	0.1	0.1	0.0001	0.4

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 5.11. Acid detergent lignin response to slope position† and tree density‡ combinations.

	Toe			Mid			Shoulder						Slope X
	Low	Med	High	Low	Med	High	Low	Med	High	SE	Slope	Density	Density
	%										P value		
2002													
May	1.4	1.6	1.8	1.5	1.6	1.8	1.6	1.7	1.6	0.1	1.0	0.1	0.7
Jun	2.1	2.2	1.8	2.5	2.3	2.2	2.3	2.2	2.4	0.1	0.2	0.3	0.3
Jul	1.9	2.1	2.4	2.1	2.1	2.4	2.1	2.1	2.6	0.1	0.8	0.001	0.6
Aug	2.3	4.5	5.9	3.0	4.4	4.8	2.7	3.9	5.4	0.4	0.8	0.0002	0.4
Nov	1.3	2.6	3.3	1.2	1.8	2.4	1.3	1.8	2.6	0.2	0.02	0.0001	0.1
Season	1.8	2.6	3.0	2.1	2.4	2.7	2.0	2.4	2.9	0.1	0.8	0.0001	0.1
2003													
May	1.4	1.9	1.8	1.5	1.8	2.0	1.6	1.4	1.8	0.1	0.7	0.01	0.1
Jun	2.3	2.4	2.1	1.6	1.7	2.4	2.0	1.8	2.0	0.1	0.3	0.2	0.02
Jul	2.8	3.0	2.9	2.9	3.0	3.2	2.7	2.9	3.2	0.2	0.8	0.1	0.5
Aug	2.8	3.7	4.3	2.7	2.9	4.0	2.5	2.7	3.4	0.2	0.06	0.0001	0.2
Sep	3.0	4.5	5.8	3.0	3.7	5.3	2.4	3.8	4.6	0.2	0.03	0.0001	0.2
Oct	2.8	5.0	5.4	2.1	3.5	5.1	1.9	3.6	4.2	0.3	0.02	0.0001	0.5
Season	2.5	3.4	3.7	2.3	2.8	3.7	2.2	2.7	3.2	0.1	0.02	0.0001	0.1
Mean	2.2	3.0	3.4	2.2	2.6	3.2	2.1	2.5	3.1	0.1	0.08	0.0001	0.1

† Toe = 3-5% slope at base of hill; Mid = 10-60% slope at side of hill; Shoulder = 3-5% slope at top of hill

‡ Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 5.12. Botanical composition response to honey locust and black walnut trees at low, medium, and high tree densities†.

	Honey Locust			Black Walnut						Species X
	Low	Med	High	Low	Med	High	SE	Species	Density	Density
	%							P value		
2002										
Tall Fescue	68.2	72.0	69.6	69.8	56.8	55.5	6.3	0.08	0.6	0.4
Cool- Season	9.2	9.8	7.6	6.6	24.2	12.6	3.7	0.2	0.09	0.1
Weed	17.2	12.6	18.1	18.1	13.5	20.1	2.8	0.4	0.1	1.0
Warm-Season	2.0	1.9	0.8	3.2	1.6	6.4	2.2	0.3	0.7	0.4
2003										
Tall Fescue	41.9	45.1	41.0	52.6	45.1	38.4	4.8	0.7	0.3	0.4
Cool- Season	16.7	14.2	15.5	12.5	24.8	22.6	2.5	0.2	0.2	0.06
Weed	10.3	15.6	16.9	9.2	15.4	17.3	2.2	0.9	0.03	0.9
Warm-Season	7.5	2.0	2.4	10.4	2.5	3.4	1.7	0.5	0.01	0.8
Clover	23.4	22.8	23.5	15.1	10.8	13.3	3.0	0.01	0.7	0.8
Dead	0.2	0.1	0.6	0.2	1.3	5.0	0.4	0.04	0.0003	0.001

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 5.13. Soil surface temperature response to tree densities† in July and August 2002; soil surface temperatures were higher at low density compared to medium and high density at 12PM and 3PM.

	Tree Density				
	Low	Medium	High	SE	Density
	°C				P value
July					
6AM	20.5	20.6	20.5	0.2	0.9
9AM	26.2	26.0	24.6	0.2	<.0001
12PM	31.5	30.6	30.2	0.2	0.009
3PM	31.6	29.1	29.3	0.2	<.0001
6PM	28.4	27.1	26.8	0.2	0.0003
August					
9AM	29.1	28.5	27.2	0.2	0.002
12PM	38.6	34.5	35.1	0.5	0.001
3PM	35.5	32.4	31.6	0.5	0.001

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

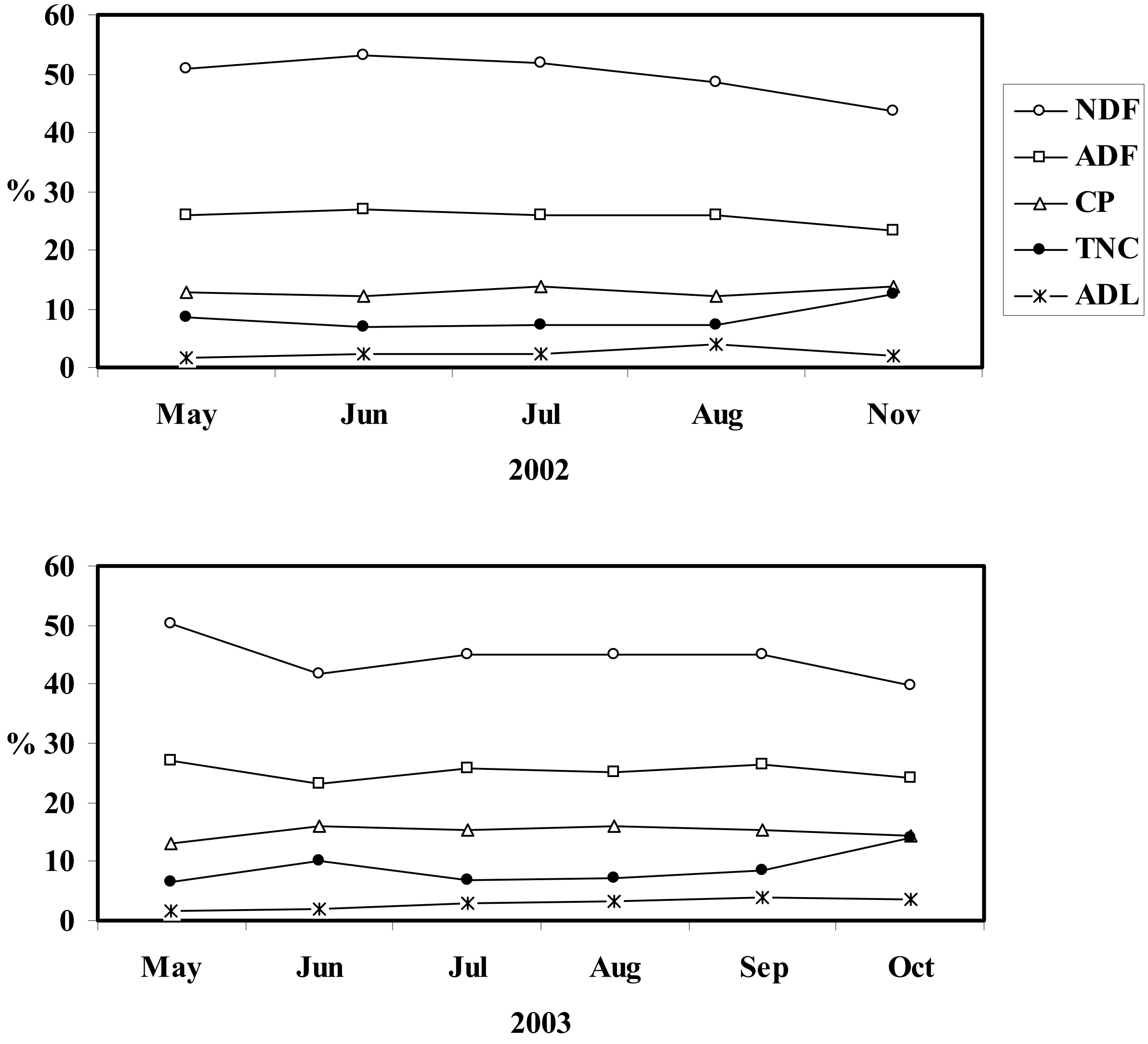


Figure 5.1. Neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), crude protein (CP) and total non-structural carbohydrate (TNC) levels across 2002 and 2003 growing seasons.

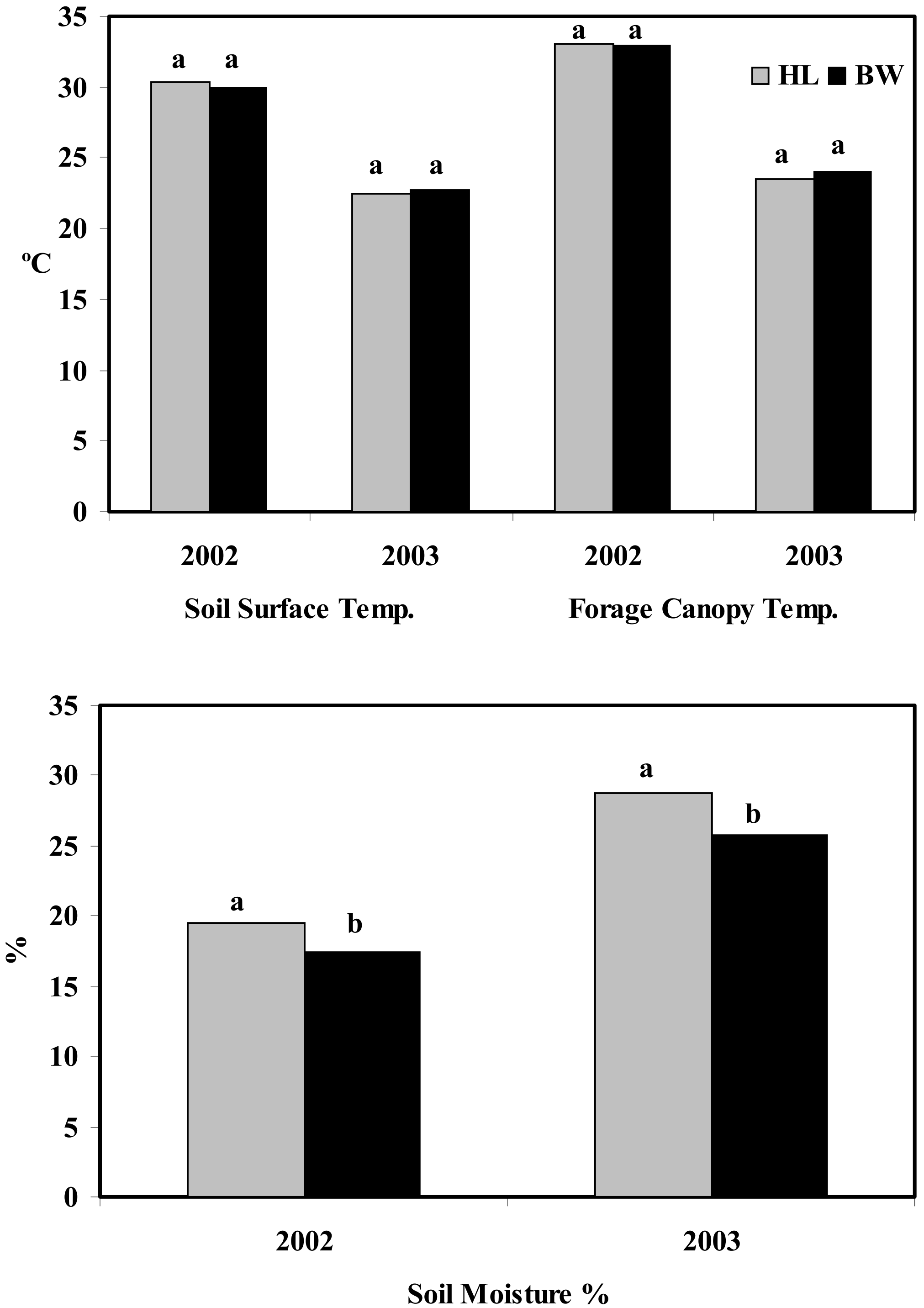


Figure 5.2. Microclimate responses to honey locust (HL) and black walnut (BW) trees in 2002 and 2003: soil surface temperature, forage canopy temperature, and soil moisture; same letters within years within each microclimate measurement are not significantly ($P<0.05$) different based on Tukey's mean separation.

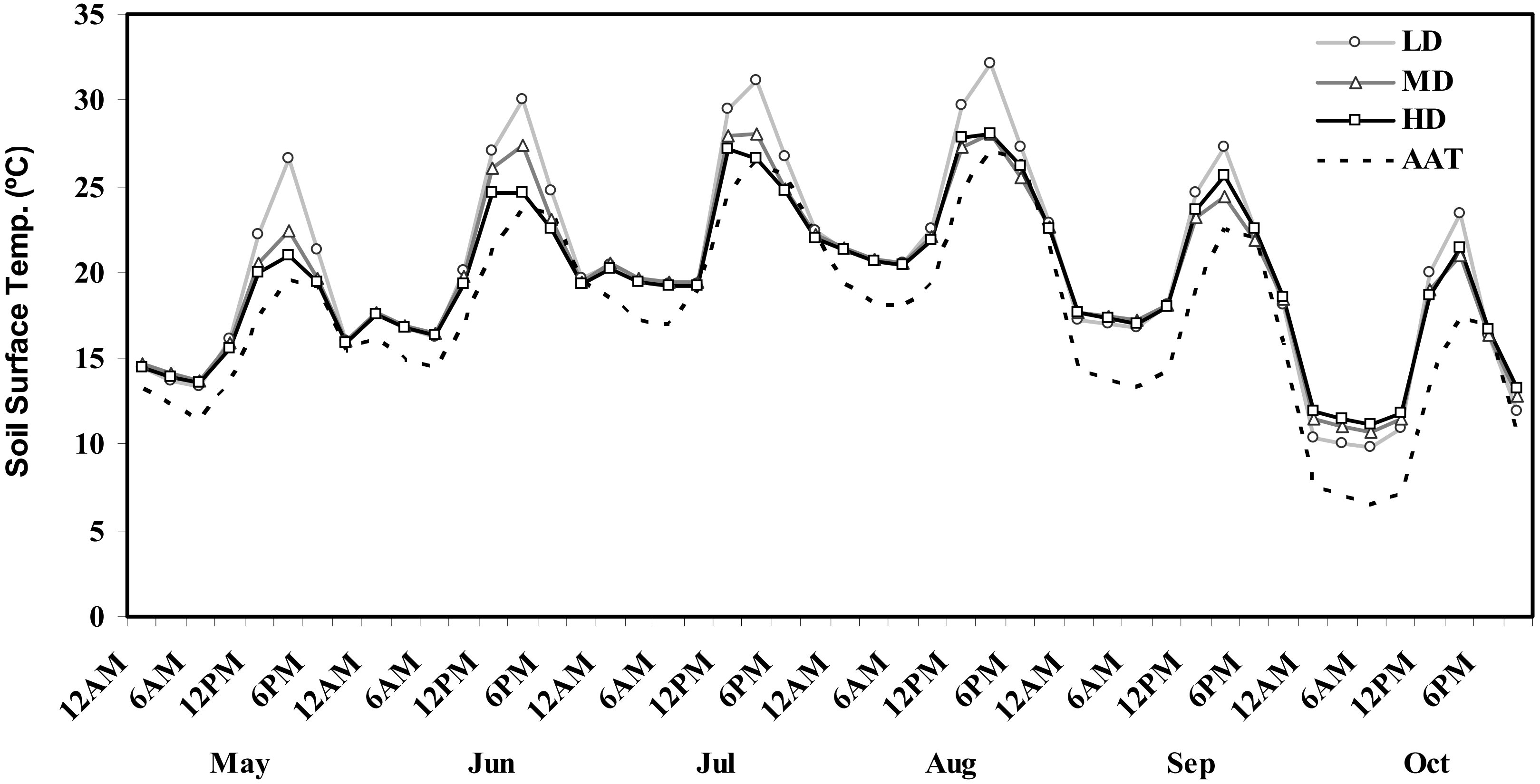


Figure 5.3. Diurnal soil surface temperatures averaged within months in response to low (LD), medium (MD), and high (HD) tree densities; measurements for each density (n=18) were taken every 3 hr. from mid May through October in 2003; AAT=ambient air temperatures; soil surface temperatures were highest ($P<0.0001$) at LD compared to MD and HD across the growing season.

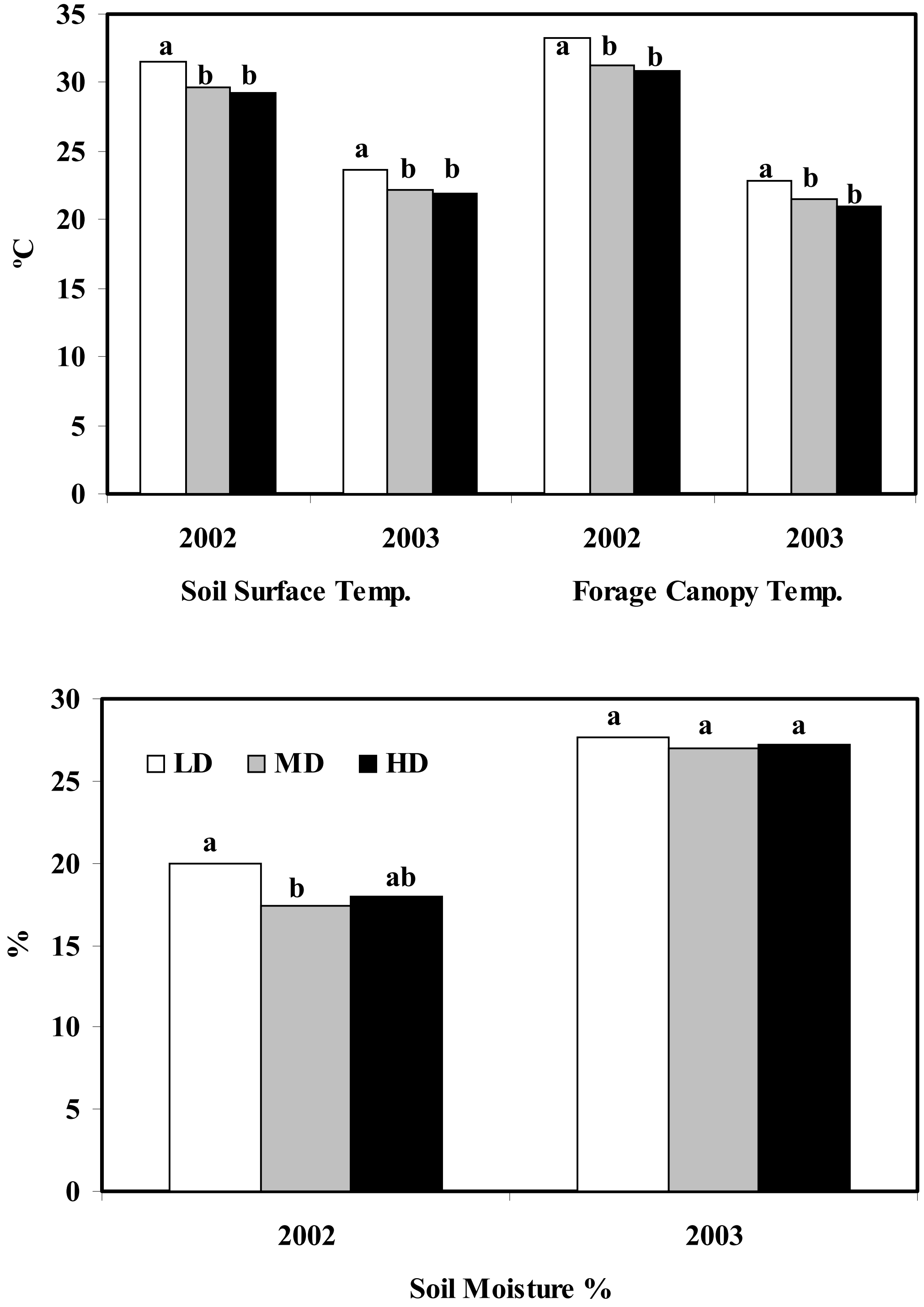


Figure 5.4. Microclimate responses to low (LD), medium (MD), and high (HD) tree densities in 2002 and 2003: soil surface temperature, forage canopy temperature, and soil moisture; same letters within years within each microclimate measurement are not significantly ($P<0.05$) different based on Tukey's mean separation.

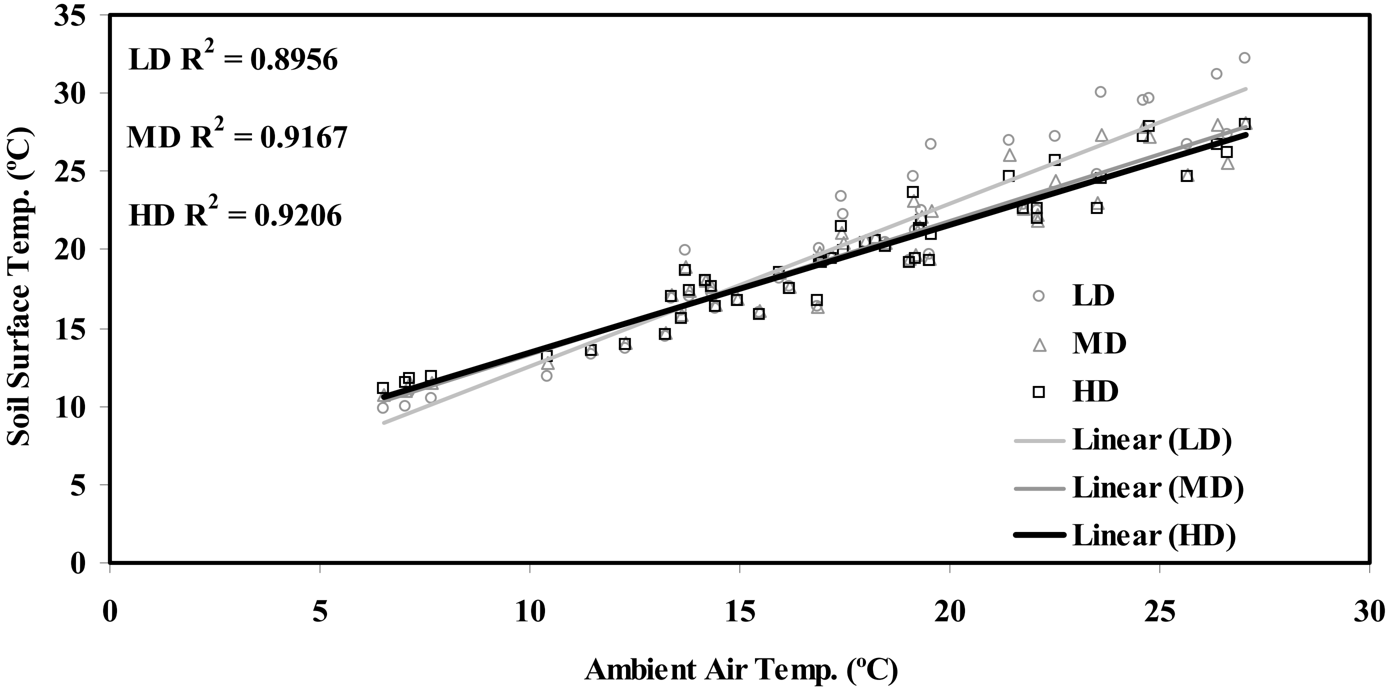


Figure 5.5. Relationship of soil surface temperature to ambient air temperature by low (LD), medium (MD), and high (HD) tree densities; R^2 values were significant ($P<0.0001$) for all densities; soil surface temperatures were better moderated at MD and HD during ambient air temperature extremes.

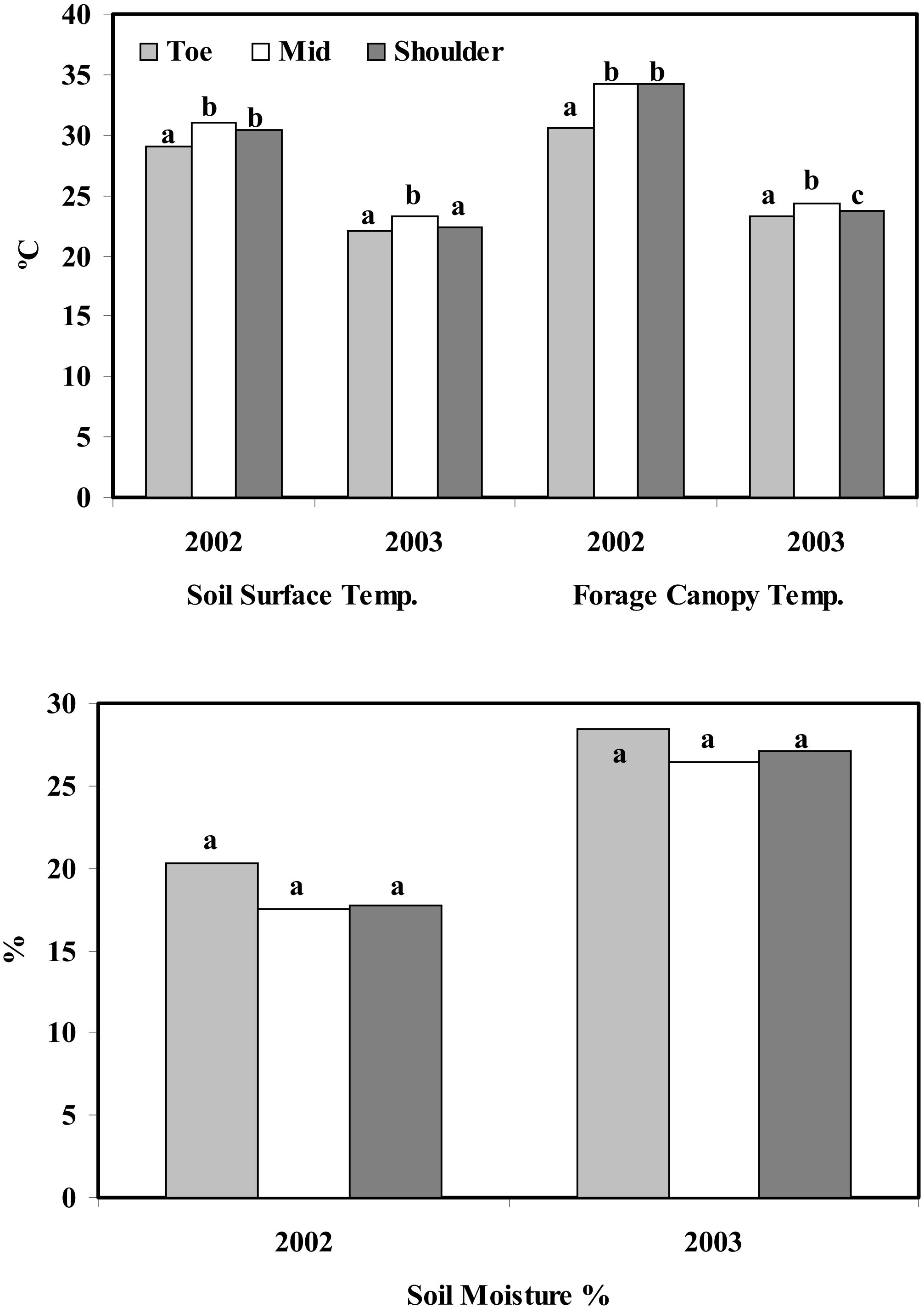


Figure 5.6. Microclimate responses to slope positions in 2002 and 2003: soil surface temperature, forage canopy temperature, and soil moisture; same letters within years within each microclimate measurement are not significantly ($P<0.05$) different based on Tukey's mean separation.

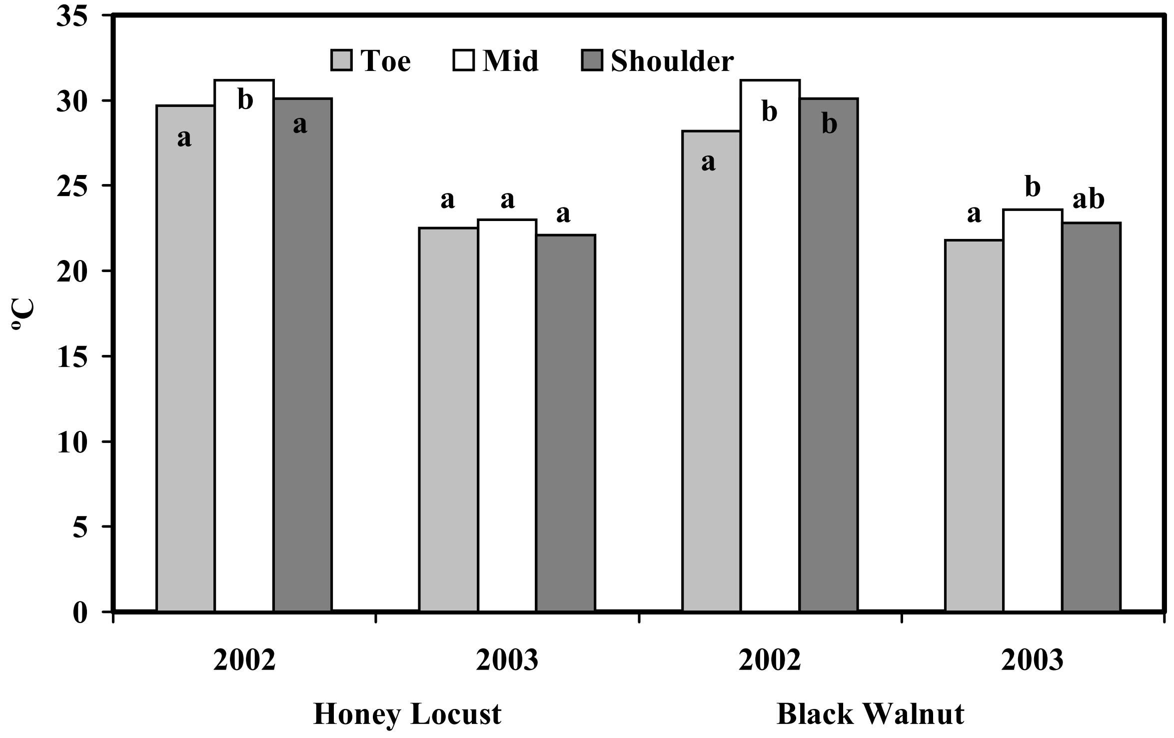


Figure 5.7. Soil surface temperature response to slope positions by tree species in 2002 and 2003; same letters within years by species are not significantly ($P<0.05$) different based on Tukey's mean separation.

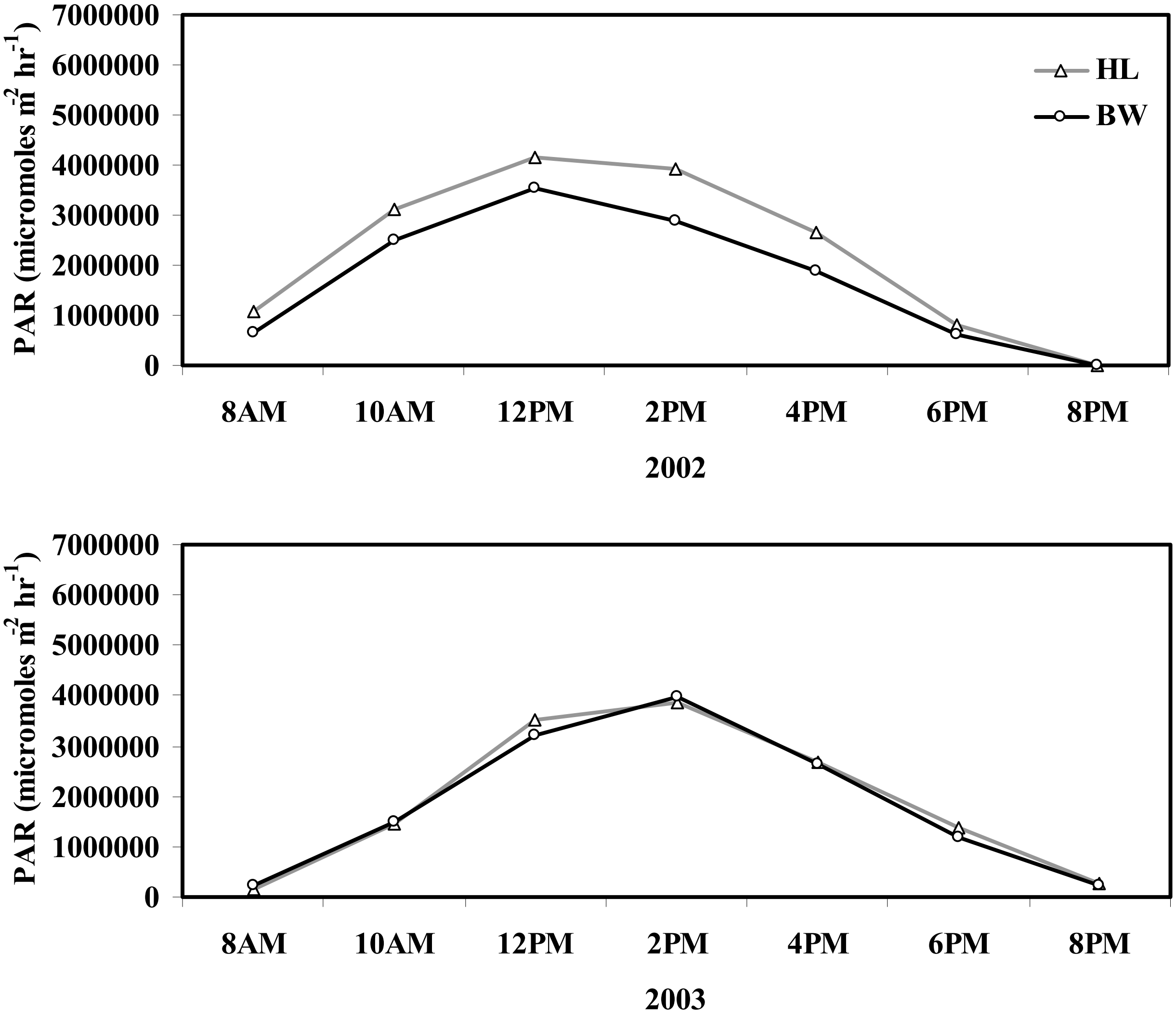


Figure 5.8. Photosynthetically active radiation (PAR) measured just above the forage canopy as affected by honey locust (HL) or black walnut (BW) trees; values averaged by time from 23-Aug through 10-Sep 2002 and 5-Aug through 21-Aug 2003.

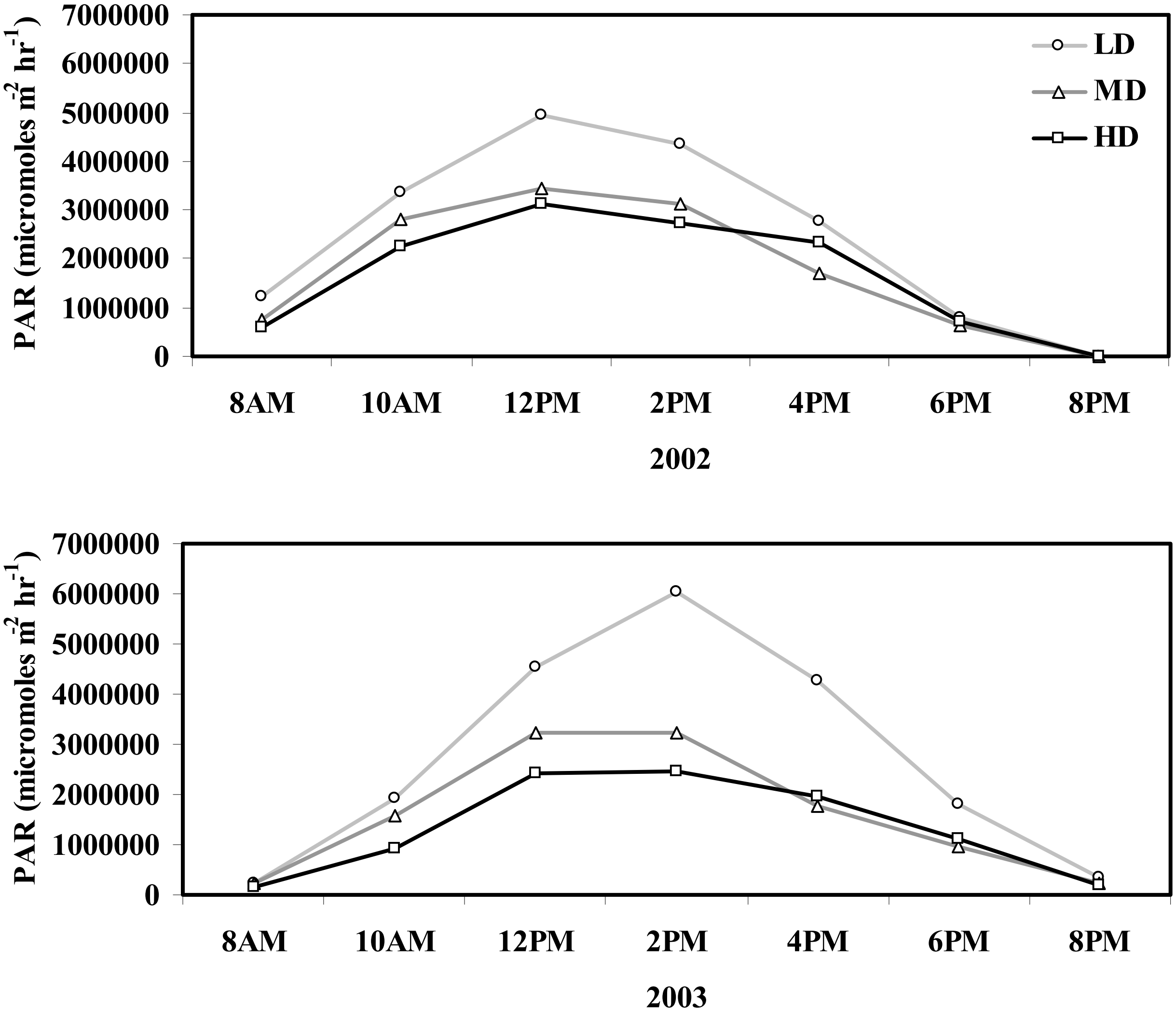


Figure 5.9. Photosynthetically active radiation (PAR) measured just above the forage canopy as affected by low (LD), medium (MD), and high (HD) tree densities; values averaged by time from 23-Aug through 10-Sep 2002 and 5-Aug through 21-Aug 2003.

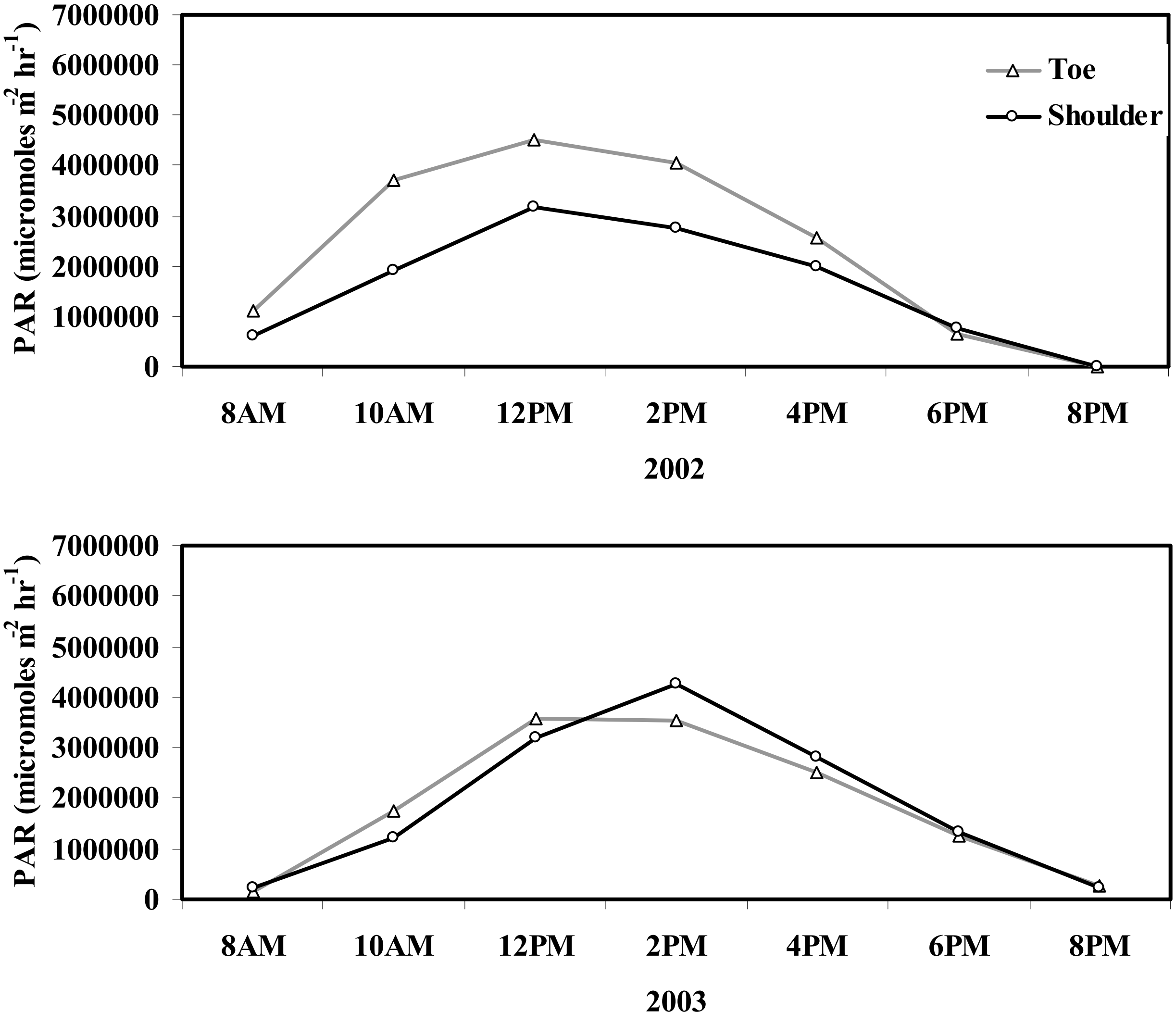


Figure 5.10. Photosynthetically active radiation (PAR) measured just above the forage canopy at to toe and shoulder slope positions; values averaged by time from 23-Aug through 10-Sep 2002 and 5-Aug through 21-Aug 2003.

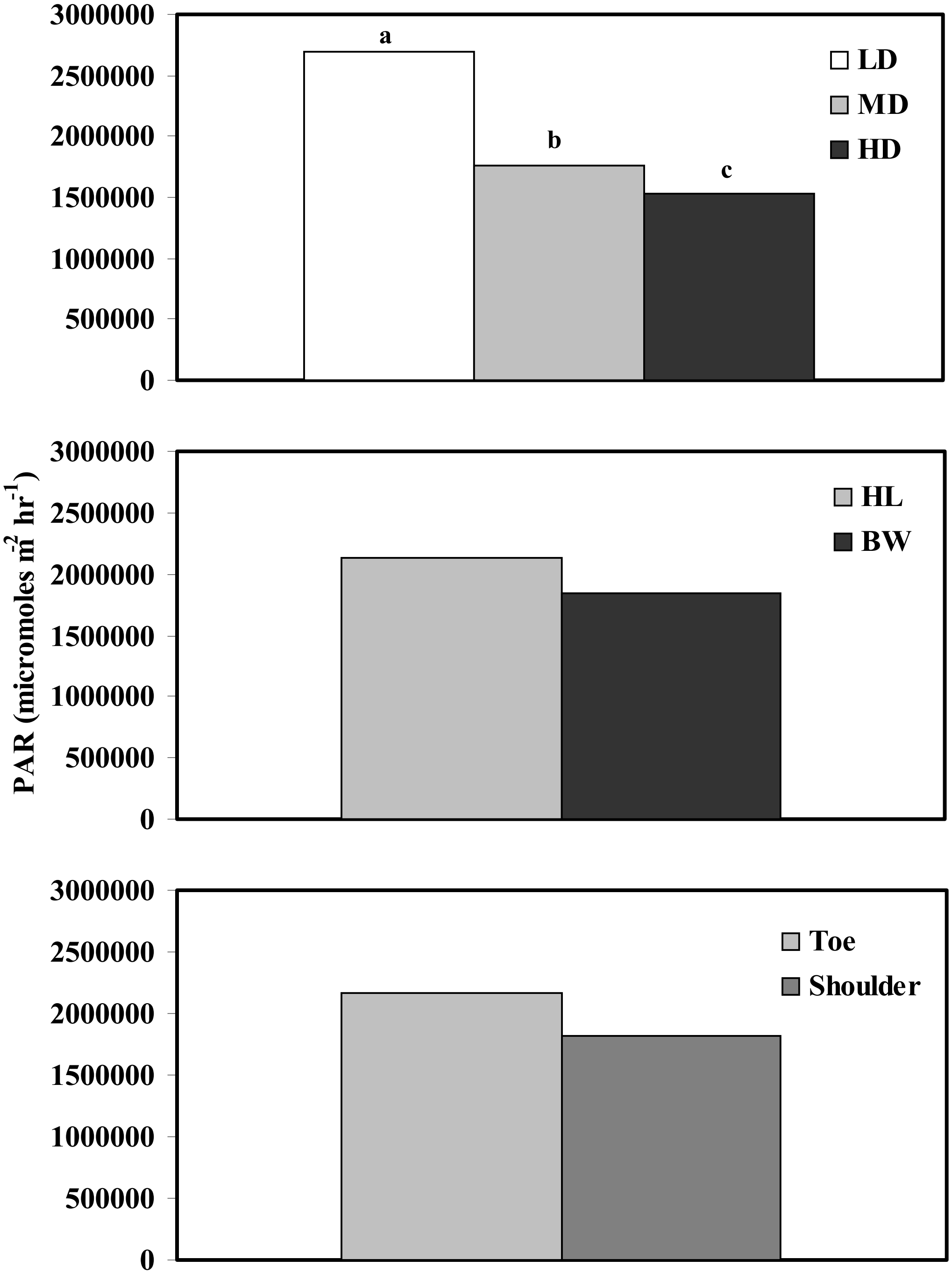


Figure 5.11. Average values of photosynthetically active radiation (PAR) in response to field treatments: low (LD), medium (MD), and high (HD) tree densities; honey locust (HL) and black walnut (BW) tree species; toe and shoulder slope positions; values with the same letter are not significantly ($P<0.05$) different based on Tukey's mean separation.

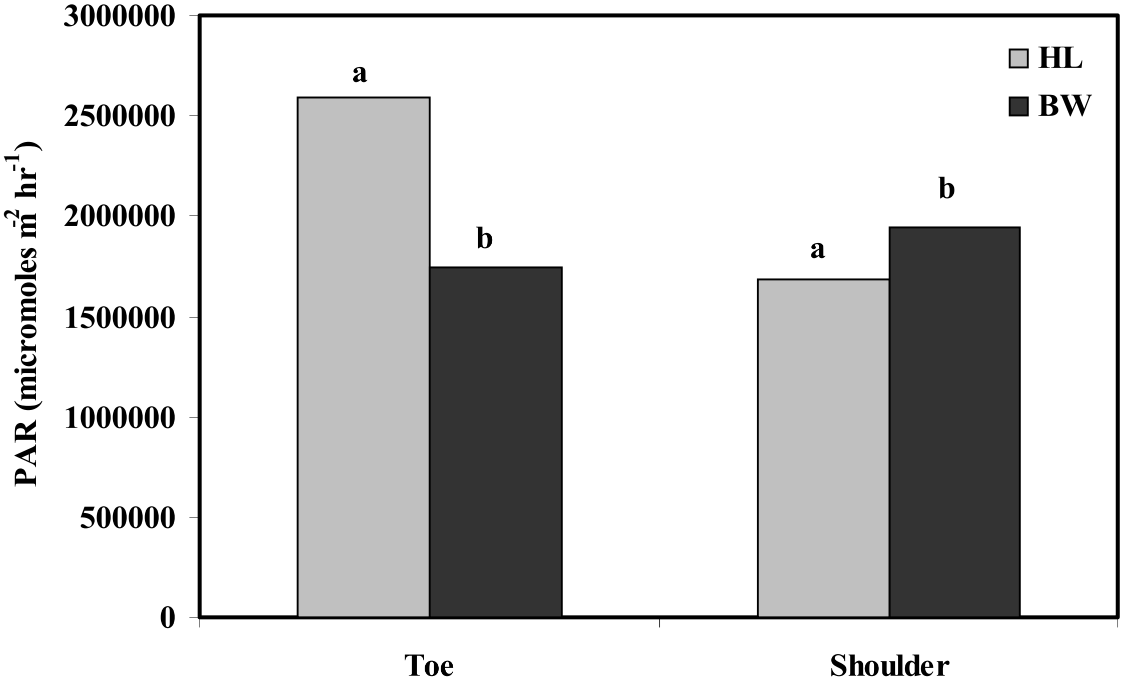


Figure 5.12. Average values of photosynthetically active radiation (PAR) in response to honey locust (HL) and black walnut (BW) trees at toe and shoulder slope positions (species X slope interaction; SE=12400); same letters within slope position are not significantly ($P<0.05$) different based on Tukey's mean separation.

Chapter 6: Cool-Season Forage Mineral Concentrations in a Temperate Silvopasture

Abstract

Integrating trees into pasture may be an effective management tool to improve resource allocation (i.e. temperature, water, light) and increase total system productivity in temperate Appalachia. In 1995, black walnut and honey locust trees were planted within plots (r=3) of predominantly tall fescue pasture. In each plot, four rows of each tree species were planted down a 12% slope with spacings of 1.8, 3.7, and 14.6 m within rows and 3.7, 7.3, and 14.6 m between rows. Spacings created field treatments of low, medium, and high tree densities at shoulder, mid, and toe slope positions within plots of honey locust and black walnut trees. Forage sampling sites (n=54) under field treatment combinations were harvested May to October at 35-d intervals in 2002 and 2003. Forage samples were ashed and diluted in 6 N HCl. Calcium, phosphorus, potassium, and magnesium concentrations were determined by atomic emission with an inductively coupled plasma spectrometer. Soil surface temperature (SST), forage canopy temperature (FCT), soil moisture, and photosynthetically active radiation (PAR) levels were measured at field treatment combinations. The objective of this study was to determine forage mineral concentration response to the field treatments as a function of resource allocation.

Across both years, field treatments had neutral effects on P, K, and Mg. Forage Ca increased ($P<0.0001$) with increasing tree density; and was greater ($P=0.02$) at T. Both SST and FCT were higher ($P\leq0.02$) at both low density and mid slope sites. Levels of PAR decreased

(P=0.0003) with increasing tree planting density. These data suggest that incorporating trees into pasture can increase forage calcium levels without negatively affecting P, K, and Mg levels.

Hypothesis

Incorporating trees into pasture benefits resource capture for cool-season forages in a temperate Appalachian silvopasture, thus affecting forage mineral concentrations.

Objectives

1) To evaluate cool-season forage mineral concentrations (calcium, phosphorus, potassium, and magnesium) in response to field treatments: tree species, tree density, and slope position;
2) To measure microclimate response to field treatments: tree species, tree density, and slope;
3) To determine the relationship between microclimate modification and forage mineral concentrations;
4) To relate field treatments to forage mineral concentrations as a function of specific microclimatic factors.

Materials and Methods

Forage Mineral Concentration

For determination of Ca, P, K, and Mg, forage samples were prepared by drying to constant weight at 60 °C for 24 h. A 0.5 g sub-sample was then weighed into ignition tubes and ashed at 500 °C in a muffle furnace (Isotemp Muffle furnace 750 series, Furnace 1.26 cuft, Fisher Scientific, Pittsburgh, PA, USA) for 24 h. Ash was dissolved in 10 ml of 6 N HCl, vortexed, and allowed to sit for one hour before dilution to 50 ml final volume with distilled water. Samples were then refrigerated in scintillation vials prior to determination by atomic emission with an inductively coupled plasma spectrometer at the Virginia Tech Soil Testing Laboratory.

Results

Calcium

Forage Ca concentrations were about 8% lower ($P=0.001$) in 2002 compared to 2003 (6850 vs. 7410 mg kg^{-1}; $SE=80$). During both years, Ca levels increased ($P<0.0001$) as the growing season progressed (Figure 6.1).

Calcium Response to Tree Species

Across both growing seasons, the effect of tree species on Ca levels ($P=0.1$) was masked by significant ($P<0.0001$) species X date interactions (Table 6.2). At the beginning of the growing season, Ca concentrations were greater ($P<0.02$)in forage grown under honey locust. However, Ca levels in forage from under black walnut were equal to or greater ($P<0.03$) than those in forage from under honey locust after the August harvest.

The difference in late-season forage Ca concentration between the two tree species was primarily driven by differences in response to tree density. At late season harvests in both years, Ca concentrations decreased in forage from under high density plantings of honey locust trees but increased under black walnut (species X density interaction; P=0.001). This response was not as strong (P= 0.08) in 2002 as in 2003 (species X density X year interaction; P=0.02).

Calcium Response to Tree Density

Across both seasons, Ca levels increased (P<0.0001) with increasing tree density (5950, 7280, and 8170 mg kg^{-1}; SE=130) (Table 6.1). Significantly greater (P=0.003) Ca levels with increasing tree density occurred at July and August harvests in 2002 and in July through October harvests in 2003 resulting in density X date (P<0.0001) interactions in both years as well as a density X year (P=0.04) interaction.

Calcium Response to Slope Position

Forage Ca levels were greater (P=0.02) at the toe slope (8110 mg kg^{-1}) compared to mid (6720 mg kg^{-1}) and shoulder (6560 mg kg^{-1}) slope positions for both growing seasons (SE=240) (Table 6.3). This effect of slope position was due to the large increase in Ca concentrations with increasing tree density under black walnut trees (slope X species interaction; P=0.01). For most harvests in both years, Ca concentrations were numerically lower at mid slope under honey locust, while under black walnut, Ca concentrations increased from shoulder to mid to toe slope positions. These patterns of response to slope within species were similar in both years, but greater magnitude of response in 2003 resulted in significant (P=0.04) slope X species X year interaction.

Forage Ca concentrations were lower (P#0.008) under honey locust than under black walnut at both medium (7360 vs. 9400 mg kg^{-1}; SE=230) and high density (7410 vs. 11410 mg kg^{-1}; SE=430) sites at the toe slope position (species X density X slope interaction; P=0.02). This interaction was not significant (P=0.10) in 2002, while in 2003, Ca concentrations were lower (P=0.004) under honey locust compared to black walnut at toe (7560 vs. 12120 mg kg^{-1}) and mid slope (6820 vs. 10660 mg kg^{-1}) positions under high density plantings (density X species X slope X year interaction; P=0.05).

Phosphorus

Similar to Ca, forage P levels were about 12% lower (P<0.0001) in 2002 compared to 2003 (3240 vs. 3680 mg kg^{-1}; SE=20). During both years, P levels peaked in mid to late summer (July or August) in both years (Figure 6.1).

Phosphorus Response to Tree Species

At most harvests, forage grown under honey locust trees had numerically greater concentrations of P, but differences between species were small and not significant (P=0.2) over both seasons (Table 6.4). Significantly greater (P<0.05) levels of P were observed in forage from honey locust plots in June 2002 and October 2003. However, P concentrations were lower (P<0.05) in forage under honey locust in July 2003, and species X date interactions were significant (P<0.004) for both seasons.

From the August harvest of each growing season, a pattern of decreased P concentration with increasing tree density was observed in forage grown under black walnut trees. This pattern resulted in significant (P<0.05) species X density interactions at late season (September through November) harvests each year, and blunted the effect of increasing density on P concentrations.

Phosphorus Response to Tree Density

Tree density had no overall effect ($P=0.3$) on P levels during both growing seasons (Table 6.4). However, trends ($P<0.10$) of increased forage P with increased tree density were observed at early harvests (May and July of 2002, and July of 2003) each season, and the response was significant ($P\leq0.02$) at harvests in June 2002 and May and June 2003. For the two years, P concentrations increased about 8% from low (6430 mg kg^{-1}) to high (6960 mg kg^{-1}) density sites over the three harvest dates.

Phosphorus Response to Slope Position

Slope position had no effect ($P=0.2$) on P levels over both growing seasons (Table 6.5), Phosphorus concentrations were about 14% greater ($P=0.02$) at toe slope (3520 mg kg^{-1}) positions than at mid (3090 mg kg^{-1}) and shoulder (3120 mg kg^{-1}) slope positions in 2002 but not significantly different among slope positions in 2003 (3680 mg kg^{-1}; slope X year interaction; $P=0.0009$).

Potassium

Unlike forage Ca, forage K concentrations were greater ($P=0.002$) in 2002 than in 2003 (22100 vs. 21200 mg kg^{-1}; SE=140), but the difference was small (Table 6.6). Forage K levels varied throughout the 2002 growing season, but decreased ($P<0.0001$) as the growing season progressed in 2003 (Figure 6.1). No fertilizer was applied in 2003 and may largely be responsible for this interaction.

Potassium Response to Tree Species

Forage K response to tree species treatment was not significant ($P=0.1$) over years but was obscured by significant ($P=0.007$) species X year interaction (Table 6.6). In 2002, forage K levels were about 22,100 mg kg^{-1} for each species over the growing season, but in 2003, K concentrations were about 7% greater in forage grown under honey locust trees (21900 vs. 20400; SE = 380).

In both years, K concentrations were at least numerically greater in forage from under honey locusts at early (May and June) and late season (September or later) harvests. Conversely, at mid-season harvests (July and August) forage K levels were similar ($P>0.6$) between species or greater ($P<0.08$) under black walnut (species X date interaction; $P<0.0001$).

Over the two growing seasons, forage K concentrations were greater ($P=0.04$) under honey locust (22870 mg kg^{-1}) than under black walnut trees (20390 mg kg^{-1}; SE=590) at high density sites (species X density interaction; $P=0.02$). This interaction was apparent in November 2002 ($P=0.02$), but not significant over the 2002 growing season ($P=0.7$; species X density X date; $P=0.0004$). In 2003, forage K concentrations were consistently lower under high density black walnut trees, and the response was most significant at the end of the growing season (species X density X date and species X density X year interactions; $P \leq 0.002$).

Potassium Response to Tree Density

Although tree density had no effect ($P=0.2$) on forage K levels across growing seasons, forage K levels were lower ($P=0.03$) for low density plots (20000 mg kg-1) than for medium (21900 mg kg^{-1}) and high density (21600 mg kg^{-1}) plots in 2003 (year X density interaction: $P=0.008$) (Table 6.6).

In 2002, the relationship between tree density and forage K levels varied by harvest within the growing season (density X date interaction; $P<0.0001$). At May and June harvests, K levels were lowest ($P\leq0.05$) at low density sites. This pattern was reversed at late-season (August and November) harvests when K was lower ($P\leq0.03$) in forage from under high density sites.

A similar pattern occurred in 2003 (density X date interaction; $P<0.0001$). However, the late-season shift to lower K in forage from under high density trees was not as strong ($P = 0.06$) and did not occur until October

Potassium Response to Slope Position

Slope position had no overall effect ($P=0.3$) on K levels across both growing seasons (Table 6.7). However, in 2002, average forage K concentrations were higher ($P=0.007$) at toe (23220 mg kg^{-1}) compared to mid (21550 mg kg^{-1}) and shoulder (21510 mg kg^{-1}; SE=210) slope positions (slope X year interaction; $P=0.02$). This general pattern occurred with all but the November harvest and was significant ($P\leq0.01$) in June and August. In November, forage K levels tended ($P=0.06$) to be lower at the toe slope (species X date; $P<0.0001$). Slope position had no effect ($P=0.8$) on forage K concentrations in 2003.

Magnesium

Forage Mg levels were about 11% lower ($P<0.0001$) in 2002 compared to 2003 (3850 vs. 4310 mg kg^{-1}; SE=30). In 2002, Mg levels increased as the growing season progressed; in 2003, Mg levels peaked in August ($P<0.0001$) (Figure 6.1)

Magnesium Response to Tree Species

Tree species did not affect ($P>0.4$) forage Mg concentrations across or within either growing season (Table 6.8). Forage Mg levels were lower ($P=0.01$) under honey locust than under black walnut in August of 2002 (species X date interaction; $P=0.0001$). Conversely, forage Mg levels were greater ($P=0.04$) under honey locust than under black walnut in May 2003 species X date interaction; $P<0.0001$).

In both years, Mg levels were greater under black walnut compared to honey locust at high density at the August harvest (species X density interaction; P≤0.02; species X density X date interaction; P=0.004).

Magnesium Response to Tree Density

Tree density (Table 6.8) had no overall effect (P=0.7) on Mg levels across both growing seasons. Patterns of response to shade were similar for both years. In May 2003 and June 2002, forage Mg concentrations were lower (P<0.03) under low density trees, and numerically lower under low density trees in May 2002 and June 2003. In July and August, 2002, forage Mg concentrations were not different (P≥0.4) among densities, but continued to be greater (P<0.04) with greater density in July and August 2003 and this tendency (P=0.10) continued in September 2003 (year X density interaction; P=0.05). In November, 2002, Mg levels were higher (P=0.05) in forage from low density sites, and this tendency (P=0.10) was observed in October 2003; density X date interaction; P=0.0002).

Slope position had no effect on Mg levels (Table 6.9).

SOIL AND MICROCLIMATE RESPONSE TO FIELD TREATMENTS

Soil Nutrients and Bulk Density

Field treatments had no effect on soil nitrogen and phosphorus levels, percent organic matter, or bulk density.

Soil Surface Temperature

Soil surface temperatures (SST) within 3-hr measurement intervals (0900-1500 h) were averaged over the year for each sampling site. The SST were higher (P<0.0001) in 2002 compared to 2003 (30.2 vs. 22.6°C; SE=0.06), most likely due to differences in ambient air temperature and rainfall.

Soil Surface Temperature Response to Tree Species

Overall, tree species did not significantly effect SST in 2002 (P=0.09) or 2003 (P=0.2).

Soil Surface Temperature Response to Tree Density

Although SST data for 2002 were generated using a thermocouple and 2003 data were generated by TidbiT® dataloggers, there were no density X year interactions. Thus, data for responses to tree density are presented for the combined years.

As expected, soil surface temperatures were generally higher at low density compared to medium and high density throughout 2002 (Table 6.10) and 2003 growing season (Figure 6.2). Across 2002 and 2003, SST were higher ($P<0.0001$) under low density (27.6 °C) compared to medium (25.7 °C) and high density (25.6°C) plantings (Figure 6.3). When ambient air temperatures were cooler (5 - 15°C), SST were lower at low density compared to medium and high density ($R^2=0.9$; $P<0.0001$) (Figure 6.4). Conversely, SST were highest at low density sites when ambient air temperatures were between 15 and 27°C.

In 2003, TidbiT® dataloggers measured soil surface temperature every 3 hours from mid May to October, gathering 1400 measurements per sampling site. This data was used to analyze field treatments effect on the length of time spent above 24°C based on the amount of measurements taken which exceeded 24°C. The total number of measurements exceeding 24°C decreased ($P<0.0001$) with increasing tree density (LD=314, MD=250, HD=234; SE=3).

These data suggest that temperature extremes are better moderated by medium and high density plantings, most likely due to the insulator effects of the tree canopy.

Soil Surface Temperature Response to Slope Position

Across 2002 and 2003, soil was warmer (P=0.02) at mid slope (27.2 °C) compared to toe slope (25.6 °C) but not different from shoulder slope positions (26.4°C; SE=0.2) (Figure 6.5). With the greater ambient air temperatures of 2002, SST were cooler (P=0.03) at toe slope positions (29.0 °C) than at mid (31.1 °C) or shoulder slope positions (30.4°C; SE=0.3). Under the lower ambient temperatures of 2003, SST were warmer (P=0.02) at mid slope (23.3 °C) than at toe (22.1 °C) or shoulder slope (22.4°C) positions (SE=0.1).

For both species, SST were numerically greater at mid slope. However, in 2002, soils at mid slope under honey locust were warmer (P=0.05; 31.2 °C) than soils at toe (29.7 °C) and shoulder slope (30.1 °C) positions, while soils at toe slope positions under black walnut were cooler (P=0.02; 28.2 °C) than soils at mid (31.0 °C) and shoulder slope (30.7 °C) positions (species X slope interaction; P=0.02).

In 2003, SST were highest (P=0.005) at mid slope (23.6 °C), and lowest at toe slope under black walnut (21.8 °C; species X slope interaction; P=0.03). Under honey locust, there was no difference (P=0.1) among toe (22.5 °C), mid (23.0 °C), and shoulder (22.1 °C).

Forage Canopy Temperature

Forage canopy temperatures measured at 1200 and 1500 h at each site were averaged across months within years prior to statistical analysis. Forage canopy temperatures were higher (P<0.0001) in 2002 compared to 2003 (33.0 vs. 23.7°C; SE=0.2).

Forage Canopy Temperature Responses to Tree Species

Tree species had no effect (P=0.6) on forage canopy temperatures.

Forage Canopy Temperature Responses to Tree Density

Across both years, canopy temperatures were higher (P<0.0001) at low density sites (30.0, 27.7, and 27.6°C for low, medium and high density sites; SE=0.2) (Figure 6.3). Forage canopy temperatures were 34.8, 32.2, and 32.1°C (P=0.003; SE=0.4) in 2002 and 25.1, 23.2, and 22.9°C (P<0.0001; SE=0.1) for low, medium, and high density sites, respectively.

Forage Canopy Temperature Responses to Slope Position

Across both years, forage canopy temperatures were lower (P=0.003) at toe slope positions (26.9 °C) compared with mid (29.2 °C) and shoulder (29.2°C) positions (SE=0.2) (Figure 6.5). In 2002, FCT were lower (P=0.001) at toe slope positions (T=30.6, M=34.2, S=34.2°C; SE=0.4), but in 2003, canopy temperatures at all three slope positions were significantly different (P=0.05) from each other, with lowest temperatures at the toe slope (23.2 °C) and the highest temperatures at mid slope (24.3 °C; SE = 0.1; slope X year interaction, P=0.003) (Figure 6.5).

Soil Moisture

Soil moisture data were averaged by year for each sampling site. Soil moisture levels were lower (P<0.0001) in 2002 compared to 2003 (18.5 vs. 27.3%; SE=0.2) because of the differences in rainfall.

Soil Moisture Response to Tree Species

Across both years, soil moisture levels were 11% higher (P=0.009) under honey locust (24.1 vs. 21.7%; SE=0.4) than under black walnut trees. Interestingly, this difference was consistent both in dry (2002; 19.5 vs. 17.5%; P=0.05; SE=0.5) and wet (2003; 28.7 vs. 25.8%; P=0.01; SE=0.5) growing seasons.

Soil Moisture Response to Tree Density

Averaged over both years, tree density did not significantly affect ($P=0.2$) soil moisture levels (Figure 6.3). However, in the drier year, 2002, soil moisture levels were lower ($P=0.05$) at medium density (17.4%) compared to low (20.0%) density sites ($SE=0.7$). Tree density had no effect ($P=0.8$) on soil moisture during the wetter year, 2003.

Soil Moisture Response to Slope Position

Surprisingly, slope position alone had no effect ($P=0.2$) on soil moisture (Figure 6.5). However, soil moisture levels at toe slope positions were numerically greater than those at mid and shoulder slope positions in 2002 (20.3, 17.5, 17.7%; $SE=0.9$) and 2003 (28.4, 26.4, 27.1%; $SE=0.1$).

Photosynthetically Active Radiation (PAR)

PAR measurements were not replicated within year, thus results were reported across both years, using year as a replicate. Although we cannot test for a year effect, it is useful to look at the numerical differences between the years to note how tree species, tree density (Figure 6.6), and slope position (Figure 6.7) affected PAR levels during the experiment.

Photosynthetically Active Radiation Response to Tree Species

PAR levels did not differ ($P=0.1$) between honey locust (2100000 micromoles m^{-2} hr^{-1}) and black walnut (1800000 micromoles m^{-2} hr^{-1}) (Figure 6.8). PAR levels were numerically greater under honey locust compared to black walnut in 2002, but were no different in 2003.

Additionally, at toe slope PAR levels were higher under honey locust compared to black walnut, while at shoulder slope PAR levels were lower under honey locust compared to black walnut (species X slope interaction; $P=0.05$). The magnitude of the difference was greater at toe slope.

Photosynthetically Active Radiation Response to Tree Density

As planned, photosynthetically active radiation (PAR) decreased (P=0.0003) with increasing tree density (Figure 6.8). PAR levels for low, medium, and high tree densities were 2700000, 1800000, and 1500000 micromoles m^{-2} hr^{-1}, respectively (SE=10750). This pattern was numerically consistent in 2002 and 2003 (Figure 6.6).

Photosynthetically Active Radiation Response to Slope Position

Slope position had no overall effect (P=0.6) on PAR levels. In 2002, PAR levels were numerically higher at toe slope position, but in 2003, the effect was variable and of a lesser magnitude than in 2002 (Figure 6.7). Additionally, at the toe slope at high and medium density, PAR levels were greater (P#0.06) under honey locust compared to black walnut (slope X species X density interaction; P=0.003).

Discussion

Calcium levels consistently increased with increasing tree density and at the toe slope position compared to mid and shoulder slope positions. Moderate shading may play a role in improving nutrient uptake, especially with calcium (Eriksen and Whitney, 1981; Krueger, 1981; Wilson et al., 1990; Myers and Robbins, 1991). Calcium levels were not only greater in forages grown at medium tree density compared to low tree density, but calcium levels were significantly greater under high tree density compared to medium tree density. These results suggest that available light is the dominant factor affecting calcium concentrations (Blair et al., 1983), and not soil surface and forage canopy temperatures.

Although levels of P, K, and Mg were influenced by field treatments during parts of the growing season, there were no overall effects on their concentrations across both years. Others

(Wilson et al., 1990; Clason, 1995; 1999) have also reported that shade has little effect on forage mineral concentrations.

Summary and Conclusions

With the exception of Ca, microclimate modification due to incorporation of honey locust or black walnut trees is unlikely to directly impact forage mineral nutrition. Although field treatments tested in this study had a neutral effect on P, K, and Mg concentrations, it should not be assumed that mineral concentrations will remain static in an active silvopasture. Camping and grazing behaviors of animals may result in removal of mineral nutrients from one area of pasture with subsequent concentration under trees. Further study is needed to determine tree-plant-animal interactions with respect to nutrient movement in temperate silvopastures.

Table 6.1. Calcium concentration in forages grown at slope position† and tree density‡ combinations.

	Toe			Mid			Shoulder						
	Low	Med	High	Low	Med	High	Low	Med	High	SE	Slope	Density	Slope X Density
	mg kg^{-1}										P value		
2002													
May	3500	4260	4890	3570	3530	3410	3290	3710	3680	280	0.01	0.1	0.2
Jun	4600	5360	5420	4530	4520	4650	4260	4430	4790	140	0.02	0.01	0.1
Jul	4750	5380	5750	4450	4650	4690	4300	4870	5610	180	0.1	0.001	0.7
Aug	5150	9480	13680	4980	7400	9120	4720	7280	8700	700	0.02	0.001	0.06
Nov	13350	13810	15140	10660	12710	13070	12280	13620	12250	970	0.6	0.2	0.9
Season	6270	7660	8980	5640	6560	6990	5770	6780	7010	260	0.04	0.001	0.1
2003													
May	7110	8180	7690	4640	6170	6530	5080	5120	6170	680	0.2	0.1	0.7
Jun	7200	7190	6870	6310	5430	7310	5800	6250	6720	530	0.6	0.3	0.3
Jul	7700	8830	9920	5800	7530	8530	6330	6940	8050	530	0.2	0.003	0.8
Aug	5780	9130	11420	5080	6720	9700	5470	6410	7680	270	0.01	0.001	0.001
Sep	5780	10210	11710	5550	7420	10570	5240	6750	8480	300	0.02	0.001	0.004
Oct	7410	11050	11440	5670	8170	9800	6210	8430	7680	800	0.03	0.002	0.4
Season	6830	9100	9840	5510	6910	8740	5690	6650	7460	310	0.04	0.001	0.1
Mean	6550	8380	9410	5570	6730	7860	5730	6720	7230	230	0.02	0.001	0.1

† Toe = 3-5% slope at base of hill; Mid = 10-60% slope at side of hill; Shoulder = 3-5% slope at top of hill

‡ Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 6.2. Calcium concentration in forages grown under honey locust and black walnut trees at low, medium, and high densities†.

	Honey Locust			Black Walnut						Species X
	Low	Med	High	Low	Med	High	SE	Species	Density	Density
	mg kg^{-1}							P value		
2002										
May	3490	3990	3910	3410	3680	4090	230	0.8	0.1	0.6
Jun	4740	5150	5160	4190	4390	4740	120	0.02	0.01	0.4
Jul	4840	5550	6070	4160	4380	4630	150	0.02	0.001	0.09
Aug	5260	8060	11040	4640	8040	9960	570	0.5	0.001	0.7
Nov	12150	11580	10300	12050	15190	16670	790	0.02	0.2	0.01
Season	6090	6860	7300	5690	7140	8020	220	0.4	0.001	0.08
2003										
May	6480	7830	7780	4730	5150	5820	550	0.01	0.1	0.7
Jun	6940	7450	7460	5930	5130	6470	430	0.003	0.3	0.3
Jul	7100	8470	8500	6120	7060	9160	430	0.09	0.003	0.09
Aug	6180	7280	7750	4710	7560	11440	220	0.1	0.001	0.001
Sep	5890	7140	8000	5160	9100	12510	240	0.03	0.001	0.001
Oct	6180	6320	5920	6680	12110	13370	650	0.001	0.002	0.002
Season	6460	7410	7570	5560	7690	9790	250	0.2	0.001	0.001
Mean	6280	7140	7430	5620	7410	8910	190	0.1	0.001	0.001

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 6.3. Calcium concentration in forages grown under honey locust and black walnut trees at toe, mid, and shoulder (Sho) slope positions†

	Honey Locust			Black Walnut						Species X
	Toe	Mid	Sho	Toe	Mid	Sho	SE	Species	Slope	Slope
				mg kg^{-1}					P value	
2002										
May	3980	3530	3870	4450	3480	3250	230	0.8	0.01	0.2
Jun	5220	4970	4870	5040	4160	4120	120	0.02	0.02	0.3
Jul	5680	5120	5660	4900	4080	4200	150	0.02	0.1	0.6
Aug	8320	7970	8070	10550	6360	5730	570	0.5	0.02	0.1
Nov	10510	10980	12540	17690	13310	12900	790	0.02	0.6	0.08
Season	6740	6510	7000	8530	6280	6040	280	0.4	0.04	0.02
2003										
May	8680	6470	6940	6640	5100	3970	550	0.01	0.02	0.4
Jun	7480	6920	7460	6700	5780	5050	430	0.003	0.6	0.08
Jul	8450	7470	8150	9180	7100	6060	430	0.09	0.2	0.03
Aug	7140	6780	7290	10410	7560	5740	220	0.1	0.01	0.03
Sep	7190	6430	7410	11280	9260	6230	240	0.03	0.02	0.04
Oct	6030	5350	7030	13910	10410	7840	650	0.001	0.03	0.01
Season	7490	6570	7380	9680	7530	5820	410	0.2	0.04	0.03
Mean	7120	6540	7190	9110	6910	5930	230	0.1	0.02	0.01

† Toe = 3-5% slope at base of hill; Mid = 10-60% slope at side of hill; Shoulder = 3-5% slope at top of hill

Table 6.4. Phosphorus concentration in forages grown under honey locust and black walnut trees at low, medium, and high densities†

	Honey Locust			Black Walnut						Species X
	Low	Med	High	Low	Med	High	SE	Species	Density	Density
	mg kg^{-1}							P value		
2002										
May	2890	2970	3170	2860	2970	2950	80	0.4	0.1	0.4
Jun	2990	3010	3440	2680	2870	3050	80	0.06	0.003	0.3
Jul	3450	3510	3640	3490	3700	3800	110	0.2	0.1	0.8
Aug	3400	3550	3560	3460	3410	3130	190	0.5	0.8	0.5
Nov	3090	3370	3490	3250	3120	2950	120	0.2	0.8	0.05
Season	3160	3280	3460	3150	3210	3180	90	0.2	0.3	0.3
2003										
May	3010	3190	3410	2940	3060	3130	70	0.2	0.01	0.4
Jun	3460	3390	3800	3430	3630	3740	100	0.6	0.02	0.3
Jul	3530	3800	3840	3870	4180	3800	120	0.05	0.1	0.2
Aug	4060	4390	4460	4370	4350	3890	190	0.6	0.6	0.1
Sep	3660	4150	4520	4210	4040	3400	140	0.2	0.5	0.001
Oct	3220	3670	3760	3380	3030	2820	110	0.03	0.8	0.003
Season	3490	3760	3960	3700	3720	3460	100	0.2	0.4	0.03
Mean	3330	3520	3710	3430	3460	3320	90	0.2	0.3	0.08

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 6.5. Phosphorus concentration in forages grown at slope position† and tree density‡ combinations.

	Toe			Mid			Shoulder						Slope X
	Low	Med	High	Low	Med	High	Low	Med	High	SE	Slope	Density	Density
	mg kg^{-1}										P value		
2002													
May	3040	3120	3210	2970	2840	2840	2620	2950	3130	80	0.04	0.1	0.08
Jun	3230	3360	3680	2660	2690	3060	2610	2770	3000	80	0.02	0.003	0.9
Jul	3780	4060	4200	3380	3290	3510	3250	3470	3460	110	0.01	0.1	0.6
Aug	3880	3890	3540	3280	3120	3260	3140	3430	3230	190	0.08	0.8	0.7
Nov	3230	3260	3360	3220	3080	3070	3060	3390	3250	120	0.4	0.8	0.5
Season	3430	3540	3600	3100	3010	3150	2940	3200	3220	110	0.02	0.3	0.6
2003													
May	3140	3440	3310	2830	2860	3250	2950	3060	3260	90	0.1	0.01	0.2
Jun	3490	3570	3840	3580	3370	3800	3270	3580	3670	120	0.7	0.02	0.4
Jul	3860	4160	3980	3850	4040	3800	3400	3770	3670	150	0.5	0.1	0.9
Aug	4440	4390	4220	4300	4350	3980	3900	4370	4320	240	0.8	0.6	0.6
Sep	3930	4220	3990	4020	4120	3940	3870	3940	3960	180	0.9	0.5	0.9
Oct	3240	3180	3330	3280	3300	3220	3380	3580	3330	130	0.5	0.8	0.7
Season	3680	3830	3780	3650	3670	3660	3460	3720	3700	130	0.7	0.4	0.9
Mean	3560	3680	3690	3370	3340	3410	3200	3460	3460	110	0.2	0.3	0.8

† Toe = 3-5% slope at base of hill; Mid = 10-60% slope at side of hill; Shoulder = 3-5% slope at top of hill

‡ Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 6.6. Potassium concentration in forages grown under honey locust and black walnut trees at low, medium, and high tree densities†

	Honey Locust			Black Walnut						Species X
	Low	Med	High	Low	Med	High	SE	Species	Density	Density
	mg kg^{-1}							P value		
2002										
May	21150	23440	23290	21940	22460	21600	440	0.07	0.03	0.05
Jun	19830	21720	23620	18420	19450	19690	860	0.01	0.05	0.4
Jul	22640	22700	21350	22700	23760	25050	830	0.03	0.8	0.1
Aug	21660	19820	16560	23140	22130	21550	1030	0.08	0.03	0.3
Nov	24260	25340	24380	25940	23550	19640	850	0.09	0.02	0.02
Season	21910	22600	21840	22430	22270	21510	550	0.9	0.4	0.7
2003										
May	21840	24600	26030	22720	23690	23500	610	0.4	0.01	0.06
Jun	20970	22770	26700	21720	22470	23760	810	0.2	0.004	0.1
Jul	18990	24320	25850	22260	24190	22800	820	1.0	0.003	0.01
Aug	18850	23380	22870	22060	23770	20640	950	0.6	0.03	0.06
Sep	17450	21380	22240	19470	19700	15090	680	0.06	0.03	0.0005
Oct	16590	20010	19740	17060	12500	9780	740	0.002	0.06	0.0003
Season	19110	22740	23910	20880	21050	19260	590	0.05	0.03	0.002
Mean	20510	22670	22870	21660	21660	20390	510	0.1	0.2	0.02

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 6.7. Potassium concentration in forages grown at slope position† and tree density‡ combinations

	Toe			Mid			Shoulder						Slope X
	Low	Med	High	Low	Med	High	Low	Med	High	SE	Slope	Density	Density
	mg kg^{-1}										P value		
2002													
May	22200	23630	23510	21160	22600	21380	21280	22620	22440	530	0.3	0.03	0.8
Jun	21660	23360	25020	17370	19190	20350	18340	19210	19590	1050	0.01	0.05	0.9
Jul	24680	25120	25550	21900	22610	21860	21430	21960	22180	1020	0.09	0.8	0.1
Aug	25990	24010	20640	20820	19860	18680	20380	19060	17860	1260	0.001	0.03	0.7
Nov	22460	21330	19090	26750	25710	23010	26080	26290	23930	1040	0.06	0.02	0.9
Season	23400	23490	22760	21600	21990	21060	21500	21830	21200	670	0.01	0.4	1.0
2003													
May	25270	26130	25380	19350	22330	24540	22210	23970	24370	750	0.3	0.01	0.09
Jun	22780	22330	25760	20270	21130	24300	20980	24400	25640	1000	0.6	0.004	0.5
Jul	22380	23250	24950	20070	24730	23950	19430	24800	24090	1000	0.6	0.003	0.3
Aug	21800	22670	20900	20150	24260	21170	19420	23790	23200	1160	1.0	0.03	0.3
Sep	18460	20090	18190	18230	21510	18600	18670	20010	19200	830	0.9	0.03	0.7
Oct	15870	14150	13520	16900	17110	14650	17700	17510	16120	910	0.2	0.06	0.8
Season	21100	21440	21450	19160	21850	21200	19740	22410	22100	730	0.8	0.03	0.5
Mean	22250	22460	22100	20380	21920	21130	20620	22120	21650	630	0.3	0.2	0.8

† Toe = 3-5% slope at base of hill; Mid = 10-60% slope at side of hill; Shoulder = 3-5% slope at top of hill

‡ Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 6.8. Magnesium concentration in forages grown under honey locust and black walnut trees at low, medium, and high tree densities†

	Honey Locust			Black Walnut						Species X
	Low	Med	High	Low	Med	High	SE	Species	Density	Density
	mg kg^{-1}							P value		
2002										
May	2710	2910	3000	2630	2740	2750	140	0.3	0.3	0.8
Jun	3610	3580	3860	3130	3390	3490	90	0.1	0.03	0.3
Jul	3910	3730	3860	3500	3770	3780	80	0.5	0.4	0.06
Aug	4080	3620	3380	3800	4480	4680	140	0.01	0.7	0.001
Nov	8050	7350	6410	8080	7850	7310	400	0.5	0.05	0.6
Season	4470	4240	4100	4230	4450	4400	130	0.4	0.7	0.1
2003										
May	3330	3540	3750	2790	3150	3120	100	0.04	0.02	0.5
Jun	3760	3750	3990	3430	3470	3540	90	0.09	0.2	0.6
Jul	4050	4140	4240	3900	4310	4470	10	0.6	0.02	0.2
Aug	4290	4220	4210	3960	4440	5030	150	0.3	0.04	0.02
Sep	4010	3970	4020	3950	4270	4520	120	0.3	0.1	0.1
Oct	3760	3460	3170	3460	3510	3510	120	0.8	0.1	0.08
Season	3870	3850	3900	3580	3860	4030	80	0.8	0.04	0.06
Mean	4170	4040	4000	3910	4150	4220	90	0.8	0.7	0.07

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 6.9. Magnesium concentration in forages grown at slope position† and tree density‡ combinations

	Toe			Mid			Shoulder						Slope X
	Low	Med	High	Low	Med	High	Low	Med	High	SE	Slope	Density	Density
	mg kg^{-1}										P value		
2002													
May	**2640**	**2970**	**3150**	**2870**	**2680**	**2550**	**2490**	**2820**	**2930**	**170**	**0.4**	**0.3**	**0.2**
Jun	**3390**	**3770**	**3900**	**3310**	**3280**	**3460**	**3400**	**3400**	**3670**	**110**	**0.2**	**0.03**	**0.4**
Jul	**3780**	**3970**	**3970**	**3690**	**3620**	**3540**	**3650**	**3670**	**3940**	**100**	**0.4**	**0.4**	**0.2**
Aug	**4030**	**4420**	**4660**	**3940**	**3730**	**3610**	**3850**	**3990**	**3820**	**170**	**0.2**	**0.7**	**0.1**
Nov	**8650**	**6670**	**6450**	**7260**	**7550**	**6860**	**8280**	**8580**	**7260**	**510**	**0.7**	**0.05**	**0.2**
Season	**4500**	**4360**	**4430**	**4210**	**4170**	**4010**	**4330**	**4490**	**4330**	**160**	**0.6**	**0.7**	**0.8**
2003													
May	**3200**	**3660**	**3440**	**2880**	**3270**	**3580**	**3110**	**3100**	**3270**	**130**	**0.7**	**0.02**	**0.1**
Jun	**3440**	**3640**	**3680**	**3640**	**3430**	**3880**	**3700**	**3760**	**3730**	**110**	**0.6**	**0.2**	**0.3**
Jul	**4030**	**4370**	**4470**	**3930**	**4230**	**4460**	**3980**	**4080**	**4130**	**130**	**0.7**	**0.02**	**0.6**
Aug	**4210**	**4600**	**4700**	**4110**	**4120**	**4740**	**4070**	**4250**	**4410**	**190**	**0.5**	**0.04**	**0.6**
Sep	**4000**	**4390**	**4210**	**3870**	**4010**	**4440**	**4070**	**3960**	**4170**	**140**	**0.6**	**0.1**	**0.2**
Oct	**3310**	**3430**	**3360**	**3560**	**3410**	**3330**	**3970**	**3600**	**3330**	**200**	**0.3**	**0.1**	**0.3**
Season	**3700**	**4020**	**3970**	**3660**	**3750**	**4070**	**3820**	**3790**	**3840**	**90**	**0.9**	**0.04**	**0.2**
Mean	**4100**	**4190**	**4200**	**3940**	**3960**	**4040**	**4070**	**4140**	**4080**	**110**	**0.7**	**0.7**	**1.0**

† Toe = 3-5% slope at base of hill; Mid = 10-60% slope at side of hill; Shoulder = 3-5% slope at top of hill

‡ Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

Table 6.10. Soil surface temperature response to tree densities† in July and August 2002; soil surface temperatures were higher at low density compared to medium and high density at 12PM and 3PM.

	Tree Density				
	Low	**Medium**	**High**	**SE**	**Density**
	°C				P value
July					
6AM	20.5	20.6	20.5	0.2	0.9
9AM	26.2	26.0	24.6	0.2	<.0001
12PM	31.5	30.6	30.2	0.2	0.009
3PM	31.6	29.1	29.3	0.2	<.0001
6PM	28.4	27.1	26.8	0.2	0.0003
August					
9AM	29.1	28.5	27.2	0.2	0.002
12PM	38.6	34.5	35.1	0.5	0.001
3PM	35.5	32.4	31.6	0.5	0.001

† Low density = almost full exposure to sunlight, low shade environment; Medium density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

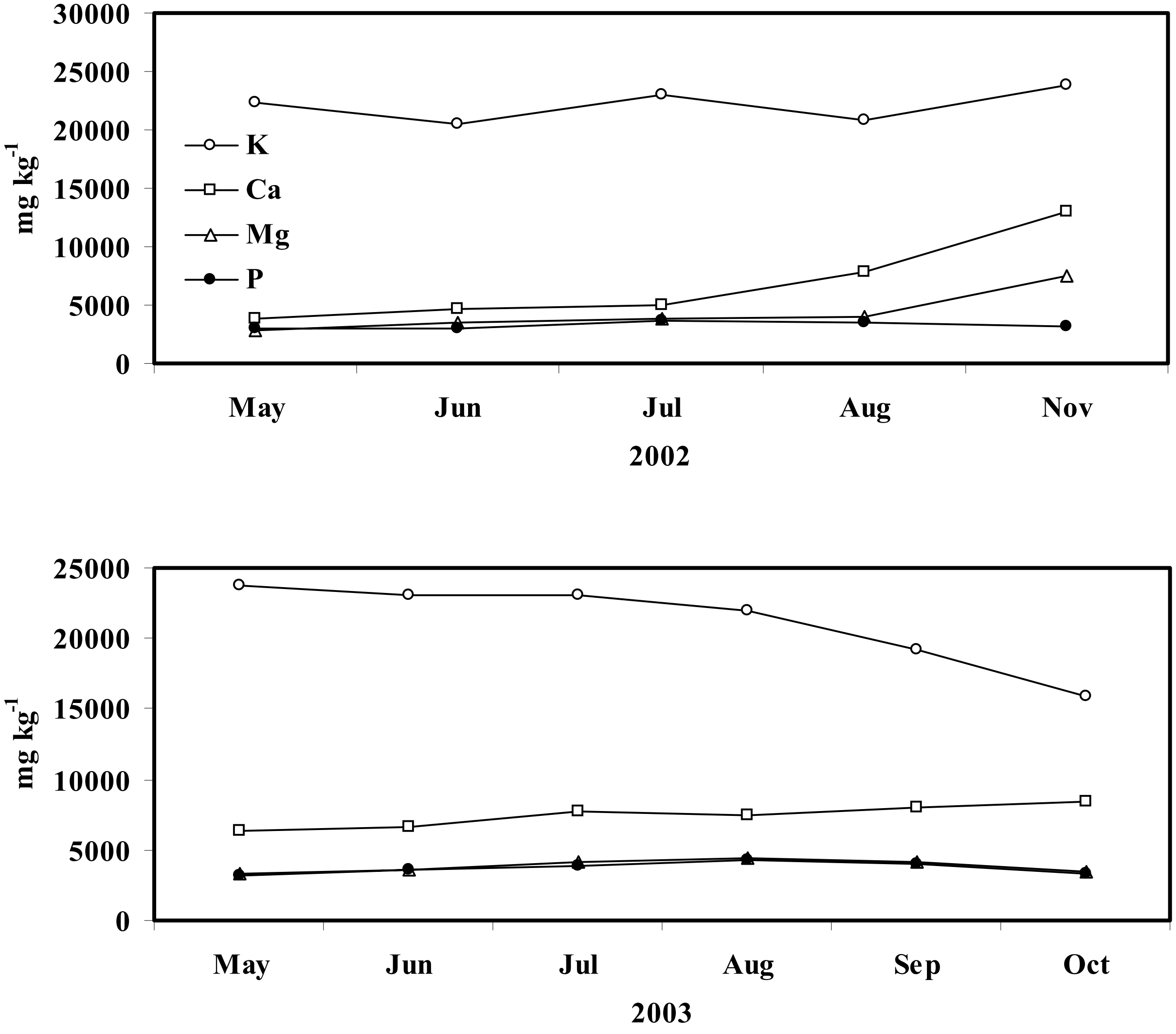


Figure 6.1. Mineral concentrations in forages across the 2002 and 2003 growing seasons

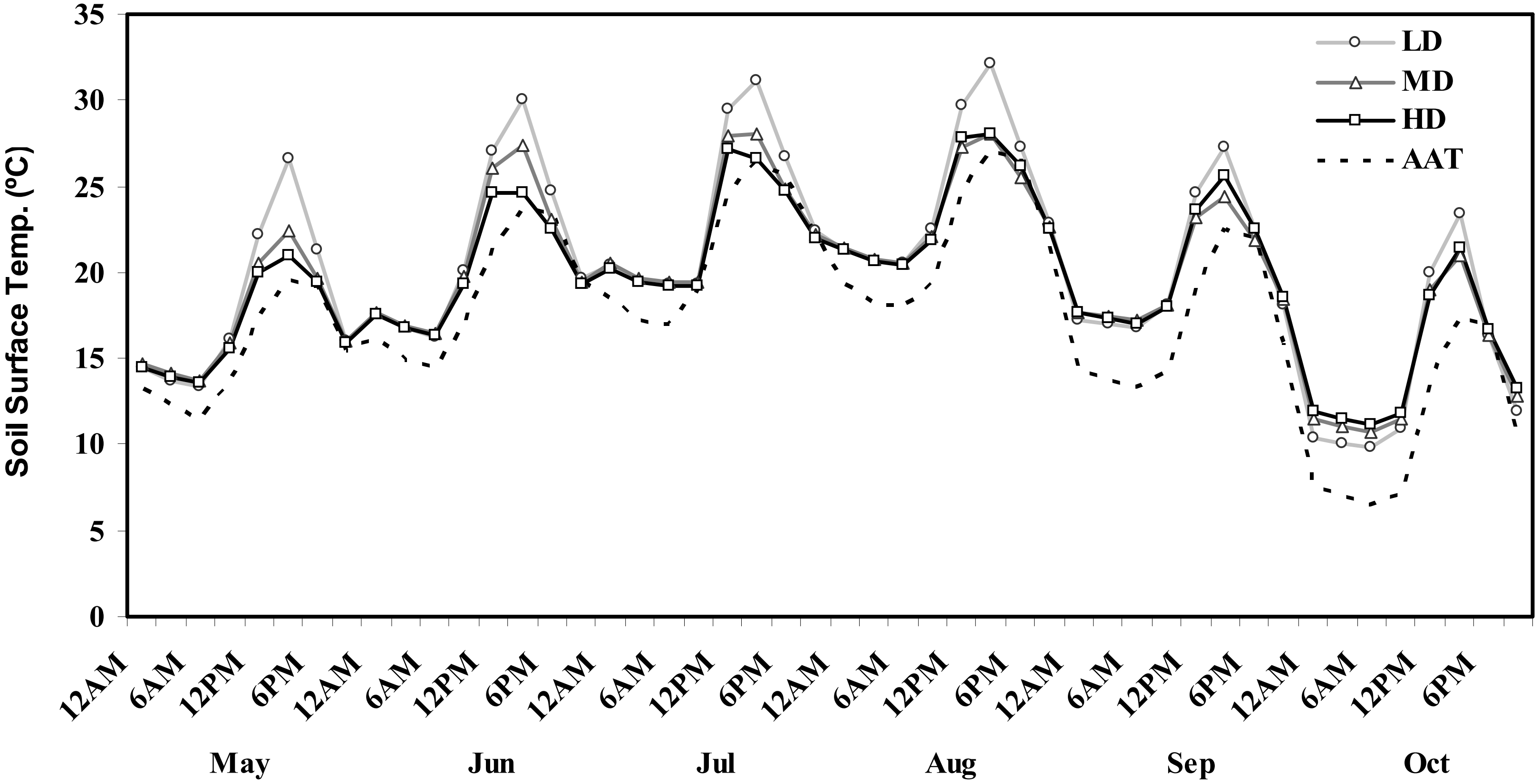


Figure 6.2. Diurnal soil surface temperatures averaged within months in response to low (LD), medium (MD), and high (HD) tree densities; measurements for each density (n=18) were taken every 3 hr. from mid May through October in 2003; AAT=ambient air temperatures; soil surface temperatures were highest (P<0.0001) at LD compared to MD and HD across the growing season.

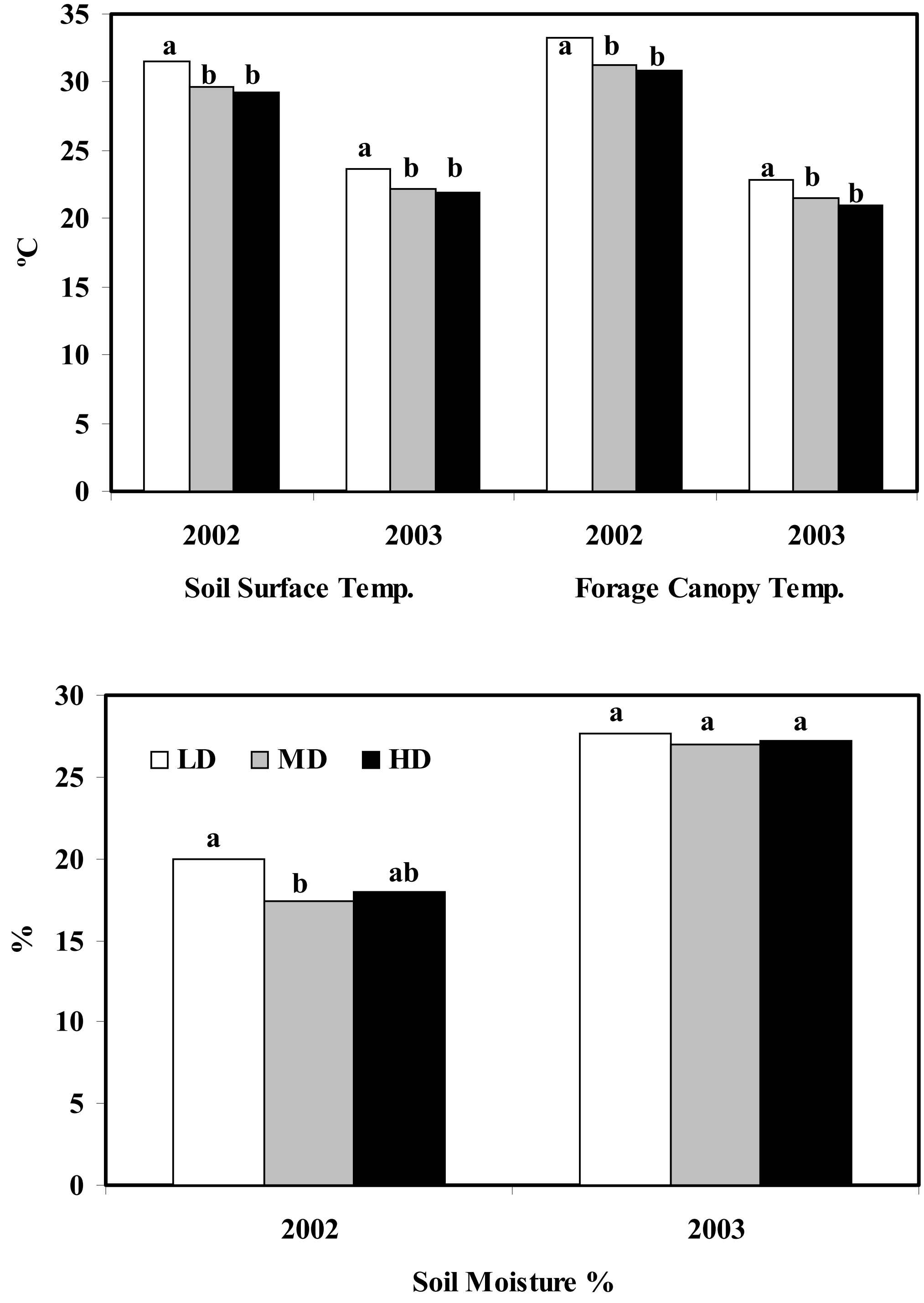


Figure 6.3. Microclimate responses to low (LD), medium (MD), and high (HD) tree densities in 2002 and 2003: soil surface temperature, forage canopy temperature, and soil moisture; same letters within years within each microclimate measurement are not significantly ($P<0.05$) different based on Tukey's mean separation.

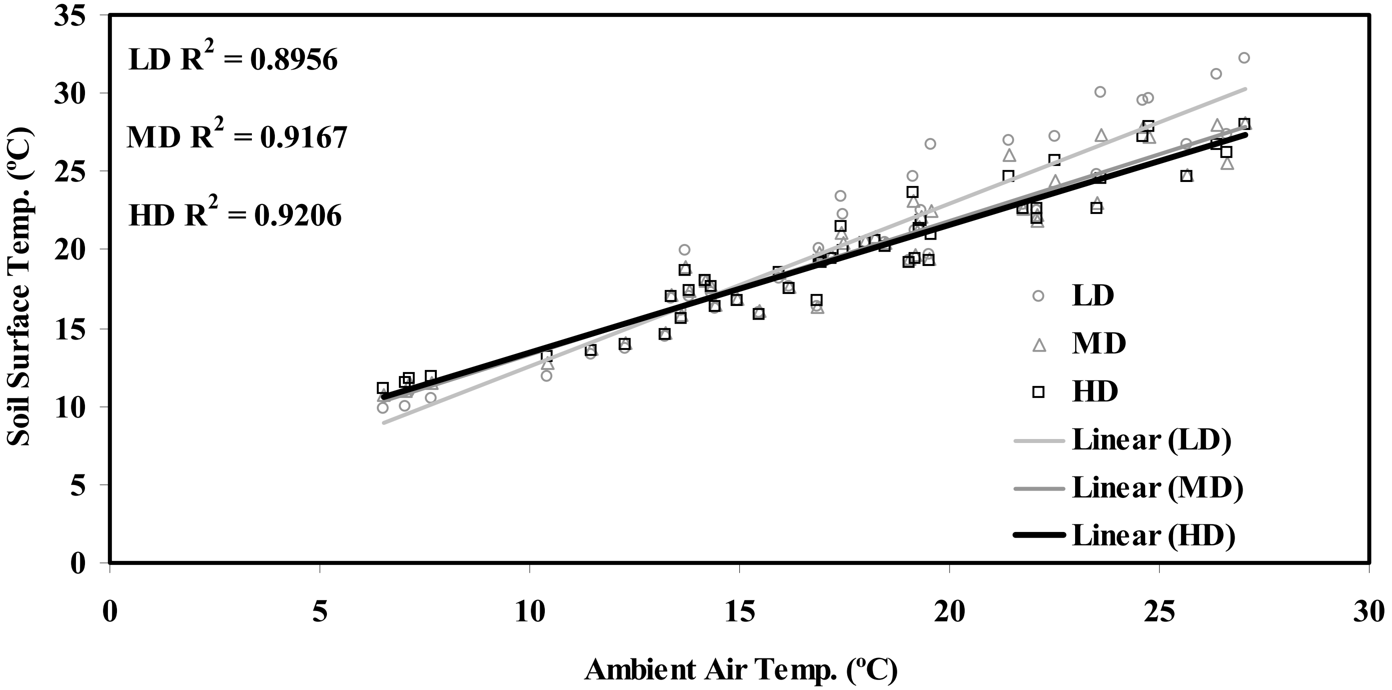


Figure 6.4. Relationship of soil surface temperature to ambient air temperature by low (LD), medium (MD), and high (HD) tree densities; R^2 values were significant ($P<0.0001$) for all densities; soil surface temperatures were better moderated at MD and HD during ambient air temperature extremes.

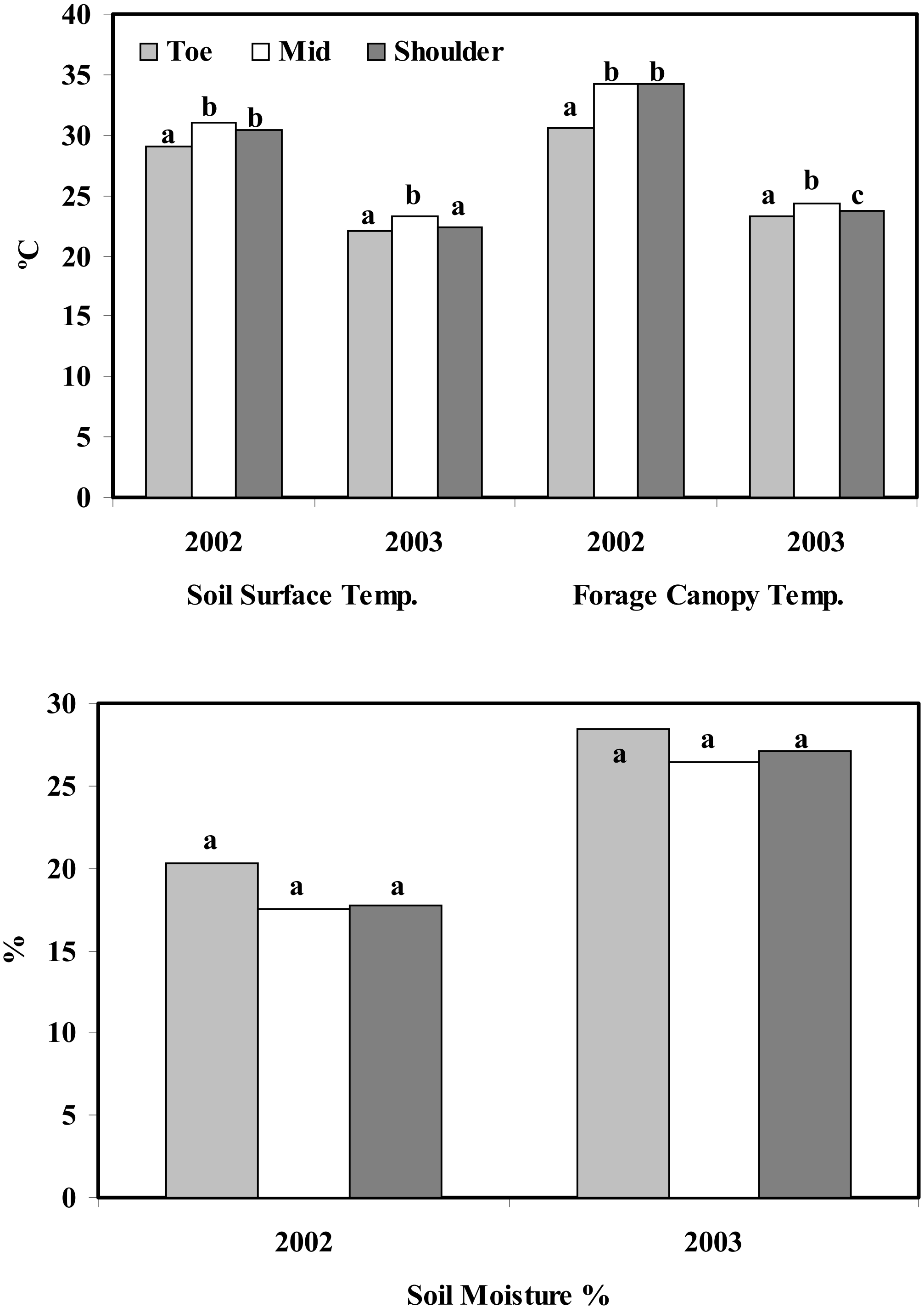


Figure 6.5. Microclimate responses to slope positions in 2002 and 2003: soil surface temperature, forage canopy temperature, and soil moisture; same letters within years within each microclimate measurement are not significantly ($P<0.05$) different based on Tukey's mean separation.

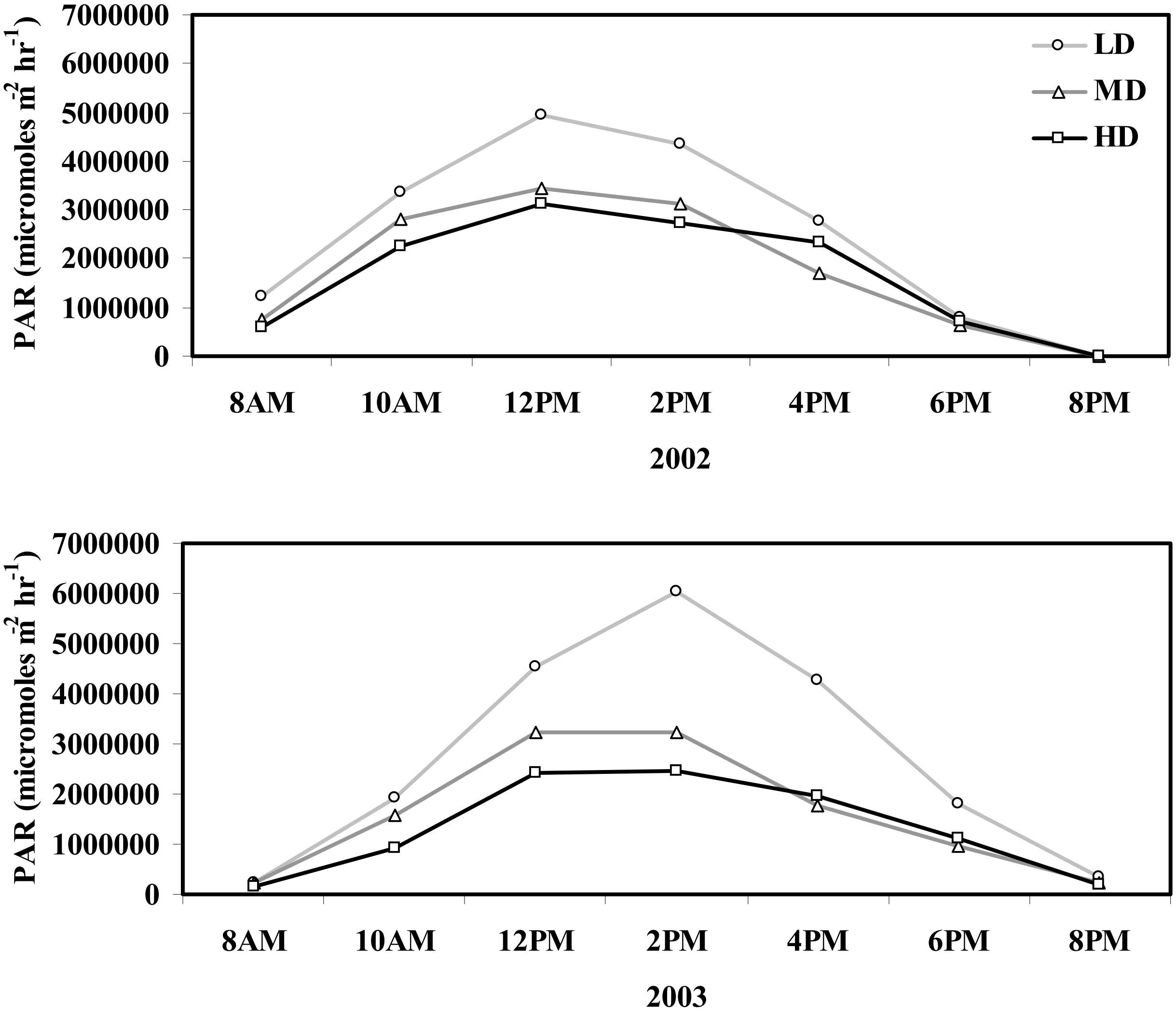


Figure 6.6. Photosynthetically active radiation (PAR) measured just above the forage canopy as affected by low (LD), medium (MD), and high (HD) tree densities; values averaged by time from 23-Aug through 10-Sep 2002 and 5-Aug through 21-Aug 2003.

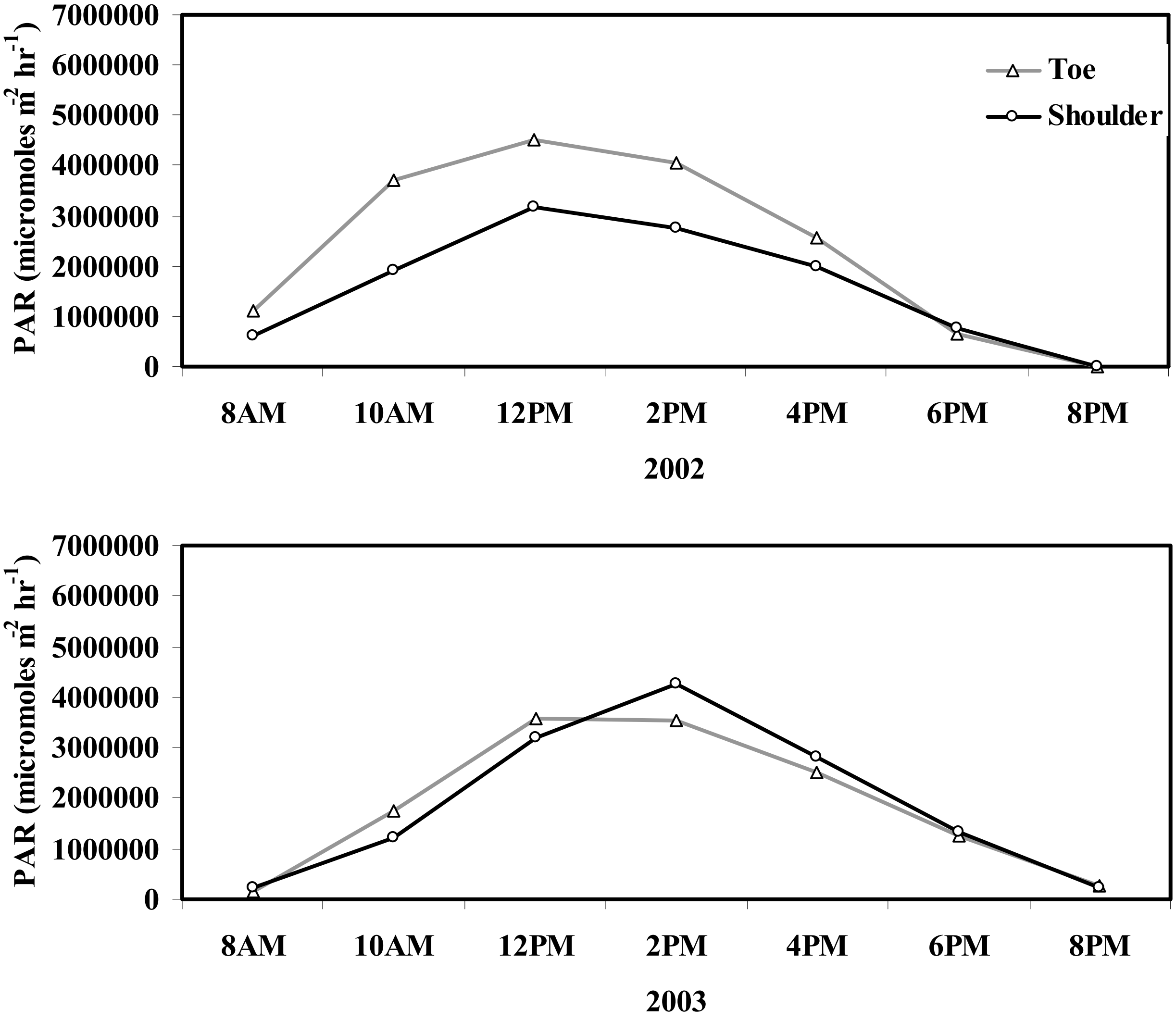


Figure 6.7. Photosynthetically active radiation (PAR) measured just above the forage canopy at to toe and shoulder slope positions; values averaged by time from 23-Aug through 10-Sep 2002 and 5-Aug through 21-Aug 2003.

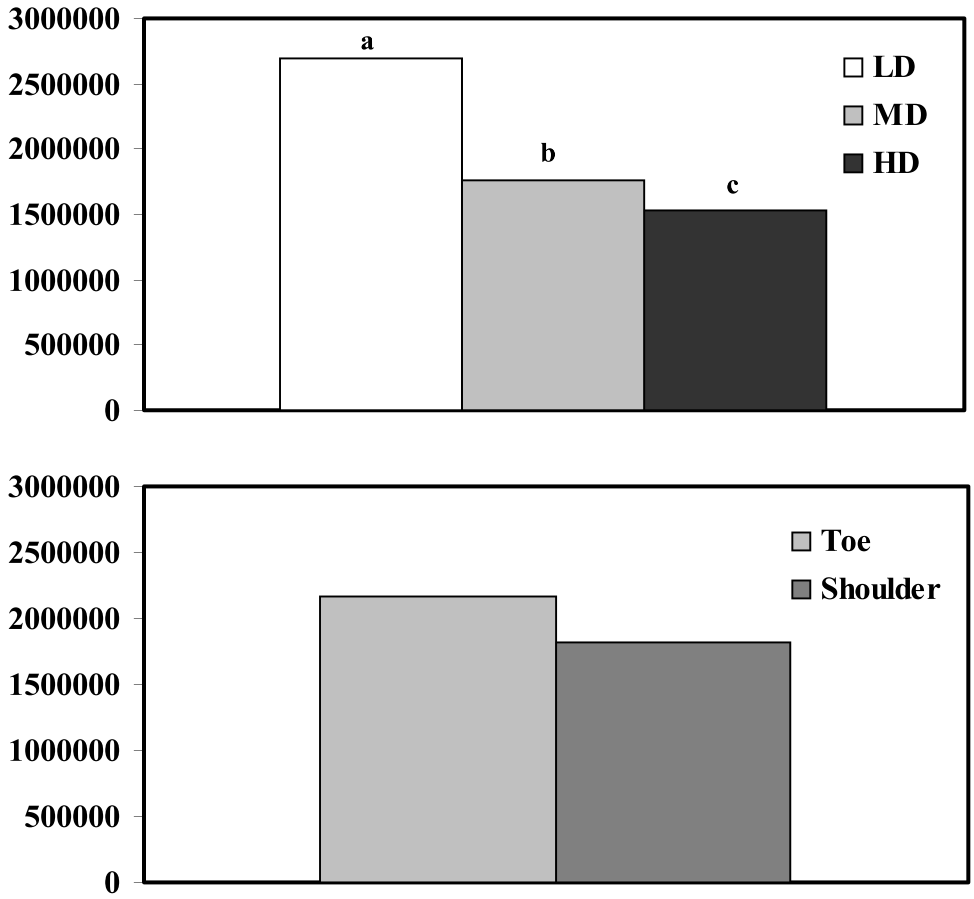


Figure 6.8. Average values of photosynthetically active radiation (PAR) in response to field treatments: low (LD), medium (MD), and high (HD) tree densities; toe and shoulder slope positions; values with the same letter are not significantly ($P<0.05$) different based on Tukey's mean separation.

Chapter 7: Conclusions

Growing trees in cool-season pastures is an effective way to influence microclimate parameters to improve forage production and nutritive value. Our results suggest that manipulating shading with stand density (or pruning) is critical for optimizing resource capture. Although slope position did influence forage parameters, the responses were not well correlated with microclimate modification. Similarly, few differences in microclimate were observed between the two tree species. Thus, the most effective way to manage the forage resource is with tree density.

Tree stand density had the most influence on soil surface temperature, which appeared to be the dominant factor affecting forage production and nutritive value where light levels were adequate. The optimum microclimate environment for maximizing resource allocation to cool season forages occurs when tree canopies moderate soil surface and forage canopy temperatures without reducing PAR levels below that needed for cool season forage production.

Medium tree density facilitated the greatest forage production compared to low and high tree density. Similarly, the presence of trees in the pasture had positive, negative, and neutral effects on nutritive value. Calcium levels were consistently increased with shade, while ADF, CP, P, K, and Mg levels were similar across tree densities, while lower NDF concentrations were possibly offset by reductions in TNC. Incorporating trees into cool-season pasture improves forage production without compromising forage nutritive value. However, more research is needed to determine the effects of shade on grazing animals in order to better characterize forage quality and animal performance in silvopasture systems.

Further research is needed to consider the affects of silvopasture design on all components (pasture, animals, trees) of the system. Despite the difference in production in forages grown under honey locust and black walnut, we were unable to determine the mechanism responsible for this difference. More detailed research is needed to closely monitor the affects of honey locust and black walnut on the different nutrient cycles and soil water movement. Additionally, more research is needed to determine how grazing animals will affect and be affected by the silvopastoral environment.

It is important to consider the influence of honey locust and black walnut on the grazing animal before making tree species recommendations to farmers. Animal performance may be drastically different in a honey locust based silvopasture system compared to a black walnut silvopasture simply due to the presence of the locust pods which could extend the grazing period by an extra month. However, a black walnut silvopasture system has the potential to produce more forage for the grazing animal and would thus be preferred over the honey locust system.

Silvopasture systems are dynamic, making them difficult to study and manage. The knowledge that forage production was greatest at medium tree density is only as useful as our ability to use that knowledge to design silvopasture systems for farmers. The next big question is: “How can a farmer create and maintain medium tree density in a silvopasture over time?” Future research must incorporate grazing animals and work to develop management guidelines for establishing and maintaining, over the long-term, the ideal microclimate for optimization of forage production and nutritive value.

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Appendices

Appendix A

Table A.1. Characterization of sampling sites (n=54)

Plot No.	Species†	Density‡	Slope§	Rep
1	L	3H	2M	1
2	L	3H	3S	1
3	L	3H	1T	1
4	L	1L	2M	1
5	L	1L	3S	1
6	L	1L	1T	1
7	L	2M	2M	1
8	L	2M	3S	1
9	L	2M	1T	1
10	L	3H	2M	2
11	L	3H	3S	2
12	L	3H	1T	2
13	L	1L	2M	2
14	L	1L	3S	2
15	L	1L	1T	2
16	L	2M	2M	2
17	L	2M	3S	2
18	L	2M	1T	2
19	L	3H	2M	3
20	L	3H	3S	3
21	L	3H	1T	3
22	L	1L	2M	3
23	L	1L	3S	3
24	L	1L	1T	3
25	L	2M	2M	3
26	L	2M	3S	3
27	L	2M	1T	3
28	W	3H	2M	1
29	W	3H	3S	1
30	W	3H	1T	1
31	W	1L	2M	1
32	W	1L	3S	1
33	W	1L	1T	1
34	W	2M	2M	1
35	W	2M	3S	1
36	W	2M	1T	1
37	W	3H	2M	2
38	W	3H	3S	2
39	W	3H	1T	2
40	W	1L	2M	2
41	W	1L	3S	2

42	**W**	**1L**	**1T**	**2**
43	**W**	**2M**	**2M**	**2**
44	**W**	**2M**	**3S**	**2**
45	**W**	**2M**	**1T**	**2**
46	**W**	**3H**	**2M**	**3**
47	**W**	**3H**	**3S**	**3**
48	**W**	**3H**	**1T**	**3**
49	**W**	**1L**	**2M**	**3**
50	**W**	**1L**	**3S**	**3**
51	**W**	**1L**	**1T**	**3**
52	**W**	**2M**	**2M**	**3**
53	**W**	**2M**	**3S**	**3**
54	**W**	**2M**	**1T**	**3**

† L= honey locust; W= black walnut

‡ 3H= high density; 2M= medium density; 1L= low density

§ 1T= toe; 2M= mid; 3S= shoulder

Table A.2. Yield values by harvest date for 2002 and 2003

	2002						2003						
Plot	5/9	6/12	7/17	8/21	11/7	Season	5/7	6/10	7/17	8/20	9/25	10/29	Season
	kg ha^{-1}												
1	1515	492	531	377	1008	3923	1492	815	1208	769	746	100	5131
2	1615	323	262	238	696	3134	931	885	931	462	862	115	4184
3	1208	262	338	308	819	2934	1215	877	1208	669	808	115	4892
4	1592	738	692	585	1058	4665	1431	1015	1854	962	923	138	6323
5	2592	738	477	323	1142	5273	1469	1138	1685	931	946	138	6307
6	1138	338	515	654	954	3600	1677	985	1869	862	769	115	6277
7	2023	662	808	538	1215	5246	1423	1477	1485	1015	1254	223	6877
8	3408	808	669	515	1492	6892	1315	792	1446	1238	1285	346	6423
9	1523	392	438	469	1038	3861	1192	1438	1646	908	1100	162	6446
10	1254	554	338	362	669	3177	1031	785	1177	515	815	154	4477
11	1615	538	315	269	846	3584	1608	1031	1615	585	1177	162	6177
12	1369	431	423	323	769	3315	1908	885	1269	800	838	123	5823
13	1446	754	523	331	1215	4269	1623	1015	1169	1015	638	131	5592
14	2308	746	546	254	1119	4973	1385	515	1269	885	1015	185	5254
15	1469	646	515	331	1161	4123	908	900	1623	1169	1015	146	5761
16	2192	762	315	246	985	4500	1738	908	1431	731	1000	123	5931
17	1808	838	431	431	885	4392	1846	854	1785	777	1154	154	6569
18	1754	700	546	331	823	4154	2077	1315	1785	769	1346	138	7430
19	1615	392	477	277	769	3531	1446	623	977	600	931	162	4738
20	1431	677	408	138	612	3265	1808	900	1615	531	708	131	5692
21	1223	508	854	400	1338	4323	2738	1146	1308	823	985	285	7284
22	1538	408	715	262	1277	4200	2092	654	1285	1131	977	162	6300
23	992	531	546	154	777	3000	1592	723	1969	1000	1015	185	6484
24	1685	569	808	415	1323	4800	1331	946	1438	1046	746	138	5646
25	1631	608	600	423	1138	4400	2092	762	1561	1192	1231	169	7007
26	2108	638	600	215	1023	4584	1885	1123	1692	754	1131	223	6807
27	1769	692	938	408	1469	5277	2261	1608	1561	1015	1169	315	7930

28	1231	446	438	454	1892	4461	862	1161	1454	885	946	123	5431
29	1554	531	423	377	1361	4246	1415	1100	1554	1069	908	308	6354
30	931	285	508	423	1500	3646	631	938	1115	800	762	331	4577
31	1223	554	515	362	1085	3738	1077	846	1031	869	823	115	4761
32	1246	792	431	208	1123	3800	1208	808	1477	1100	862	208	5661
33	1492	531	485	277	1111	3896	1692	1169	1554	892	992	208	6507
34	1592	1077	777	508	1669	5623	1338	1077	1161	969	854	323	5723
35	2323	754	431	354	1131	4992	1546	1000	1392	1138	1008	254	6338
36	1461	469	554	600	1346	4431	1385	1408	2400	1015	1323	585	8115
37	2185	485	731	423	1227	5050	2446	1161	1200	1161	846	285	7100
38	2738	554	562	338	1361	5554	2131	746	1500	777	908	115	6177
39	2061	600	692	762	1623	5738	1185	646	1231	908	838	454	5261
40	2546	954	562	377	1308	5746	1846	738	1415	1031	954	215	6200
41	2146	792	800	431	1038	5207	1508	685	1138	915	823	146	5215
42	1677	577	846	631	2285	6015	1923	731	1485	1477	1261	208	7084
43	2100	569	669	508	1508	5354	3108	646	1377	885	1246	354	7615
44	2069	862	738	392	1492	5554	3492	992	1985	1361	1354	269	9453
45	2085	769	592	462	1800	5707	1169	623	1446	1177	1592	585	6592
46	2185	554	708	408	2069	5923	2192	700	1000	669	831	769	6161
47	2431	554	931	408	1831	6154	3400	592	1323	746	962	292	7315
48	2077	546	677	469	1277	5046	1254	600	1115	754	931	454	5107
49	1392	762	615	262	1100	4131	2215	538	1331	946	785	162	5977
50	1761	492	508	269	1385	4415	2146	800	1361	915	962	200	6384
51	1992	631	923	585	1423	5554	2061	885	1477	1061	1077	354	6915
52	2538	585	554	477	1904	6057	2223	708	1208	946	1085	785	6954
53	1777	769	815	338	1915	5615	3215	838	1485	823	1077	338	7777
54	2477	677	985	615	1985	6738	1792	946	1400	1038	1461	700	7338

Table A.3. Neutral detergent fiber values by harvest date for 2002 and 2003

	2002						2003						
Plot	5/9	6/12	7/17	8/21	11/7	Season	5/7	6/10	7/17	8/20	9/25	10/29	Season
							%						
1	47.0	50.3	50.0	48.3	46.8	48.5	50.9	42.0	41.3	41.7	44.4	42.9	43.9
2	50.4	52.4	52.6	48.9	48.2	50.5	46.7	40.2	41.1	43.2	44.7	44.6	43.4
3	49.1	45.9	50.8	49.9	45.8	48.3	39.6	34.8	39.4	41.7	41.5	40.9	39.6
4	49.4	54.4	51.0	50.8	46.8	50.5	44.7	38.8	43.4	47.0	51.8	40.8	44.4
5	51.7	54.6	51.3	53.7	43.4	50.9	49.8	39.7	43.7	45.0	49.3	42.8	45.1
6	48.7	48.1	46.6	46.6	47.8	47.6	45.8	36.0	39.9	41.9	45.7	39.1	41.4
7	51.7	52.5	51.6	51.6	47.4	50.9	55.8	45.2	42.4	44.3	49.4	40.3	46.2
8	53.8	56.9	51.6	48.7	49.8	52.1	54.2	46.6	47.2	49.1	55.9	45.1	49.7
9	48.4	52.1	50.7	50.5	45.6	49.5	46.4	37.7	42.8	43.8	49.8	38.8	43.2
10	51.5	52.6	56.7	48.9	44.0	50.7	51.3	36.9	41.4	39.7	42.5	41.1	42.1
11	52.0	53.9	54.3	49.1	44.3	50.7	45.9	32.5	40.3	38.2	42.4	43.8	40.5
12	45.5	42.7	50.5	48.0	42.7	45.9	42.4	38.2	40.4	41.2	42.6	40.1	40.8
13	50.6	54.8	51.7	53.3	43.3	50.8	52.3	38.8	45.5	44.5	48.1	41.1	45.0
14	52.6	54.6	56.2	54.1	48.5	53.2	55.3	45.1	48.1	53.4	49.4	41.4	48.8
15	47.8	50.5	50.5	48.7	47.0	48.9	45.2	39.7	41.7	42.7	42.5	38.6	41.7
16	48.6	54.1	56.3	49.6	42.3	50.2	45.5	39.1	41.6	42.2	42.5	36.6	41.3
17	53.1	54.2	55.0	50.8	44.3	51.5	45.8	37.6	43.0	43.0	43.7	38.0	41.9
18	47.9	48.0	48.0	48.8	43.0	47.2	38.9	34.0	39.9	40.3	38.0	33.7	37.5
19	58.0	55.0	55.2	49.9	41.8	52.0	55.2	46.3	47.3	46.7	48.0	42.6	47.7
20	49.7	53.8	50.6	55.4	41.5	50.2	54.9	40.7	43.8	42.8	44.8	43.2	45.0
21	54.9	55.9	54.8	47.9	42.0	51.1	52.5	46.1	48.9	48.9	47.5	43.3	47.9
22	57.1	51.7	50.9	54.6	42.2	51.3	51.0	44.2	46.1	52.6	56.9	42.3	48.9
23	52.3	52.1	47.1	42.4	41.3	47.0	47.6	37.4	42.7	35.3	38.0	33.5	39.1
24	55.4	55.4	54.2	55.3	43.0	52.7	51.6	46.2	44.9	50.9	50.6	38.6	47.1
25	57.5	54.8	51.1	50.8	41.4	51.1	51.7	44.0	46.1	45.2	45.2	44.7	46.1
26	56.1	51.4	50.6	54.8	41.4	50.9	53.5	37.9	44.4	47.2	44.6	41.6	44.9
27	55.3	52.2	53.3	48.7	42.7	50.5	55.0	34.0	50.3	48.4	46.3	44.5	46.4

28	**50.0**	**54.9**	**52.6**	**40.7**	**41.9**	**48.0**	**42.4**	**39.0**	**41.9**	**39.0**	**38.0**	**31.2**	**38.6**
29	**51.0**	**56.1**	**49.9**	**44.9**	**44.3**	**49.2**	**47.1**	**41.5**	**46.4**	**45.6**	**44.3**	**38.4**	**43.9**
30	**46.2**	**52.0**	**46.6**	**38.2**	**38.4**	**44.3**	**45.8**	**40.2**	**40.2**	**33.3**	**29.7**	**26.3**	**35.9**
31	**48.4**	**57.0**	**51.6**	**52.2**	**43.0**	**50.4**	**54.0**	**41.5**	**44.5**	**47.3**	**49.5**	**39.7**	**46.1**
32	**51.0**	**56.9**	**55.4**	**54.5**	**45.4**	**52.6**	**51.0**	**43.9**	**48.8**	**48.7**	**53.9**	**46.4**	**48.8**
33	**49.2**	**53.9**	**51.2**	**50.1**	**47.8**	**50.4**	**47.0**	**34.4**	**41.5**	**48.4**	**47.7**	**41.8**	**43.5**
34	**49.7**	**55.0**	**51.9**	**44.1**	**45.4**	**49.2**	**51.3**	**53.4**	**50.0**	**45.2**	**43.8**	**36.3**	**46.7**
35	**54.4**	**58.8**	**51.8**	**50.6**	**45.1**	**52.1**	**51.2**	**44.5**	**52.3**	**53.0**	**55.5**	**39.9**	**49.4**
36	**45.8**	**47.9**	**45.5**	**40.5**	**39.8**	**43.9**	**45.8**	**35.5**	**38.3**	**35.8**	**33.4**	**24.3**	**35.5**
37	**52.5**	**58.2**	**56.5**	**49.5**	**40.5**	**51.5**	**60.8**	**39.0**	**45.1**	**45.4**	**38.7**	**40.1**	**44.9**
38	**50.0**	**48.7**	**48.6**	**48.5**	**44.0**	**48.0**	**49.1**	**40.9**	**44.6**	**43.7**	**42.3**	**48.2**	**44.8**
39	**48.7**	**51.7**	**55.3**	**39.6**	**39.4**	**46.9**	**44.6**	**40.8**	**37.9**	**41.8**	**38.6**	**36.8**	**40.1**
40	**49.9**	**56.9**	**57.0**	**53.0**	**44.7**	**52.3**	**51.5**	**45.3**	**51.1**	**55.0**	**47.9**	**44.7**	**49.3**
41	**53.2**	**54.4**	**53.2**	**55.0**	**44.8**	**52.1**	**59.0**	**48.4**	**54.3**	**54.0**	**48.8**	**46.3**	**51.8**
42	**47.1**	**45.5**	**49.5**	**46.9**	**52.6**	**48.3**	**53.6**	**38.9**	**44.9**	**51.0**	**53.7**	**42.1**	**47.4**
43	**51.2**	**54.6**	**52.2**	**51.1**	**46.2**	**51.1**	**56.7**	**46.2**	**48.7**	**47.8**	**54.0**	**40.0**	**48.9**
44	**48.3**	**51.1**	**52.0**	**45.0**	**44.1**	**48.1**	**51.2**	**39.9**	**44.4**	**43.7**	**41.7**	**40.8**	**43.6**
45	**45.8**	**47.0**	**51.4**	**40.9**	**39.4**	**44.9**	**44.7**	**43.7**	**44.4**	**42.1**	**42.2**	**31.3**	**41.4**
46	**53.4**	**55.3**	**56.0**	**48.4**	**39.4**	**50.5**	**57.8**	**46.7**	**45.8**	**35.6**	**31.9**	**39.8**	**42.9**
47	**48.8**	**58.3**	**48.4**	**49.9**	**42.3**	**49.5**	**59.8**	**46.5**	**49.8**	**47.4**	**44.7**	**35.7**	**47.3**
48	**48.7**	**47.3**	**52.8**	**32.3**	**37.3**	**43.7**	**49.1**	**42.8**	**44.0**	**41.5**	**41.0**	**42.1**	**43.4**
49	**52.8**	**60.0**	**51.1**	**53.9**	**39.4**	**51.4**	**51.2**	**42.8**	**45.9**	**51.0**	**44.5**	**43.9**	**46.5**
50	**52.2**	**60.1**	**54.5**	**53.5**	**41.7**	**52.4**	**50.9**	**43.5**	**47.2**	**48.1**	**50.5**	**41.1**	**46.9**
51	**50.3**	**51.5**	**48.6**	**46.0**	**41.8**	**47.7**	**47.1**	**42.3**	**45.9**	**47.9**	**40.0**	**36.3**	**43.3**
52	**53.6**	**53.8**	**54.2**	**49.1**	**42.6**	**50.7**	**53.5**	**51.1**	**49.0**	**50.2**	**42.1**	**28.5**	**45.7**
53	**52.0**	**57.9**	**52.4**	**49.0**	**42.2**	**50.7**	**56.9**	**49.2**	**51.8**	**47.8**	**48.8**	**42.5**	**49.5**
54	**48.5**	**49.0**	**51.8**	**39.3**	**39.7**	**45.7**	**55.4**	**47.5**	**46.7**	**45.2**	**38.9**	**36.0**	**44.9**

Table A.4. Acid detergent fiber values by harvest date for 2002 and 2003

	2002						2003						
Plot	5/9	6/12	7/17	8/21	11/7	Season	5/7	6/10	7/17	8/20	9/25	10/29	Season
							%						
1	23.7	25.2	24.7	27.3	24.9	25.2	27.1	23.0	24.1	24.5	26.5	23.7	24.8
2	26.6	26.3	27.0	29.7	25.5	27.0	25.9	24.0	26.7	26.7	27.1	25.1	25.9
3	25.4	23.7	26.0	30.6	24.9	26.1	23.4	21.4	23.8	24.2	25.7	23.4	23.7
4	24.9	27.8	24.6	25.9	24.2	25.5	24.6	22.5	25.7	25.2	28.0	21.9	24.6
5	25.6	28.0	25.3	27.7	23.2	26.0	28.0	23.9	26.3	25.3	27.1	22.4	25.5
6	24.5	24.4	22.8	24.7	24.6	24.2	25.2	21.9	24.6	24.0	25.7	21.9	23.9
7	26.1	26.0	26.6	27.5	24.3	26.1	28.5	24.0	25.1	24.9	27.9	21.7	25.3
8	27.4	28.8	24.4	24.2	26.7	26.3	28.7	25.2	27.0	26.9	29.2	24.9	27.0
9	24.1	26.4	24.7	28.9	24.0	25.6	26.0	23.1	24.7	25.2	28.7	21.8	24.9
10	25.4	26.5	29.1	30.5	24.1	27.1	28.2	22.3	25.1	23.2	25.7	24.7	24.9
11	26.8	27.8	28.3	29.7	25.7	27.7	26.7	20.7	24.8	22.2	26.4	25.1	24.3
12	23.1	22.1	26.6	29.3	23.3	24.9	24.9	22.3	23.6	24.7	26.3	22.4	24.0
13	25.9	28.1	25.5	26.9	23.0	25.9	28.3	22.5	25.6	24.6	26.2	21.9	24.8
14	27.0	28.0	27.4	27.0	25.0	26.9	29.2	24.0	26.1	27.3	26.3	21.7	25.7
15	24.2	25.5	26.3	25.2	24.5	25.1	25.2	23.0	25.0	25.8	25.3	20.9	24.2
16	24.1	28.3	27.9	29.2	22.5	26.4	25.4	22.0	25.5	23.4	24.8	20.8	23.7
17	26.5	27.8	27.3	29.5	24.0	27.0	26.0	23.0	26.9	25.4	26.8	22.9	25.2
18	24.6	25.2	26.3	28.0	23.5	25.5	23.0	21.1	24.8	23.3	23.5	20.5	22.7
19	30.2	27.6	27.7	30.1	22.5	27.6	29.9	25.4	27.4	25.8	27.7	23.9	26.7
20	26.2	27.3	26.3	29.1	22.8	26.3	30.1	23.0	25.6	22.7	26.0	25.2	25.4
21	27.2	26.3	27.8	28.7	21.7	26.3	27.8	23.9	26.7	27.1	27.2	24.4	26.2
22	29.4	26.5	25.7	26.7	21.7	26.0	28.2	24.1	27.1	28.1	29.8	21.6	26.5
23	27.1	27.0	24.6	24.0	22.1	25.0	27.8	21.8	26.0	21.4	22.6	19.6	23.2
24	28.0	27.0	25.7	26.9	22.3	26.0	26.4	24.0	26.0	27.6	27.8	20.9	25.4
25	29.8	29.3	25.4	28.3	21.5	26.8	27.3	24.2	28.4	25.2	26.2	23.8	25.9
26	29.3	26.3	26.4	28.9	22.2	26.6	29.2	22.4	26.0	25.5	26.5	23.3	25.5
27	27.5	26.5	26.5	26.3	22.4	25.8	28.8	21.1	27.3	26.6	27.2	25.2	26.0

28	**25.7**	**28.0**	**25.7**	**20.9**	**24.2**	**24.9**	**25.0**	**23.3**	**26.3**	**23.6**	**24.6**	**25.9**	**24.8**
29	**25.4**	**28.8**	**23.6**	**23.4**	**24.1**	**25.1**	**25.4**	**23.3**	**26.1**	**26.0**	**26.5**	**26.8**	**25.7**
30	**24.8**	**25.8**	**23.3**	**20.0**	**24.1**	**23.6**	**24.9**	**23.7**	**23.5**	**21.3**	**21.5**	**24.4**	**23.2**
31	**24.8**	**29.3**	**24.6**	**25.7**	**22.1**	**25.3**	**27.6**	**22.2**	**25.0**	**25.7**	**26.4**	**21.2**	**24.7**
32	**25.2**	**28.9**	**25.8**	**26.4**	**23.1**	**25.9**	**26.3**	**23.6**	**27.1**	**26.5**	**27.6**	**25.0**	**26.0**
33	**25.3**	**27.1**	**24.8**	**25.0**	**24.3**	**25.3**	**25.8**	**20.9**	**24.1**	**25.9**	**26.0**	**24.6**	**24.5**
34	**24.6**	**28.6**	**25.9**	**22.9**	**24.8**	**25.4**	**27.1**	**29.2**	**28.1**	**26.9**	**25.9**	**25.7**	**27.1**
35	**26.9**	**30.2**	**24.4**	**25.3**	**23.4**	**26.1**	**26.4**	**23.3**	**28.5**	**28.8**	**30.6**	**27.0**	**27.4**
36	**23.4**	**24.7**	**22.7**	**21.5**	**23.2**	**23.1**	**25.8**	**21.5**	**24.0**	**22.9**	**21.7**	**22.6**	**23.1**
37	**26.6**	**29.2**	**27.9**	**25.4**	**22.6**	**26.3**	**31.7**	**23.3**	**26.7**	**24.7**	**24.2**	**26.9**	**26.2**
38	**24.3**	**24.8**	**24.7**	**24.2**	**23.2**	**24.2**	**26.6**	**22.2**	**26.9**	**25.8**	**25.7**	**28.9**	**26.0**
39	**25.6**	**25.7**	**27.1**	**22.3**	**23.1**	**24.8**	**24.7**	**22.3**	**22.9**	**24.7**	**27.2**	**29.9**	**25.3**
40	**24.1**	**29.4**	**27.6**	**26.5**	**23.0**	**26.1**	**26.4**	**23.4**	**26.7**	**27.6**	**27.6**	**23.4**	**25.8**
41	**26.4**	**26.7**	**25.4**	**26.1**	**22.4**	**25.4**	**29.6**	**24.1**	**27.0**	**26.2**	**25.8**	**22.1**	**25.8**
42	**23.3**	**23.3**	**24.8**	**23.8**	**27.7**	**24.6**	**26.8**	**20.6**	**24.9**	**27.5**	**29.5**	**24.8**	**25.7**
43	**25.5**	**28.0**	**26.3**	**26.3**	**24.4**	**26.1**	**29.4**	**24.0**	**26.1**	**25.5**	**29.3**	**23.0**	**26.2**
44	**24.2**	**26.0**	**25.8**	**23.9**	**23.2**	**24.6**	**26.4**	**22.1**	**26.2**	**24.1**	**25.1**	**24.1**	**24.7**
45	**23.4**	**24.0**	**25.9**	**21.5**	**23.0**	**23.6**	**23.5**	**22.9**	**25.4**	**24.7**	**24.3**	**26.9**	**24.6**
46	**27.0**	**27.8**	**27.4**	**25.1**	**22.5**	**26.0**	**30.4**	**24.3**	**25.9**	**22.4**	**23.8**	**32.0**	**26.5**
47	**25.0**	**29.4**	**24.1**	**25.5**	**21.9**	**25.2**	**30.6**	**22.9**	**27.3**	**24.0**	**26.1**	**22.8**	**25.6**
48	**24.6**	**24.6**	**26.0**	**18.1**	**23.4**	**23.4**	**26.8**	**22.9**	**24.9**	**24.7**	**28.6**	**33.1**	**26.8**
49	**27.0**	**31.2**	**26.3**	**26.8**	**20.2**	**26.3**	**26.8**	**23.0**	**26.7**	**27.7**	**26.1**	**22.9**	**25.6**
50	**26.7**	**29.9**	**26.1**	**26.4**	**21.1**	**26.0**	**26.9**	**23.6**	**26.3**	**24.6**	**26.3**	**21.9**	**24.9**
51	**25.0**	**25.0**	**24.5**	**24.2**	**21.8**	**24.1**	**25.9**	**23.5**	**25.0**	**25.0**	**23.6**	**23.4**	**24.4**
52	**27.2**	**27.9**	**25.7**	**25.1**	**22.8**	**25.7**	**27.9**	**26.3**	**26.2**	**26.5**	**23.8**	**25.3**	**26.0**
53	**25.9**	**29.2**	**25.7**	**25.5**	**21.6**	**25.5**	**29.7**	**24.1**	**26.3**	**26.2**	**27.8**	**25.6**	**26.6**
54	**24.1**	**24.3**	**25.6**	**19.3**	**23.4**	**23.4**	**29.4**	**24.4**	**25.3**	**24.9**	**24.2**	**29.0**	**26.2**

Table A.5. Crude protein values by harvest date for 2002 and 2003

	2002						2003						
Plot	**5/9**	**6/12**	**7/17**	**8/21**	**11/7**	**Season**	**5/7**	**6/10**	**7/17**	**8/20**	**9/25**	**10/29**	**Season**
	%												
1	14.1	13.9	14.1	11.1	13.8	13.4	14.6	16.3	15.8	16.8	15.6	13.6	15.4
2	12.1	13.4	12.5	9.0	14.0	12.2	13.5	15.9	15.1	15.1	14.9	12.5	14.5
3	13.0	14.7	13.6	9.6	13.5	12.9	15.8	18.6	16.9	17.8	18.1	15.7	17.1
4	12.2	11.8	13.3	12.1	13.0	12.5	14.7	16.2	17.0	17.3	15.3	15.0	15.9
5	12.3	11.0	13.7	10.3	14.8	12.4	14.4	17.8	16.7	18.2	16.3	15.2	16.4
6	13.0	14.2	14.7	13.3	13.0	13.6	15.1	20.3	19.0	18.8	16.3	15.7	17.5
7	12.8	12.8	12.4	10.6	12.9	12.3	13.6	17.6	17.2	17.2	15.8	14.2	15.9
8	12.8	14.0	13.7	12.6	13.8	13.4	11.1	13.2	13.4	15.5	12.8	13.6	13.3
9	13.6	13.7	13.5	10.7	14.1	13.1	17.3	17.9	17.3	17.3	15.7	14.9	16.7
10	12.4	12.3	12.1	11.1	13.1	12.2	13.4	16.6	16.5	17.4	16.3	13.6	15.6
11	11.6	12.3	12.6	9.9	13.5	12.0	15.8	19.1	17.9	18.8	17.0	14.6	17.2
12	13.6	14.4	13.4	10.3	14.0	13.2	16.3	17.2	17.1	17.1	16.5	15.1	16.5
13	12.3	11.5	14.4	12.0	14.0	12.8	10.6	16.2	13.9	14.9	14.5	13.9	14.0
14	12.2	12.3	13.8	11.3	12.2	12.4	11.2	13.8	13.4	13.9	13.7	14.0	13.3
15	12.8	13.0	14.5	12.2	12.4	13.0	13.9	15.9	15.7	16.8	15.9	14.9	15.5
16	13.1	11.6	13.0	10.0	13.4	12.2	14.9	17.0	17.3	17.6	16.5	14.7	16.4
17	12.4	12.2	13.7	10.7	13.0	12.4	12.5	15.8	16.0	17.5	16.2	15.0	15.5
18	13.4	14.1	14.0	11.7	13.8	13.4	16.8	18.1	17.1	18.6	17.7	15.9	17.4
19	11.8	11.9	13.0	11.1	13.8	12.3	13.6	16.2	14.1	15.4	15.5	13.7	14.7
20	13.4	13.1	12.9	11.0	15.3	13.1	13.9	16.4	16.6	16.9	14.8	14.1	15.5
21	13.1	11.7	12.4	11.1	17.0	13.1	12.4	16.2	15.1	15.5	15.4	14.6	14.9
22	12.3	12.3	13.6	12.8	15.6	13.3	10.3	14.3	13.7	14.9	13.5	14.0	13.5
23	13.4	12.3	13.7	13.9	16.1	13.9	14.1	16.6	16.3	19.3	19.4	18.7	17.4
24	12.1	11.8	12.7	12.3	14.1	12.6	12.0	14.0	15.0	14.5	14.1	14.9	14.1
25	12.7	11.5	14.6	10.9	15.9	13.1	11.7	14.3	14.3	16.4	14.6	12.3	14.0
26	13.3	12.7	13.3	11.0	15.5	13.1	15.0	17.1	15.7	16.2	16.4	14.3	15.8
27	13.4	12.7	13.1	12.6	15.6	13.5	12.5	18.1	13.3	15.2	15.3	13.7	14.7

28	**12.2**	**11.6**	**14.5**	**12.1**	**12.7**	**12.6**	**16.0**	**18.2**	**17.2**	**18.1**	**16.0**	**12.6**	**16.3**
29	**12.2**	**11.0**	**15.8**	**13.8**	**14.4**	**13.4**	**14.3**	**15.9**	**15.5**	**16.0**	**14.6**	**12.9**	**14.9**
30	**12.9**	**12.4**	**15.5**	**13.8**	**10.3**	**13.0**	**14.5**	**16.9**	**17.5**	**16.8**	**15.0**	**14.0**	**15.8**
31	**12.6**	**9.5**	**14.4**	**12.1**	**13.7**	**12.5**	**12.3**	**14.9**	**14.7**	**15.3**	**16.3**	**14.8**	**14.7**
32	**11.9**	**10.2**	**12.5**	**11.2**	**13.2**	**11.8**	**12.2**	**14.6**	**14.5**	**15.2**	**13.5**	**12.5**	**13.7**
33	**12.0**	**12.0**	**13.0**	**12.7**	**13.9**	**12.7**	**15.2**	**19.3**	**18.3**	**17.4**	**15.0**	**13.9**	**16.5**
34	**13.1**	**10.5**	**14.2**	**12.6**	**13.2**	**12.7**	**12.3**	**12.0**	**12.9**	**15.5**	**14.2**	**13.7**	**13.4**
35	**12.3**	**9.9**	**15.3**	**12.8**	**15.9**	**13.3**	**13.7**	**15.0**	**13.9**	**15.2**	**14.0**	**13.6**	**14.2**
36	**13.9**	**13.0**	**14.8**	**14.5**	**12.2**	**13.7**	**16.4**	**18.9**	**19.1**	**19.2**	**19.3**	**14.8**	**17.9**
37	**12.1**	**11.3**	**14.2**	**12.6**	**12.7**	**12.6**	**10.6**	**18.2**	**13.9**	**14.4**	**13.9**	**12.6**	**13.9**
38	**13.9**	**14.7**	**17.1**	**13.8**	**14.9**	**14.9**	**12.0**	**15.5**	**14.4**	**15.8**	**14.6**	**12.9**	**14.2**
39	**13.1**	**13.7**	**14.4**	**13.8**	**10.3**	**13.0**	**15.4**	**17.0**	**17.2**	**14.5**	**13.5**	**13.8**	**15.2**
40	**14.0**	**10.5**	**13.3**	**11.5**	**13.5**	**12.6**	**11.1**	**14.0**	**13.5**	**13.7**	**13.4**	**13.4**	**13.2**
41	**12.1**	**12.4**	**15.0**	**12.3**	**14.2**	**13.2**	**11.8**	**13.9**	**12.8**	**14.8**	**13.8**	**14.2**	**13.5**
42	**14.5**	**14.4**	**15.4**	**13.3**	**13.9**	**14.3**	**11.5**	**16.7**	**16.1**	**14.9**	**14.2**	**15.5**	**14.8**
43	**12.6**	**11.6**	**14.6**	**12.6**	**13.2**	**12.9**	**11.4**	**13.7**	**13.3**	**14.3**	**12.5**	**14.1**	**13.2**
44	**13.4**	**11.6**	**14.6**	**12.2**	**13.6**	**13.1**	**13.7**	**15.2**	**15.9**	**16.1**	**16.2**	**14.1**	**15.2**
45	**13.9**	**13.2**	**14.9**	**13.9**	**13.5**	**13.9**	**14.0**	**15.5**	**16.2**	**16.9**	**16.3**	**16.6**	**15.9**
46	**11.8**	**11.5**	**13.7**	**12.9**	**12.4**	**12.5**	**12.7**	**15.9**	**14.3**	**13.2**	**13.1**	**12.9**	**13.7**
47	**14.6**	**11.8**	**14.9**	**12.4**	**15.0**	**13.7**	**11.1**	**14.5**	**13.6**	**15.8**	**15.1**	**15.4**	**14.2**
48	**12.3**	**12.8**	**14.2**	**12.4**	**10.3**	**12.4**	**10.8**	**15.2**	**15.3**	**14.2**	**12.0**	**13.8**	**13.5**
49	**11.9**	**9.1**	**13.1**	**11.6**	**15.5**	**12.2**	**10.5**	**14.1**	**13.0**	**13.2**	**14.6**	**13.1**	**13.1**
50	**11.2**	**10.2**	**13.4**	**12.0**	**16.7**	**12.7**	**10.6**	**15.3**	**15.1**	**14.4**	**13.8**	**13.9**	**13.9**
51	**13.4**	**12.9**	**13.0**	**13.0**	**14.3**	**13.3**	**11.9**	**14.3**	**14.0**	**15.7**	**16.8**	**15.0**	**14.6**
52	**11.6**	**10.9**	**13.2**	**12.7**	**12.8**	**12.2**	**11.2**	**13.0**	**14.5**	**15.7**	**16.2**	**15.6**	**14.4**
53	**12.9**	**10.7**	**13.8**	**12.0**	**15.5**	**13.0**	**11.5**	**13.8**	**13.6**	**15.3**	**14.1**	**13.6**	**13.7**
54	**13.9**	**14.3**	**14.7**	**13.7**	**13.5**	**14.0**	**12.2**	**14.0**	**15.7**	**16.9**	**15.7**	**14.9**	**14.9**

Table A.6. Total nonstructural carbohydrates by harvest date for 2002 and 2003

	2002						2003						
Plot	5/9	6/12	7/17	8/21	11/7	Season	5/7	6/10	7/17	8/20	9/25	10/29	Season
							%						
1	9.3	7.0	8.5	6.6	10.6	8.4	4.1	9.3	6.6	7.7	8.9	17.4	9.0
2	7.2	6.8	7.0	5.4	9.7	7.2	7.4	6.7	4.1	6.7	8.2	17.0	8.4
3	8.4	7.4	7.4	5.4	10.1	7.8	6.5	8.7	7.1	6.3	7.1	15.7	8.6
4	9.7	6.9	11.1	7.5	10.5	9.1	10.0	9.9	6.4	7.1	9.0	19.0	10.2
5	9.8	6.1	9.8	7.1	9.4	8.4	5.3	8.0	6.0	6.7	9.2	17.7	8.8
6	9.2	8.0	11.0	8.6	11.5	9.7	4.8	6.4	5.0	6.4	9.9	17.6	8.3
7	8.5	8.9	8.0	7.0	13.5	9.2	4.7	9.1	6.4	7.8	8.7	20.2	9.5
8	4.5	5.9	9.7	8.4	4.9	6.7	6.6	10.2	7.2	5.8	10.1	16.4	9.4
9	8.8	5.9	9.6	5.8	10.1	8.1	3.5	7.3	6.8	6.5	7.1	18.3	8.3
10	9.3	7.2	4.9	6.6	13.1	8.2	4.0	9.6	7.0	8.5	10.4	16.3	9.3
11	8.7	6.2	4.5	5.4	14.0	7.8	3.1	8.1	6.6	8.1	8.6	15.8	8.4
12	9.3	8.6	4.7	5.5	16.2	8.9	5.1	8.9	7.4	7.0	8.5	17.5	9.0
13	9.4	6.5	5.6	8.1	14.9	8.9	8.8	9.9	8.6	8.8	10.9	19.3	11.1
14	7.3	5.5	5.6	8.1	13.2	7.9	5.0	11.3	9.4	9.4	11.0	19.0	10.8
15	10.8	8.2	5.4	10.1	14.6	9.8	7.2	11.5	8.8	7.3	10.3	20.1	10.9
16	9.5	6.3	6.3	5.4	15.8	8.6	4.5	10.5	5.8	7.7	9.5	20.0	9.7
17	8.6	6.6	5.9	5.4	14.1	8.1	10.8	10.4	5.4	6.5	7.8	16.2	9.5
18	9.4	8.0	4.9	7.8	14.4	8.9	9.8	10.0	7.5	8.6	9.7	19.2	10.8
19	4.4	7.1	7.5	6.6	17.7	8.6	3.0	7.3	6.8	8.4	9.0	16.7	8.5
20	6.2	7.2	7.4	6.5	15.5	8.6	2.1	9.6	6.7	10.8	11.4	16.1	9.5
21	5.2	7.8	5.7	5.0	12.3	7.2	5.2	8.7	6.0	7.7	8.6	16.0	8.7
22	4.7	8.6	9.0	9.2	16.2	9.5	12.0	13.4	9.3	9.2	10.9	21.4	12.7
23	5.3	7.4	9.0	7.5	14.1	8.7	4.5	12.9	7.9	10.0	11.7	17.3	10.7
24	5.9	8.4	9.0	8.8	15.5	9.5	8.4	11.4	9.3	8.3	10.1	20.1	11.3
25	3.8	5.3	8.7	5.7	14.3	7.6	10.8	9.6	4.3	8.1	10.8	19.0	10.4
26	3.0	8.0	8.0	6.1	15.8	8.2	2.2	10.1	7.7	8.3	9.8	18.1	9.4
27	4.7	8.1	7.8	7.8	13.9	8.5	3.8	10.0	7.5	6.9	8.0	15.7	8.7

28	8.8	6.0	8.3	7.2	14.2	8.9	6.5	7.8	3.5	3.3	4.8	2.4	4.7
29	9.5	5.5	9.3	7.7	8.6	8.1	6.5	9.9	6.0	5.8	8.0	7.9	7.4
30	9.1	6.1	6.4	7.7	9.5	7.8	8.4	6.8	6.6	5.3	6.9	2.4	6.1
31	10.0	6.5	9.7	8.1	13.2	9.5	6.2	11.3	8.3	8.8	8.1	18.8	10.2
32	10.7	6.9	10.8	8.5	13.5	10.1	9.5	11.7	7.2	8.6	11.5	17.8	11.1
33	9.1	7.0	11.2	9.7	10.0	9.4	4.2	9.1	8.2	7.0	11.5	17.3	9.5
34	8.8	5.3	6.9	7.1	5.0	6.6	6.2	8.8	6.3	5.4	5.9	9.3	7.0
35	8.4	4.2	9.5	7.2	9.3	7.7	6.6	10.5	5.0	4.0	6.3	8.4	6.8
36	9.9	7.1	8.8	8.7	5.9	8.1	3.4	8.8	5.3	4.7	6.4	4.1	5.5
37	8.7	6.4	3.8	7.0	14.2	8.0	2.8	7.8	6.2	6.7	6.6	9.2	6.6
38	8.8	7.2	3.9	7.7	12.1	7.9	10.3	12.2	6.1	5.9	7.9	10.6	8.8
39	9.1	6.4	3.4	7.7	9.5	7.2	6.4	9.7	6.3	4.0	3.1	-0.4	4.8
40	10.2	5.7	5.5	8.4	13.5	8.6	8.0	10.9	8.0	7.2	9.6	18.5	10.4
41	9.0	8.1	4.9	9.5	15.9	9.5	5.9	12.7	9.3	9.9	12.2	19.4	11.6
42	10.4	9.1	5.1	7.9	6.9	7.9	5.6	11.4	7.1	5.3	6.9	9.9	7.7
43	9.5	6.3	4.2	6.9	12.3	7.8	5.0	12.4	8.1	9.3	9.1	16.2	10.0
44	10.5	7.5	4.5	6.2	13.9	8.5	6.6	12.4	6.0	8.9	10.5	15.5	10.0
45	9.9	9.2	4.3	7.7	9.2	8.1	11.4	10.4	4.9	3.4	5.7	2.3	6.4
46	8.1	5.8	5.7	5.7	10.8	7.2	3.2	9.2	5.3	4.8	3.3	-0.8	4.2
47	8.2	7.1	8.8	7.6	14.4	9.2	3.3	12.6	6.7	8.4	8.3	12.9	8.7
48	11.6	7.8	5.7	7.6	9.5	8.5	12.2	9.9	6.0	4.3	1.0	-3.0	5.1
49	8.9	5.7	9.0	8.4	16.5	9.7	13.3	12.5	9.4	9.6	10.0	19.5	12.4
50	10.5	7.3	9.3	7.8	12.8	9.5	12.1	10.6	7.7	11.9	12.0	20.0	12.4
51	9.3	9.0	8.4	8.0	15.5	10.1	8.7	11.4	9.6	8.8	9.2	12.2	10.0
52	8.7	6.6	7.8	6.4	13.4	8.6	7.0	10.0	6.8	5.5	6.6	2.6	6.4
53	9.5	6.7	7.0	7.4	15.0	9.1	3.4	12.5	8.1	8.6	8.8	11.9	8.9
54	9.9	8.4	6.4	5.6	11.0	8.2	4.3	10.2	5.6	3.6	5.4	1.1	5.0

Table A.7. Acid detergent lignin by harvest date for 2002 and 2003

	2002						2003						
Plot	5/9	6/12	7/17	8/21	11/7	Season	5/7	6/10	7/17	8/20	9/25	10/29	Season
							%						
1	1.3	1.9	2.2	6.5	2.1	2.8	2.0	2.2	3.0	3.6	4.8	2.8	3.1
2	2.3	2.2	3.1	9.7	3.0	4.1	1.4	2.0	3.5	4.5	5.3	3.2	3.3
3	1.5	1.9	3.1	10.6	2.6	4.0	2.0	2.6	3.1	4.1	5.6	3.4	3.5
4	1.2	2.7	1.9	3.0	1.4	2.0	1.8	1.9	3.5	2.9	2.9	2.5	2.6
5	1.1	2.1	2.2	3.0	1.6	2.0	2.0	2.9	3.4	3.0	2.9	2.1	2.7
6	1.9	2.3	1.8	2.3	1.7	2.0	2.0	3.0	3.4	3.0	3.2	2.3	2.8
7	1.3	2.0	2.1	3.8	1.1	2.0	1.7	2.0	3.3	3.8	4.7	2.1	2.9
8	1.8	2.3	1.7	2.4	2.6	2.2	1.5	1.8	2.3	2.6	3.0	2.9	2.3
9	1.3	2.1	2.5	7.8	1.7	3.1	2.3	3.0	3.5	3.3	4.4	2.6	3.2
10	1.7	2.2	3.5	6.5	2.9	3.4	2.0	2.4	3.7	3.9	4.8	3.8	3.4
11	1.6	2.4	3.5	9.3	4.6	4.3	2.2	2.5	3.3	3.5	5.3	4.3	3.5
12	1.7	2.0	3.5	8.8	2.4	3.7	2.2	2.3	3.0	4.4	5.3	2.7	3.3
13	1.5	2.7	2.2	3.0	1.5	2.2	1.6	1.9	2.7	2.3	2.7	1.7	2.1
14	1.8	2.1	1.9	2.5	0.9	1.9	1.5	1.5	2.3	2.2	2.0	1.6	1.9
15	1.3	2.6	2.3	2.8	0.9	2.0	1.8	2.6	2.6	2.9	2.8	1.9	2.4
16	1.3	2.3	2.5	8.2	1.7	3.2	2.1	2.2	3.6	3.3	4.3	2.2	2.9
17	1.5	1.8	2.5	8.1	2.3	3.2	1.1	2.2	3.6	3.1	5.1	3.3	3.1
18	1.7	2.6	3.0	6.1	2.2	3.1	1.9	2.6	3.7	3.7	4.6	2.7	3.2
19	2.1	1.9	3.0	6.5	1.9	3.1	1.6	2.2	2.8	3.8	4.8	2.7	3.0
20	2.1	2.1	2.8	5.6	3.2	3.2	2.3	2.4	3.4	2.7	4.9	4.4	3.4
21	1.5	1.4	2.7	7.7	1.4	2.9	0.7	1.1	2.2	3.6	4.1	2.7	2.4
22	2.4	2.6	2.6	3.0	1.1	2.4	1.5	1.9	3.3	3.3	3.2	2.0	2.5
23	2.7	3.1	2.7	3.4	2.1	2.8	2.6	2.4	3.1	3.1	3.3	3.1	2.9
24	1.6	2.3	1.9	2.4	0.8	1.8	1.3	1.8	2.9	2.7	2.9	1.9	2.2
25	2.3	2.1	2.0	5.7	1.2	2.7	1.6	1.6	3.5	2.6	3.1	2.0	2.4
26	2.6	2.1	2.5	3.8	1.8	2.6	1.7	2.1	2.9	2.7	4.6	3.0	2.8
27	1.8	2.0	2.0	4.2	1.1	2.2	1.5	2.6	2.1	3.4	4.2	3.1	2.8

28	**2.0**	**2.6**	**1.9**	**3.5**	**2.1**	**2.4**	**2.6**	**3.0**	**4.2**	**4.5**	**5.5**	**8.3**	**4.7**
29	**1.4**	**2.3**	**1.7**	**3.0**	**2.2**	**2.1**	**1.7**	**1.6**	**3.0**	**2.9**	**3.8**	**4.5**	**2.9**
30	**2.2**	**1.6**	**1.5**	**3.0**	**4.5**	**2.6**	**2.3**	**2.7**	**3.0**	**3.8**	**5.4**	**7.1**	**4.0**
31	**1.3**	**2.1**	**2.0**	**2.7**	**1.3**	**1.9**	**1.6**	**1.5**	**2.9**	**2.6**	**3.2**	**2.5**	**2.4**
32	**1.1**	**2.2**	**2.0**	**2.7**	**1.1**	**1.8**	**1.4**	**1.9**	**2.6**	**2.2**	**2.6**	**1.3**	**2.0**
33	**1.2**	**2.2**	**1.8**	**2.3**	**1.5**	**1.8**	**1.7**	**2.6**	**3.3**	**3.0**	**2.2**	**2.4**	**2.5**
34	**1.6**	**2.9**	**2.1**	**2.8**	**3.3**	**2.5**	**2.0**	**2.0**	**2.9**	**3.5**	**4.1**	**4.9**	**3.2**
35	**1.5**	**2.5**	**2.0**	**3.2**	**2.0**	**2.2**	**1.6**	**1.4**	**3.1**	**3.3**	**4.2**	**5.4**	**3.1**
36	**1.8**	**2.4**	**1.6**	**2.2**	**3.5**	**2.3**	**2.3**	**2.6**	**3.5**	**3.8**	**4.4**	**6.7**	**3.9**
37	**1.6**	**2.5**	**2.2**	**3.0**	**2.1**	**2.3**	**1.9**	**3.0**	**3.1**	**3.5**	**5.3**	**5.1**	**3.6**
38	**1.1**	**2.6**	**2.4**	**3.0**	**2.0**	**2.2**	**1.7**	**1.9**	**3.7**	**3.6**	**4.6**	**4.3**	**3.3**
39	**1.9**	**1.9**	**1.8**	**3.0**	**4.5**	**2.6**	**1.9**	**2.0**	**3.4**	**4.9**	**6.6**	**8.5**	**4.5**
40	**0.9**	**2.3**	**2.0**	**2.9**	**1.0**	**1.8**	**1.3**	**1.3**	**2.5**	**2.1**	**2.4**	**2.1**	**2.0**
41	**1.4**	**2.1**	**1.4**	**2.0**	**0.9**	**1.6**	**1.3**	**1.3**	**2.1**	**2.1**	**1.5**	**1.6**	**1.6**
42	**1.2**	**1.9**	**2.0**	**1.9**	**1.6**	**1.7**	**1.0**	**1.8**	**2.7**	**2.5**	**3.3**	**3.7**	**2.5**
43	**1.5**	**2.4**	**2.3**	**3.0**	**1.6**	**2.2**	**1.6**	**1.2**	**2.2**	**2.0**	**2.6**	**3.2**	**2.1**
44	**1.5**	**1.9**	**1.9**	**3.1**	**1.4**	**2.0**	**1.6**	**1.9**	**3.1**	**2.6**	**3.1**	**3.4**	**2.6**
45	**1.8**	**2.2**	**2.0**	**3.1**	**3.7**	**2.6**	**1.8**	**2.0**	**3.2**	**3.8**	**4.4**	**7.3**	**3.8**
46	**1.9**	**2.0**	**1.8**	**2.8**	**3.3**	**2.4**	**1.9**	**1.6**	**2.7**	**4.7**	**6.8**	**7.7**	**4.2**
47	**1.4**	**2.7**	**1.9**	**2.0**	**0.8**	**1.8**	**1.3**	**1.4**	**2.5**	**2.9**	**3.6**	**4.1**	**2.6**
48	**1.7**	**2.1**	**2.0**	**2.0**	**4.5**	**2.5**	**1.9**	**1.8**	**2.6**	**4.7**	**7.7**	**8.2**	**4.5**
49	**1.9**	**2.6**	**2.1**	**3.2**	**1.1**	**2.2**	**1.1**	**1.2**	**2.8**	**2.7**	**3.5**	**1.7**	**2.2**
50	**1.3**	**2.3**	**2.1**	**2.4**	**1.2**	**1.9**	**0.8**	**2.2**	**2.7**	**2.0**	**2.3**	**1.6**	**1.9**
51	**1.4**	**1.5**	**1.8**	**2.1**	**1.0**	**1.6**	**0.9**	**1.9**	**2.1**	**2.4**	**3.6**	**4.9**	**2.6**
52	**1.9**	**1.8**	**1.6**	**2.7**	**1.8**	**2.0**	**1.7**	**1.1**	**2.3**	**2.4**	**3.8**	**6.8**	**3.0**
53	**1.6**	**2.5**	**2.1**	**2.9**	**0.9**	**2.0**	**1.3**	**1.5**	**2.3**	**2.0**	**2.8**	**3.7**	**2.3**
54	**1.2**	**2.0**	**1.7**	**3.3**	**3.2**	**2.3**	**1.4**	**1.6**	**2.2**	**3.9**	**5.0**	**7.4**	**3.6**

Table A.8. Botancial composition values for 2002

	17-Jul				11-Nov				
Plot	**Tall fescue**	**Cool- season**	**Warm-season**	**Weed**	**Tall fescue**	**Cool- season**	**Warm-season**	**Weed**	**Dead**
	%								
1	50.0	10.0	0.0	40.0	78.3	4.3	0.0	8.7	8.7
2	42.9	14.3	0.0	42.9	81.5	3.7	0.0	7.4	7.4
3	62.5	12.5	12.5	12.5	76.6	4.3	2.1	4.3	12.8
4	78.6	7.1	7.1	7.1	82.9	9.8	0.0	4.9	2.4
5	69.2	0.0	15.4	15.4	85.7	2.0	0.0	8.2	4.1
6	57.1	14.3	0.0	28.6	55.2	3.4	6.9	31.0	3.4
7	71.4	0.0	7.1	21.4	80.6	9.7	0.0	3.2	6.5
8	80.0	6.7	6.7	6.7	80.0	2.0	0.0	10.0	8.0
9	60.0	10.0	20.0	10.0	75.0	7.1	0.0	10.7	7.1
10	75.0	0.0	0.0	25.0	84.2	5.3	0.0	5.3	5.3
11	75.0	0.0	0.0	25.0	81.0	4.8	0.0	4.8	9.5
12	66.7	0.0	0.0	33.3	50.0	18.2	0.0	27.3	4.5
13	53.3	6.7	0.0	40.0	83.3	6.7	0.0	3.3	6.7
14	92.3	0.0	0.0	7.7	86.6	1.5	0.0	3.0	9.0
15	66.7	4.8	0.0	28.6	75.0	8.3	0.0	8.3	8.3
16	75.0	0.0	0.0	25.0	77.3	4.5	0.0	9.1	9.1
17	55.6	22.2	0.0	22.2	75.0	10.0	0.0	5.0	10.0
18	75.0	0.0	0.0	25.0	72.2	11.1	0.0	16.7	0.0
19	57.1	14.3	0.0	28.6	76.0	8.0	0.0	12.0	4.0
20	62.5	12.5	0.0	25.0	74.4	7.0	0.0	4.7	14.0
21	83.3	8.3	0.0	8.3	75.0	10.0	0.0	10.0	5.0
22	70.0	10.0	0.0	20.0	68.4	10.5	0.0	10.5	10.5
23	14.3	35.7	7.1	42.9	48.3	31.0	0.0	10.3	10.3
24	60.0	6.7	0.0	33.3	80.0	6.7	0.0	6.7	6.7
25	44.4	44.4	0.0	11.1	62.2	18.9	0.0	10.8	8.1
26	83.3	8.3	0.0	8.3	64.7	11.8	0.0	11.8	11.8
27	78.6	7.1	0.0	14.3	86.5	2.7	0.0	5.4	5.4

28	**77.8**	**0.0**	**0.0**	**22.2**	**75.0**	**9.1**	**0.0**	**13.6**	**2.3**
29	**77.8**	**11.1**	**0.0**	**11.1**	**56.3**	**12.5**	**9.4**	**12.5**	**9.4**
30	**41.7**	**8.3**	**0.0**	**50.0**	**63.6**	**9.1**	**0.0**	**22.7**	**4.5**
31	**75.0**	**0.0**	**0.0**	**25.0**	**71.8**	**10.3**	**0.0**	**12.8**	**5.1**
32	**83.3**	**0.0**	**0.0**	**16.7**	**72.5**	**10.0**	**0.0**	**15.0**	**2.5**
33	**84.6**	**0.0**	**0.0**	**15.4**	**69.3**	**4.0**	**5.3**	**21.3**	**0.0**
34	**61.5**	**7.7**	**0.0**	**30.8**	**76.7**	**11.6**	**0.0**	**9.3**	**2.3**
35	**16.7**	**75.0**	**0.0**	**8.3**	**51.9**	**33.3**	**3.7**	**3.7**	**7.4**
36	**50.0**	**25.0**	**0.0**	**25.0**	**79.4**	**5.9**	**2.9**	**5.9**	**5.9**
37	**88.2**	**5.9**	**0.0**	**5.9**	**85.1**	**2.1**	**0.0**	**4.3**	**8.5**
38	**25.0**	**6.3**	**37.5**	**31.3**	**32.1**	**0.0**	**53.6**	**7.1**	**7.1**
39	**40.9**	**4.5**	**0.0**	**54.5**	**62.5**	**0.0**	**0.0**	**9.4**	**28.1**
40	**72.7**	**0.0**	**0.0**	**27.3**	**82.4**	**5.9**	**0.0**	**5.9**	**5.9**
41	**61.1**	**5.6**	**27.8**	**5.6**	**80.8**	**7.7**	**0.0**	**7.7**	**3.8**
42	**52.4**	**4.8**	**23.8**	**19.0**	**35.3**	**11.8**	**0.0**	**43.1**	**9.8**
43	**58.3**	**8.3**	**8.3**	**25.0**	**83.8**	**8.1**	**0.0**	**2.7**	**5.4**
44	**82.4**	**5.9**	**0.0**	**11.8**	**63.9**	**25.0**	**0.0**	**5.6**	**5.6**
45	**6.7**	**46.7**	**13.3**	**33.3**	**23.8**	**47.6**	**0.0**	**11.9**	**16.7**
46	**72.7**	**9.1**	**0.0**	**18.2**	**76.6**	**2.1**	**0.0**	**0.0**	**21.3**
47	**40.0**	**15.0**	**0.0**	**45.0**	**54.3**	**22.9**	**0.0**	**11.4**	**11.4**
48	**7.1**	**50.0**	**14.3**	**28.6**	**21.6**	**59.5**	**0.0**	**13.5**	**5.4**
49	**54.5**	**9.1**	**0.0**	**36.4**	**75.0**	**3.1**	**0.0**	**12.5**	**9.4**
50	**58.3**	**16.7**	**0.0**	**25.0**	**75.0**	**16.7**	**0.0**	**5.6**	**2.8**
51	**75.0**	**6.3**	**0.0**	**18.8**	**78.1**	**6.3**	**0.0**	**12.5**	**3.1**
52	**45.5**	**36.4**	**0.0**	**18.2**	**68.2**	**14.1**	**0.0**	**1.2**	**16.5**
53	**66.7**	**13.3**	**0.0**	**20.0**	**48.9**	**35.6**	**0.0**	**6.7**	**8.9**
54	**70.6**	**11.8**	**0.0**	**17.6**	**67.4**	**23.9**	**0.0**	**6.5**	**2.2**

Table A.9. Botancial composition values for May and July of 2003

	6-May				16-Jul				
Plot	Tall fescue	Cool-season	Legume	Weed	Tall fescue	Cool-season	Warm-season	Legume	Weed
					%				
1	75.0	14.3	3.6	7.1	25.0	20.0	10.0	25.0	20.0
2	61.1	5.6	22.2	11.1	23.1	0.0	7.7	7.7	61.5
3	65.0	5.0	25.0	5.0	17.6	11.8	0.0	52.9	17.6
4	73.1	3.8	15.4	7.7	13.9	22.2	2.8	52.8	8.3
5	81.5	3.7	11.1	3.7	31.6	0.0	10.5	57.9	0.0
6	39.4	24.2	30.3	6.1	3.2	9.7	3.2	83.9	0.0
7	60.7	17.9	14.3	7.1	17.4	21.7	4.3	52.2	4.3
8	91.7	0.0	0.0	8.3	68.2	18.2	0.0	4.5	9.1
9	66.7	0.0	26.7	6.7	23.1	11.5	3.8	53.8	7.7
10	50.0	13.6	13.6	22.7	21.4	14.3	7.1	42.9	14.3
11	65.1	9.3	23.3	2.3	25.0	5.0	0.0	55.0	15.0
12	33.3	16.7	33.3	16.7	15.0	15.0	5.0	50.0	15.0
13	84.7	10.2	3.4	1.7	50.0	0.0	5.0	25.0	20.0
14	90.9	4.5	2.3	2.3	54.5	3.0	6.1	30.3	6.1
15	75.0	8.3	8.3	8.3	35.0	0.0	5.0	40.0	20.0
16	61.1	8.3	5.6	25.0	27.3	4.5	0.0	36.4	31.8
17	60.0	10.0	23.3	6.7	12.5	9.4	6.3	53.1	18.8
18	52.0	12.0	28.0	8.0	13.0	13.0	4.3	60.9	8.7
19	55.2	17.2	17.2	10.3	41.7	25.0	8.3	16.7	8.3
20	46.2	41.0	7.7	5.1	22.7	13.6	4.5	31.8	27.3
21	78.7	8.5	6.4	6.4	57.9	15.8	5.3	15.8	5.3
22	84.9	11.0	2.7	1.4	22.2	5.6	27.8	22.2	22.2
23	24.1	41.4	20.7	13.8	1.9	15.1	15.1	52.8	15.1
24	76.7	10.0	10.0	3.3	12.5	12.5	29.2	29.2	16.7
25	53.7	17.1	17.1	12.2	34.8	13.0	4.3	4.3	43.5
26	56.3	37.5	3.1	3.1	27.3	0.0	0.0	57.6	15.2
27	92.8	2.9	1.4	2.9	47.8	13.0	8.7	8.7	21.7
28	68.8	6.3	6.3	18.8	15.0	10.0	5.0	50.0	20.0
29	78.8	6.1	6.1	9.1	28.6	17.9	7.1	35.7	10.7
30	69.2	0.0	7.7	23.1	11.8	5.9	0.0	41.2	41.2
31	79.2	4.2	4.2	12.5	26.3	10.5	15.8	26.3	21.1
32	89.5	7.9	0.0	2.6	40.7	3.7	11.1	37.0	7.4
33	46.3	7.3	43.9	2.4	16.7	16.7	0.0	66.7	0.0
34	68.2	13.6	4.5	13.6	30.0	20.0	5.0	5.0	40.0
35	25.0	56.3	9.4	9.4	31.6	36.8	5.3	21.1	5.3

36	**58.3**	**12.5**	**25.0**	**4.2**	**6.3**	**15.6**	**3.1**	**65.6**	**9.4**
37	**73.7**	**10.5**	**2.6**	**13.2**	**73.3**	**6.7**	**0.0**	**13.3**	**6.7**
38	**14.0**	**62.8**	**7.0**	**16.3**	**9.1**	**31.8**	**4.5**	**22.7**	**31.8**
39	**68.2**	**4.5**	**9.1**	**18.2**	**11.8**	**5.9**	**47.1**	**29.4**	**5.9**
40	**89.2**	**1.5**	**6.2**	**3.1**	**60.0**	**6.7**	**20.0**	**6.7**	**6.7**
41	**86.4**	**4.5**	**4.5**	**4.5**	**31.3**	**25.0**	**18.8**	**18.8**	**6.3**
42	**73.5**	**20.6**	**2.9**	**2.9**	**8.7**	**17.4**	**43.5**	**21.7**	**8.7**
43	**69.2**	**19.2**	**0.0**	**11.5**	**66.7**	**16.7**	**0.0**	**5.6**	**11.1**
44	**66.7**	**27.1**	**0.0**	**6.3**	**16.7**	**16.7**	**4.2**	**33.3**	**29.2**
45	**30.8**	**42.3**	**11.5**	**15.4**	**4.5**	**40.9**	**13.6**	**27.3**	**13.6**
46	**61.4**	**6.8**	**22.7**	**9.1**	**47.4**	**36.8**	**0.0**	**5.3**	**10.5**
47	**41.2**	**51.5**	**1.5**	**5.9**	**25.0**	**62.5**	**0.0**	**6.3**	**6.3**
48	**14.8**	**51.9**	**11.1**	**22.2**	**7.1**	**57.1**	**7.1**	**7.1**	**21.4**
49	**77.6**	**4.1**	**4.1**	**14.3**	**40.9**	**13.6**	**13.6**	**13.6**	**18.2**
50	**62.8**	**18.6**	**11.6**	**7.0**	**44.4**	**16.7**	**5.6**	**33.3**	**0.0**
51	**91.2**	**1.5**	**1.5**	**5.9**	**34.8**	**4.3**	**26.1**	**26.1**	**8.7**
52	**64.3**	**16.7**	**4.8**	**14.3**	**38.1**	**19.0**	**19.0**	**9.5**	**14.3**
53	**64.7**	**31.4**	**0.0**	**3.9**	**80.8**	**15.4**	**0.0**	**3.8**	**0.0**
54	**69.7**	**21.2**	**0.0**	**9.1**	**43.5**	**13.0**	**17.4**	**4.3**	**21.7**

Table A.10. Botancial composition values for September of 2003

	9-Sep					
Plot	Tall fescue	Cool-season	Warm-season	Legume	Weed	Dead
	%					
1	25.0	25.0	0.0	0.0	50.0	0.0
2	29.4	11.8	11.8	11.8	23.5	11.8
3	22.2	22.2	0.0	44.4	11.1	0.0
4	15.8	63.2	0.0	15.8	5.3	0.0
5	25.0	8.3	37.5	20.8	4.2	4.2
6	16.7	33.3	0.0	25.0	25.0	0.0
7	36.8	31.6	0.0	15.8	15.8	0.0
8	44.0	8.0	12.0	12.0	20.0	4.0
9	38.9	22.2	0.0	16.7	22.2	0.0
10	30.8	7.7	0.0	38.5	23.1	0.0
11	41.2	17.6	0.0	29.4	11.8	0.0
12	23.5	17.6	0.0	17.6	41.2	0.0
13	40.0	33.3	0.0	6.7	20.0	0.0
14	42.9	9.5	28.6	9.5	9.5	0.0
15	64.7	17.6	0.0	17.6	0.0	0.0
16	35.0	15.0	0.0	25.0	25.0	0.0
17	27.8	11.1	11.1	33.3	16.7	0.0
18	26.9	23.1	0.0	26.9	23.1	0.0
19	42.1	21.1	5.3	15.8	10.5	5.3
20	42.9	21.4	0.0	21.4	14.3	0.0
21	70.6	23.5	0.0	5.9	0.0	0.0
22	31.6	57.9	0.0	0.0	10.5	0.0
23	10.0	35.0	0.0	30.0	25.0	0.0
24	30.8	7.7	30.8	7.7	23.1	0.0
25	61.1	22.2	0.0	0.0	16.7	0.0
26	40.0	20.0	0.0	20.0	20.0	0.0
27	42.1	21.1	0.0	15.8	21.1	0.0
28	21.4	14.3	0.0	35.7	14.3	14.3
29	35.7	35.7	0.0	7.1	21.4	0.0
30	26.7	13.3	0.0	13.3	20.0	26.7
31	41.7	16.7	0.0	8.3	33.3	0.0
32	50.0	21.4	0.0	21.4	7.1	0.0
33	40.0	15.0	35.0	5.0	5.0	0.0
34	25.0	41.7	0.0	0.0	33.3	0.0
35	42.1	31.6	0.0	10.5	15.8	0.0

36	**16.7**	**29.2**	**0.0**	**29.2**	**20.8**	**4.2**
37	**85.7**	**0.0**	**0.0**	**0.0**	**0.0**	**14.3**
38	**10.5**	**26.3**	**21.1**	**10.5**	**15.8**	**15.8**
39	**25.0**	**6.3**	**0.0**	**6.3**	**31.3**	**31.3**
40	**47.1**	**41.2**	**0.0**	**0.0**	**11.8**	**0.0**
41	**68.4**	**5.3**	**10.5**	**5.3**	**5.3**	**5.3**
42	**15.0**	**0.0**	**80.0**	**5.0**	**0.0**	**0.0**
43	**72.2**	**11.1**	**0.0**	**0.0**	**16.7**	**0.0**
44	**47.6**	**19.0**	**0.0**	**9.5**	**23.8**	**0.0**
45	**15.0**	**60.0**	**0.0**	**0.0**	**25.0**	**0.0**
46	**54.5**	**18.2**	**0.0**	**0.0**	**27.3**	**0.0**
47	**57.1**	**28.6**	**0.0**	**0.0**	**14.3**	**0.0**
48	**0.0**	**33.3**	**0.0**	**0.0**	**33.3**	**33.3**
49	**50.0**	**30.0**	**0.0**	**10.0**	**10.0**	**0.0**
50	**72.2**	**11.1**	**0.0**	**5.6**	**11.1**	**0.0**
51	**37.5**	**12.5**	**0.0**	**18.8**	**31.3**	**0.0**
52	**66.7**	**0.0**	**0.0**	**0.0**	**33.3**	**0.0**
53	**66.7**	**11.1**	**0.0**	**11.1**	**0.0**	**11.1**
54	**31.6**	**31.6**	**0.0**	**0.0**	**15.8**	**21.1**

Table A.11. Calcium values by harvest date for 2002 and 2003

	2002						2003						
Plot	5/9	6/12	7/17	8/21	11/7	Season	5/7	6/10	7/17	8/20	9/25	10/29	Season
							mg kg^{-1}						
1	3642	4972	5010	8203	10334	6432	6143	7319	7596	7193	7356	5137	6791
2	4362	5276	5762	10501	14944	8169	6202	7528	9322	8905	8673	6042	7779
3	4196	5510	6384	12694	10284	7814	9834	9106	9330	8267	7892	5945	8396
4	3350	4625	4146	5045	11065	5646	6140	8028	7660	6925	5489	6101	6724
5	3167	4598	4266	4444	13653	6026	6400	7787	7201	6369	5743	5435	6489
6	4035	4707	5002	5560	9232	5707	9074	9240	9595	6304	6077	6010	7717
7	3380	4820	4618	6104	11762	6137	7466	7962	9241	7435	6410	5071	7264
8	6126	5366	4896	5926	18388	8140	4123	5539	5922	6342	3647	6676	5375
9	4062	5338	5418	8284	9223	6465	11158	9689	7673	6496	6158	5673	7808
10	3181	5119	6196	13713	11875	8017	8074	7484	7913	7776	8658	5766	7612
11	3562	4955	6928	14828	10209	8096	10569	11264	11451	9646	9971	7154	10009
12	4672	6241	7190	11730	8060	7579	11603	7934	9860	8371	8495	6569	8806
13	4102	4974	5001	4903	9735	5743	5065	8028	5089	5123	4615	5092	5502
14	3341	4787	4643	5393	14351	6503	4027	4779	4729	3983	4521	4954	4499
15	3303	5468	5658	6538	19498	8093	8873	6713	8996	7176	7294	5787	7473
16	3701	5497	5386	10096	10512	7039	10183	6755	9325	8524	7652	6739	8196
17	3339	4960	5430	11057	12138	7385	6749	8813	9077	7853	9451	8350	8382
18	4204	5896	6689	9295	8922	7001	12034	8902	11543	8956	9352	6794	9597
19	3301	4894	5410	10857	9144	6721	5954	5356	6943	6885	6643	4577	6060
20	4167	4844	6599	7848	8800	6451	7213	6839	8067	6819	8244	5932	7186
21	4070	4665	5162	8981	9060	6388	4423	4295	6028	5904	6105	6131	5481
22	3544	5095	4663	5080	14560	6589	4346	5582	5740	5654	4936	5261	5253
23	3226	4381	5891	5557	10682	5947	8590	6455	8143	8109	8203	11848	8558
24	3342	3992	4300	4784	6543	4592	5843	5891	6753	5953	6088	5114	5940
25	3574	4698	5636	7705	9856	6294	4819	5733	7754	5490	6122	4431	5725

26	**3526**	**4624**	**6486**	**7039**	**9672**	**6270**	**8608**	**8107**	**9419**	**7621**	**8272**	**6910**	**8156**
27	**3969**	**5127**	**5353**	**7020**	**13734**	**7041**	**5292**	**5506**	**6285**	**6839**	**7227**	**6213**	**6227**
28	**3992**	**4413**	**4067**	**9762**	**17586**	**7964**	**9653**	**9653**	**11616**	**12258**	**12970**	**15413**	**11927**
29	**3041**	**4079**	**3802**	**6465**	**17070**	**6891**	**5728**	**5603**	**6090**	**6583**	**7435**	**9441**	**6813**
30	**6798**	**5909**	**6173**	**13210**	**21467**	**10712**	**6922**	**8345**	**9998**	**13984**	**14755**	**17038**	**11840**
31	**3892**	**4036**	**3821**	**4350**	**9735**	**5167**	**4311**	**6538**	**5745**	**5105**	**5736**	**7399**	**5806**
32	**3706**	**4060**	**3889**	**4511**	**13962**	**6026**	**4309**	**6296**	**7014**	**6244**	**4888**	**5231**	**5663**
33	**3478**	**4157**	**4274**	**4884**	**12032**	**5765**	**10290**	**10751**	**7914**	**5431**	**4318**	**6204**	**7485**
34	**3560**	**3817**	**4165**	**7886**	**17286**	**7343**	**5373**	**4268**	**7024**	**7057**	**9774**	**12021**	**7586**
35	**2591**	**3383**	**3650**	**5197**	**14142**	**5793**	**4403**	**5219**	**5165**	**5763**	**5795**	**9881**	**6038**
36	**4354**	**5349**	**5400**	**6970**	**16048**	**7624**	**9629**	**9120**	**9753**	**10781**	**11266**	**16737**	**11214**
37	**3357**	**3739**	**3755**	**4894**	**10790**	**5307**	**4025**	**9653**	**8546**	**9108**	**11704**	**11819**	**9142**
38	**2699**	**4846**	**5490**	**6866**	**8164**	**5613**	**3464**	**5606**	**7127**	**7670**	**8527**	**7245**	**6606**
39	**5421**	**5230**	**4661**	**16296**	**20815**	**10485**	**8670**	**5998**	**13917**	**15186**	**15104**	**17256**	**12689**
40	**2733**	**4376**	**4104**	**5239**	**10671**	**5425**	**4022**	**4461**	**4800**	**3181**	**4257**	**4991**	**4285**
41	**3265**	**4056**	**3617**	**4120**	**8958**	**4803**	**3617**	**4022**	**4343**	**3454**	**4249**	**4993**	**4113**
42	**3225**	**4643**	**4138**	**4191**	**23153**	**7870**	**4219**	**5438**	**7060**	**4528**	**3926**	**9486**	**5776**
43	**3524**	**4487**	**4409**	**5990**	**11418**	**5966**	**4899**	**4154**	**5958**	**5201**	**6491**	**9040**	**5957**
44	**3589**	**4524**	**5052**	**8191**	**10140**	**6299**	**3102**	**6066**	**7702**	**5990**	**7517**	**8742**	**6520**
45	**4449**	**5425**	**4598**	**11687**	**17493**	**8731**	**6132**	**5690**	**9718**	**10532**	**13811**	**17412**	**10549**
46	**3015**	**4771**	**3714**	**7278**	**18682**	**7492**	**5353**	**4365**	**8554**	**14979**	**16108**	**16101**	**10910**
47	**4249**	**4721**	**5077**	**5703**	**14299**	**6810**	**3848**	**3452**	**6229**	**6445**	**8031**	**10264**	**6378**
48	**4206**	**4950**	**4951**	**19188**	**21131**	**10885**	**4715**	**5530**	**10401**	**16789**	**17916**	**15721**	**11845**
49	**3792**	**4046**	**4977**	**5265**	**8200**	**5256**	**3947**	**5252**	**5794**	**4492**	**8249**	**5201**	**5489**
50	**3005**	**3682**	**3502**	**4282**	**12089**	**5312**	**3541**	**5451**	**6541**	**4647**	**3808**	**4784**	**4795**
51	**3627**	**4653**	**5118**	**4950**	**9618**	**5593**	**4341**	**5181**	**5861**	**5283**	**6987**	**11857**	**6585**
52	**3456**	**3795**	**3664**	**6600**	**15443**	**6591**	**4281**	**3693**	**5873**	**6630**	**8059**	**11703**	**6706**
53	**3104**	**3721**	**3689**	**6265**	**17231**	**6802**	**3728**	**3763**	**4366**	**4888**	**5799**	**10020**	**5427**
54	**4509**	**5027**	**4818**	**13599**	**17469**	**9085**	**4833**	**4205**	**8001**	**11157**	**13430**	**13446**	**9179**

Table A.12. Phosphorus values by harvest date for 2002 and 2003

	2002						2003						
Plot	**5/9**	**6/12**	**7/17**	**8/21**	**11/7**	**Season**	**5/7**	**6/10**	**7/17**	**8/20**	**9/25**	**10/29**	**Season**
	mg kg^{-1}												
1	3259	3736	4033	4074	3626	3746	3272	4136	4304	4881	4832	3827	4209
2	3172	3374	3451	3271	3343	3322	3093	3686	3656	4479	4097	3162	3695
3	3052	4237	3709	2814	3160	3394	3048	3807	3276	3850	4009	3281	3545
4	2886	3190	3751	4070	3200	3419	2806	3923	4098	4710	3585	3373	3749
5	2789	2706	3273	2906	3239	2983	2772	3180	2930	3380	2870	2289	2903
6	3362	3991	3824	3691	3424	3658	3296	4310	3863	3968	3683	3246	3728
7	2879	3135	3580	3724	3123	3288	2683	2797	3495	4025	3923	3249	3362
8	3324	3355	4255	4865	3966	3953	3191	4232	4237	5194	2785	4006	3941
9	2908	3623	3659	3188	3638	3403	3399	3838	3200	3866	3597	3228	3521
10	2733	3193	3434	3367	3305	3206	3336	3480	2975	3687	4219	3482	3530
11	3036	3259	3680	3677	3316	3394	3377	3853	3192	3866	3935	3381	3601
12	3639	4176	4315	4144	3350	3925	3307	3826	4234	4648	5001	4397	4235
13	2829	2848	3826	3462	2943	3182	2623	3923	3302	4388	3706	3186	3521
14	2506	2708	3082	2798	2264	2671	2731	3251	2997	3192	3549	3056	3129
15	2715	3016	3772	3715	2475	3139	2911	3088	3820	4253	3983	3615	3612
16	2949	2922	3479	3220	3257	3165	3185	2942	3208	3998	4119	3546	3500
17	2733	2500	3215	3191	2907	2909	2571	3090	2970	3498	3787	3161	3180
18	3259	3381	3925	3997	2300	3372	3156	3413	4217	4522	4778	3894	3997
19	3178	3085	3257	3293	3302	3223	3630	4077	4230	4499	4353	3790	4096
20	3159	2993	3356	3269	3719	3299	4050	3634	4037	4719	5027	4096	4261
21	3283	2949	3556	4127	4330	3649	3578	3716	4618	5491	5212	4449	4511
22	3250	3178	3253	3569	3700	3390	3232	3393	3998	4528	4155	3695	3834
23	2689	2532	2837	2798	3125	2796	3562	3273	3221	3801	3501	3075	3406
24	2986	2696	3440	3631	3447	3240	3126	2840	3572	4319	3942	3412	3535
25	2951	2455	3058	2986	3721	3034	3079	3941	4523	4769	4390	3731	4072
26	2852	2971	3135	3132	3603	3139	4007	3452	3836	4416	4750	4090	4092
27	2919	2730	3281	3627	3851	3282	3396	2761	4537	5242	5185	4146	4211

28	**2766**	**3036**	**3664**	**3007**	**2653**	**3025**	**3112**	**3673**	**3612**	**3524**	**3323**	**2313**	**3259**
29	**2944**	**2584**	**3519**	**2836**	**2765**	**2930**	**3333**	**3603**	**3568**	**3903**	**3228**	**2804**	**3407**
30	**3057**	**3267**	**4337**	**3680**	**2937**	**3456**	**3114**	**3746**	**3533**	**4034**	**3203**	**2512**	**3357**
31	**3003**	**2768**	**3558**	**3340**	**3244**	**3183**	**2856**	**3828**	**4329**	**4590**	**4101**	**3161**	**3811**
32	**2696**	**2378**	**3155**	**3133**	**2485**	**2769**	**2430**	**2890**	**2912**	**3227**	**3143**	**2417**	**2837**
33	**2971**	**3147**	**3825**	**4214**	**3245**	**3480**	**3118**	**3471**	**3045**	**3460**	**3079**	**2887**	**3177**
34	**2961**	**2551**	**2950**	**2818**	**2869**	**2830**	**2984**	**3404**	**3959**	**4090**	**3768**	**3115**	**3553**
35	**2811**	**2309**	**2921**	**2551**	**3052**	**2729**	**3107**	**3573**	**3728**	**4100**	**3407**	**2920**	**3472**
36	**3371**	**3517**	**4598**	**4471**	**3150**	**3821**	**3647**	**3780**	**3731**	**4243**	**4192**	**2488**	**3680**
37	**2631**	**2546**	**3079**	**2808**	**2830**	**2779**	**2827**	**3673**	**3622**	**4094**	**3670**	**3056**	**3490**
38	**2832**	**2864**	**3294**	**2438**	**2750**	**2836**	**2649**	**3814**	**3314**	**4201**	**3470**	**3307**	**3459**
39	**3045**	**4130**	**5267**	**4110**	**3255**	**3961**	**3629**	**4232**	**4112**	**4120**	**3773**	**2952**	**3803**
40	**3164**	**2349**	**3234**	**2917**	**2975**	**2928**	**2721**	**3268**	**4100**	**4388**	**3751**	**3409**	**3606**
41	**2445**	**3028**	**3682**	**4011**	**3482**	**3330**	**3369**	**3725**	**4490**	**5314**	**5656**	**5335**	**4648**
42	**3055**	**3438**	**3934**	**4001**	**2911**	**3468**	**3294**	**3796**	**4988**	**5933**	**4710**	**3401**	**4354**
43	**2615**	**2579**	**3237**	**2735**	**2694**	**2772**	**2342**	**3230**	**3983**	**3803**	**3412**	**3003**	**3296**
44	**2827**	**2716**	**3691**	**3211**	**3101**	**3109**	**2384**	**3566**	**3304**	**3859**	**3900**	**3391**	**3401**
45	**3008**	**3499**	**4591**	**4408**	**3243**	**3750**	**3557**	**3863**	**4760**	**4672**	**4109**	**2735**	**3949**
46	**2444**	**2761**	**3565**	**3014**	**2712**	**2899**	**3298**	**3752**	**4085**	**3208**	**3228**	**2852**	**3404**
47	**3656**	**2946**	**3489**	**3897**	**3577**	**3513**	**3032**	**3448**	**4238**	**4771**	**3991**	**3230**	**3785**
48	**3213**	**3321**	**4006**	**2373**	**3104**	**3203**	**3170**	**3733**	**4099**	**3179**	**2740**	**2398**	**3220**
49	**2666**	**1646**	**2629**	**2327**	**3251**	**2504**	**2730**	**3171**	**3276**	**3216**	**4839**	**2865**	**3349**
50	**2566**	**2318**	**3454**	**3187**	**3782**	**3061**	**2850**	**3276**	**3846**	**4488**	**4491**	**4094**	**3841**
51	**3172**	**3082**	**3903**	**4051**	**3873**	**3616**	**3124**	**3436**	**3876**	**4689**	**4158**	**2883**	**3694**
52	**2678**	**2517**	**3461**	**3265**	**2834**	**2951**	**2874**	**3918**	**5090**	**5413**	**5088**	**3170**	**4259**
53	**3142**	**2768**	**3580**	**3605**	**3735**	**3366**	**3117**	**3584**	**4525**	**5169**	**5019**	**3910**	**4221**
54	**3283**	**3398**	**4280**	**3637**	**3397**	**3599**	**3490**	**3747**	**4539**	**3821**	**3451**	**2574**	**3604**

Table A.13. Potassium values by harvest date for 2002 and 2003

	2002						2003						
Plot	5/9	6/12	7/17	8/21	11/7	Season	5/7	6/10	7/17	8/20	9/25	10/29	Season
	mg kg^{-1}												
1	24935	22863	23580	21990	26244	23922	23136	27757	28712	25346	22981	19599	24588
2	23352	24076	17962	15941	28329	21932	21226	27495	27341	26073	24272	21293	24617
3	25120	28344	25297	18012	27007	24756	25589	33478	26812	23006	22464	19793	25190
4	22641	19814	21838	24568	26934	23159	17849	21126	18793	17491	14270	15508	17506
5	22576	18243	21293	19480	32740	22867	21730	23610	19656	18879	17149	17796	19803
6	22617	22836	27586	26052	24683	24755	26731	29940	24348	20666	19217	18363	23211
7	22699	22089	19885	22350	25091	22423	18589	17557	21703	20637	17939	18267	19115
8	25060	24082	25061	26426	30493	26224	22870	26250	26864	27797	16600	22118	23750
9	22604	20882	24168	21292	28489	23487	26820	27594	21806	21881	20640	20337	23180
10	19966	22756	19791	13144	23173	19766	31873	25361	21738	20194	22931	19794	23649
11	22361	20886	21462	15357	21906	20395	26697	31054	25030	22814	21925	18700	24370
12	25109	28576	24833	18068	25663	24450	30797	27570	29301	23713	24008	21089	26080
13	20399	20059	26136	21561	26711	22973	21748	21126	17902	22510	20684	19496	20578
14	19860	21026	22573	20093	19703	20651	23541	23598	19593	20293	23301	21987	22052
15	20602	24046	23799	23159	20004	22322	23010	19002	21135	20996	17166	16344	19609
16	23875	21834	20772	14402	23965	20970	29684	21597	24347	24852	23655	20712	24141
17	23652	20134	21849	17998	22778	21282	23631	26984	26947	24173	24616	21144	24583
18	24704	27620	25562	21601	23638	24625	26334	22988	24544	22364	21718	19264	22869
19	22613	19178	20260	11705	23905	19532	22925	21142	25995	22136	21689	21063	22492
20	20953	22113	17793	13086	19741	18737	25433	21506	23152	21656	16802	17281	20972
21	25219	23746	21158	21767	23420	23062	26593	24941	24612	20864	23047	19073	23188
22	19606	14775	17342	17160	20510	17879	15315	13991	13807	12971	10768	10269	12853
23	19536	19233	21646	19438	23633	20697	24037	18235	15898	16557	15743	12549	17170
24	22540	18423	21539	23388	23379	21854	22589	18077	19760	19309	18733	16985	19242
25	23365	17589	26541	17199	28898	22719	21130	24514	27593	27482	26063	20008	24465
26	21711	19547	19842	14787	23016	19781	28783	21308	22846	20929	19374	19355	22099
27	23270	21710	20661	22282	21705	21925	23581	16095	22262	20300	21821	18905	20494

28	19501	17409	21108	20846	17257	19224	19894	24739	20649	18247	12930	6614	17179
29	22573	17006	25383	22363	25086	22482	24931	24158	23863	23128	17499	12326	20984
30	20617	21277	33025	27846	13157	23185	23378	28256	25776	24533	16550	6904	20899
31	20917	15101	20919	20350	27971	21052	17779	21529	20246	18955	17583	15378	18578
32	22928	16677	18463	20992	26951	21202	20074	22785	21413	20478	18232	16557	19923
33	20946	17204	23096	27051	25845	22828	26727	26023	19404	19803	19446	17055	21410
34	22588	15499	20346	22565	24877	21175	20682	20573	22163	20689	17576	13905	19265
35	22529	13638	21347	18953	27285	20751	20936	22440	22149	21911	14822	12782	19173
36	24544	22895	30192	31000	18545	25435	30181	26749	24717	24265	22261	7766	22656
37	21481	18725	22690	20355	24847	21620	23588	24739	20359	22223	17288	12523	20120
38	22734	18126	26513	19434	21700	21701	22267	26316	21060	23469	18736	13707	20926
39	21673	27014	26264	20484	15205	22128	28124	21873	20725	16373	12600	7147	17807
40	21015	19317	24685	23362	28816	23439	23952	23261	26834	29147	22400	21950	24591
41	22043	17775	22174	21120	23265	21276	21265	18265	17395	17053	17460	16803	18040
42	21898	24289	24900	28074	18346	23502	28960	21722	25904	28365	17306	13555	22635
43	19778	18638	24077	21429	26425	22069	22025	22088	25892	24718	22304	19710	22790
44	22562	20629	25389	19340	27815	23147	20855	24761	23226	22333	22411	15430	21503
45	21309	24084	25134	23978	17594	22420	25509	19881	23182	25116	17534	8945	20028
46	19808	21182	23751	24028	22609	22276	25818	22076	26223	18865	13784	8315	19180
47	22686	15331	23980	20960	26839	21959	25670	23310	24092	22046	15983	13399	20750
48	23307	21138	22737	17641	10104	18985	17802	18414	22473	16889	10459	7121	15526
49	22369	15129	20492	17916	29530	21087	19484	20594	22812	19838	23703	18772	20867
50	20756	17103	22433	21177	30208	22335	22636	19376	22612	23272	20159	20504	21426
51	24607	23164	27166	28245	22505	25137	23617	21908	23752	21668	18900	12947	20465
52	23276	19487	24035	21200	25025	22605	21858	20480	26652	27182	21549	10059	21297
53	20194	17207	18271	16832	26339	19769	26740	24634	26753	25625	22226	14219	23366
54	25351	22956	25025	23911	18020	23053	24384	20665	22990	22082	16584	9710	19402

Table A.14. Magnesium values by harvest date for 2002 and 2003

	2002						2003						
Plot	5/9	6/12	7/17	8/21	11/7	Season	5/7	6/10	7/17	8/20	9/25	10/29	Season
						mg kg^{-1}							
1	3105	4401	3908	3826	7080	4464	3585	4496	4638	4729	4372	3334	4192
2	2857	3754	3284	3055	8688	4327	3264	3884	4230	4323	4154	3030	3814
3	2845	3902	3639	3112	6220	3944	3537	4020	3943	4068	3559	2910	3673
4	2762	3662	3781	4333	7596	4427	3390	3970	4228	4596	3546	3724	3909
5	2553	3496	3633	3469	9261	4482	3374	3867	3698	3994	3823	3755	3752
6	2924	3720	3741	3618	5836	3968	3618	4104	4297	4062	3709	3195	3831
7	2602	3593	3369	3635	7781	4196	3660	3837	4340	4337	3957	3283	3902
8	4068	4087	4015	4682	11147	5600	2860	4063	4220	4517	3122	3425	3701
9	2645	3595	3628	3075	5810	3751	3875	3687	3331	3528	3289	2953	3444
10	2561	3983	4017	3107	7217	4177	4000	3901	3747	3921	4143	2760	3745
11	2474	3207	3551	3167	5236	3527	3761	4036	3955	3895	3677	2813	3689
12	3588	4653	4241	3360	4945	4157	4369	4057	4706	4265	4037	3545	4163
13	2883	3707	4207	4004	7016	4364	2992	3970	3230	3836	3300	3681	3502
14	2486	3678	4030	4218	9197	4722	2654	3672	3525	3413	3763	3320	3391
15	2567	3982	4401	4772	12310	5606	3793	3541	4770	4917	4907	3947	4313
16	2791	3756	3677	3226	6441	3978	3959	3321	3983	4254	3956	3602	3846
17	2426	3265	3392	2979	7268	3866	2860	3827	3691	3667	3789	3443	3546
18	3120	3816	4054	3647	5438	4015	4104	3850	5028	4683	4625	3778	4345
19	2716	3299	3478	2881	5954	3666	3535	3496	3940	3833	3571	3043	3570
20	3634	3964	4911	4106	5819	4487	4503	4504	4963	5043	4730	3696	4573
21	3249	3593	3702	3789	6530	4173	3173	3503	4019	3784	3978	3420	3646
22	3037	3657	3911	4256	9617	4896	2926	3691	4424	5201	4779	4114	4189
23	2550	3475	4004	4219	6950	4240	4342	4029	4485	4780	4529	4835	4500
24	2588	3093	3486	3819	4625	3522	2915	3026	3828	3835	3754	3252	3435
25	2593	2807	3534	3048	6851	3767	2760	3408	3783	3591	3841	3214	3433
26	2986	3853	4257	4154	6465	4343	4512	4151	4639	4621	4491	3775	4365
27	2926	3430	3642	4098	8928	4605	3290	3562	4221	4748	4698	3631	4025

28	**2424**	**3249**	**3477**	**4398**	**7289**	**4167**	**4021**	**3999**	**5009**	**5324**	**4471**	**3272**	**4349**
29	**2292**	**2963**	**3129**	**3663**	**9468**	**4303**	**3001**	**3334**	**3757**	**4220**	**4036**	**3407**	**3626**
30	**3321**	**3929**	**4559**	**5095**	**5872**	**4555**	**3197**	**3945**	**4487**	**5533**	**4568**	**3238**	**4161**
31	**3100**	**3512**	**3853**	**3986**	**7156**	**4321**	**3050**	**4051**	**4180**	**4109**	**4085**	**3652**	**3854**
32	**2728**	**3065**	**3260**	**3940**	**9298**	**4458**	**2730**	**3689**	**4204**	**4701**	**4158**	**3447**	**3822**
33	**2557**	**3126**	**3555**	**3891**	**7630**	**4152**	**3512**	**3517**	**3336**	**3528**	**3464**	**3160**	**3419**
34	**2774**	**3201**	**3549**	**4341**	**8761**	**4525**	**3347**	**3229**	**4200**	**3949**	**4066**	**3569**	**3727**
35	**2096**	**2620**	**2973**	**3273**	**8980**	**3988**	**2964**	**3301**	**3596**	**4050**	**3517**	**3543**	**3495**
36	**2915**	**3765**	**4047**	**4398**	**6465**	**4318**	**4042**	**3676**	**4285**	**5021**	**4896**	**3391**	**4219**
37	**2372**	**2735**	**3181**	**3362**	**5157**	**3361**	**3037**	**3999**	**4670**	**4963**	**4929**	**3768**	**4227**
38	**2194**	**3907**	**4103**	**4015**	**4640**	**3772**	**2270**	**3584**	**3787**	**4698**	**4331**	**3420**	**3682**
39	**2751**	**3591**	**3886**	**5846**	**8001**	**4815**	**3491**	**3028**	**4690**	**4629**	**4178**	**3441**	**3909**
40	**2698**	**2726**	**3084**	**3246**	**6900**	**3731**	**2538**	**2916**	**3654**	**2972**	**3040**	**2757**	**2979**
41	**2150**	**3772**	**3639**	**3766**	**6829**	**4031**	**3090**	**3602**	**4004**	**3854**	**4576**	**4708**	**3973**
42	**2279**	**3063**	**3427**	**3720**	**15321**	**5562**	**2616**	**2852**	**4178**	**4927**	**4381**	**3358**	**3719**
43	**2640**	**3260**	**3863**	**3764**	**6824**	**4070**	**3060**	**3438**	**4654**	**4111**	**4159**	**3715**	**3856**
44	**2658**	**3595**	**3945**	**4560**	**6298**	**4211**	**2332**	**3903**	**4116**	**4159**	**4557**	**3705**	**3795**
45	**2654**	**3844**	**3876**	**5022**	**6517**	**4383**	**3311**	**3229**	**4362**	**4349**	**4128**	**3200**	**3763**
46	**2118**	**3114**	**3203**	**4081**	**8464**	**4196**	**3325**	**3401**	**4770**	**5679**	**5167**	**3776**	**4353**
47	**4115**	**4216**	**4671**	**4935**	**9732**	**5534**	**2849**	**3055**	**4069**	**4304**	**4076**	**3625**	**3663**
48	**3160**	**3737**	**3817**	**6755**	**7139**	**4922**	**2849**	**3507**	**4958**	**5905**	**4917**	**3606**	**4291**
49	**2745**	**2607**	**3319**	**3814**	**5250**	**3547**	**2378**	**3269**	**3837**	**3922**	**4466**	**3405**	**3546**
50	**2446**	**2905**	**3315**	**3461**	**8141**	**4053**	**2474**	**3354**	**3985**	**3680**	**3572**	**3770**	**3473**
51	**2945**	**3382**	**4081**	**4366**	**6197**	**4194**	**2727**	**3615**	**3758**	**3975**	**3796**	**2925**	**3466**
52	**2695**	**3074**	**3717**	**4367**	**8654**	**4501**	**2833**	**3331**	**4414**	**4486**	**4097**	**3083**	**3707**
53	**2710**	**2995**	**3408**	**4313**	**11348**	**4955**	**3082**	**3293**	**4213**	**4499**	**4261**	**3730**	**3847**
54	**3531**	**4143**	**4596**	**6280**	**6839**	**5078**	**3349**	**3832**	**4964**	**5292**	**4725**	**3634**	**4299**

Appendix B

Table B.1. Soil surface temperatures for 2002

	16-Jul					13-Aug							
Plot	**6AM**	**9AM**	**12PM**	**3PM**	**6PM**	**6AM**	**9AM**	**12PM**	**3PM**	**6PM**	**9PM**	**12AM**	**3AM**
							°C						
1	21	25	30	29	27	21.0	25.8	35.5	29.8	30.8	25.8	22.5	20.5
2	20	24	30	30	28	22.5	25.3	36.8	32.1	31.5	26.7	23.1	20.8
3	21	24	30	28	27	20.7	27.5	34.2	32.7	30.3	25.7	22.0	20.0
4	21	25	34	33	29	19.4	28.0	41.7	35.9	32.2	26.0	21.8	19.3
5	21	25	29	31	29	22.3	25.5	38.5	36.3	31.5	27.5	26.6	19.8
6	21	26	33	31	29	20.1	25.9	36.3	36.7	31.6	25.7	21.1	20.2
7	21	25	30	31	28	21.1	27.5	36.5	32.5	29.8	25.4	22.6	19.6
8	21	24	30	30	27	21.9	25.0	35.5	29.5	29.8	26.6	23.0	20.3
9	21	25	31	28	28	20.4	27.3	35.2	33.0	29.9	25.8	21.9	20.6
10	20	25	31	29	27	20.8	28.5	40.5	32.3	29.9	26.0	23.5	21.5
11	20	25	30	29	26	19.7	28.0	34.0	32.2	30.1	25.6	23.5	19.9
12	20	24	29	30	27	20.6	26.2	31.4	32.4	30.6	25.1	21.5	20.2
13	20	26	32	32	29	19.8	30.2	45.2	36.3	31.7	26.3	22.2	20.1
14	20	26	30	32	28	19.7	29.3	38.8	35.8	31.6	25.6	22.7	19.4
15	21	25	31	32	29	20.1	28.7	39.8	34.0	31.1	24.9	20.5	19.6
16	21	27	33	30	27	20.5	30.0	34.0	34.3	30.3	26.0	22.6	20.6
17	20	27	31	29	26	19.8	28.1	33.0	33.0	29.3	25.6	23.1	20.3
18	21	25	29	30	27	19.6	26.5	31.4	34.3	29.2	25.1	21.5	19.9
19	21	25	31	31	28	20.5	32.1	37.4	35.4	30.7	26.6	23.1	19.3
20	20	25	31	28	27	20.0	29.1	38.0	32.5	29.9	25.4	22.6	22.8
21	21	25	29	27	26	19.2	27.7	32.0	30.1	28.2	23.7	21.0	20.4
22	21	27	33	33	29	20.5	33.2	38.2	36.2	31.2	25.6	22.9	18.3
23	20	27	32	31	28	19.4	31.1	37.0	34.7	30.9	25.8	22.7	19.1
24	21	26	30	30	27	19.9	29.8	41.8	32.8	29.6	24.5	21.1	20.0
25	20	27	34	31	28	21.0	34.0	33.2	35.4	31.5	26.4	22.9	19.0

26	**21**	**26**	**32**	**28**	**26**	**20.3**	**29.3**	**36.0**	**33.8**	**30.0**	**25.8**	**22.3**	**20.3**
27	**21**	**26**	**29**	**28**	**27**	**19.7**	**29.8**	**35.2**	**30.9**	**28.8**	**24.4**	**21.1**	**19.4**
28	**21**	**24**	**31**	**30**	**28**	**21.1**	**26.7**	**37.4**	**31.8**	**29.3**	**26.2**	**22.2**	**20.0**
29	**21**	**23**	**30**	**30**	**27**	**22.1**	**24.8**	**38.0**	**32.2**	**31.0**	**26.9**	**22.0**	**20.1**
30	**20**	**24**	**29**	**28**	**26**	**20.1**	**25.4**	**29.8**	**29.1**	**28.6**	**25.7**	**21.8**	**19.9**
31	**20**	**26**	**30**	**32**	**29**	**20.6**	**27.7**	**39.1**	**36.7**	**32.8**	**26.3**	**21.3**	**18.8**
32	**20**	**27**	**30**	**32**	**29**	**21.0**	**27.0**	**38.5**	**37.2**	**31.4**	**26.7**	**22.5**	**19.7**
33	**21**	**26**	**32**	**31**	**29**	**21.1**	**27.2**	**35.4**	**33.4**	**30.5**	**25.0**	**21.0**	**19.0**
34	**21**	**26**	**30**	**29**	**28**	**20.9**	**27.7**	**35.2**	**30.7**	**30.9**	**26.5**	**22.5**	**19.2**
35	**21**	**25**	**30**	**30**	**29**	**22.1**	**26.1**	**34.5**	**33.7**	**31.3**	**26.8**	**21.7**	**19.3**
36	**21**	**25**	**30**	**28**	**27**	**20.8**	**27.1**	**34.2**	**29.7**	**28.9**	**25.2**	**22.1**	**19.9**
37	**21**	**25**	**32**	**33**	**28**	**19.9**	**27.8**	**40.2**	**34.8**	**31.0**	**26.3**	**23.0**	**20.1**
38	**20**	**25**	**32**	**31**	**28**	**19.7**	**29.1**	**40.0**	**33.2**	**31.0**	**25.6**	**25.1**	**19.2**
39	**21**	**24**	**28**	**27**	**25**	**20.0**	**24.1**	**27.9**	**30.0**	**27.0**	**24.6**	**21.0**	**18.4**
40	**21**	**29**	**34**	**34**	**29**	**20.7**	**29.1**	**42.0**	**35.8**	**31.7**	**25.7**	**24.3**	**19.3**
41	**20**	**27**	**32**	**32**	**27**	**19.1**	**29.6**	**35.9**	**34.9**	**30.3**	**25.1**	**21.7**	**18.2**
42	**20**	**25**	**31**	**30**	**28**	**19.6**	**27.7**	**34.0**	**39.0**	**30.1**	**24.5**	**21.5**	**18.0**
43	**20**	**28**	**33**	**29**	**28**	**20.5**	**30.1**	**38.7**	**35.8**	**31.4**	**25.9**	**22.8**	**20.0**
44	**20**	**27**	**31**	**29**	**27**	**19.5**	**29.6**	**37.2**	**34.6**	**28.5**	**25.8**	**23.2**	**20.4**
45	**20**	**24**	**30**	**27**	**27**	**20.0**	**26.4**	**30.0**	**31.0**	**27.9**	**24.7**	**21.1**	**19.7**
46	**21**	**26**	**31**	**29**	**26**	**20.6**	**27.7**	**31.8**	**28.5**	**28.6**	**25.4**	**22.4**	**20.1**
47	**20**	**25**	**31**	**31**	**26**	**18.8**	**29.0**	**40.2**	**31.2**	**29.4**	**24.8**	**21.7**	**18.9**
48	**20**	**24**	**28**	**27**	**25**	**19.7**	**25.5**	**26.8**	**28.8**	**27.4**	**23.5**	**20.8**	**20.9**
49	**20**	**27**	**33**	**32**	**28**	**20.7**	**34.0**	**38.7**	**38.0**	**31.7**	**25.4**	**22.6**	**20.5**
50	**20**	**26**	**32**	**31**	**27**	**19.8**	**30.5**	**43.7**	**34.4**	**31.8**	**24.9**	**21.6**	**18.7**
51	**21**	**26**	**29**	**30**	**28**	**19.1**	**28.4**	**30.7**	**31.2**	**28.4**	**23.7**	**20.5**	**18.9**
52	**21**	**30**	**30**	**30**	**27**	**21.0**	**31.2**	**34.6**	**30.4**	**29.1**	**24.8**	**22.0**	**20.0**
53	**20**	**26**	**30**	**30**	**25**	**19.8**	**30.5**	**40.3**	**32.1**	**30.4**	**24.8**	**21.5**	**19.4**
54	**20**	**25**	**28**	**26**	**25**	**20.0**	**27.1**	**26.8**	**28.8**	**27.0**	**23.8**	**21.3**	**19.9**

Table B.2. Forage canopy temperatures for 2002

	16-Jul					13-Aug							
Plot	**6AM**	**9AM**	**12PM**	**3PM**	**6PM**	**6AM**	**9AM**	**12PM**	**3PM**	**6PM**	**9PM**	**12AM**	**3AM**
	°C												
1	16.6	24.0	26.0	27.5	26.0	16.2	26.5	34.6	37.1	31.2	18.8	15.7	13
2	16.4	23.4	33.0	29.7	26.3	16.9	25.3	42.9	40.5	33.5	20	16.8	13.8
3	16.6	23.4	27.0	27.3	26.3	16.6	24.8	39.1	37.9	32.5	19.3	15.9	13.8
4	16.1	25.8	34.0	31.5	26.0	15.6	26.4	38.3	41.5	28.5	17.6	14.8	12.4
5	15.9	25.2	30.0	30.2	25.5	16.2	26.6	43.4	44.2	31.3	18.6	15	12.9
6	16.6	23.2	32.0	31.5	26.0	14.5	23.3	35	37.6	28.1	17.5	14.6	12
7	16.4	26.5	30.0	27.5	26.0	16.3	25.5	38.8	38.4	29	18.5	15.5	12.6
8	16.5	27.3	30.0	27.9	25.5	16.5	26	36.5	32.1	31.1	19.5	16.1	13.3
9	16.4	25.4	28.0	26.5	26.0	15.6	26.2	36.3	37	29.5	18.4	15.5	12.9
10	17.6	25.2	37.0	28.8	26.0	16.2	29.3	45	33.4	30	19.2	16.2	14
11	17.0	24.3	32.0	26.8	26.0	16.5	26.6	38.2	33.2	29.8	20	16.7	14.5
12	16.7	23.5	28.0	26.8	25.0	15.9	23.4	34.8	34.5	31	19.1	15.8	13.5
13	17.0	26.5	34.0	29.7	26.0	15	30	46.8	34	29.7	17	14.4	12.2
14	17.4	26.8	32.0	31.8	27.0	15.2	33.1	43.5	44.1	30.9	17.7	15.3	12.9
15	16.5	25.8	33.0	30.0	26.0	15.3	26.2	38.8	37.3	28.1	16.9	14.2	11.8
16	17.4	29.2	32.0	27.2	26.0	16	33.4	35.5	33.4	29.3	19.6	16.1	14.8
17	17.4	29.0	28.0	27.0	25.0	16	33	33.3	33.2	28	19.3	15.8	14
18	16.8	27.0	29.0	27.0	25.0	15.4	26.7	31.9	37	29	18.8	15.5	12.8
19	17.4	27.5	32.0	28.4	25.0	16.7	31.1	39.6	44.5	30.5	19	16.3	14.4
20	17.4	24.7	30.0	27.2	26.0	16.5	29.1	42.2	37.7	31.2	19.4	17	14.9
21	17.6	24.0	26.0	26.8	26.0	16.5	25	35	37.1	29.2	17.6	15.5	12.6
22	17.5	27.5	36.0	31.7	25.0	16	31.4	39.6	41.1	27.9	17.4	14.4	12.5
23	18.0	25.0	31.0	28.8	26.0	16	32.7	49.3	43.5	30	17.4	14.5	11.9
24	17.3	27.0	32.0	30.0	25.0	16.3	28.5	43.4	38.9	26.4	16.6	13.9	11.8
25	17.5	27.7	35.0	29.5	24.0	17.2	34.6	40.2	46.1	29.5	18.7	16	14

26	17.4	27.0	30.0	32.8	25.0	16.3	32	41.8	39.8	29.2	18.9	16	13.3
27	17.5	27.3	25.0	28.6	25.0	16.3	28	42.4	36	26.5	17.4	14.8	12.5
28	16.7	24.3	36.0	28.0	26.0	16.5	25.4	45.3	37	30.4	19.5	16.1	13.9
29	17.1	23.8	34.0	29.0	25.5	16.8	23.3	40	37.5	31.7	20.5	16.5	13.3
30	16.8	23.0	33.0	27.2	25.0	16.4	23.4	29.8	32.6	29.1	19.5	16.2	13.8
31	16.4	26.3	35.0	32.7	26.0	15.6	27.7	45.4	40.1	31.5	18.5	15	12.2
32	16.8	26.1	31.0	31.5	27.0	16	29.1	44.2	39.7	31.7	18.5	16	12.8
33	16.4	25.7	26.0	27.5	26.0	14.6	25.5	35.6	35.1	26.6	17.1	14.5	12
34	16.8	24.8	32.0	28.8	25.5	16.3	26	33.1	37.2	31.8	20	16.2	13.3
35	16.8	25.4	29.0	30.8	26.0	15.7	26.3	33.4	42.6	35	19.1	16	13.2
36	16.5	27.6	28.0	27.4	25.0	15.6	26	31.3	34.1	28.1	18.6	15.7	13
37	16.9	25.5	39.0	32.0	26.0	15.3	26	46	35.8	29	18.3	15.7	12.9
38	17.0	25.0	37.0	30.9	25.0	15.5	30	44.7	38.4	29.9	20	16	14.5
39	17.4	25.0	26.0	25.4	25.0	15.7	22.5	28.8	31.6	27.6	19.4	16	13.5
40	16.8	28.0	36.0	30.7	27.0	15.8	32.2	45	40	28.3	19	15	12.9
41	17.3	26.3	29.0	29.2	25.0	15.1	28.7	43.5	44.6	30	17.9	14.5	12.5
42	16.9	26.0	32.0	30.1	26.0	13.6	26.6	39.4	40.5	30	16.2	13.2	11.2
43	16.8	28.5	30.0	30.2	26.0	16	33.8	36.4	35	28.9	18	15.9	13
44	17.3	25.5	29.0	26.9	25.0	15.2	31.2	43.3	42.7	31	18.5	15.9	13.5
45	16.9	25.6	25.0	30.0	26.0	15.1	28.4	30.7	34.3	27.6	19	15.1	12.5
46	17.3	24.5	29.0	28.5	25.0	16.8	25.7	35.5	34.3	28.8	20.1	16.4	14.6
47	17.3	23.3	29.0	29.8	25.0	15	25.2	40.1	42.1	31.1	17.8	14.4	13
48	17.0	24.0	34.0	26.7	24.0	17	25.8	31.3	31.3	27.9	19.2	16.5	14.5
49	17.6	27.7	35.0	31.0	26.0	16.3	34.7	48.2	43.5	29	17.7	14.8	13.3
50	17.0	25.7	35.0	30.1	25.0	15.8	31.1	43.8	41.5	29.1	17.2	14.1	12.5
51	17.3	27.0	27.0	31.1	26.0	15	26.5	34.5	35.1	24.7	15.6	13.8	11.2
52	18.2	30.0	29.0	32.2	25.0	17	34.6	33.1	34.1	27.6	19.1	15.3	13.6
53	17.0	27.8	35.0	31.8	24.0	15.4	30.3	42.2	40	30.6	18.3	14	12.9
54	17.6	29.1	28.0	26.3	24.0	16.5	28.3	30	30.8	25.5	18	15.2	13.5

Table B.3. Soil moisture values for 16 July 2002

Plot	% Soil Moisture
1	20.4
2	15.5
3	16.7
4	21.1
5	21.7
6	26.1
7	20.5
8	21.9
9	23.1
10	21.0
11	18.2
12	21.6
13	18.0
14	17.6
15	20.6
16	20.5
17	19.1
18	21.4
19	16.1
20	17.9
21	17.5
22	22.0
23	21.8
24	19.2
25	13.1
26	18.0
27	17.0
28	18.5
29	13.7
30	21.5
31	21.3
32	16.0
33	25.9
34	11.5
35	12.3
36	16.8
37	18.5
38	15.5
39	22.4
40	18.8
41	16.0
42	9.5
43	11.9
44	15.9
45	21.4
46	16.0
47	12.6
48	21.1
49	16.7
50	25.4
51	23.1
52	9.2
53	19.3
54	20.9

Table B.4. Photosynthetic active radiation summary for Black Walnut in 2002

Slope	Toe†			Shoulder‡		
Density	Low	Medium	High	Low	Medium	High
			micromoles m^{-2} hr^{-1}			
7AM	172407	102328	66203	145842	140827	124895
8AM	1008935	815284	357082	625267	615773	526613
9AM	2682044	2032455	804844	1240558	1196687	1064532
10AM	4444813	2678852	1933599	2012047	2062134	1853995
11AM	5459933	3466127	2568282	2649709	2431481	2551701
12AM	6038714	2888076	2352619	3471603	3085368	3370321
1PM	5830887	2568324	1706004	3216599	3078195	3330396
2PM	5089246	2083542	1577098	2870601	2745054	2944636
3PM	3941397	783188	2023963	2412543	2322115	2446673
4PM	2949403	619981	1859419	2232510	1792311	1901811
5PM	2156990	550992	996590	1736005	1397033	1473092
6PM	597702	279460	479236	836543	721379	796626
7PM	134668	59709	52754	207376	192492	197286
8PM	-274	313	76	2547	2760	2411

† values averaged from 4-Sep through 10 Sep 2002

‡ values averaged from 23-Aug through 4-Sep 2002

Table B.5. Photosynthetic active radiation summary for honey locust in 2002

Slope	Toe†			Shoulder‡		
Density	Low	Medium	High	Low	Medium	High
	micromoles m^{-2} hr^{-1}					
7AM	1094794	215775	177981	172547	132063	114250
8AM	2458790	985634	1041909	754178	611212	505182
9AM	3256186	2781714	2386089	1372621	1100417	865879
10AM	4809987	4648075	3813929	2243196	1893440	1336529
11AM	6018667	5520199	5593895	2892281	2324396	2126825
12AM	6527111	5110432	4254867	3784622	2682739	2569443
1PM	6467076	5769254	3886181	3719342	2806528	2320303
2PM	6005967	5270149	4299009	3490233	2457650	2115768
3PM	4824454	3182149	3704031	2888037	2023383	1801209
4PM	3347522	2785333	3725876	2612163	1678462	1782277
5PM	2318162	2114770	2415769	1820739	1275879	1361824
6PM	886276	781773	857666	855254	689051	694669
7PM	166048	144808	138794	234915	188576	170551
8PM	5562	2242	3594	4243	3540	3874

† values averaged from 4-Sep through 10 Sep 2002

‡ values averaged from 23-Aug through 4-Sep 2002

Table B.6. Soil surface temperatures at 9AM and 12PM by month in 2003

	9AM						12PM					
Plot	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
	°C											
1	15.9	19.8	21.8	22.1	18.5	12.6	21.0	25.3	28.4	28.3	24.2	18.2
2	15.3	18.7	21.0	21.9	18.4	12.4	20.2	22.5	25.8	26.8	23.0	17.5
3	15.4	19.1	21.5	22.4	18.2	12.0	18.9	22.3	26.1	31.3	27.0	18.9
4	15.6	20.2	22.0	22.3	17.9	10.8	20.9	26.2	29.0	30.0	25.6	20.2
5	15.9	19.8	22.0	22.5	18.3	11.0	20.9	26.4	30.0	29.9	24.6	20.8
6	15.9	19.5	21.8	22.6	18.2	11.0	22.2	24.7	28.7	30.4	24.4	18.8
7	15.4	19.2	21.5	22.0	18.3	12.2	19.6	24.1	27.1	27.4	23.2	19.0
8	15.2	19.3	21.5	22.0	18.2	12.2	18.1	22.0	26.4	27.0	22.1	17.0
9	15.8	19.9	22.1	22.4	18.4	10.8	19.3	24.5	27.8	27.3	23.5	19.0
10	15.6	20.5	22.2	22.3	18.5	11.8	19.5	24.6	29.2	29.3	24.4	20.3
11	15.5	19.2	21.4	22.0	18.3	12.1	19.9	22.8	27.0	28.5	23.9	17.6
12	15.3	18.9	21.0	21.9	17.9	11.1	19.3	21.5	25.2	26.8	22.7	18.1
13	16.6	20.7	22.8	22.8	18.6	11.6	24.4	28.7	32.6	32.2	25.0	20.6
14	16.3	20.3	22.3	22.7	18.3	11.1	22.6	26.9	29.7	29.8	24.2	19.2
15	16.5	20.5	22.4	22.7	17.8	10.7	23.5	26.7	29.9	30.5	24.8	18.7
16	15.7	19.4	21.8	22.2	18.5	11.7	20.0	26.2	28.7	28.5	25.1	21.4
17	15.9	20.1	22.2	22.2	18.2	12.1	20.2	25.9	30.5	28.4	22.5	17.9
18	15.8	19.9	22.1	22.4	18.4	10.8	19.3	24.5	27.8	27.3	23.5	19.0
19	15.7	19.6	22.0	22.6	18.8	12.7	19.5	22.4	29.8	31.8	27.3	19.9
20	14.5	17.6	20.0	20.8	17.3	11.5	18.0	20.4	24.5	24.0	20.4	15.4
21	15.0	18.5	20.5	21.3	17.7	11.9	18.4	21.6	24.2	25.9	22.1	16.8
22	16.1	20.2	22.5	22.4	18.1	11.2	22.7	26.2	31.4	29.4	24.6	20.9
23	16.0	19.5	21.4	22.1	17.7	10.6	21.7	23.9	26.1	27.8	24.5	19.8
24	16.1	19.9	21.5	22.1	17.6	10.3	21.7	25.6	27.8	28.9	23.9	17.5
25	16.4	20.1	22.4	23.0	19.0	12.9	21.3	25.9	29.9	29.3	26.3	19.2

26	**15.2**	**19.0**	**21.4**	**21.7**	**18.2**	**12.0**	**18.7**	**22.8**	**27.0**	**26.5**	**21.8**	**16.5**
27	**15.1**	**18.8**	**21.1**	**21.5**	**17.6**	**11.7**	**20.0**	**25.0**	**29.0**	**27.8**	**21.9**	**15.4**
28	**15.5**	**19.4**	**21.2**	**21.9**	**17.6**	**11.3**	**20.2**	**25.9**	**29.5**	**29.8**	**23.4**	**19.6**
29	**15.5**	**19.1**	**21.3**	**22.0**	**17.8**	**11.8**	**19.6**	**24.9**	**27.6**	**26.5**	**24.5**	**19.2**
30	**15.7**	**19.0**	**20.9**	**21.5**	**17.7**	**11.1**	**19.5**	**22.8**	**23.4**	**24.4**	**23.7**	**21.8**
31	**16.5**	**20.6**	**23.1**	**23.3**	**18.4**	**11.4**	**24.0**	**27.1**	**31.1**	**32.2**	**25.1**	**19.6**
32	**15.9**	**19.8**	**22.0**	**22.5**	**18.3**	**11.6**	**21.2**	**24.3**	**27.0**	**27.6**	**23.3**	**19.1**
33	**15.6**	**19.2**	**21.6**	**22.1**	**17.4**	**10.8**	**19.8**	**22.4**	**27.9**	**27.7**	**21.6**	**17.0**
34	**16.7**	**21.3**	**22.7**	**22.3**	**18.1**	**12.1**	**23.0**	**28.5**	**31.0**	**27.2**	**24.1**	**18.8**
35	**15.8**	**19.8**	**22.0**	**22.2**	**18.1**	**12.0**	**19.5**	**25.0**	**26.4**	**26.7**	**23.3**	**19.8**
36	**16.2**	**19.4**	**21.0**	**21.5**	**17.4**	**9.1**	**22.0**	**24.6**	**25.7**	**25.7**	**21.5**	**21.4**
37	**15.4**	**19.1**	**21.7**	**22.1**	**18.4**	**12.7**	**20.0**	**24.3**	**28.9**	**28.4**	**25.1**	**19.0**
38	**15.9**	**19.9**	**22.2**	**22.5**	**18.0**	**11.4**	**21.2**	**26.7**	**31.5**	**32.1**	**26.4**	**21.0**
39	**15.7**	**19.5**	**20.9**	**21.5**	**17.4**	**11.2**	**20.4**	**23.8**	**25.1**	**26.0**	**21.0**	**17.2**
40	**17.8**	**22.3**	**23.6**	**23.6**	**19.1**	**11.2**	**24.6**	**29.0**	**31.5**	**31.3**	**29.7**	**28.7**
41	**15.8**	**20.3**	**22.4**	**22.4**	**18.1**	**11.2**	**23.2**	**28.9**	**32.3**	**30.4**	**25.1**	**18.3**
42	**15.9**	**19.4**	**21.7**	**22.0**	**17.6**	**9.4**	**20.9**	**24.0**	**28.0**	**29.0**	**24.0**	**22.1**
43	**16.5**	**20.9**	**22.7**	**22.7**	**18.3**	**12.9**	**23.9**	**27.3**	**30.0**	**30.9**	**25.4**	**18.6**
44	**15.8**	**19.8**	**22.0**	**22.2**	**18.1**	**12.0**	**19.5**	**25.1**	**26.4**	**26.7**	**23.3**	**19.8**
45	**16.2**	**19.4**	**21.0**	**21.5**	**17.4**	**9.1**	**22.0**	**24.6**	**25.7**	**25.7**	**21.5**	**21.4**
46	**16.5**	**20.5**	**22.2**	**21.7**	**17.9**	**12.3**	**22.6**	**27.6**	**31.2**	**28.8**	**22.0**	**18.9**
47	**15.5**	**19.6**	**21.6**	**22.0**	**17.9**	**11.5**	**21.4**	**26.5**	**28.2**	**27.5**	**22.8**	**18.3**
48	**15.8**	**19.4**	**20.8**	**21.3**	**17.5**	**11.3**	**19.8**	**21.3**	**23.2**	**24.6**	**21.1**	**17.7**
49	**17.0**	**20.8**	**23.0**	**23.1**	**18.8**	**12.0**	**24.3**	**27.9**	**31.8**	**30.9**	**26.1**	**20.9**
50	**15.8**	**19.6**	**21.8**	**22.3**	**17.5**	**10.9**	**22.0**	**25.6**	**28.1**	**29.0**	**24.5**	**17.6**
51	**15.1**	**18.6**	**21.1**	**21.6**	**17.4**	**9.4**	**19.6**	**23.4**	**28.6**	**27.0**	**22.7**	**19.4**
52	**16.5**	**21.0**	**22.9**	**22.3**	**18.1**	**12.0**	**22.3**	**27.6**	**31.3**	**26.6**	**22.3**	**19.1**
53	**15.3**	**18.8**	**21.2**	**21.8**	**17.6**	**11.0**	**20.4**	**23.9**	**27.1**	**27.2**	**24.1**	**22.6**
54	**15.7**	**19.1**	**20.7**	**21.1**	**17.3**	**10.8**	**19.9**	**24.2**	**24.5**	**24.1**	**21.1**	**15.4**

Table B.7. Soil surface temperatures at 3PM and 6PM by month in 2003

	3PM						6PM					
Plot	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
	°C											
1	20.2	23.7	26.2	26.7	24.3	19.9	19.3	21.5	24.4	25.6	22.3	16.6
2	20.2	21.5	25.2	28.1	25.0	19.7	19.1	21.1	23.9	26.1	22.3	16.4
3	19.5	21.9	26.2	31.5	28.8	20.7	19.2	21.7	25.0	28.3	24.4	16.9
4	26.4	29.4	30.5	31.8	27.4	22.5	20.8	23.7	26.3	27.5	22.8	16.3
5	24.8	29.5	31.7	33.0	28.1	24.7	20.3	23.4	26.4	27.3	22.5	17.0
6	28.5	28.0	29.6	31.5	27.3	26.6	21.7	23.6	26.0	27.1	22.6	17.0
7	22.0	25.9	26.6	29.5	26.4	21.7	19.1	21.5	24.3	25.1	22.2	16.5
8	18.7	22.2	24.7	25.6	22.1	19.1	18.5	21.9	24.5	25.4	21.4	16.3
9	20.7	24.6	27.3	28.5	24.8	21.2	19.6	22.5	25.4	26.1	22.5	16.9
10	19.3	22.3	26.8	27.7	26.4	21.7	18.2	21.9	25.3	25.9	22.0	15.7
11	19.6	21.4	25.0	27.8	26.0	19.9	18.6	20.9	23.8	25.4	22.0	16.3
12	21.5	22.6	27.1	30.3	26.6	22.2	19.7	21.6	25.9	27.1	22.5	16.3
13	30.0	31.8	33.5	34.1	27.7	24.8	22.2	24.5	27.8	27.8	22.7	16.9
14	25.6	29.6	31.1	32.3	26.7	23.5	21.5	24.0	26.2	27.3	22.4	16.6
15	29.7	29.8	31.4	32.7	27.1	22.1	22.4	24.4	27.3	27.9	22.4	15.9
16	20.8	24.6	26.4	29.8	26.0	23.6	18.7	21.3	24.0	25.3	21.8	15.8
17	22.4	27.0	30.9	30.5	24.8	20.0	18.9	22.3	25.1	25.6	21.4	16.0
18	20.7	24.6	27.3	28.5	24.8	21.2	19.6	22.5	25.4	26.1	22.5	16.9
19	19.8	22.9	26.9	28.7	29.0	22.0	18.9	21.6	24.7	26.7	23.4	17.4
20	22.3	26.7	29.9	28.6	23.5	19.5	19.8	22.4	24.9	26.4	22.8	17.7
21	19.4	21.7	24.7	26.6	24.6	19.1	18.7	21.7	24.1	25.9	22.0	16.1
22	26.6	29.8	32.5	33.1	28.5	23.6	21.2	24.8	27.1	27.0	22.6	17.0
23	26.4	27.0	29.3	30.4	26.5	21.8	21.1	23.3	27.0	25.9	21.8	15.7
24	25.4	28.5	30.2	33.7	29.5	22.9	21.3	24.0	27.0	28.4	23.1	16.5
25	22.0	25.7	28.4	29.5	27.7	22.2	19.9	21.9	24.8	26.3	23.2	17.9

26	19.6	22.7	25.7	26.1	23.6	18.5	18.1	21.1	24.0	24.8	21.6	16.0
27	21.2	26.2	29.0	29.4	23.5	17.2	19.0	21.7	24.6	25.8	21.7	15.6
28	20.8	24.7	26.1	29.9	28.7	24.1	19.4	21.5	24.3	26.8	23.5	17.0
29	20.2	22.9	25.2	26.7	24.9	21.0	19.3	21.9	24.6	25.7	22.4	16.5
30	21.7	24.2	24.8	25.8	24.6	24.3	20.1	22.2	24.1	25.5	22.8	16.7
31	27.7	29.8	31.9	33.9	26.2	21.7	22.0	24.2	28.1	28.0	22.1	16.2
32	25.1	27.4	29.2	30.5	25.7	21.1	20.8	23.5	26.0	26.7	22.2	16.2
33	22.9	24.9	29.7	31.0	24.4	20.8	19.9	22.6	25.8	26.7	21.7	16.2
34	26.7	30.3	31.8	27.6	23.9	20.3	21.6	24.4	26.7	25.9	21.7	16.8
35	20.7	26.9	27.2	28.5	24.4	20.8	19.6	23.1	26.0	26.4	22.0	16.1
36	25.0	28.5	28.7	26.5	22.4	25.1	20.5	22.3	24.3	24.6	21.3	15.9
37	20.7	23.4	28.0	28.0	27.7	21.8	19.3	21.7	26.0	26.3	22.7	16.8
38	24.6	28.3	31.0	30.9	25.2	23.1	19.7	22.2	25.8	26.9	22.5	16.8
39	20.8	22.0	24.1	26.4	25.2	22.6	19.7	21.4	23.6	25.7	22.9	17.0
40	28.4	31.6	32.5	32.6	29.7	30.7	22.1	24.4	26.7	27.5	22.7	16.1
41	29.7	32.3	33.6	32.1	27.0	21.1	21.4	24.9	27.0	27.1	22.3	15.8
42	23.8	26.7	29.7	30.6	27.5	27.1	20.6	23.3	27.0	27.2	22.6	17.4
43	27.2	30.0	29.0	28.5	25.9	19.9	21.8	22.9	25.1	25.9	22.6	16.4
44	20.7	26.9	27.2	28.5	24.4	20.8	19.6	23.1	26.0	26.4	22.0	16.1
45	25.0	28.5	28.7	26.5	22.4	25.1	20.5	22.4	24.3	24.6	21.3	15.9
46	22.4	25.9	26.9	26.2	23.5	21.8	20.6	22.8	24.8	25.0	21.7	17.0
47	23.8	28.6	30.9	28.5	25.0	21.2	19.9	22.7	25.5	26.8	22.4	16.4
48	21.0	22.6	24.4	26.1	22.9	21.4	19.5	21.6	23.9	25.6	21.7	16.7
49	29.2	31.0	32.1	33.5	28.8	24.4	22.2	24.4	27.2	27.8	23.4	16.9
50	26.2	29.5	31.0	31.4	27.7	19.4	21.2	24.6	26.4	27.3	23.0	15.6
51	23.4	27.1	30.6	30.4	24.9	21.9	20.1	24.1	26.2	26.8	21.7	15.7
52	24.2	27.4	29.4	28.7	26.4	20.9	20.3	22.4	25.1	25.4	21.8	16.7
53	23.8	27.9	30.4	27.9	24.5	22.0	19.5	21.8	24.2	25.6	21.6	15.6
54	22.6	26.7	25.4	24.4	21.2	18.8	19.3	21.6	23.4	23.8	20.6	15.9

Table B.8. Soil surface temperatures at 9PM by month in 2003

Plot	May	Jun	Jul	Aug	Sep	Oct	Plot	May	Jun	Jul	Aug	Sep	Oct
			°C							°C			
1	15.8	18.5	21.9	22.7	19.1	14.0	28	16.1	18.6	22.0	22.4	17.8	12.6
2	14.7	18.1	21.7	22.8	19.1	13.7	29	16.3	18.8	22.3	22.9	18.3	13.3
3	16.1	18.6	21.8	22.6	18.2	13.5	30	16.1	18.8	21.6	22.1	18.2	12.3
4	15.7	18.8	22.5	23.0	17.9	11.7	31	16.4	19.4	22.5	22.2	17.8	12.5
5	16.2	19.0	22.4	23.1	18.9	12.0	32	16.4	19.5	22.9	23.3	18.7	12.7
6	15.6	19.1	22.6	22.8	17.9	12.2	33	15.9	19.5	22.6	22.7	18.3	12.4
7	16.1	18.7	22.1	22.6	18.7	13.4	34	16.0	18.3	22.0	22.4	18.4	13.8
8	15.5	18.7	22.3	22.9	19.0	13.8	35	16.3	19.0	22.4	23.0	18.6	13.0
9	16.9	19.2	22.9	23.4	19.0	12.7	36	16.1	18.9	21.8	22.0	17.8	10.3
10	15.5	17.9	21.7	22.5	18.5	12.2	37	16.0	18.8	22.0	22.1	18.4	13.8
11	15.4	18.2	21.8	22.6	18.6	13.4	38	16.2	18.7	21.9	22.4	18.0	12.4
12	16.0	19.0	22.1	22.7	18.7	12.5	39	16.0	18.6	21.6	22.3	18.2	12.8
13	16.1	19.0	22.6	23.3	19.1	12.8	40	16.6	19.2	23.4	23.7	18.3	11.1
14	15.9	19.3	22.7	23.0	18.3	12.1	41	15.2	17.7	21.8	22.3	17.8	12.1
15	16.2	19.6	22.9	23.0	17.9	12.0	42	16.1	19.0	22.1	22.4	17.5	10.3
16	15.9	18.4	21.9	22.6	18.5	12.0	43	15.2	18.6	22.2	22.3	18.2	14.0
17	15.7	18.7	22.1	22.4	18.5	13.3	44	16.3	19.0	22.4	23.0	18.6	13.0
18	16.9	19.3	22.9	23.4	19.0	12.7	45	16.1	19.0	21.8	22.0	17.8	10.3
19	16.1	18.8	22.0	22.6	18.7	14.0	46	16.2	19.3	22.4	22.5	18.8	13.9
20	16.9	19.9	23.1	23.7	19.8	14.4	47	14.9	18.0	21.8	22.3	18.1	12.5
21	15.7	18.6	21.6	22.6	18.7	13.3	48	16.0	18.6	21.5	22.3	18.5	12.9
22	16.4	18.8	22.2	22.6	18.0	12.7	49	16.1	19.2	22.3	22.9	18.9	12.5
23	15.9	19.4	22.6	22.7	17.8	11.6	50	15.5	18.6	22.2	22.4	17.1	12.0
24	15.9	19.1	22.3	22.7	17.7	11.4	51	16.0	18.5	21.7	22.5	17.7	10.2
25	16.5	19.0	22.6	23.1	19.1	14.6	52	16.4	19.0	22.4	22.5	18.4	13.4
26	15.7	18.7	22.3	22.9	19.2	13.5	53	15.3	18.2	21.6	22.0	17.4	11.3
27	16.1	18.6	21.8	22.6	18.5	13.1	54	16.1	18.9	21.6	22.0	18.2	12.6

Table B.9. Forage canopy temperatures for April through June in 2003

	12-Apr			27-Apr			20-May				10-Jun		
Plot	9AM	12PM	3PM	9AM	12PM	3PM	9AM	12PM	3PM	6PM	9AM	12PM	3PM
							°C						
1	15.0	24.3	22.4	19.0	28.0	20.7	19.4	25.1	21.1	19.3	17.9	26.5	23.1
2	16.3	21.4	23.0	18.0	24.6	25.0	16.9	21.2	21.7	19	16.3	24.3	22.4
3	15.6	23.7	21.0	16.5	24.5	23.0	16.7	21.0	20.3	18.8	16.4	23.5	22.0
4	16.0	24.4	20.7	17.4	25.0	27.0	19.9	28.2	25.2	21	19.0	29.6	26.0
5	12.4	26.2	23.2	18.4	27.0	25.5	18.7	29.0	25.5	20.7	18.9	27.7	28.5
6	14.0	24.0	22.2	19.0	25.0	27.1	16.2	31.1	24.2	20.6	17.5	27.0	28.1
7	14.5	25.0	23.0	20.9	26.2	24.0	20.0	23.4	23.2	20.5	18.5	26.4	20.6
8	14.8	23.4	21.3	18.0	26.1	21.0	18.5	23.5	22.3	19.6	17.5	21.8	23.1
9	14.3	21.0	23.0	18.6	22.0	21.2	20.7	24.6	21.1	18.7	18.0	23.5	22.3
10	15.4	25.2	22.7	20.0	26.0	23.5	17.6	26.5	22.4	19.9	17.1	22.0	22.2
11	14.5	25.0	20.0	21.0	23.5	22.5	19.4	22.4	21.2	19.5	17.6	24.1	22.5
12	14.0	24.3	20.2	14.4	19.0	19.8	15.5	22.3	20.7	19.1	16.5	23.4	22.6
13	16.8	25.0	23.4	19.7	28.1	24.5	21.3	32.9	30.3	21.5	24.0	27.0	28.7
14	15.0	27.0	22.0	20.4	24.0	24.7	23.4	33.0	24.5	22	22.0	24.4	26.5
15	14.2	22.1	21.7	19.2	25.0	26.2	20.5	30.7	26.5	21.5	21.0	28.7	28.1
16	15.5	24.0	23.3	18.7	22.2	20.3	21.2	21.0	22.2	19.6	21.5	21.2	23.0
17	16.0	27.0	22.0	18.0	22.0	21.6	22.2	22.0	22.3	19.5	21.3	23.6	26.3
18	14.2	21.4	23.0	19.0	24.0	20.4	19.7	20.4	20.8	20.2	20.0	21.5	25.2
19	20.0	25.0	23.1	21.6	27.0	26.9	19.3	23.3	21.5	19.6	19.9	22.6	24.7
20	13.0	21.7	19.9	16.0	23.0	21.2	21.0	24.2	22.4	20.1	17.9	23.0	26.1
21	13.8	21.0	20.2	17.4	22.0	21.3	16.9	22.0	21.4	20.8	18.3	23.0	23.1
22	16.8	24.4	23.1	20.8	27.0	24.2	24.6	31.0	26.0	21.5	23.0	27.0	29.0
23	14.9	24.3	20.3	18.0	27.0	22.9	22.1	32.5	26.2	22.3	20.0	26.0	29.0
24	16.7	23.9	22.0	18.3	27.0	23.6	23.0	31.8	24.3	22.1	24.2	24.7	29.7
25	17.0	26.0	20.8	20.0	25.0	23.6	24.2	22.5	22.3	20	22.0	23.1	25.0

26	14.5	23.3	21.2	17.7	22.0	22.2	21.2	23.3	21.3	20.1	20.1	25.5	25.0
27	13.5	22.0	19.2	17.9	22.0	19.8	20.0	23.1	23.0	20.6	21.8	22.2	24.5
28	15.0	23.0	22.1	18.6	25.0	22.0	16.5	24.5	24.1	20.2	18.3	25.4	23.0
29	12.2	21.6	21.8	16.0	27.0	25.2	16.8	26.4	24.1	20	16.5	24.0	25.0
30	14.0	27.0	25.0	19.4	26.0	24.6	15.5	21.5	22.0	19.2	16.3	23.0	24.5
31	16.0	25.6	23.6	20.4	29.8	27.0	21.4	30.0	27.7	21.8	21.2	28.0	26.4
32	15.6	25.4	22.2	18.2	25.0	24.0	19.0	30.0	25.7	21.9	20.5	27.4	29.4
33	13.2	21.0	21.0	18.0	24.0	24.0	20.3	28.3	23.7	20.7	20.6	28.1	25.8
34	13.5	23.0	22.0	20.4	23.0	24.0	20.1	25.8	26.8	20.8	20.5	27.6	30.0
35	12.7	23.0	20.9	17.7	23.0	24.0	17.8	27.5	25.7	20	18.0	26.0	29.0
36	16.6	21.2	25.7	19.0	23.5	23.1	21.0	24.9	21.3	19.3	18.3	26.1	26.1
37	18.5	26.0	23.0	21.2	29.0	25.2	17.5	29.1	24.3	22.3	19.0	30.1	23.3
38	14.5	23.0	20.2	18.2	26.0	25.3	22.3	28.6	25.0	21.2	19.5	23.7	27.2
39	15.2	22.0	24.0	17.3	24.3	20.2	16.2	22.8	21.0	20.4	19.2	22.2	20.5
40	17.8	27.0	24.0	22.0	30.0	25.1	23.5	28.7	25.0	22.1	21.7	31.0	27.0
41	14.0	23.5	21.8	18.0	27.0	25.6	23.2	31.7	25.5	22.1	21.5	23.7	31.5
42	14.6	20.7	21.0	16.5	24.7	24.8	21.0	28.6	24.3	21	21.4	26.9	26.5
43	18.5	26.0	22.4	21.3	27.0	26.7	23.2	31.3	25.1	22.1	22.3	32.5	32.0
44	14.0	24.0	20.0	16.0	24.0	23.6	21.2	30.3	25.0	21.7	21.0	23.2	28.3
45	14.7	26.1	24.4	17.5	24.4	22.8	20.3	22.0	24.1	21.4	19.8	21.9	24.5
46	23.0	28.0	23.3	21.9	23.0	24.0	22.7	26.8	24.4	21.3	22.0	28.6	23.8
47	12.0	20.0	20.0	16.6	25.0	23.2	20.1	34.5	25.4	22	18.3	22.5	30.4
48	14.0	27.0	21.6	18.6	28.0	22.6	17.9	22.9	21.4	20.4	18.0	22.4	23.2
49	18.0	25.0	21.9	22.0	29.0	22.5	21.4	28.3	25.0	21.7	22.0	23.7	30.1
50	13.0	20.6	20.7	15.6	24.0	24.8	21.8	35.3	26.1	22.5	19.9	24.2	30.7
51	15.0	21.2	21.0	18.5	26.0	25.7	21.9	33.2	26.0	23	22.5	25.0	27.8
52	18.6	23.3	22.8	22.7	26.0	24.4	21.2	32.9	24.0	21	23.0	26.0	24.6
53	14.5	20.0	20.7	18.2	25.0	24.7	22.7	33.3	27.2	22.4	20.2	22.4	27.8
54	14.0	20.5	20.8	17.7	24.0	22.3	21.4	22.8	22.5	20.7	20.7	22.2	26.0

Table B.10. Forage canopy temperatures for August through October 2003

	29-Aug		12-Sep			3-Oct		30-Oct		
Plot	12PM	3PM	9AM	12PM	3PM	12PM	3PM	9AM	12PM	3PM
	°C									
1	30.0	32.2	17.1	21.5	22.5	23.0	17.0	13.5	21.5	20.1
2	30.0	32.6	15.6	20.5	23.6	18.6	15.4	13.8	20.6	18.9
3	31.4	31.4	17.9	22.0	21.7	21.4	16.9	14.0	26.6	22.6
4	38.0	34.7	19.3	21.2	23.8	23.5	16.8	15.8	24.8	18.8
5	35.0	38.0	19.1	21.2	23.7	19.9	16.6	14.1	26.7	20.4
6	40.7	38.1	17.0	22.3	22.2	23.0	18.9	13.3	22.7	18.3
7	31.5	30.3	17.7	22.4	23.4	23.7	15.5	14.8	23.1	16.4
8	30.5	27.3	18.4	20.4	20.1	19.7	17.3	14.6	20.6	19.0
9	36.0	31.9	18.0	21.8	22.8	19.7	16.4	16.1	23.9	18.6
10	33.0	30.1	20.5	21.9	22.5	14.8	15.9	15.6	20.6	19.8
11	32.0	29.7	19.1	21.4	21.3	16.4	15.1	14.9	22.0	17.1
12	31.3	30.1	20.2	20.9	21.6	16.5	16.0	14.3	20.3	18.6
13	40.0	35.6	18.7	23.5	20.7	20.6	14.4	11.5	20.4	19.1
14	35.1	32.9	20.5	22.0	25.6	19.6	14.9	14.4	19.0	18.4
15	36.0	34.8	20.2	22.1	20.8	21.0	14.5	13.9	25.5	19.4
16	32.5	30.3	18.8	21.1	19.6	17.2	15.2	15.6	26.6	21.1
17	32.0	28.2	18.6	20.2	20.8	16.6	14.9	16.6	22.9	19.7
18	28.9	30.3	19.2	21.5	20.6	16.8	15.4	13.1	19.8	16.8
19	33.8	32.1	22.4	22.3	23.2	19.5	15.6	13.2	21.8	16.1
20	30.3	28.7	18.1	20.4	22.2	19.3	14.2	13.3	18.1	18.1
21	31.6	31.3	18.1	22.8	21.0	17.4	16.1	13.3	18.7	14.2
22	35.8	32.9	22.6	24.8	24.8	20.8	15.7	13.7	21.5	17.6
23	33.6	30.8	21.1	25.0	20.6	18.9	14.4	12.5	20.5	18.1
24	32.9	33.8	19.1	23.1	19.8	20.3	17.3	14.2	23.8	17.9
25	34.0	31.8	23.3	23.1	26.1	21.4	15.7	20.9	22.5	18.1

26	31.4	28.2	19.5	22.6	21.5	21.4	14.5	16.6	25.0	18.6
27	30.9	28.5	18.5	22.6	19.3	15.8	17.5	19.6	26.8	17.0
28	30.4	28.5	15.9	19.2	20.6	18.8	16.6	17.7	19.5	17.9
29	30.5	29.7	15.5	19.9	21.3	19.1	17.6	17.4	18.0	14.6
30	29.5	29.3	17.2	20.6	20.9	16.6	16.1	16.2	18.2	15.7
31	42.0	38.9	21.8	19.9	22.3	22.3	15.9	13.0	19.5	14.6
32	33.6	33.0	19.0	21.1	21.8	19.8	15.0	12.9	18.6	16.4
33	36.0	34.7	17.8	22.7	21.9	19.2	14.9	17.4	23.9	17.6
34	31.5	30.2	20.8	21.2	21.4	22.1	14.6	14.5	23.0	19.0
35	30.5	32.3	18.6	21.7	21.3	19.3	15.4	14.5	19.0	18.1
36	30.5	29.1	21.4	21.3	20.7	19.6	15.6	12.9	24.1	20.2
37	32.8	31.5	18.0	26.5	20.6	17.3	16.2	13.6	23.6	19.6
38	31.9	28.6	19.8	22.4	25.3	16.7	14.7	14.9	20.7	18.3
39	31.5	29.7	15.7	21.9	21.9	13.8	18.1	13.2	23.1	17.2
40	43.0	36.2	20.1	24.2	21.4	25.7	16.0	11.5	23.4	16.5
41	36.0	33.7	18.4	22.1	27.2	21.8	16.9	10.8	22.7	17.9
42	38.0	35.6	19.6	24.7	22.4	21.8	16.8	13.0	18.1	16.4
43	32.5	30.1	17.9	23.9	19.6	20.4	15.5	15.0	23.2	20.7
44	32.8	30.5	18.0	21.5	26.0	18.5	15.8	14.0	23.6	21.2
45	29.7	29.5	19.1	21.2	20.4	21.2	16.4	18.8	21.1	18.2
46	30.7	29.1	17.7	22.7	23.8	14.2	15.0	18.6	24.7	18.7
47	33.0	31.5	17.7	22.0	27.1	18.2	16.1	16.7	21.8	19.1
48	29.9	29.8	18.9	24.9	21.7	16.3	15.5	21.5	24.6	21.7
49	39.3	35.7	19.5	25.4	23.5	20.3	14.6	12.1	24.1	20.2
50	37.0	33.3	17.4	24.0	23.9	20.1	15.8	11.7	20.5	19.3
51	33.7	34.6	19.3	26.0	21.2	19.8	16.8	12.6	20.8	18.3
52	30.4	28.9	20.0	21.3	21.7	14.3	13.8	10.2	20.3	16.8
53	34.0	32.1	18.3	22.6	24.2	21.4	16.2	10.4	20.7	17.7
54	31.7	29.2	18.9	21.4	19.9	14.7	15.2	11.8	21.2	18.0

Table B.11. Soil moisture values by measurement date in 2003

Plot	12-Apr	27-Apr	22-May	10-Jun	8-Jul	11-Jul	18-Jul	26-Aug	29-Aug	23-Sep
	%									
1	30.7	31.7	32.6	31.2	31.6	29.9	25.5	25.5	23.1	29.6
2	35.8	27.9	29.7	29.1	29.4	26.5	21.7	22.0	21.0	27.0
3	35.1	31.0	31.8	33.2	25.4	31.8	26.2	26.5	22.5	30.0
4	35.9	32.3	32.3	30.2	35.3	33.7	28.8	26.4	24.8	27.8
5	30.4	28.7	32.0	31.4	33.4	30.2	25.2	24.1	20.3	29.8
6	32.3	28.1	31.2	29.5	29.9	30.5	25.4	25.5	25.4	29.3
7	30.7	29.3	29.9	29.8	31.8	29.5	27.9	25.3	22.6	28.6
8	32.9	30.8	32.4	31.6	30.2	30.2	26.3	26.4	26.0	32.0
9	35.5	32.2	35.6	33.8	35.5	35.1	30.5	29.5	26.9	33.7
10	35.6	32.7	35.0	33.7	35.2	35.0	29.0	27.9	26.3	29.5
11	37.6	33.6	38.6	38.0	32.7	36.2	27.4	25.9	23.7	36.4
12	36.9	34.8	30.6	35.4	28.5	30.1	32.3	31.2	30.3	34.3
13	33.3	28.9	32.4	30.1	31.8	33.4	28.5	26.6	24.7	34.8
14	31.9	29.6	28.5	26.5	27.1	27.4	19.5	17.6	14.2	20.5
15	33.9	32.1	30.5	30.0	30.1	29.3	26.3	25.8	23.7	31.3
16	35.6	33.2	35.7	31.8	29.9	33.9	27.0	26.4	20.8	34.7
17	30.3	28.5	30.7	31.5	31.0	31.5	28.3	23.6	23.4	30.2
18	39.3	35.9	26.6	28.9	38.0	38.3	29.9	26.4	28.6	36.6
19	30.8	28.9	29.7	26.7	28.3	25.4	20.8	19.2	17.2	23.9
20	36.3	31.8	28.7	34.0	29.3	33.9	26.1	25.8	24.4	33.8
21	23.1	21.6	25.1	21.9	23.3	25.2	18.9	16.5	11.1	22.0
22	31.8	28.5	26.2	28.2	29.8	28.6	25.7	23.1	21.3	27.2
23	38.2	31.6	23.1	34.3	35.1	35.3	27.0	26.1	25.4	34.8
24	26.1	21.8	28.8	26.8	24.3	26.8	22.5	16.5	12.9	26.1
25	29.2	24.2	26.5	25.8	25.6	26.1	24.1	19.5	17.6	30.3

26	30.4	26.8	35.0	29.0	29.6	28.0	23.8	25.5	21.8	31.0
27	30.8	26.3	30.7	26.4	28.8	24.6	25.4	23.8	21.5	24.2
28	31.4	27.9	30.5	29.4	22.8	27.8	26.3	26.2	24.3	26.0
29	28.1	27.2	30.6	33.6	29.7	29.1	26.9	25.0	24.5	27.8
30	31.5	29.5	29.5	29.7	29.6	31.8	25.2	24.2	22.4	27.5
31	31.8	26.6	29.6	28.9	28.2	25.0	24.0	20.5	19.3	30.2
32	35.2	32.8	33.0	32.8	30.2	31.8	24.4	23.6	21.9	30.5
33	37.2	34.1	36.0	37.0	35.1	36.2	32.3	29.2	27.2	30.7
34	27.6	24.0	22.5	19.5	29.9	32.1	28.2	24.0	19.8	33.8
35	24.2	16.8	21.4	22.5	22.1	28.2	16.0	15.3	13.3	26.8
36	26.0	27.0	27.7	25.7	26.2	26.4	24.0	25.8	24.5	29.2
37	31.3	27.4	26.1	12.3	18.9	14.1	10.1	12.1	9.7	19.1
38	29.8	25.8	30.2	27.7	27.6	29.1	19.3	18.7	16.0	26.2
39	30.5	28.3	28.8	30.5	31.2	30.3	26.8	25.9	25.0	29.4
40	31.4	28.6	32.8	30.1	29.6	30.3	25.7	25.1	22.9	28.7
41	31.3	26.4	25.1	25.2	23.5	25.7	17.6	16.5	9.4	23.2
42	32.4	29.7	30.2	28.7	25.6	35.8	20.5	22.2	17.2	24.6
43	28.1	25.7	26.1	27.8	24.2	21.4	17.7	16.3	14.9	24.3
44	33.6	27.7	25.2	25.1	24.6	24.7	17.4	18.1	16.0	23.9
45	30.9	30.0	33.5	31.9	33.2	32.9	28.8	27.1	26.6	32.2
46	27.2	24.7	27.8	26.0	25.6	25.4	17.4	15.6	13.8	21.6
47	29.2	23.8	27.0	26.3	26.8	25.8	15.9	17.4	14.4	27.1
48	35.0	31.8	33.1	32.4	27.5	28.4	22.6	23.2	21.0	28.2
49	29.5	25.7	26.9	27.9	26.3	18.3	9.7	9.5	9.0	22.7
50	36.3	28.8	35.8	32.5	33.5	33.6	28.6	26.0	25.9	32.1
51	28.9	25.5	29.8	25.7	26.7	26.9	21.0	22.2	20.3	29.1
52	21.6	22.5	27.4	27.8	27.8	27.3	22.3	24.4	20.7	26.8
53	31.8	27.6	24.6	21.7	23.7	26.3	15.1	14.7	11.7	21.2
54	33.6	30.5	30.5	27.3	28.4	29.9	21.1	20.6	19.0	26.9

Table B.12. Photosynthetic active radiation summary for Black Walnut in 2003

Slope	Toe†			Shoulder‡		
Density	Low	Medium	High	Low	Medium	High
	micromoles*m^{-2}*hr^{-1}					
7AM	172407	102328	66203	145842	140827	124895
8AM	1008935	815284	357082	625267	615773	526613
9AM	2682044	2032455	804844	1240558	1196687	1064532
10AM	4444813	2678852	1933599	2012047	2062134	1853995
11AM	5459933	3466127	2568282	2649709	2431481	2551701
12AM	6038714	2888076	2352619	3471603	3085368	3370321
1PM	5830887	2568324	1706004	3216599	3078195	3330396
2PM	5089246	2083542	1577098	2870601	2745054	2944636
3PM	3941397	783188	2023963	2412543	2322115	2446673
4PM	2949403	619981	1859419	2232510	1792311	1901811
5PM	2156990	550992	996590	1736005	1397033	1473092
6PM	597702	279460	479236	836543	721379	796626
7PM	134668	59709	52754	207376	192492	197286
8PM	-274	313	76	2547	2760	2411

† values averaged from 14-Aug through 21 Aug 2003

‡ values averaged from 5-Aug through 13-Aug 2003

Table B.13. Photosynthetic active radiation summary for honey locust in 2003

Slope	Toe†			Shoulder‡		
Density	Low	Medium	High	Low	Medium	High
	micromoles*m^{-2}*hr^{-1}					
7AM	1094794	215775	177981	172547	132063	114250
8AM	2458790	985634	1041909	754178	611212	505182
9AM	3256186	2781714	2386089	1372621	1100417	865879
10AM	4809987	4648075	3813929	2243196	1893440	1336529
11AM	6018667	5520199	5593895	2892281	2324396	2126825
12AM	6527111	5110432	4254867	3784622	2682739	2569443
1PM	6467076	5769254	3886181	3719342	2806528	2320303
2PM	6005967	5270149	4299009	3490233	2457650	2115768
3PM	4824454	3182149	3704031	2888037	2023383	1801209
4PM	3347522	2785333	3725876	2612163	1678462	1782277
5PM	2318162	2114770	2415769	1820739	1275879	1361824
6PM	886276	781773	857666	855254	689051	694669
7PM	166048	144808	138794	234915	188576	170551
8PM	5562	2242	3594	4243	3540	3874

† values averaged from 14-Aug through 21 Aug 2003

‡ values averaged from 5-Aug through 13-Aug 2003

Table B.14. Tree measurement values taken on 1 April 2003

Plot	dbh† (cm)	ht‡ (m)
1	5.13	4.71
2	6.40	5.72
3	5.94	5.30
4	4.20	3.90
5	5.25	3.99
6	6.27	5.95
7	5.73	5.32
8	7.00	4.79
9	5.37	4.36
10	5.06	5.01
11	6.40	5.72
12	5.87	5.62
13	4.63	4.33
14	4.45	4.01
15	4.82	4.68
16	5.81	5.66
17	7.00	4.79
18	5.59	5.70
19	4.73	5.05
20	4.78	4.52
21	6.11	6.09
22	5.38	5.55
23	6.05	5.51
24	6.90	6.38
25	4.93	4.77
26	5.54	4.81
27	6.21	6.02
28	3.08	2.78
29	4.00	5.09
30	4.76	3.57
31	3.53	3.01
32	2.65	2.47
33	3.36	2.85
34	3.23	2.88
35	3.05	2.68
36	4.88	3.61
37	3.31	2.93
38	1.92	2.09
39	7.69	4.95
40	3.27	2.83
41	3.50	2.64
42	5.25	3.74
43	3.24	2.79
44	2.87	2.66
45	5.25	3.41
46	4.55	3.52
47	2.35	2.29
48	5.85	4.31
49	3.22	2.84
50	2.84	2.42
51	6.64	4.18
52	4.16	3.12
53	2.60	2.38
54	7.06	4.49

† dbh= diameter at breast height

‡ ht= tree height

Table B.15. Bulk density, organic matter, and soil nutritent values from 2002

Plot	**Bulk Density**	**Soil Organic Matter**	**Total Soil N**	**Total Inorganic P**
	g cm^{-3}	**%**	**kg ha^{-1}**	
1	**1.33**	**4.28**	**6408**	**0.27**
2	**1.56**	**4.04**	**6312**	**0.18**
3	**1.48**	**4.73**	**7248**	**0.40**
4	**1.28**	**4.20**	**6384**	**0.39**
5	**1.50**	**4.74**	**6816**	**0.25**
6	**1.44**	**4.24**	**6672**	**0.42**
7	**1.54**	**3.65**	**5952**	**0.20**
8	**1.36**	**3.40**	**5328**	**0.36**
9	**1.41**	**4.74**	**7416**	**0.33**
10	**1.52**	**3.93**	**6120**	**0.23**
11	**1.48**	**3.55**	**5376**	**0.25**
12	**1.34**	**6.82**	**10224**	**0.66**
13	**1.56**	**3.42**	**5424**	**0.30**
14	**1.57**	**4.21**	**6168**	**0.21**
15	**1.43**	**4.85**	**7536**	**0.55**
16	**1.47**	**4.30**	**6120**	**0.29**
17	**1.57**	**4.11**	**6168**	**0.29**
18	**1.23**	**5.94**	**8736**	**0.72**
19	**1.48**	**4.54**	**6720**	**0.63**
20	**1.52**	**4.01**	**6096**	**0.27**
21	**1.56**	**3.47**	**5376**	**0.17**
22	**1.38**	**4.00**	**5832**	**0.38**
23	**1.39**	**4.53**	**6912**	**0.28**
24	**1.54**	**3.39**	**5304**	**0.12**
25	**1.47**	**4.42**	**6120**	**0.90**

26	**1.40**	**4.63**	**6648**	**0.29**
27	**1.52**	**3.79**	**6144**	**0.15**
28	**1.40**	**5.92**	**8616**	**0.48**
29	**1.45**	**5.06**	**7512**	**0.30**
30	**1.24**	**5.57**	**8688**	**0.45**
31	**1.36**	**6.20**	**8256**	**0.55**
32	**1.57**	**4.40**	**6504**	**0.13**
33	**1.35**	**5.71**	**8544**	**0.46**
34	**1.32**	**5.45**	**7728**	**0.62**
35	**1.49**	**4.44**	**6048**	**0.30**
36	**1.30**	**5.75**	**8736**	**0.65**
37	**1.38**	**4.51**	**6264**	**0.61**
38	**1.49**	**4.65**	**7104**	**0.28**
39	**1.38**	**5.93**	**9312**	**1.19**
40	**1.57**	**3.95**	**6072**	**0.31**
41	**1.53**	**6.50**	**9072**	**1.11**
42	**1.50**	**4.50**	**7152**	**0.68**
43	**1.32**	**4.32**	**6432**	**0.44**
44	**1.33**	**4.15**	**6408**	**0.29**
45	**1.42**	**6.22**	**8952**	**1.11**
46	**1.51**	**3.92**	**5952**	**0.48**
47	**1.43**	**6.41**	**9048**	**1.39**
48	**1.53**	**4.59**	**7320**	**0.40**
49	**1.59**	**3.14**	**5040**	**0.12**
50	**1.51**	**4.24**	**6144**	**0.19**
51	**1.52**	**3.46**	**5448**	**0.18**
52	**1.47**	**4.04**	**6120**	**0.46**
53	**1.41**	**6.94**	**9840**	**1.27**
54	**1.39**	**3.49**	**5736**	**0.21**

Appendix C

SAS code

Sas Code 1. Analysis of an individual harvest date or seasonal value

```
proc glm data=silvopasture;
class rep slope species density;
model response=rep|slope|species|density;
test h=slope E=rep*slope;
test h=species slope*species E=rep*slope*species;
test h=density density*species slope*density slope*density*species
E=rep*slope*species*density;
lsmeans species density slope slope*species density*species slope*density
slope*density*species /pdiff stderr adjust=Tukey e=rep*slope*species*density;
run; quit;
```

Sas Code 2. Analysis of harvest date within year

```
proc glm data=silvopasture;
class rep slope species density date;
model response=rep|slope|species|density|date;
test h=slope E=rep*slope;
test h=species slope*species E=rep*slope*species;
test h=density density*species slope*density slope*density*species
E=rep*slope*species*density;
test h=date date*density date*species date*slope date*slope*density date*species*density
date*slope*species date*density*species*slope E=rep*slope*species*density*date;

lsmeans slope /pdiff adjust=tukey stderr E=rep*slope;
lsmeans species slope*species /pdiff adjust=tukey stderr E=rep*slope*species;
lsmeans density density*species slope*density slope*density*species /pdiff adjust=tukey
stderr E=rep*slope*species*density;
lsmeans date date*density date*species date*slope date*slope*density date*species*density
date*slope*species date*density*species*slope/ pdiff adjust=tukey stderr
E=rep*slope*species*density*date;
run;quit;
```

Sas Code 3. Analysis of year across both growing seasons using seasonal values

```
proc glm data=silvopasture;
class rep slope species density year;
model response=rep|slope|species|density|year;
test h=slope E=rep*slope;
test h=species slope*species E=rep*slope*species;
```

```
test h=density density*species slope*density slope*density*species
E=rep*slope*species*density;
test h=year year*density year*species year*slope year*slope*density year*species*density
year*slope*species year*density*species*slope E=rep*slope*species*density*year;

lsmeans slope /pdiff adjust=tukey stderr E=rep*slope;
lsmeans species slope*species /pdiff adjust=tukey stderr E=rep*slope*species;
lsmeans density density*species slope*density slope*density*species /pdiff adjust=tukey
stderr E=rep*slope*species*density;
lsmeans year year*density year*species year*slope year*slope*density year*species*density
year*slope*species year*density*species*slope/ pdiff adjust=tukey stderr
E=rep*slope*species*density*year;
run;quit;
```

Sas Code 4. Analysis of photosynthetically active radiation (no mid slope; year functions as rep)

```
class aspect species density year;
model PAR=aspect|species|density|year;
test h=aspect E=year*aspect;
test h=species aspect*species E=year*aspect*species;
test h=density density*species aspect*density aspect*density*species
E=year*aspect*species*density;

lsmeans species density aspect aspect*species density*species aspect*density
aspect*density*species
year year*aspect year*density year*species year*aspect*species year*aspect*density
year*species*density
aspect*species*density*year
/pdiff stderr adjust=Tukey stderr e=year*aspect*species*density;
run;
```

Sas Code 5. Analysis of correlation among response and regressor variables:

```
proc corr data=silvopasture;
var yield ST Moisture FCT;run;
```

Sas Code 6. Regression analysis using centered values for soil surface temperature (ST) and soil moisture (SM):

```
data silvopasture;
input Plot $ Spp $ Den $ Slp $ Rep $ Year yield ST SM FCT;

ST = ST - 26.4032;
SM = SM - 22.8973;
```

```
if (spp='L') and (den='3H') and (slp='2M') then do;
D2=0; D3=0; D4=0; D5=0; D6=0; D7=0; D8=0; D9=0;
D10=0; D11=0; D12=0; D13=0; D14=0; D15=0; D16=0; D17=0; D18=0;end;

if (spp='L') and (den='3H') and (slp='3S') then do;
D2=1; D3=0; D4=0; D5=0; D6=0; D7=0; D8=0; D9=0;
D10=0; D11=0; D12=0; D13=0; D14=0; D15=0; D16=0; D17=0; D18=0;end;

if (spp='L') and (den='3H') and (slp='1T') then do;
D2=0; D3=1; D4=0; D5=0; D6=0; D7=0; D8=0; D9=0;
D10=0; D11=0; D12=0; D13=0; D14=0; D15=0; D16=0; D17=0; D18=0;end;

if (spp='L') and (den='1L') and (slp='2M') then do;
D2=0; D3=0; D4=1; D5=0; D6=0; D7=0; D8=0; D9=0;
D10=0; D11=0; D12=0; D13=0; D14=0; D15=0; D16=0; D17=0; D18=0;end;

if (spp='L') and (den='1L') and (slp='3S') then do;
D2=0; D3=0; D4=0; D5=1; D6=0; D7=0; D8=0; D9=0;
D10=0; D11=0; D12=0; D13=0; D14=0; D15=0; D16=0; D17=0; D18=0;end;

if (spp='L') and (den='1L') and (slp='1T') then do;
D2=0; D3=0; D4=0; D5=0; D6=1; D7=0; D8=0; D9=0;
D10=0; D11=0; D12=0; D13=0; D14=0; D15=0; D16=0; D17=0; D18=0;end;

if (spp='L') and (den='2M') and (slp='2M') then do;
D2=0; D3=0; D4=0; D5=0; D6=0; D7=1; D8=0; D9=0;
D10=0; D11=0; D12=0; D13=0; D14=0; D15=0; D16=0; D17=0; D18=0;end;

if (spp='L') and (den='2M') and (slp='3S') then do;
D2=0; D3=0; D4=0; D5=0; D6=0; D7=0; D8=1; D9=0;
D10=0; D11=0; D12=0; D13=0; D14=0; D15=0; D16=0; D17=0; D18=0;end;

if (spp='L') and (den='2M') and (slp='1T') then do;
D2=0; D3=0; D4=0; D5=0; D6=0; D7=0; D8=0; D9=1;
D10=0; D11=0; D12=0; D13=0; D14=0; D15=0; D16=0; D17=0; D18=0;end;

if (spp='W') and (den='3H') and (slp='2M') then do;
D2=0; D3=0; D4=0; D5=0; D6=0; D7=0; D8=0; D9=0;
D10=1; D11=0; D12=0; D13=0; D14=0; D15=0; D16=0; D17=0; D18=0;end;

if (spp='W') and (den='3H') and (slp='3S') then do;
D2=0; D3=0; D4=0; D5=0; D6=0; D7=0; D8=0; D9=0;
D10=0; D11=1; D12=0; D13=0; D14=0; D15=0; D16=0; D17=0; D18=0;end;

if (spp='W') and (den='3H') and (slp='1T') then do;
```

```
D2=0; D3=0; D4=0; D5=0; D6=0; D7=0; D8=0; D9=0;
D10=0; D11=0; D12=1; D13=0; D14=0; D15=0; D16=0; D17=0; D18=0;end;

if (spp='W') and (den='1L') and (slp='2M') then do;
D2=0; D3=0; D4=0; D5=0; D6=0; D7=0; D8=0; D9=0;
D10=0; D11=0; D12=0; D13=1; D14=0; D15=0; D16=0; D17=0; D18=0;end;

if (spp='W') and (den='1L') and (slp='3S') then do;
D2=0; D3=0; D4=0; D5=0; D6=0; D7=0; D8=0; D9=0;
D10=0; D11=0; D12=0; D13=0; D14=1; D15=0; D16=0; D17=0; D18=0;end;

if (spp='W') and (den='1L') and (slp='1T') then do;
D2=0; D3=0; D4=0; D5=0; D6=0; D7=0; D8=0; D9=0;
D10=0; D11=0; D12=0; D13=0; D14=0; D15=1; D16=0; D17=0; D18=0;end;

if (spp='W') and (den='2M') and (slp='2M') then do;
D2=0; D3=0; D4=0; D5=0; D6=0; D7=0; D8=0; D9=0;
D10=0; D11=0; D12=0; D13=0; D14=0; D15=0; D16=1; D17=0; D18=0;end;

if (spp='W') and (den='2M') and (slp='3S') then do;
D2=0; D3=0; D4=0; D5=0; D6=0; D7=0; D8=0; D9=0;
D10=0; D11=0; D12=0; D13=0; D14=0; D15=0; D16=0; D17=1; D18=0;end;

if (spp='W') and (den='2M') and (slp='1T') then do;
D2=0; D3=0; D4=0; D5=0; D6=0; D7=0; D8=0; D9=0;
D10=0; D11=0; D12=0; D13=0; D14=0; D15=0; D16=0; D17=0; D18=1;end;

DST2=ST*D2;
DST3=ST*D3;
DST4=ST*D4;
DST5=ST*D5;
DST6=ST*D6;
DST7=ST*D7;
DST8=ST*D8;
DST9=ST*D9;
DST10=ST*D10;
DST11=ST*D11;
DST12=ST*D12;
DST13=ST*D13;
DST14=ST*D14;
DST15=ST*D15;
DST16=ST*D16;
DST17=ST*D17;
DST18=ST*D18;

DSM2=SM*D2;
```

```
DSM3=SM*D3;
DSM4=SM*D4;
DSM5=SM*D5;
DSM6=SM*D6;
DSM7=SM*D7;
DSM8=SM*D8;
DSM9=SM*D9;
DSM10=SM*D10;
DSM11=SM*D11;
DSM12=SM*D12;
DSM13=SM*D13;
DSM14=SM*D14;
DSM15=SM*D15;
DSM16=SM*D16;
DSM17=SM*D17;
DSM18=SM*D18;

cards;
. . . . . . . . . . .
;
run;

proc means data=silvopasture;
var ST SM;
run;

proc reg data=silvopasture;
model yield = ST SM DSTSM D2-D18 DST2-DST18 DSM2-DSM18/ selection=stepwise
include=2; run; quit;

proc reg data=silvopasture;
model yield = ST SM D2 D3 D9 D12 D15 D16 D17 D18
          DST2 DST3 DST9 DST18 DSM2 DSM17 / clm VIF; run; quit;
```

Sas Code 7. Presentation of regression analysis as a scatter graph and a predicted response surface:

```
options ls=77 ps=50 nodate nonumber;
goptions aspect = 5;

data FittedReg;
label pred = 'predicted yield';
set silvopasture;
if (spp='L') and (den='3H') and (slp='2M') then do;
  pred = 5475.15063 - 238.95763*ST - 62.44219*SM;
```

```
  output;
end;
if (spp='L') and (den='1L') and (slp='2M') then do;
  pred = 5475.15063 - 238.95763*ST - 62.44219*SM;
  output;
end;
if (spp='L') and (den='1L') and (slp='3S') then do;
  pred = 5475.15063 - 238.95763*ST - 62.44219*SM;
  output;
end;
if (spp='L') and (den='1L') and (slp='1T') then do;
  pred = 5475.15063 - 238.95763*ST - 62.44219*SM;
  output;
end;
if (spp='L') and (den='2M') and (slp='2M') then do;
  pred = 5475.15063 - 238.95763*ST - 62.44219*SM;
  output;
end;
if (spp='L') and (den='2M') and (slp='3S') then do;
  pred = 5475.15063 - 238.95763*ST - 62.44219*SM;
  output;
end;
if (spp='W') and (den='3H') and (slp='2M') then do;
  pred = 5475.15063 - 238.95763*ST - 62.44219*SM;
  output;
end;
if (spp='W') and (den='3H') and (slp='3S') then do;
  pred = 5475.15063 - 238.95763*ST - 62.44219*SM;
  output;
end;
if (spp='W') and (den='1L') and (slp='2M') then do;
  pred = 5475.15063 - 238.95763*ST - 62.44219*SM;
  output;
end;
if (spp='W') and (den='1L') and (slp='3S') then do;
  pred = 5475.15063 - 238.95763*ST - 62.44219*SM;
  output;
end;
run;

proc g3d data=FittedReg;
format yield f4.2;
scatter ST*SM=yield /
        shape='balloon' size=0.35
        tilt=60 rotate=280;
run;
```

```
proc g3grid data=FittedReg out=DispREG;
grid ST*SM=pred / spline
  axis1=-10.4 to 9.1 by 1.0
  axis2=-5.6 to 6.7 by 1.0;
run;

proc g3d data=DispREG;
plot ST*SM=pred / tilt=75 rotate=200;
run;
```

Appendix D

Table D.1. "Dummy" variables (D1-D18) created for regression analysis of 18 treatment combinations; all analysis is considering the relationship of treatments D2 through D18 to D1

Treatment	Species†	Density‡	Slope§
D1	L	3H	2M
D2	L	3H	3S
D3	L	3H	1T
D4	L	1L	2M
D5	L	1L	3S
D6	L	1L	1T
D7	L	2M	2M
D8	L	2M	3S
D9	L	2M	1T
D10	W	3H	2M
D11	W	3H	3S
D12	W	3H	1T
D13	W	1L	2M
D14	W	1L	3S
D15	W	1L	1T
D16	W	2M	2M
D17	W	2M	3S
D18	W	2M	1T

† L= honey locust; W= black walnut

‡ 3H= high density; 2M= medium density; 1L= low density

§ 1T= toe; 2M= mid; 3S= shoulder

Table D.2. Parameter estimates generated by Proc Reg Procedure for Multiple Linear Regression for analysis of the relationship of forage yield to soil surface temperature (ST) and soil moisture (SM) by species, slope, and density (yield = ST SM); variables listed were left in the model ($R^2 = 0.7$) and represent shifts in intercept (D*) and change in slope (DST* and DSM*); variables not listed are not significantly different in slope or intercept to D1

	DF	Parameter Estimate	SE	t value	P value	Variance Inflation
Intercept	1	5475.156	97.80335	55.98	<.0001	
ST	1	-238.958	30.14418	-7.93	<.0001	2.89843
SM	1	-62.4422	21.24277	-2.94	0.0042	2.96715
D2	1	-1180.91	336.205	-3.51	0.0007	1.17498
D3	1	-1247.79	335.3783	-3.72	0.0003	1.16921
D9	1	191.884	322.691	0.59	0.5536	1.08242
D12	1	-1004.07	323.0089	-3.11	0.0025	1.08455
D15	1	566.6395	316.5729	1.79	0.0768	1.04176
D16	1	552.4898	336.5602	1.64	0.1041	1.17746
D17	1	1678.906	462.9357	3.63	0.0005	2.22774
D18	1	420.6248	357.6447	1.18	0.2426	1.32961
DST2	1	432.9384	246.9001	1.75	0.0829	12.26178
DST3	1	-208.51	86.69825	-2.41	0.0182	1.17815
DST9	1	-232.15	84.3222	-2.75	0.0071	1.11254
DST18	1	-146.093	97.9007	-1.49	0.1391	1.33336
DSM2	1	345.0966	153.3209	2.25	0.0268	11.95249
DSM17	1	204.4268	81.21224	2.52	0.0136	2.12503

Regression equation for the general response of forage yield to soil surface temperature (ST) and soil moisture (SM) in a temperate silvopasture: Yield = 5475.15603 - 238.95763*ST - 62.44219*SM

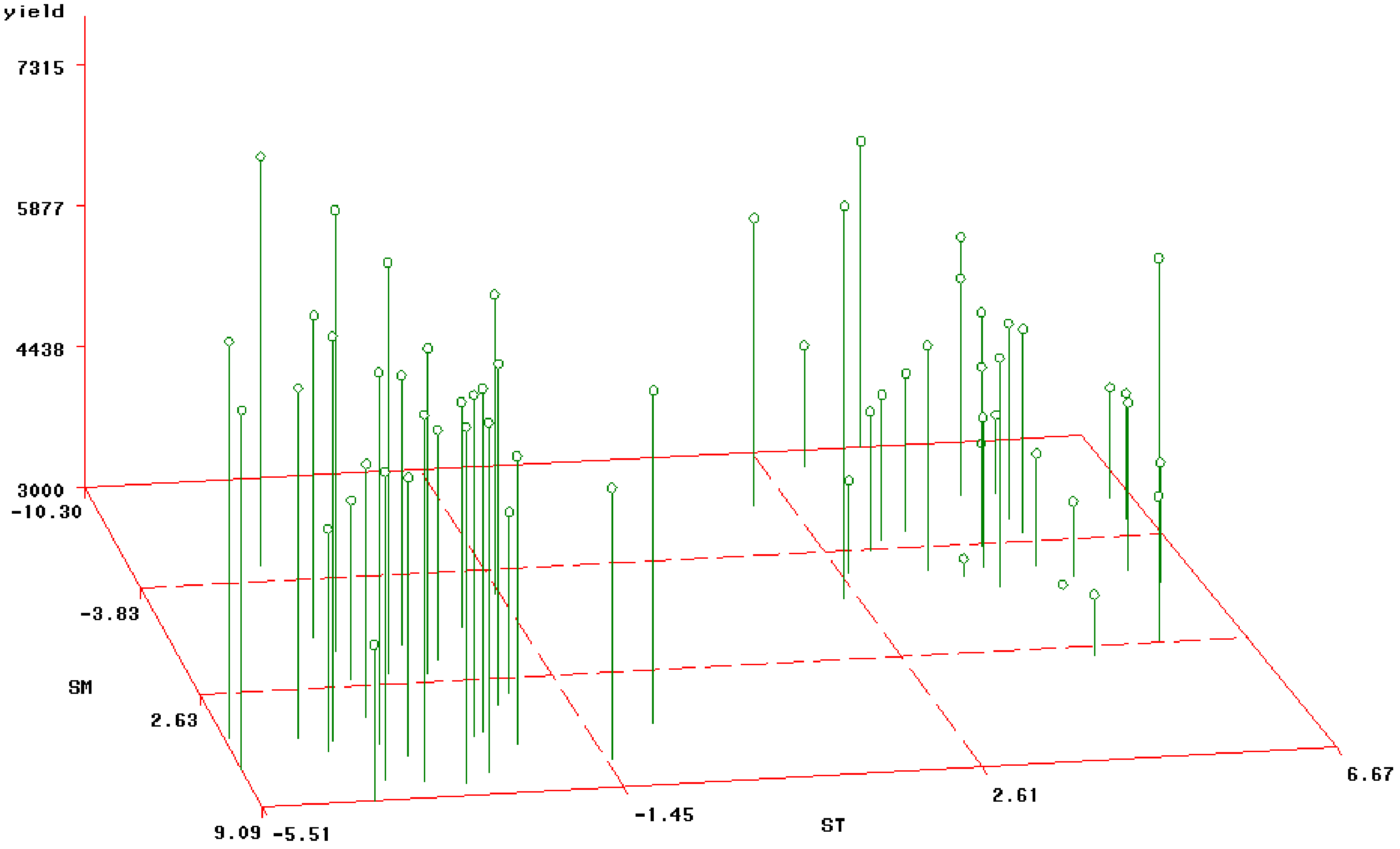

Figure D.1. Scatter plot generated from yield, soil surface temperature, and soil moisture data collected in 2002 and 2003; soil temperature and soil moisture values are centered

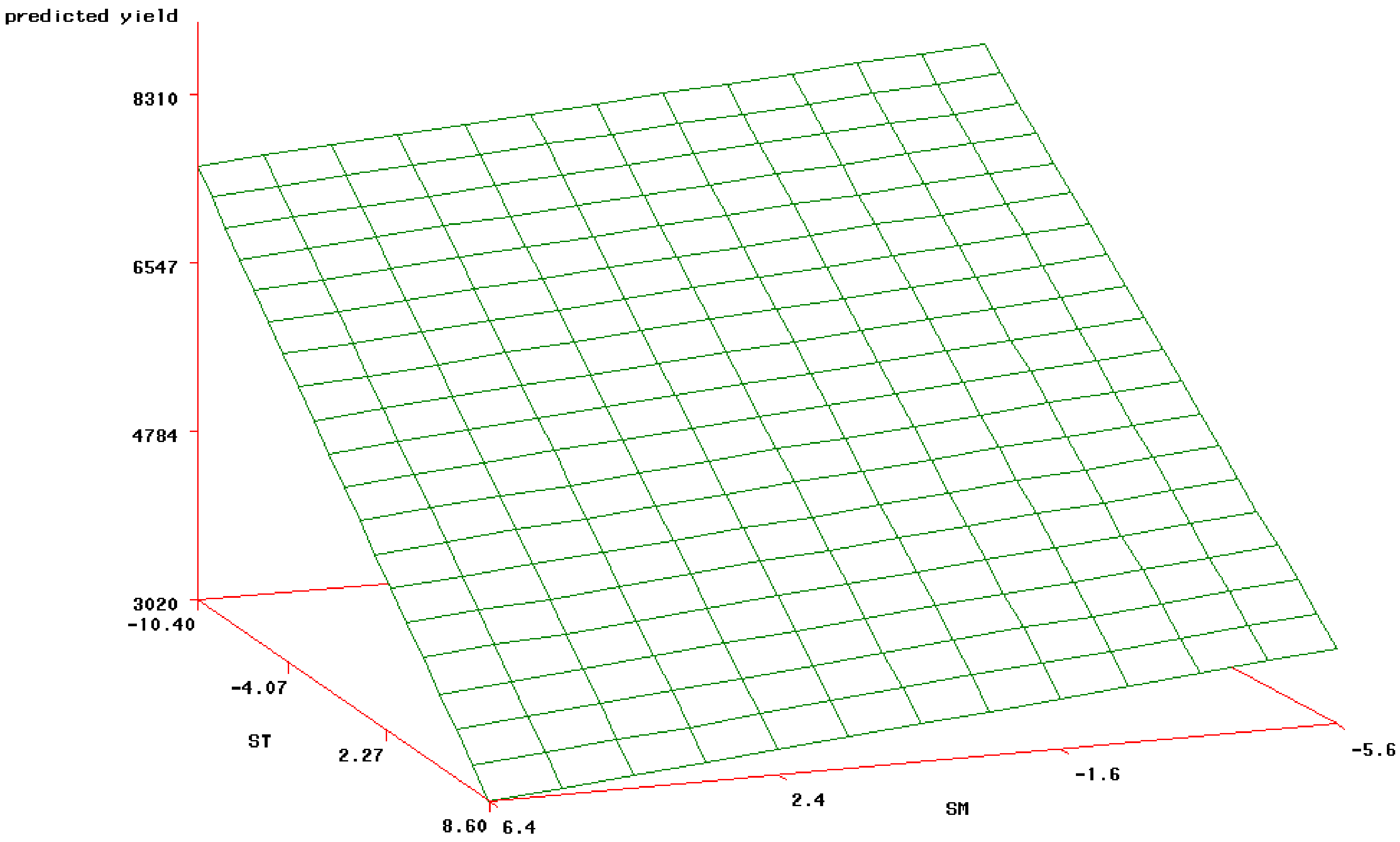

Figure D.2. Predicted response plane for yield = 5475.15603 - 238.95763*ST - 62.44219*SM; axis 1 = soil surface temperature (ST °C); axis 2 = soil moisture (SM %); ST and SM values are centered; where ST and SM values are less than the mean (ST=26.40°C; SM=22.90%), forage yield increases. Data suggest that elevated ST limited forage growth, and SM values reflected increased forage growth and water usage.

Table D.3. Regression equation for those treatments which were significantly different from the general response (Yield = 5475.15603 - 238.95763*ST - 62.44219*SM) of forage yield to soil surface temperature (ST) and soil moisture (SM) in a temperate silvopasture

---

Treatments which have significantly different intercepts than the general response:

D2 Yield = 4294.24391 - 238.95763*ST - 62.44219*SM (P=0.0007)
D3 Yield = 4227.36274 - 238.95763*ST - 62.44219*SM (P=0.0003)
D12 Yield = 4471.08358 - 238.95763*ST - 62.44219*SM (P=0.0025)
D17 Yield = 7154.0617 - 238.95763*ST - 62.44219*SM (P=0.0005)

Treatments which have significantly different soil surface temperature slopes than the general response:

DST3 Yield = 5475.15603 - 447.46804 *ST - 62.44219*SM (P=0.02)
DST9 Yield =5475.15603 - 471.10756*ST - 62.44219*SM (P=0.007)

Treatments which have significantly different soil moisture slopes than the general response:

DSM2 Yield = 5475.15603 - 238.95763*ST + 282.6544*SM (P=0.03)
DSM17 Yield = 5475.15603 - 238.95763*ST + 141.98461*SM (P=0.01

Vita

Alicia Lenore Buergler was born on August 10, 1976 in Fayetteville, AR to Jean and David Buergler. She is the older sister of Julia Christine Buergler and Gregory Lawrence Buergler. After graduating from Bethesda-Chevy Chase High School in 1994, she attended the University of Maryland at College Park, receiving a B.S. in Agronomy and a B.A. in Creative Writing and Literature. After college, she joined the Peace Corps and worked as an agricultural extensionist in a village near Choré, Paraguay. Upon completion of her Peace Corps service, she traveled around South America with an extended stay in Barra Grande, Brazil. She returned to the United States to pursue a Master's degree at Virginia Polytechnic Institute and State University in hopes of returning to South America to do further development work.