Honeylocust and Black Walnut Tree Products within a Temperate Appalachian Silvopasture

by

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ABSTRACT

Incorporating high-sugar varieties of honeylocust (*Gleditsia triacanthos* L.) or black walnut trees (*Jugulans nigra* L.) into pasture systems may improve soil and water quality, increase biodiversity, and diversify farm incomes. Studies of productivity and management are needed to understand the trees' potential. Research was conducted in the agroforestry demonstration plots at Virginia Tech's Kentland Farms to 1) estimate both the variability of seedpod yield and nutritive value from juvenile Millwood honeylocust trees, 2) measure changes in nutritive value and digestibility over-winter in Millwood and wild-type honeylocust seedpods, and 3) estimate black walnut biomass productivity, timber quality, nut production, and kernel quality in response to tree density and topography within an emulated silvopasture.

Ground Millwood seedpods were comparable to whole-ear dent corn in terms of nutritive value. Both ground pods and seeds were highly digestible (78.7 and 96.3%, respectively) and low in fiber and lignin. Seeds, with over 20% crude protein (CP), have potential as a CP supplement. Millwood trees displayed alternate bearing patterns with 3-yr average yields of approximately 12 kg tree^{-1}.

Total aboveground biomass for black walnut trees planted on toe-slopes (109.0 kg) was 72% greater than at back slopes (63.2 kg) and nearly 3-fold more than at shoulder-slopes (37.6 kg). Nut yields ranged from 0 to 7.9 kg of dried, hulled nuts tree^{-1} year^{-1}. All walnut trees displayed alternate nut bearing patterns and nut production was marked by high variability.

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Chapter 1: Introduction and Objectives

Introduction

Farm policies and subsidies that favor economies of scale have facilitated the movement of agricultural systems towards increased mechanization, agricultural specialization, diminished commodity prices, farmland consolidation, and a heavy dependence on pesticides, chemical fertilizers, and fossil fuels (Lehrer, 2009; Taylor, 2001). Although agricultural intensification has substantially increased food production, the negative environmental, economic, and social impacts associated with modern agriculture are numerous (Matson et al., 1997). Thus, there is increasing interest in designing more sustainable systems of food production. The American Society of Agronomy (1989) defines a sustainable system of agriculture as "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." Therefore, sustainable agriculture is not a specified set of production *practices*, but rather a general *goal* of achieving environmental, social, and economic viability (Bezdicek and DePhelps, 1994).

Agroforestry, a sustainable land-use practice, optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock (Gold et al., 2000). Land managers that utilize agroforestry principles design farming systems that more closely mimic natural forest ecosystems. Properly managed agroforestry systems can increase production on agricultural lands and help foster the long-term sustainability of environmental, economic, and social resources.

Agroforestry has many environmental benefits, including soil conservation, improved water quality, increased biodiversity, carbon sequestration, and reduced dependence on outside inputs to maintain agro-ecosystem productivity (Nobel and Dirzo, 1997; Young, 1997; Montagnini and Nair, 2004). There are also many economic advantages to agroforestry. In contrast to monocultural production systems, diversified agroforestry systems have less risk and more stable revenue streams because individual components require different inputs and are subject to different market fluctuations (Kurtz, 2000). Agroforestry trees may function as a long-term investment in timber, while crops or livestock provide annual incomes. Farmers may further diversify farm output by incorporating and managing fruit, nut, or fodder trees that generate annual revenue. These systems may especially benefit rural communities where decreasing farm productivity and an increasingly degraded natural resource base is a familiar reality (Rule et al., 2000). When implemented properly, agroforestry practices increase farm productivity, diversify incomes, protect the integrity of on-farm natural resources, and may revitalize rural communities (Rule et al., 2000).

Silvopasture, one of the most challenging agroforestry practices, *integrates* intensive animal husbandry, silviculture, and forage management to facilitate beneficial interactions among system components (Garrett et al., 2004). Silvopasture has potential to provide greater production than conventional forestry and forage-livestock systems (Fike et al., 2004). Biological and economic benefits occur only when trees acquire resources of water, light, and nutrients that forage crops would not otherwise acquire (Cannell et al., 1996). Therefore, land managers can increase system productivity by optimizing the number of beneficial tree-forage-livestock interactions at interface regions (Buck, 1986). Trees may create microclimates that benefit livestock by increasing comfort due to shade, providing protection from weather extremes, and improving forage production. Silvopastures can be created by thinning existing woodlots to accommodate the planting of forages, however planting trees into established pastures gives land managers complete control over tree species composition and allows inclusion of improved varieties of multi-purpose trees (Fike et al., 2004).

Two tree species that have gained particular interest for temperate agroforestry systems are black walnut (*Jugulans nigra* L.) and high-sugar varieties of honeylocust (*Gleditsia triacanthos* L.). Both species may be advantageous within silvopastural systems due to relatively fast growth rates, soil stabilization, improved nutrient capture and cycling, provision of shade for livestock, and the generation of marketable products such as timber, walnuts, and edible seed pods (Bendfeldt et al., 2001; Wilson, 1991). Further, incorporating black walnut and honeylocust trees into pasture systems has been shown to increase forage production when compared to open pasture systems (Buergler et al., 2005; Houx, 2006; Scott and Sullivan, 2007; Smith, 1942).

The crops produced by these two trees offer farm managers opportunity to capture additional harvestable products. Honeylocust trees produce edible seed pods that livestock may consume after pod drop over the course of several months in autumn and winter. Millwood, a high-sugar honeylcust variety, produces pods that contain elevated levels of non-structural carbohydrates relative to pods from wild honeylocust trees (Gold and Hanover, 1993). Black walnut, the most valuable timber species in the United States, produces flavorful nut meats and the crushed nut shells are often used as an industrial abrasive (Kurtz et al., 1984; Garrett and Harper, 1999). However, since honeylocust and black walnut silvopasture practices have not been commonly used in the Appalachian region, studies focusing on management strategies are necessary to understand their potential.

Therefore we designed a study to accomplish the following objectives:

Objectives

1. To review and synthesize the literature regarding agroforestry and silvopasture production, with emphasis on temperate systems that incorporate honeylocust and black walnut trees.
2. To estimate the nutritional variability of seed pods among Millwood honeylocust trees managed in a temperate silvopasture.
3. To estimate fodder yields of juvenile Millwood honeylocust trees managed within silvopastures and estimate seasonal production variation by tree.
4. To measure the changes in nutritive value and digestibility over winter – after pod drop – in seedpods from Millwood and wild-type honeylocust trees.
5. To estimate black walnut biomass productivity and timber quality in response to tree density and topography within an emulated silvopasture.
6. To determine black walnut nut production and kernel quality in response to tree density and topography within an emulated silvopasture.
7. To describe the management implications of the data.

Chapter 2: Literature Review

Objectives

1. To review and synthesize the literature regarding agroforestry and silvopasture production, with emphasis on temperate systems that incorporate honeylocust and black walnut trees.

The Need for Sustainable Agriculture

Farm policies and subsidies that favor economies of scale have facilitated the movement towards increased mechanization, agricultural specialization, diminished commodity prices, farmland consolidation, and a heavy dependence on pesticides, chemical fertilizers, and fossil fuels (Lehrer, 2009; Taylor, 2001). Although agricultural intensification has substantially increased food production, the environmental consequences associated with modern agriculture are numerous and adversely impact natural systems on a variety of scales (Matson et al., 1997). At the local scale, many farms have experienced lower soil fertility, increased erosion, biodiversity loss, and increased pest populations (Schoeneberger et al., 1994; Worrell and Hampson, 1997; Huang et al., 2002; Araújo et al., 2009; Liu et al., 2010). The use of fertilizers and pesticides has resulted in regional concerns regarding eutrophication of streams and lakes, ground water contamination, and the disruption in lifecycles of sensitive aquatic species (Matson et al., 1997; Nair and Graetz, 2004; Dinehart et al., 2010). At the global scale, agricultural dependence on fossil fuels and other non-renewable energy sources is a significant contributor to climate change (Montagnini and Nair, 2004).

In addition to environmental concerns, agricultural industrialization has led to many negative socioeconomic consequences. Many small, independent, family farms cannot fairly compete with large-scale industrial cropping systems (Wright and Gardener, 1995). The number of small farmers has declined, and as a result, many rural communities have experienced a tremendous loss of economic vitality as populations dwindle (Lehrer, 2009). Thus, conventional methods of agriculture may not facilitate both the growing demands of production and the long-term sustainability of environmental and social resources.

There is increasing interest in designing more sustainable systems of food production. The American Society of Agronomy (1989) defines a sustainable system of agriculture as "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." Therefore, sustainable agriculture is not a specified set of production *practices*, but rather a general *goal* of achieving environmental, social, and economic viability (Bezdicek and DePhelps, 1994). Practices to reach sustainability goals include using diverse crop species to enhance biological and economic stability, improving natural nutrient cycling to minimize nutrient losses from farmlands, and enhancing ecological conditions that suppress weeds and insect pests (Lockeretz, 1998).

Sustainable Agriculture through Agroforestry

Land managers that utilize agroforestry principles design farming systems to more closely mimic natural forest ecosystems. Agroforestry, a sustainable land-use practice, optimizes the benefits (physical, biological, ecological, economic, and social) from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock (Gold et al., 2000). This approach is holistic in that systems are designed to enhance interactions between multiple components, as opposed to conventional methods of production that aim to boost the productivity of individual components through reductionism (Bezdicek and DePhelps, 1994). Agroforestry practices increase productivity through increasing functional complexity. The integrative management of trees and crops and/or livestock may be considerably more intensive than conventional systems. Detailed planning and intimate knowledge of all components, including the timing and management of harvests, are required to avoid labor shortages and potential conflicts between land uses (Workman et al., 2003). The five recognized temperate agroforestery practices (Shultz et al., 1994; Clason and Sharrow, 2000; Gold et al., 2000, Hill and Buck, 2000; Garrett et al., 2004) include:

1. *Windbreaks:* trees and shrubs planted as barriers (shelterbelts, timberbelts, hedgerows) to reduce wind speed in crop and livestock operations and managed to provide harvestable products;
2. *Alleycropping:* production of agricultural or horticultural crops within alleyways of rows of trees (single or multiple) planted at wide spacing;
3. *Forest Farming:* the intentional manipulation of forested lands to create microclimate conditions suitable for the cultivation of high-value, shade-tolerant specialty crops such as nuts, fruits, medicinals, bee products, botanicals, mushrooms, and saps;
4. *Silvopasture:* integration of intensive animal husbandry, silviculture, and forage management. Trees can provide both short- and long-term returns, while livestock grazing of the understory generates an annual income;
5. *Riparian Forest Buffers:* narrow belts of trees, shrubs, and grasses that serve as a buffer between uplands and aquatic ecosystems (rivers, streams, lakes, wetlands) to reduce agricultural runoff, stabilize stream banks, and generate harvestable products.

When properly managed, agroforestry systems can increase production on agricultural lands and help foster the long-term sustainability of environmental, economic, and social resources.

Environmental Benefits

Trees and other woody perennials enhance the soil health of agroecosystems by increasing soil organic matter, fixing nitrogen, and increasing water infiltration. Trees also benefit soils by providing protection from erosion, retrieving and recycling nutrients, improving soil physical properties, and supporting increased activity of soil fauna (Schaefer, 1989; Young, 1997). Since tree roots occupy deeper regions of the soil profile, they reduce losses of nutrients that seep below the rooting zones of many agricultural crops (Ong et al., 1991; Schroth, 1995; Allen et al., 2004; Nair and Graetz, 2004). Trees reduce soil erosion: roots increase water infiltration and decrease rates of overland flow after precipitation events, and canopies slow the velocity of raindrops and winds (Young, 1997; Brandle et al., 2000). Thus trees improve the soil's overall chemical, physical, and biological characteristics (Young, 1997).

Agroforestry practices enhance the water quality of local and regional watersheds. Riparian forest buffers reduce non-point source pollution by preventing large amounts of suspended sediments, inorganic fertilizers, manures, and pesticides from entering nearby stream channels (Schultz et al., 2000). A mature, 30-m-wide riparian buffer can remove 68 to 92% of nitrogen (N) and 70 to 80% of phosphorous (P) from highly contaminated overland flow (Palone and Todd, 1997). Trees stabilize river banks, reduce flood risks, and increase local water storage and groundwater recharge. Further, tree canopies provide inputs of organic matter essential for the health of downstream aquatic organisms, and thus contribute to the functioning of entire stream ecosystems (Vannote et al. 1980; Schultz et al., 2000).

Farming systems that more closely mimic natural ecosystems may have reduced requirements for outside inputs to maintain productivity (Mollison, 1988; Dix et al., 1995; Young, 1997). Agroforestry improves soil organic matter content and nutrient cycling, and thus reduces the need for fertilizer inputs (Young, 1997). Trees also create microclimates that enhance the productivity of understory crops and/or livestock (Olson et al., 2000). Shelterbelts and hedgerows reduce the need for pesticides by increasing forest edge effects which facilitate biological control of crop pests (Pimentel et al., 1992; Dix et al., 1995; Shanker, 2000). Tree canopies create favorable habitats and refuges for endemic populations of natural enemies, such as parasitic wasps (*Hymenoptera*), ants (*Hymenoptera: Formicidae*), ladybird beetles (*Coleoptera: Coccinellidae*), birds, and spiders (*Araneae*), which can regulate the abundance of most pest insects (Dix et al., 1995). In addition, trees protect understory crops by serving as a physical barrier for pests (Shanker, 2000). In Nebraska, plots surrounded by tree shelter-belts had more abundant predatory insects and less abundant pests associated with muskmelon production when compared to open areas (Schoeneberger et al., 1994).

Polycultures that incorporate woody perennials enhance the compositional, structural, and functional diversity of agroecosystems relative to conventional monocultures. Biodiversity is further increased over time because agroforests often attract and establish other plant and animal communities (Schoeneberger et al., 1994). Agroforestry also can serve to reduce buffer biodiversity loss at the interface of agricultural regions and natural forest ecosystems and to mitigate the effects of fragmentation and isolation of woodland habitat within agroecosystems (Allen, 1994; Huang et al., 2002). Systems can be designed to provide corridors between existing forests and wetlands for wildlife species, such as migratory birds (Allen, 1994). Studies of several agroforestry systems in Sumatra, Indonesia, found that many sites had 50 to 80% of the diversity of comparable natural forests (Nobel and Dirzo, 1997). Further, the cultivation of woody crops in agricultural lands can also relieve demands placed on adjacent forests, thus increasing conservation of natural timber stands.

In 1997, countries participating in the Kyoto Protocol agreed to reduce greenhouse gas emissions to 5% or below 1990 levels by 2012 (Montagnini and Nair, 2004). One of the key concepts of the agreement was the ability of countries to purchase carbon offsets to counter any emissions that exceed these limits. Carbon sequestration, or the net gain of carbon within an ecosystem due to photosynthesis, is a crucial mechanism in greenhouse gas reduction (Nair and Nair, 2003). Agroforestry has strong potential to increase carbon (C) sequestration in agricultural regions, especially if the practices serve to reduce stress on natural forest stands (Sharrow and Ismail, 2004; Montagnini and Nair, 2004). Nair and Nair (2003) estimate that agroforestry development in areas of the United States of high to medium potential for agroforestry has the potential to sequester up to 90 Tg C yr^{-1}.

Economic benefits

Agroforestry systems can be more productive per unit area of land than monoculture systems (Keesman et al. 2007; Pagano et al., 2008). Land equivalent ratios (LER) are commonly used in production studies to quantify relative increases in biomass or crop productivity within agroforestry systems when compared to monocultures (Ghosh, 2004; Tewary, 2006; Raddad and Luukkanen. 2007; Pagano et al., 2008; Fadl and El sheikh, 2010; Graves et al., 2010; Rivest et al., 2010). An LER is defined as the land amount equivalent needed to grow different crops together compared to the amount of land needed to grow a pure stand of each; LER is calculated by dividing the intercrop yield of one culture by the yield of its corresponding monoculture (Mead and Willey, 1980; Pagano et al., 2008).

Agroforestry-based production systems often increase LER. In northern Sudan, Fadl and El sheikh (2010) studied the effect of 15-yr-old Arabic gum trees (*Acacia senegal* L.; spacing of 375 trees ha^{-1}) on the performance and yield of intercropped groundnut (*Arachis hypogaea* L.), sesame (*Sesamum indicum* L.) and roselle (*Hibiscus sabdariffa* L.) in an agroforestry system. All combinations of intercrops had an LER greater than 1.0, but the highest LER (1.7) was obtained when roselle was intercropped with Arabic gum trees. Rivest et al. (2010) reported an

LER of 2.4 when 5- to 7-yr-old hybrid poplars (*Populus nigra* L. × *P. maximowiczii* A. Henry) in an 8-m x 8-m spacing were intercropped for two years with fertilized soybean (*Glycine max* L.).

Many farmers produce only a single agricultural commodity, leaving them subject to risky and often unpredictable market fluctuations (Wright and Gardener, 1995). In contrast to monocultural production systems, diversified agroforestry systems have less risk and more stable revenue streams because individual components require different inputs and are subject to different market fluctuations (Kurtz, 2000). Further, cost sharing between timber, crops, and livestock reduces individual component production costs and enhances market flexibility (Clason and Sharrow, 2000). Agroforestry trees may function as a long-term investment in timber, while crops or livestock provide annual incomes. However, relatively fast-growing tree species such as loblolly pine (*Pinus taeda* L.) may suit some land managers' need for shorter timber rotation lengths.

Farmers may further diversify by managing trees that generate annual revenue, such as nuts, fruit, or fodder. For example, black walnut (*Juglans nigra* L.), a highly valued timber species, also produces commercially-viable nut meats. Relative to many species, black walnut timber is a long-term investment, requiring 30 to 50 years' growth before being suitable for veneer (Williams et al., 1997). In 2010, The Missouri Department of Conservation reported that statewide stumpage price for black walnut veneer was $1,665 for 5000 board feet (Int. BF). Hatcher et al. (1993) found that veneer harvests in a typical black walnut plantation thinned to 105 stems ha^{-1} had the highest internal rates of return (IRR) and net present value (NPV) when harvested at age 60. At final harvest, average tree diameter at breast height (DBH) was 53.8 cm and total timber yields were 16,180 Int. BF ha^{-1}. In the short-term, black walnut nutmeats can generate over $6.00 per pound and un-cracked walnuts range in price from $0.75 to $1.25 per pound (Das et al., 2001). Kurtz et al. (1984) analyzed the profitability of black walnut-based timber and farming systems managed with different levels of intensity. Strategies included timber, nut *and* timber production, as well as nut and timber production in various agroforestry systems. More intensive management accrued the greatest internal rates of return (Kurtz et al., 1984). Thus, timber and nut producing trees can quickly become the most profitable component of the system. Ares and Brauer (2006) found that the profitability of pecan (*Carya illinoinensis* (Wangenh.) K.Koch) silvopastures, including cow-calf operations, was highly dependent on nut and timber price trends. A 30% increase of pecan prices increased NPV four-fold over 20 years; while changes in revenue generated from livestock operations had relatively little impact on the profitability of the system (Ares and Brauer, 2006).

Silvopastoral practices have great economic potential. Pine silvopastures in the southeastern United States may have IRR 7.3% greater than open pasture systems and NPV 71% greater than conventional forestry (Dangerfield and Harwell, 1990; Clason, 1995). Lundgren et al. (1983) analyzed the profitability of grazing cattle in pine silvopastures under various timber thinning regimes and rotation lengths (30, 40, and 60 years). Silvopastures had profitable IRR that ranged from 0.5 to 4.5%. Adding wildlife activities, (e.g., issuing hunting leases) may increase profitability of silvopastures by 3.1 to 30.6% (Husak and Grado, 2002).

Social benefits

In many rural communities, decreasing farm productivity and an increasingly degraded natural resource base is a familiar reality (Rule et al., 2000). When implemented properly, agroforestry can increase farm productivity, diversify incomes, protect the integrity of on-farm natural resources, and revitalize rural communities (Rule et al., 2000). Further, agroforestry can be a mechanism by which rural communities are empowered. Since many decisions regarding natural resources take place in the context of watersheds and eco-regions, community collaboration and regional partnerships may be necessary to increase the use of agroforestry (Francis et al., 1994). When analyzing agroforestry potential in the United States, both Hardesty and Lyon (1994) and Workman et al. (2003) recognized that changing management strategies will require intimate knowledge of local ecosystems and a broader geographic cooperation. Therefore the use of agroforestry may further stimulate local knowledge and resource sharing.

In addition, agroforestry may be used as a management tool to achieve environmental benefits for the general public. The broader public is becoming increasingly interested in preserving local and regional environmental quality. Shrestha and Alavalapati (2004) studied the public willingness to pay for improvements in water quality, carbon sequestration, and wildlife habitat through silvopasture in the Lake Okeechobee watershed, Florida. Willingness to pay for modest environmental improvements amounted to $137.97 per household per year. Considering the 1.34 million households in the Lake Okeechobee watershed, the authors estimated that total willingness to pay for environmental improvement would be $924.4 million (Shrestha and Alavalapati, 2004). This study underscored the general public's recognition of the social benefits of environmental quality through agroforestry.

Silvopastures

Utilizing forested land for livestock production is not a new concept, because approximately 25% of all forest land (70 million ha) in the United States is currently grazed by livestock (Clason and Sharrow, 2000). However, because many forests and woodlots are not actively managed to optimize forage and livestock production, they are not considered silvopastures. Silvopasture is the *integration* of intensive animal husbandry, silviculture, and forage management to facilitate beneficial interactions between components (Garrett et al., 2004). Although considered one of the most challenging agroforestry practices, silvopasture has great potential to provide greater production than conventional forestry and forage-livestock systems (Fike et al., 2004).

Resource sharing within silvopastures

A common approach to address the dynamic nature of silvopasture systems is to assess the use of resource pools by components within the system. These resource pools can occur vertically and horizontally within the silvopasture, as well as through time. When land managers pair species together that are competitive in association, preferential treatment is usually given to the forage and livestock components. However, the ultimate goal is to find tree-crop pairings that allow land managers to partition the use of resource pools in space and time (Buck, 1986). Biological and economic benefits occur only when trees acquire resources of water, light, and nutrients that understory crops would not otherwise acquire (Cannell et al., 1996). Therefore, land managers can increase system productivity by maximizing the number of beneficial tree-forage-livestock interactions at interface regions (Buck, 1986).

Aboveground interactions

Increased shade caused by tree canopies does not necessarily decrease herbage yield, as many forages become light-saturated at about 50% (C_3 plants) and 85% (C_4 plants) of full sunlight (Hay and Porter, 2006). In many studies, moderate shade produced by trees has increased the yield of understory forages when compared to open pasture systems (Smith, 1942;

Wilson et al., 1990; Buergler et al., 2005). In semi-arid rangelands, tree-canopy shade creates cooler, moister microclimates that have positive impacts on organic matter breakdown, and nutrient availability (Wilson, 1996). In semi-arid Australia, 50% artificial shade increased forage dry matter yields by 37% when compared to open pastures (Wilson, 1996). In southern Queensland, Wilson et al. (1990) compared the growth of bahiagrass (*Paspalum notatum* Flueggé) under the shade of a 5-yr-old rose gum (*Eucalyptus grandis*) plantation to adjacent open pastures. Over a two-year period, accumulated dry matter in spring and summer was 33% greater under the tree canopy than in full sunlight (Wilson et al., 1990).

In temperate regions, tree-shade microclimate effects on forage yields are more varied since moisture and nutrient availability are more abundant and light availability is more limiting. Newly established trees have little effect on forage productivity since their demand on above- and below-ground resources is minimal (Lehmkuhler et al., 2003). For example, cool-season forage production under 7- and 8-yr-old honeylocust (*Gleditsia triacanthos* L.) and black walnut trees was 20% greater under moderately-spaced trees (spacings of 175 to 375 stems ha^{-1}) compared to heavy and light tree cover (Buergler et al., 2006). However, as trees grow demand for resources increases, resulting in a change in pasture composition and forage yield (Sibbald et al., 1994; Clason and Sharrow, 2000).

Integrating trees with pastures for increased production requires thoughtful management of trees and forages. For example, alfalfa (*Medicago sativa*) production was reduced 29% in 10- to 11-yr-old radiata pine (*Pinus radiata* D. Don) silvopastures (200 stems ha^{-1}) when compared to open pastures in New Zealand. This may reflect both greater shading by the coniferous pine trees and alfalfa's greater sensitivity to shade as compared to other forage crops. Burner and Brauer (2003) found that tall fescue (*Schedonorus phoenix* (Scop.) Holub) and bermudagrass

(*Cynodon dactylon* L.) herbage yield was unaffected by pine trees in rows spaced wider than 4.9 m, but yields drastically decreased with narrower row spacing. Usually, forage yields are considerably reduced when trees reach maturity and canopy closure occurs due to insufficient levels of light reaching the understory (Clason and Sharrow, 2000). Pruning or harvesting mature trees (or both) may be necessary to maintain sufficient light levels for forage and livestock production (Garrett et al., 2004).

Forage yield is not the ultimate indicator of system productivity, however. In Missouri, Kallenbach et al. (2006) compared forage production and beef heifer performance of a 6- to 7-yr-old pine and black walnut silvopasture to open pastures. Although annual ryegrass (*Lolium multiflorum* Lam.) and cereal rye (*Secale cereale* L.) yields were 20% lower in silvopastures, animal performance was similar in both treatments.

Incorporating trees in pasture systems changes forage nutritional characteristics in both positive and negative ways. Reduced light associated with trees can reduce non-structural carbohydrate concentrations in grasses (Norton et al., 1990; Burner, 2003, Buergler et al., 2006). Although this decline may be disadvantageous for ruminants, whose production typically is energy-limited (Lindsay, 1959), it may be offset by increased total digestibility (Garrett and Kurtz, 1983). Reduced non-structural carbohydrates may also prove useful in horse production systems because some horses are prone to laminitis associated with intake of diets high in non-structural carbohydrates (Longland and Byrd, 2006).   Forage crude protein (CP), calcium (Ca), and phosphorous (P) concentrations are usually higher in silvopastures when compared to open pastures (McEwen and Dietz, 1965; Burner and Brauer, 2003; Buergler et al., 2006).

Belowground interactions involving water

Incorporating trees in pasture production systems also creates both positive and negative impacts on soil water availability. Trees positively influence moisture dynamics in silvopastures (Young, 1997) by:

1. Increasing the efficiency of water uptake by utilizing resources deeper in the soil profile and at different times of the year than forages
2. Reducing water losses caused by runoff, thus increasing system uptake by infiltration
3. Improving water holding capacity of the soil via the addition of organic matter
4. Reducing levels of evapotranspiration, through shading by the tree canopy and reduction of wind speed

Further, trees enhance soil macroporosity by creating root channels and penetrating hardened subsoil layers (Schroth, 1995). Such changes in soil physical properties may increase water use by expanding rooting depth of forages.

Many studies suggest that in the presence of grasses, trees become deeper-rooted in order to reduce competition for moisture in soil surface layers (Huxley et al., 1994; Weltzin and McPherson, 1997; Lehmann et al., 1998; Fernandez et al., 2008). Weltzin and McPherson (1997) used stable isotope analysis to partition water use of trees and bunchgrasses in an Arizona temperate savannah and found that mature oaks obtain the majority of water from a depth greater than 50 cm. Fernandez et al. (2008) compared water use of 20-yr-old ponderosa pines (*Pinus ponderosa* Laws.) and understory grasses within a semi-arid silvopasture (350 trees ha^{-1}) in Patagonia. During spring and autumn, 90% of water consumed by silvopasture grasses originated from upper soil layers (0 to 20cm), while 80% of water utilized by silvopasture pines came from deeper soil layers. In contrast, monoculture trees measured in the spring were found to use 75% of water resources from the upper layers of the soil. There is a certain degree of competition over water resources in silvopastures, since trees acquire 20% of their water from the rooting zone of grasses (Fernandez et al., 2008). This zone of resource sharing may negatively impact grass productivity in the summer, when periods of very low water content in upper soil layers are frequent and roots must acquire moisture from deeper in the profile. Grass utilization of water in the upper soil layer decreased by 75% in the summer season, indicating a higher level of competition between trees and forages (Fernandez et al., 2008).

Although it is difficult to separate belowground competition over water from that over nutrients, competitive interactions involving water are considered the most influential forces driving productivity in silvopasture systems (Jose et al., 2004). Water stress can cause large reductions in plant height and leaf area of crop plants in agroforestry systems (Jose et al., 2004). Understory crops can be negatively impacted by competition with trees over water resources during dry summer months (Schroth, 1995; Jose et al., 2000a; Wanvestraut et al., 2004). In New Zealand, evapotranspiration rates of newly established radiata pine silvopastures equaled to those of open pastures for the first three or four growing seasons, but this balance subsequently declined in favor of pine trees (Pollock et al., 2009). By the end of the fifth summer, soil moisture deficits were sufficiently large to require slightly higher-than-normal winter rainfall to recharge the soil to field capacity before the next summer (Pollock et al., 2009).

Belowground interaction involving nutrients

The overall influence of trees on the nutrient dynamics of a unit area of silvopasture is the summation of individual tree influence patterns (Rhoades, 1997). Generally, trees improve soil fertility via the addition of organic matter from decaying roots and litter. Although leaf litter provides significant nutrient inputs, root sloughing and decomposition released of N and P are faster (39% and 30%) than from litter decay (Jose et al.., 2000b). Net mineralized N in soils and the nutrient's uptake by forages is greater beneath trees than in open pastures (Menezes et al., 2002), and soil nutrient content and cation exchange capacity vary with radial distance away from an individual tree (Zinke, 1962).

Since nutrient acquisition by trees and crops is often temporally and spatially partitioned, competition for mineral nutrients is minimal (Jose et al., 2000b). Deep-rooted trees obtain nutrients from soil regions below the rooting zones of crop species, incorporate them into above-ground biomass, and eventually make them available to crops via litterfall (Ong et al., 1991; Schroth, 1995; Allen et al., 2004). Thus, trees increase the efficiency of nutrient use, improve nutrient cycling, and retain nutrients within the system for longer periods of time (Nair and Graetz, 2004). For example, in a 47-yr-old pecan and cotton (*Gossypium hirsutum* L.) alleycropping system (18.3-m × 18.3-m tee spacing), N losses from plots containing freely rooting trees were less than from plots containing barriers separating tree roots from the alleyways (Allen et al., 2004). Soil N concentrations in non-barrier treatments were uniform, but barrier treatments increased N concentrations below the rooting zones of cotton (60-cm depth and below). Non-barrier treatments reduced N leaching losses by 64% (Allen et al., 2004).

Tree nutrition and growth rates benefit from nutrient management strategies typically used in forage production systems (Nair and Graetz, 2004). Trees also demonstrate improved nutritional status in unfertilized pastures that incorporate leguminous forage species as a source of N. Walnut seedlings intercropped with alfalfa (*Medicago sativa* L.) had higher foliar N content when compared to seedlings intercropped with tall fescue (Dupraz et al., 1999). Walnuts in mixed legume stands had elevated levels of foliar N at the same time unmanaged control treatments showed signs of N deficiency such as a yellowing of the leaves (Dupraz et al., 1999).

Nutrient tranfer from animals to trees (via urine and feces) may be a benefit associated with grazing livestock in silvopastures. However, these transfers may be sporadic and hard to quantify (Clason and Sharrow, 2000) given animal grazing and deposition patterns on the landscape. No studies were found that quantify nutrient transfer via manures from livestock grazing within silvopastures. However, a few studies have examined tree growth responses to large, uniform applications of manure in silvopastures. Blazier et al. (2008) found that 16- to 20-yr-old loblolly pines (247 trees ha^{-1}) growing in bahiagrass and subterranean clover (*Trifolium subterraneum* L.) responded well to pasture poultry litter applications. The mean basal area growth of pines was 10% greater in pastures receiving 10 Mg litter ha^{-1} as compared to trees growing in unfertilized pastures and pastures treated with inorganic fertilizers (114, 39, and 20 kg ha^{-1} of N, P, and K).

Livestock within silvopastures

Overall livestock performance within silvopastures depends on the yield and quality of available forage as well as animal comfort. Generally, newly-established hardwood and conifer trees have little impact on pasture composition and forage quality; therefore livestock performance may not be affected by the presence of saplings (Sharrow, 1991; Fike et al. 2004). Simmental cow-calf pairs in a 1-yr-old mixed hardwood silvopasture (12-m × 12-m tree spacing) had similar performance to that of cow-calf pairs in open pastures (Lehmkuhler et al., 2003). Similar animal performance also was noted in young pine-walnut silvopastures (Kallenbach et al., 2006). Crossbred beef heifers grazed annual ryegrass (*Lolium multiflorum* Lam.) and cereal rye (*Secale cereale* L.) mixtures in open pastures or under 6- to 7-yr-old black walnut and hybrid pitch pine (*P.rigida* Mill.) × loblolly pine trees planted in 3-m × 9.1-m spacings. Although open pastures yielded an average 20% more forage over two years, heifer average daily gain and gain ha^{-1} were equal for both treatments. Improved forage quality within silvopasture treatments and protection from temperature extremes afforded by tree canopies may have mitigated the effects of lower cumulative forage production (Kallenbach et al., 2006).

As trees grow, demand for above- and below-ground resources increases, but only a few studies have focused on animal performance within mature silvopastures in temperate regions, and most of those reports have involved livestock production beneath conifers. Hawke et al. (1993) compared the performance of young sheep grazing 13- to15-yr-old radiata pine silvopastures under various planting densities. Satisfactory mean live weight gains (155 g $sheep^{-1}$ day^{-1}) were achieved at a tree spacing of 50 stems ha^{-1} and weight gains decreased with increasing tree density. In Northern Ireland, satisfactory gains (8 to 11 kg $season^{-1}$) were achieved when 6 lambs ha^{-1} grazed forages beneath a 9- to 10-yr-old Sitka spruce (*Picea sitchensis* (Bong.) Carr.) plantation with 2-m × 2-m tree spacing (Adams, 1986). However, animal performance declined to 4 to 6 kg $season^{-1}$ upon canopy closure due to substantially less forage availability (Adams, 1986). Reduced forage production was most likely caused by low light availability associated with dense tree spacing. In systems managed for trees, stocking rates should be reduced. For example, in Louisiana, a stocking rate of 0.10 grazing units ha^{-1} was recommended for pastures beneath maturing pine plantations with a basal area of 18.5 m^2 ha^{-1} (Clason and Sharrow, 2000). Such declines in pasture production and reduced livestock carrying capacity should be viewed in light of the increasing value of the maturing tree crop.

Even though production may decline as trees mature, this may be offset in part by the ability of trees to buffer the environment for livestock (Kallenbach et al., 2006). In subtropical and warm, temperate regions, livestock grazing within silvopastures may benefit greatly from the shade provided by tree canopies. Shade increases animal comfort and trees within silvopastures can provide shade uniformly throughout the grazing area. During times of extremely high ambient temperatures (>30°C) and light intensity, cattle without access to shade have significantly higher body temperatures, experience higher respiration rates, spend less time grazing, reduce intake, have more aggressive behavior, and demonstrate poor daily weight gains (Cartwright, 1955; Mitloehner and Laube, 2003; Kendall et al., 2006; Schütz et al., 2010).

Provision of shade has improved animal performance in many studies (McDaniel and Roark, 1956; McIlvan and Sloop, 1971; Roman-Ponce et al., 1977; Karki and Goodman, 2010). In Florida, lactating dairy cows with access to shade produced 11% greater milk yields (16.6 kg day^{-1}) than those without shade (15.0 kg day^{-1}) and had 43% greater conception rates (Roman-Ponce et al., 1977). McIlvan and Sloop (1971) found that Hereford steers grazing in Oklahoma rangeland with access to artificial shade out-gained steers without shade by an average of 8.6 kg steer^{-1}. Shade reduced the occurrence of spot gazing in open areas and was nearly as effective as water location in promoting more uniform grazing of pastures. Karki and Goodman (2010) reported that cattle utilized pastures more evenly in a loblolly pine-bahiagrass silvopasture versus open-pasture.

In more northern regions, protecting animals from wind chill and snow drift is of more concern for livestock managers. Extremely cold temperatures cause animals to divert dietary energy away from productive functions to generate heat and maintain critical body temperatures (Young, 1983; Webster, 1970). Livestock encountering long-term exposure to extreme cold and wind spend less time grazing and have reduced forage intake, feed-use efficiency, and weight gain (Malechek and Smith, 1976; Young, 1983; Adams et al., 1986). Karki and Goodman (2010) found that wind speeds were 29 - 58% lower in a 20yr-old loblolly pine silvopasture versus open-pasture systems. Properly positioned trees and shrubs can reduce wind speed and may protect livestock from extreme temperatures caused by high winds (Garrett et al, 2004). Sufficient wind protection reduces the direct effects of cold and increases the average daily gain and feed efficiency of livestock (Webster, 1970; Brandle and Hodges, 2000).

Livestock influence on soils, trees, and pastures

The presence of livestock within silvopastures can alter soil quality. Animal hoof impact can directly compact soil surface layers, leading to the collapse of large soil pores, formation of smaller pores, an increase of soil bulk density, and a reduction of infiltration rates. Nevertheless, light to moderate grazing on well-drained pastures generally has little effect on long-term soil compaction (Greenwood and McKenzie, 2001). Increased forage production and tree leaf litter decomposition within silvopastures may compensate for the effects of trampling through increases in soil organic matter (Sharrow and Ismail, 2004; Tate et al., 2004). However, as the interactions among silvopasture components are highly complex, net effects on soil physical properties are difficult to predict (Sharrow, 2007).

Given that livestock trampling alters soil physical properties, it may also influence forage and tree productivity within silvopastures. Grazing had no effect on slash pine (*P. elliottii* Engelm) tree form, growth rates, or wood quality compared with trees in ungrazed plots (Cutter et al., 1999). Sharrow (2007) investigated the effect of livestock trampling on soil compaction within Douglas fir (*Pseudotsuga menziesii*)/subclover silvopastures (2.5-m x 4-m spacing) in Oregon. After 11 years of moderate grazing, soils within silvopastures had 13% higher bulk density, 7% lower total porosity, and 38% less water infiltration than ungrazed Douglas fir forestland. Despite reductions in soil quality, trees within silvopastures had similar growth rates to those within ungrazed forest. Grazing was then ceased for two years and soil infiltration rates quickly increased to 90% more than infiltration rates measured at the end of the 11-year grazing period (Sharrow, 2007).

Negative impacts of cattle on soils may be reduced by proper grazing management. Rotational stocking is generally recommended within silvopastures (Garrett et al., 2004). Although such management may not increase daily gains of livestock, rotational stocking can reduce soil disturbance around trees and increase forage production and quality when compared to continuously stocked silvopasture systems (Lehmkuhler et al., 1999; Jacobo et al., 2006).

Silvopasture Establishment

Silvopastures can be created by thinning existing woodlots to accommodate the planting of forages. Timber stand improvement techniques relieve competitive interactions in young forest stands, improve growth rates of valued trees retained within the system, and increase understory light levels (Garrett et al., 2004). Removing 43% and 77% of basal area in a hardwood forest increased understory light intensities 35% and 65% respectively (Dey and Parker, 1996); a range which may be sufficient for forage production. Individual forest trees may vary in their ability to meet a land manager’s expectations and logging activities may damage up to a third of residual stands (Garrett et al., 2004).

Planting trees into established pastures gives land managers complete control over tree species composition and allows inclusion of improved varieties of multi-purpose trees. However, transplanting seedlings into pasture sods may slow rates of tree growth and establishment due to competition for light, water, and nutrients (Schroth, 1995). Thus, fertilization and the control of grass growth around seedlings is generally recommended for tree planting in established pastures (Benfeldt et al., 2001 Garrett et al., 2004; Fike et al., 2004). Mulching and herbicide applications to control grass growth significantly increased walnut and honeylocust seedling stem volume when compared to untreated control plots in southwest Virginia (Bendfeldt et al., 2001).

In addition to direct competition for resources, many forage species suppress sapling growth via the production of allelopathic chemicals (Walters and Gilmore, 1976). In a greenhouse experiment, black locust (*Robinia pseudoacacia* L.) seedling growth was inhibited by additions of dried, ground alfalfa, birdsfoot trefoil (*Lotus corniculatus* L.), tall fescue, and bluegrass (*Poa pratensis* L.), but was stimulated by dried red clover (*Trifolium pratense* L.) (Larson and Patel, 1992). Since all environmental conditions were held constant and resources were non-limiting, tree growth decline was attributed to allelopathy.

During establishment, young trees need protection from trampling and browsing by livestock and wildlife. Lehmkuhler et al. (2003) tested a variety of tree protection methods when establishing a hardwood silvopasture in Missouri. A single strand of electrified poly-wire was sufficient for protecting saplings from Simmental cow-calf pairs (Lehmkuhler et al., 2003). Other effective protection techniques include poultry wire cages, plastic tube shelters, electrified fencing, and/or the removal of livestock during establishment (Bendfeldt et al., 2001; Fike et al. 2004).

Honeylocust Silvopasture

Honeylocust trees have gained particular interest for silvopasture systems. Honeylocust's advantages within temperate silvopasture systems include a relatively fast growth rate, as well as morphological and phenological characteristics that compliment cool-season grass production.

In addition, the species stabilizes soil, improves nutrient capture and cycling, and produces high quality fodder and shade for livestock (Smith, 1950; Wilson, 1991; Gold and Hanover, 1993). Honeylocust browse is highly palatable, and the trees produce edible seedpods that livestock can consume after pod drop over the course of several months in autumn and winter. Silvopastoral designs incorporating honeylocust include widely-spaced “fodder orchards,” where pods function primarily as an animal feed supplement (Gold and Hanover 1993).

Habitat

Honeylocust is a leguminous hardwood native to the central and eastern United States; its natural range stretches from southwest Georgia to New England (Figure 2.1; Fowells, 1965). Honeylocust has been successfully naturalized to many regions outside of its native range and it is widely used as an ornamental tree in urban landscapes. Due to its agroforesty potential, it is also grown throughout Europe, Central Asia, India, South Africa, and New Zealand.

Honeylocust tolerates climates with temperatures as low as -34°C and annual precipitation as low as 51 cm (Wilson, 1991). In its natural range, honeylocust trees are commonly found in alluvial flood plains and bottom lands, but the species tolerates a broad range of soils (Fowells 1965; Seibert 1986; Gold and Hanover 1993). Due in part to a relatively low water demand, honeylocust can tolerate both drought and salinity and can thus grow on many types of marginal or degraded lands (Detwiler 1947, Gold and Hanover 1993; Roberts and Schnipke 1994).

Morphology, phenology, and growth characteristics

The honeylocust tree has many morphological characteristics considered advantageous for silvopasture systems. It has a deep, penetrating taproot that may extend 3 to 6 meters into the subsoil (Fowells, 1965). This allows nutrient capture from deeper regions of the soil and minimizes competition between trees and forages at the soil surface (Schroth, 1995; Fernandez et al., 2008). Honeylocust also has an open stem form and pinnate leaf structure; both allow sufficient light to penetrate the tree canopy and facilitate cool-season forage growth (Wilson, 1991; Clason and Sharrow, 2000). In contrast with large leaves from other deciduous trees, leaves from honeylocust are less likely to create a physical barrier for light to penetrate to the forage canopy upon leaf drop. The tree's small, brittle leaflets can pass through the forage canopy and break down rapidly upon reaching the ground. Trunks of wild honeylocust trees can produce branched thorns that may pose a danger to livestock, but several thornless varieties of honeylocust have been successfully propagated (Chase, 1947). Eliminating thorns, however, may increase investments required in tree protection.

Honeylocust leafs out in late spring and drops leaves early in the fall. Such phenology compliments the production of cool-season grasses by minimizing competition for light in spring and fall, when grass growth rates are greatest (Clason and Sharrow, 2000). Shade and evaporative cooling from the canopy during the summer may also reduce stress to forages at a time when temperatures exceed the optimum (24°C) for cool-season grass growth (Sprague 1943).

In favorable growing conditions, honeylocust has a relatively fast growth rate. Scanlon (1980) reported average growth rates of around 45.7 cm yr^{-1} in height and 0.7 to 1.3 cm in diameter for honeylocusts in the Tennessee Valley. In the same study, mature free-growth honeylocust trees reached heights of 12 to 15 m (Scanlon, 1980). Slower growth rates are expected in marginal areas and more northern regions.

Forage production in honeylocust silvopastures

Incorporating honeylocust trees into pasture systems may increase the yield and quality of understory forages when compared to open pasture systems (Smith, 1950; Buergler et al., 2005). Buergler et al. (2005, 2006) found that forage plots under young (7- and 8-yr-old), moderately-spaced honeylocust trees yielded about 16% more forage (6130 vs. 5280 kg ha^{-1}) and had greater Ca, P, and CP concentrations than plots under widely-spaced trees. Le Roux (1959a) did not report an increase of forage yield or quality, but observed that honeylocust grown in irrigated croplands (tree spacing and age not known) had no adverse effect on oat and sudangrass crops within alleyways.

Forage yield and nutritive value are functions of climate, soil quality, grazing management, and the design and arrangement of system components. Zarger and Lutz (1961) conducted a 17-year study at Virginia Tech to determine the effects of honeylocust trees on pastures. Honeylocusts (cv ‘Millwood’) spaced at 54 trees per acre decreased yields in unfertilized pastures by 9%. The authors suggested that the decline in production was the result of high tree density and poorly managed livestock. Conversely, at the Auburn experiment station in Alabama, Moore (1948) observed that a spacing of 80 trees ha^{-1} or more achieved high forage productivity. Sericia lespedeza (*Lespedeza cuneata* L.) hay yielded around 6,268 kg ha^{-1} yr^{-1} over 5 yr under a stand of young honeylocust trees (Moore, 1948). These conflicting results indicate the challenge facing land managers to both properly control livestock and to maintain tree spacing wide enough to allow sufficient sunlight through the canopy for forage production.

Improved varieties

In addition to potential beneficial interactions with forages, honeylocust offers farm managers the opportunity to capture additional harvestable products. Coppiced honeylocust trees provide highly palatable browse for livestock (Baertsche et al., 1986). Further, the trees' seed pods ripen and fall as early as mid-September, providing a supplemental source of protein and energy for grazing livestock. Pod drop can extend into mid to late winter; a time in which cool-season grass production is negligible (Fowells, 1965).

Efforts to propagate honeylocust varieties that bear pods with high sugar content and produce high pod yields began in 1926 by the American Genetic Association (Chase, 1949). The Tennessee Valley Authority (TVA) began exploring improved varieties as a potential source of cattle feed in 1934. Millwood, and 'Calhoun,' the first two distinct improved cultivars, were selected through TVA efforts (Scanlon, 1980). These originally thorny selections were propagated by grafting thornless scion wood from parent trees, which in turn produced thornless daughter clones (Moore, 1948; Chase, 1949). Thus, thornless, high-sugar honeylocust cultivars provide land managers the ability to optimize the beneficial services of honeylocust while reducing its limitations.

Today, select cultivars are generally propagated with common nursery budding and grafting techniques (Gold and Hanover, 1993). Root-stock propagation has since been recognized as the most effective way to generate large numbers of improved honeylocust trees (Scanlon, 1980). Some of the most common improved honeylocust cultivars within the United States include Millwood, Calhoun, 'Hershey', and 'Ashworth.'

Pod production

Improved honeylocust varieties may produce considerably high pod yields; however, few studies have focused on the long-term yield characteristics of improved varieties. In a 5-year pod production study in Alabama, 5- to 10-yr-old Millwood and Calhoun cultivars yielded an average of 32.9 kg of pods per tree (Table 2.1), however it is unclear whether or not these figures are on a dry matter basis (Moore, 1948). Older trees produced as much as 81.6 kg of pods yr^{-1}. Calhoun yielded considerably lower pod weights per tree (14.4 kg yr^{-1}). Determining the 5-year average yields in this study was complicated by honeylocust's alternate bearing pattern, in which pod production is highly irregular from year to year (Moore, 1948; Gold and Hanover, 1993). Despite year-to-year yield variation, Moore (1948) estimated that 86 trees ha^{-1} could produce average annual yields equivalent to 227 bushels ha^{-1} of oats, while farm managers also would receive the benefit of harvesting livestock or hay crops from the understory.

Alternate bearing pattern

Honeylocust's irregular fruiting from year-to-year, or alternate bearing pattern, is a commonly occurring phenomenon in many fruit, nut, and mast producing trees. More well-known, economically and ecologically valuable tree species that display alternate bearing include oak (*Quercus* L.), beech (*Fagus* L.), apple (*Malus* Mill.), pear (*Pyrus* L.), avacoado (*Persea* Mill.), walnut (*Juglans* L.), citrus (*Citrus* L.), and pistachio (*Pistacia vera* L.) (Hodgson and Cameron, 1935; Jonkers, 1979; Dennis and Neilsen, 1993; Crawley and Long, 1995; Rosecrance et al., 1998; Hilton and Packham, 1997; Maeto, K. and K. Ozaki. 2003; Bukovac et al. 2010). Patterns within most species are generally biennial, where high yielding years are immediately followed by low yielding years.

The exact cause of alternate bearing pattern is not known, but research suggests it may be the result of several species-specific and environmental factors. One prevalent theory proposes that bearing patterns are an evolutionary adaptation that facilitates the satiation of seed-feeding animals in years of peak seed production, and thus increases the probability of seedling recruitment in subsequent years (Crawley and Long, 1995). Some studies focusing citrus and apple production suggest that seeds in high yielding years can be sources for hormone compounds (gibberellins) that inhibit flowering in low yielding years (Jonkers, 1979; Dennis and Neilsen, 1993). However, yield irregularities may also be the result of resource limitations. Rosecrance et al. (1998) studied acquisition, storage, and use of nutrients in an alternately bearing variety of pistachio. Results suggest that pistachios store carbohydrates and nutrients in the vegetative plant body during low-yielding years, and use these stored nutrients for reproductive growth during the subsequent high-yielding year (Rosecrance et al., 1998). Assessment of internal regulation of fruiting patterns is complicated by seasonal fluctuations in temperature, light, and water (Hodgson and Cameron, 1935; Jonkers, 1979). It is likely that alternate bearing is the result of genetic influences as well as local environmental conditions. Several strategies, such as pruning, girdling, nutrient management, and breeding programs, are utilized in fruit/nut orchards to adjust bearing patterns; however yield responses to these techniques are species-specific (Jonkers, 1979; Davie et al., 1995). Studies focusing on honeylocust pod yields, such as Moore (1948) and Papanastasis et al. (1999), show the tree’s tendency to alternately bear, however there is no reported evidence concerning the genetic or environmental causes of such patterns.

Pod nutritive value

Seedpods from improved honeylocust varieties contain elevated non-structural carbohydrate levels relative to pods from wild honeylocust trees. Millwood pods may have sugar concentrations as high as 36.8% and Calhoun pods as high as 38% (Detwiler, 1947; Moore, 1948). Pod sugar content varies geographically; trees in southern regions of the United States have the highest sugar levels, due to more favorable growing conditions (Detwiler 1947). Chemical analyses of pods harvested from the original Millwood tree (Table 2.2) indicate the whole seedpods contain approximately 10.2% CP and 14.2% crude fiber (Scanlon, 1980). Papanastasis et al. (1999) found that Millwoods grown in southern France had pod CP concentrations as high as 12.3%. Pod dry matter digestibility measured 67.7% and neutral and acid detergent fibers were found to be 44.0% and 25.6%, respectively (Table 2.3). Freedman (1980) reported that the nutrient composition, total digestible nutrients, fiber, and CP fractions of fermented honeylocust pods were comparable to that of alfalfa hay (Table 2.4).

In 1939, the University of Tennessee compared the feed value of honeylocust pods to that of corn (*Zea mays* L.) in a 77-d feeding trial with calves. Although not statistically significant, weight gain of calves fed honeylocust pod meal was 82% of that for calves fed corn meal (Scanlon, 1980). In a second test, laboratory rats gained 85% as much weight as rats fed corn meal (Scanlon, 1980). Both tests used pods harvested from common honeylocust trees, thus it is probable that improved varieties could support greater gains and feed efficiency. For instance, Gold and Hanover (1993) cited a 2-year feed study from the Alabama Experiment Station, in which ground pods from improved honeylocust varieties were successfully substituted 1:1 for oats in a dairy ration. More recently, Foroughbakhch et al. (2008) conducted 4-week feeding trials in which six castrated rams were fed a daily ration of 1.4 kg of whole seedpods from improved honeylocust cultivars, as well as an alfalfa supplement. Averaged over two years, sheep gained 157 g day^{-1} and by the end of the study sheep had developed a preference for pods over alfalfa (Papanastasis et al., 1999; Foroughbakhch et al., 2008).

Seed nutritive value

About five percent of the honeylocust pod by weight is digestible protein and a significant proportion is contained within the seed. Chemical analysis indicated Millwood seeds have nearly 29% CP (Table 2.2; Scanlon, 1980). Other studies examining the protein and amino acid composition of honeylocust seeds have suggested that they are similar in nutritive value to soybeans (Bagley, 1981).

Although honeylocust seeds have excellent nutritional profile, their utility as a feed varies by livestock species. Cattle (*Bos taurus*) cannot digest whole honeylocust seeds, likely because they lack the upper teeth needed to crack the hard seed coat (Wilson, 1991). Sheep (*Ovis ares*), however, can digest honeylocust seeds (leRoux, 1959b; Small, 1983; Foroughbakhch et al., 2007), and apparent digestibilities of 75 to 90% have been reported (Small, 1983). Foroughbakhch et al. (2007) tested the *in vivo* digestibility of seeds from four honeylocust varieties using Merino sheep fed a standard diet. Across varieties, apparent digestibility of seeds averaged 76%. Despite high potential digestibility, a great deal of variability existed at the animal level (Foroughbakhch et al., 2007).

Establishment

Control of grass growth and fertilization around seedlings is generally recommended when planting trees in established pastures (Fike et al., 2004; Garrett et al., 2004). Transplanting honeylocust seedlings into pasture sods may slow rates of tree growth and establishment, due to competition for light, water, and nutrients (Schroth, 1995). Only a few studies have specifically focused on honeylocust establishment within pastures and results are variable. Both mulching and herbicide application to control grasses increased seedling stem diameter, but fertilizer treatments had no effect on height or stem volume (Bendfeldt et al., 2001). Conversely, Khatamian et al. (1984) reported that turf clearing did not increase growth of honeylocust bare-root seedlings, but that nitrogen application increased tree diameter.

During establishment, honeylocust trees need physical protection from livestock and wildlife. Browse damage is a particular concern when planting high-sugar varieties because the trees are very palatable. Seedling biomass is greater than 20% digestible CP (Baertsche et al. 1986), and deer (*Odocoileus virginianus*) selectively browse the foliage and bark of unprotected Millwood cultivars vs. wildtype honeylocusts (Benfeldt et al., 2001). Both 60-cm-tall poultry-wire cages and 2.2-m-tall plastic tube shelters successfully prevented damage caused by deer and groundhogs (*Marmota monax*) browsing (Bendfeldt et al., 2001).

Management

Little is known about the active management or economics of honeylocust production in silvopastures, as both farmer participation and long-term research are lacking. It is likely that land managers would allow pods to fall without intervention and livestock would consume pods freely from the ground. However, mechanical harvesting of pods may be considered valuable for some land managers, particularly if the pods have alternative uses such as ethanol production (Bagley, 1981). Such management may be complicated by honeylocust’s pattern of pod drop, which occurs over an extended period of time (Bagley, 1981). Potential exists to harvest pods with tree-shaking machines and conventional haying equipment (Seibert, et al, 1986). LeRoux (1959a) noted that dry pods of common honeylocust can be stored in dry conditions for many years with minimum decay.

Black Walnut Silvopasture

Black walnut is considered one of the most advantageous tree species for silvopasture systems. In addition to stabilizing soil, improving nutrient capture and cycling, and providing shade for livestock, walnut trees generate high-value products (Clason and Sharrow, 2000). Black walnut is the most valuable timber species in the United States; the trees produce flavorful nut meats, and the crushed nut shells are often used as an industrial abrasive (Kurtz et al., 1984; Garrett and Harper, 1999). Thus black walnut has a great potential for offering a variety of short- and long-term income sources for land managers.

Black walnut's growth patterns and morphology are highly compatible with cool season forage production in silvopasture systems. It has a deep, penetrating taproot that may extend more than 2 to 3 m into the subsoil (Garrett and Harper, 1999). This morphology allows nutrient capture from the subsoil and minimizes competition between trees and forages at the soil surface (Schroth, 1995; Fernandez et al., 2008). Black walnut also has an open canopy and pinnate leaf structure; both features allow light to penetrate the tree canopy and facilitate cool-season forage growth (Clason and Sharrow, 2000). Black walnut trees can create favorable microclimates for forage growth, and production under black walnuts can be greater than in open pasture systems (Smith, 1942; Buergler et al., 2005). Conversely, walnut tree growth can benefit from associations with compatible understory crops (Cabanettes et al., 1999; Chifflot et al., 2006).

Site quality factors influencing black walnut growth

Naturally occurring black walnut is found throughout the eastern United States (Figure 2.2). Its native range stretches as far north as southern Michigan and southern New England, and as far south as eastern Texas and northern Florida (Fowells, 1965). A minor component of natural forest stands, walnut trees grow best along stream banks and on the lower portion of north or east facing slopes (Fowells, 1965; Ponder, 2004). However, black walnut has been grown successfully on a variety of sites outside of its native range and performs well on intensively managed agricultural soils (Garrett and Harper, 1999).

A variety of biotic and abiotic factors influence walnut timber quality and nut production. These factors must be understood by land managers prior to utilizing black walnut for agroforestry practices. Because black walnuts are highly site sensitive, trees should be planted on the most suitable sites when incorporated into silvopastures (Garrett and Harper, 1999).

Soil depth is one of the largest influences on black walnut productivity (Auten, 1945; Geyer et al., 1980; Kalisz et al., 1989). Geyer and Ponder (2004) studied relationships between various site quality factors and the growth of native black walnut stands in Kansas. The largest simple correlation of site index was with soil depth to a restrictive layer ($r = +0.85$). A rooting depth of 1 to 1.5 meters is often necessary for optimal growth (Ponder, 2004). Walnuts growing on soils with rooting depths less than 1 meter (Figure 2.3) often exhibit dramatically slower growth rates (Reid et al., 2007).

Many studies have also found that soil texture has a significant effect on the growth of black walnut (Auten, 1945; Geyer et al., 1980; Kalisz et al., 1989; Schultz and DeLoach, 2004). Black walnut often prefers medium to fine textured soils such as loams, sandy clay loams, or silt loams (Table 1) (Fowells, 1965; Ponder, 2004). In a Kansas study, site quality for black walnut increased as silt percentage increased, while increased clay content frequently was detrimental to tree growth (Geyer et al., 1980). In Kentucky, seventy-five percent of the soils deemed questionable for black walnut were limited by the presence of a clayey subsoil (Kalisz et al., 1989). Remaining soil limitations included shallowness to bedrock (10%) imperfect drainage (10%), and the presence of a fragipan (5%) (Kalisz et al., 1989).

Topography can also influence the growth of black walnut. Walnuts growing on concave upper slopes have shallower rooting depth and reduced access to moisture (Jones and Saviello, 1991). Slopes of 10% or more decrease the site index (base age 50 years) of black walnut by at least 1.3 m (Geyer et al., 1980). Sites with slopes greater than 30% are considered unsuitable for walnut production (Table 2.4) (Ponder, 2004). As with most hardwoods, walnut trees tend to be more productive on north or east facing slopes (Fowells, 1965) largely because trees located on south and west facing slopes are often subjected to drier, harsher conditions due to intense solar radiation (Jones and Saviello, 1991).

Most factors influencing black walnut growth are related – whether directly or indirectly – to the availability of moisture. Deep soils with low clay and high silt content hold more water and have more space for root development (Geyer and Ponder, 2004). Slope directs the movement of water through the landscape and aspect influences soil temperature and plant transpiration rates (Jones and Saviello, 1991). Water availability is essential, given that most of black walnut’s root structure occupies the upper 60 cm (2 feet) of the soil profile and evapotranspiration often draws available moisture from this region during the growing season (Pham et al., 1978; Lucier and Hinckley, 1982). Black walnut does not tolerate excessively dry conditions and responds to drought by initiating stomata closure and restricting photosynthesis (Lucier and Hinckley, 1982). Thus, black walnut growing on shallow soils with low levels of moisture in surface layers will likely experience slower growth rates (Auten, 1945; Geyer et al., 1980; Kalisz et al., 1989).

Nut productivity

Land managers utilizing black walnut in agroforestry systems must consider alternative approaches to managing this multi-purpose tree. Conventional methods of black walnut management emphasize tall, straight trees that are grown close together so as to maximize the clear length of a walnut log (Kurtz et al., 1984). However, walnuts planted close together often experience canopy crowding and a loss of lower limbs due to shading effects, which can dramatically decrease nut production and quality (Reid et al., 2007). In contrast, walnut trees managed for nut production are spaced widely and as a result have shorter boles, broad-spreading branches, and a full canopy (Reid et al., 2007). Financial analyses of black walnut agroforestry systems in Missouri suggested internal rates of return and net present worth are maximized by sacrificing log length for greater crown area (Garrett and Harper, 1999). However, many land managers seek a compromise by facilitating the dual production of nuts and timber to improve cash flow in the short-term and obtain a high-value timber product for the long-term (Kurtz et al., 1984). To achieve such goals, it is recommended that trees be pruned to accommodate a 3-m bole and planted on a 12-m x 3-m spacing to encourage development of large crowns, while providing for selection gain (Kurtz et al., 1984).

Nut production of black walnut is extremely variable (both within and among stands), and the full nut bearing potential is not known (Zarger, 1946; Reid et al., 2007). Ares and Brauer (2004) studied nut production of 54 wild and improved black walnut stands in various stages of management and stand densities. Estimated yields ranged from 0 to 1370 kg ha^{-1} of dried, hulled nuts. However, little research exists related to nut production within actively managed black walnut agroforestry systems. In Missouri, Jones et al. (1995) studied various agroforestry systems that incorporated wild, genetically-nondescript black walnut trees. The 934 trees in the study were planted on a medium quality site (site index of 18 m) in 12-m × 6-m spacing and ranged in age from 7 to 15 years. On average, 80% produced fewer than 100 nuts tree^{-1} yr^{-1}, 2% produced over 200 nuts tree^{-1} yr^{-1}, and only three trees averaged more than 300 nuts tree^{-1} yr^{-1} (Jones et al. 1995).

Future agroforestry enterprises can improve such relatively low nut yields through the grafting of select, improved black walnut varieties. Cultivars vary in their capability to generate nuts annually, and many are selected for characteristics such as increased percent kernel within the nut and greater cracking quality (Reid et al., 2004). Many cultivars with high nut quality characteristics exhibit alternate-year nut bearing patterns, in which high yields in one year are followed by low yields in the subsequent year (Brauer et al., 2006). Heavy nut crops occur in intervals of two to three years (Garrett and Harper, 1999). Thus many years of data are needed to obtain a clear picture of average nut yields and account for alternate bearing patterns. Brauer et al. (2006) recommend that stand managers observe at least two years' worth of nut yields prior to selective thinning.

Fertilization and weed control are often recommended when managing walnuts for nut production (Reid et al., 2007). Black walnut responds best to improved nutrition at times when flower and fruit production draw heavily on stored carbohydrate reserves. Trees receiving late summer fertilization yielded 47% more nuts than those receiving spring fertilization (Jones et al., 1995). Weed control around the base of trees ensures maximum benefit from fertilizer applications and reduces competition for water resources. Garrett and Harper (1999) recommend the widths of control zones along tree rows should be a minimum of 1 m on both sides in agroforestry systems. Both mechanical and chemical controls of vegetation have proven successful in black walnut production (Garrett and Harper, 1999).

Forages within black walnut silvopastures

Due to the allelopathic effects associated with black walnut, the range of possible companion crops is limited. Black walnut leaves, stems, fruit hulls, and roots produce juglone, an allelopathic compound that inhibits the growth of a variety of vegetable and row crops (Ercisli et al., 2005; Scott and Sullivan, 2007). Most forage grasses are insensitive to juglone and growing forages for livestock is considered one of the most profitable practices in black walnut agroforestry (Scott and Sullivan, 2007). Cool-season grasses, such as Kentucky bluegrass, orchardgrass (*Dactylis glomerata* L.), and tall fescue are compatible with black walnut trees (Smith, 1942; Buergler et al., 2005; Houx et al., 2008). Legumes such as red clover and white clover (*Trifolium repens* L.) may also be successfully grown in walnut silvopastures or alley cropping systems, although production may be reduced (Brooks, 1951; Boes, 1986; Buergler et al., 2005). In a Missouri alley-cropping study, red clover and orchardgrass hay plots grown between 15- to 20-yr-old walnut trees (12-m × 3-m spacing) produced average yields of 6.3 Mg $ha^{-1}yr^{-1}$ over 5 years (Garrett and Harper, 1999).

In many cases, incorporating walnut trees into pasture systems has increased the yield and nutritive value of understory forages (Smith, 1942; Buergler et al., 2005; Houx et al., 2008). Buergler et al. (2005) found that yields of mixed cool-season pastures dominated by fescue were significantly greater under medium density black walnut stands (spacing of 3.7-m × 7.3-m and 7.3-m × 7.3-m) when compared to open pastures, although the trees were still quite young (7 and

8 yr old). Further, forages grown under black walnut and honeylocust trees had greater Ca, P, and CP concentrations when compared with open pastures, indicating forages under walnut had greater nutritive value (Buergler et al., 2006).

Other important forage legumes such as crimson clover (*Trifolium incarnatum* L.), sericea lespedeza and alfalfa, demonstrate a susceptibility to juglone through dramatically decreased yields (Rietveld, 1983; McGraw et al., 2008). McGraw et al. (2008) compared the yields of alfalfa in the alleyways of 20-yr-old black walnuts to open alfalfa production systems. Alfalfa yields increased linearly with distance from beneath the canopy to the center of alleyways and effects of juglone on yield could be observed to a distance of 11.5 m from the tree row. Parsing the effects of juglone from resource competition is difficult, however. Alfalfa's deep and extensive root structure occupies the rooting zone of black walnut, and yield reductions may be due to competition over water resources (McGraw et al., 2008) and reduced light at the forage canopy.

Competition with (and perhaps allelopathy from) understory forages can also influence the growth of black walnut. Tree heights of 26-yr-old black walnut stands growing within Kentucky blue grass had a site index 5 m greater than trees growing within tall fescue (Ares and Brauer, 2004). Walnuts intercropped with leguminous forages often have higher foliar N content than those intercropped with grasses, suggesting N transfer from legume to tree (Dupraz et al., 1999). However, deep-rooted perennial legumes may be more competitive with black walnut over water resources when compared to grasses, as noted above (Dupraz et al., 1999).

Conclusion

Incorporating actively-managed trees into pasture-based production systems, or silvopasture, may improve soil and water quality, increase biodiversity, and diversify farm incomes. Further, improved varieties of honeylocust and black walnut trees may provide land-managers the opportunity to harvest both short- and long-term tree-products, such as nuts, timber, and fodder for livestock. However, studies concerning the productivity and management of these two possibly valuable trees are needed to understand their potential within temperate silvopasture systems.

Table 2.1. Pod yields of 5- to 10-yr-old honeylocust trees collected from 1943 to 1947 (adapted from Scanlon, 1980).

	Age, years						Average
Variety	5	6	7	8	9	10	
	——— kg tree^{-1} ———						
Calhoun	12.0	0.0	14.7	29.0	10.0	20.9	14.4
Millwoood	26.5	0.0	66.3	17.9	81.7	5.4	33.0

Table 2.2. Chemical analysis of pods harvested from the original Millwood honeylocust tree (adapted from: Scanlon, 1980).

Constituents	Whole Seedpod	Pods	Seeds
	——— % ———		
Ash	3.75	3.82	10.23
Crude Fat	0.81	0.52	3.06
Crude Protein	10.15	8.21	28.74
Crude Fiber	14.19	13.81	11.02
Nitrogen-free extract	71.1	73.64	46.95
Glucose	2.86	3.32	–
Sucrose	29.12	32.22	–
Total Sugars	31.98	35.54	–

Table 2.3. Chemical composition and *in vitro* digestibility of Millwood pods and seeds (adapted from Papanastasis et al., 1999).

	Pods	Seeds
	——— % ———	
Dry Matter	90.7	90.2
In vitro Digestibility	67.7	94.7
Crude Protein	12.3	29.7
Neutral Detergent Fiber	44.0	29.2
Acid Detergent Fiber	25.6	13.4
Lignin	10.0	1.5

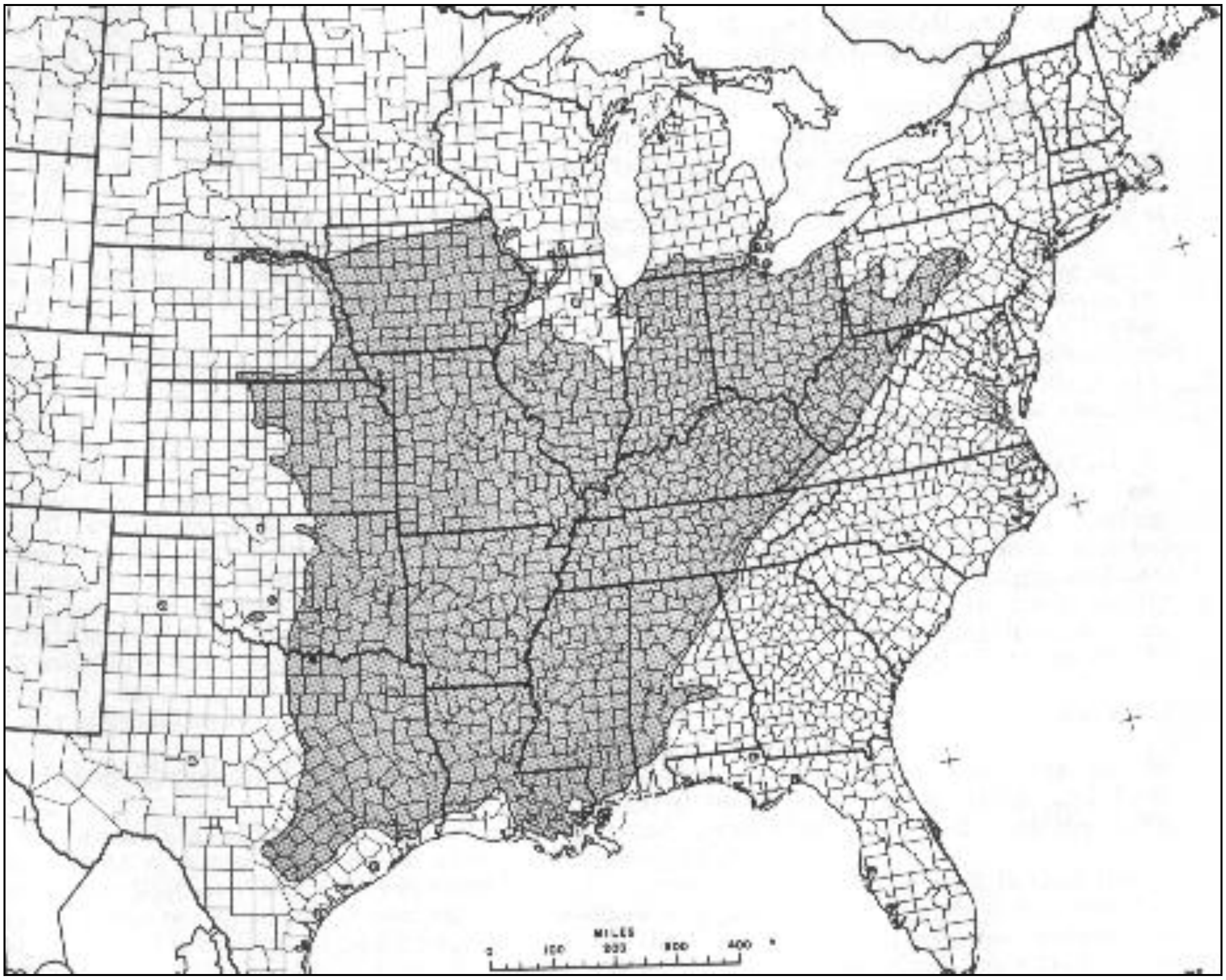

Figure 2.1. Natural range of the honeylocust tree (from: Fowells, 1965)

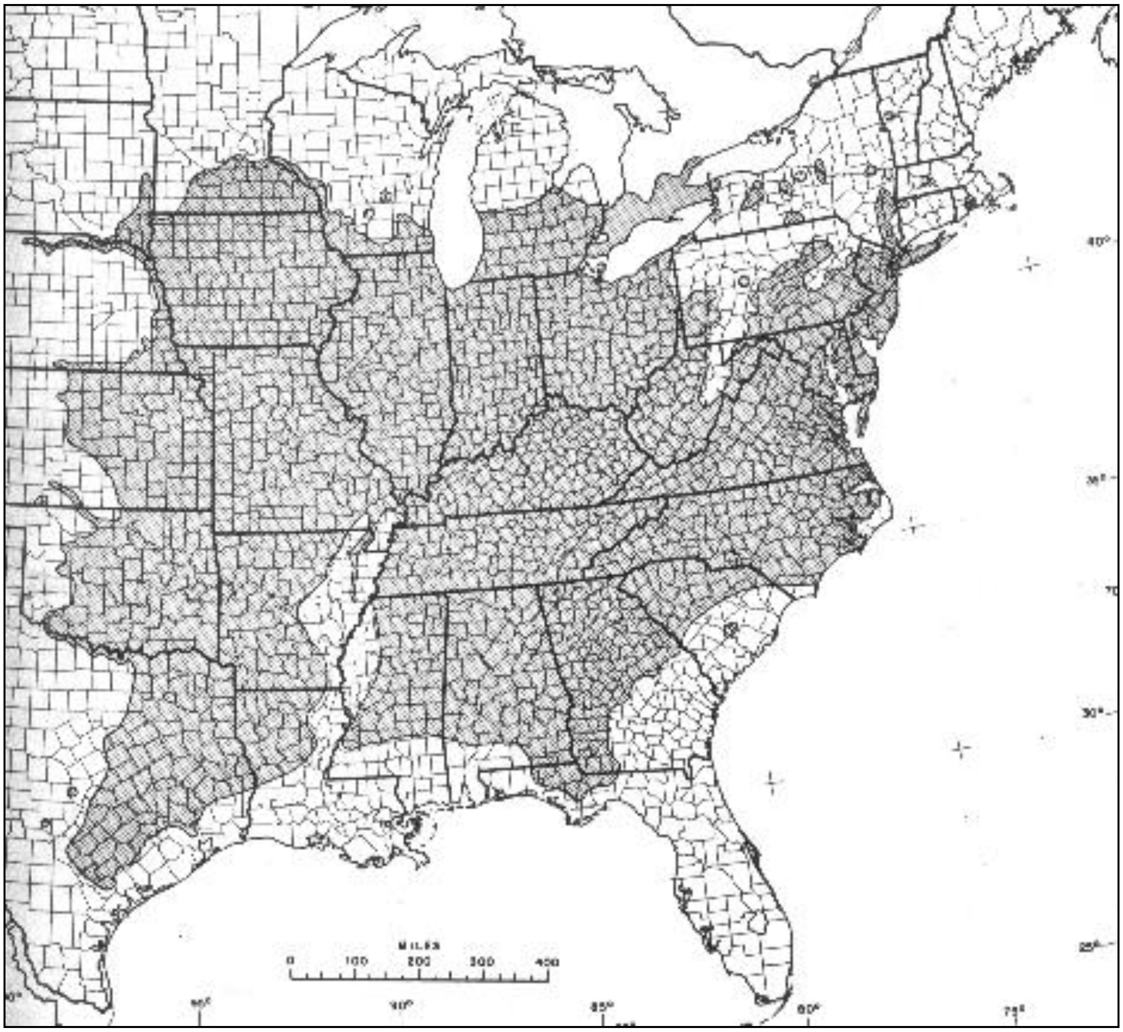

Figure 2.2. Native range of eastern black walnut (from: Fowells, 1965).

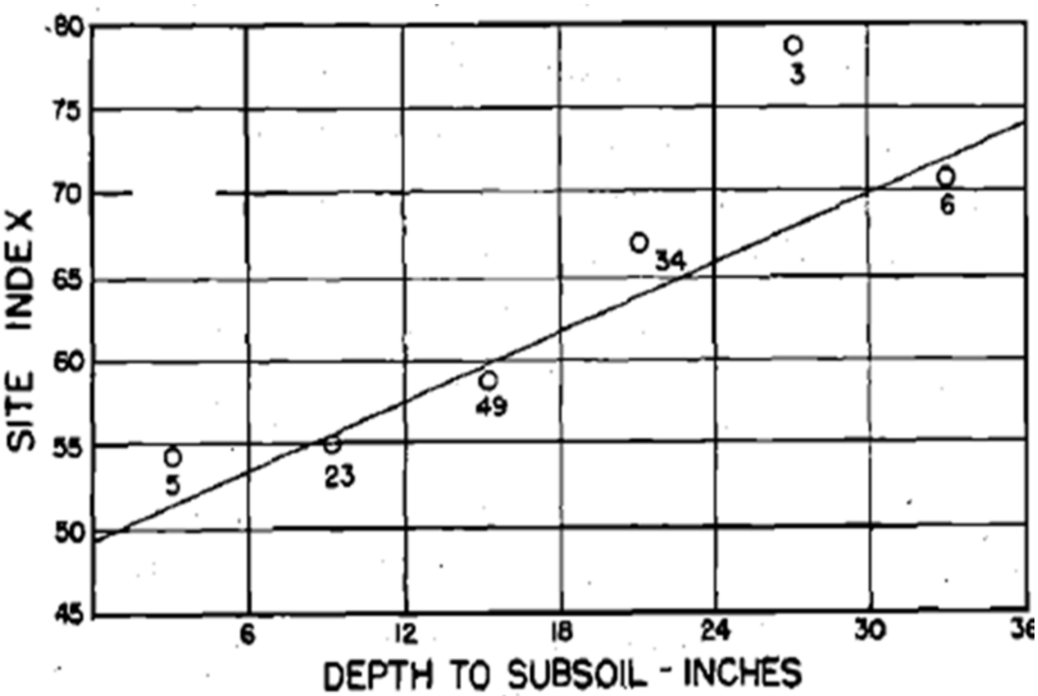

Figure 2.3. Mean correlation between site index and depth to subsoil for black walnut. Each plotted point is the mean of site-index residuals accumulated by 6-inch intervals of the surface horizon depth from 0 to 36 inches (from: Auten, 1945).

Chapter 3: Research Site Characterization

Objectives

1. To describe site characteristics relevant for all chapters, while data specific to each study may be further detailed in each chapter.

Research Site Characterization

Research was conducted in the agroforestry research and demonstration plots at Virginia Tech's Kentland Farms (37°11' N latitude, 80°35' W longitude, 545 m elevation above sea level). Soils on the site are fine-textured, mixed mesic, Typic Hapludults and are described as well-drained with sloped topography ranging from 10 – 25%. Soils are characterized by moderate permeability and available water capacity, as well as low organic matter and fertility. Generally, precipitation is evenly distributed throughout the year and the long-term average is 1085 mm year^{-1} (Figure 3.1; Hayden and Michaels, 2000). However, precipitation during the course of the growing season in 2008 was below average and the winter of 2009 was characterized by above average precipitation (Table 3.1). Monthly minimum, maximum, and mean ambient air temperatures at the Kentland Farm research site during 2008, 2009 and 2010 are presented in Figure 3.2. During this study, temperatures from year to year were comparable.

The site consists of both an active silvopastural study and an emulated silvopasture known as the Resource Allocation Site (RAS; Figure 3.3). The silvopastoral study site contains three treatments, black walnut silvopasture, honeylocust silvopasture, and open pasture, in a randomized complete block design with three replications. In 2008 through 2010, pastures were seasonally grazed as part of an ongoing silvopastural study testing sheep performance. Trees were originally planted as bare root seedlings in the spring of 1995 at 2.5-m × 12.5-m spacing.

Stands were thinned (removing 40% of all trees) in 2008, leaving a 5-m × 12.5-m spacing. Ultimate spacing for "leave" trees in the mature stands will be about 12.5 m × 12.5 m.

Honeylocust silvopastures were created using both wild type and Millwood trees. Millwood trees were created by grafting Millwood scion wood to rootstock grown from seeds collected from mature Millwood trees that were grown on Virginia Tech's main campus. Millwood trees were planted as the fifth tree in each row – about 12.5 m apart within rows. The remaining wild type trees were planted within the row between the Millwood trees. This configuration was designed to minimize the need for graft trees while also creating the shading environment desired for silvopastures during establishment phase. Over time, wild type trees will be removed from the system as trees mature.

The resource allocation site (RAS) consists of three replications of both black walnut and honeylocust plots planted within existing pastures in the spring of 1995. Pastures predominantly contain tall fescue, among other cool season grasses. Four tree rows were planted down-slope within each tree plot. Tree spacings were designed to create a tree density gradient across a southeast facing slope. From west to east, within-row spacings are 1.8, 3.7, 7.3 and 14.6 m, and between-row spacings are 3.7, 7.3, and 14.6 m (Figure 3.4). All walnut trees within the RAS were seeded from a single unknown, wild variety chosen for its greater-than-average nut production and all honeylocust trees within the RAS are wild type.

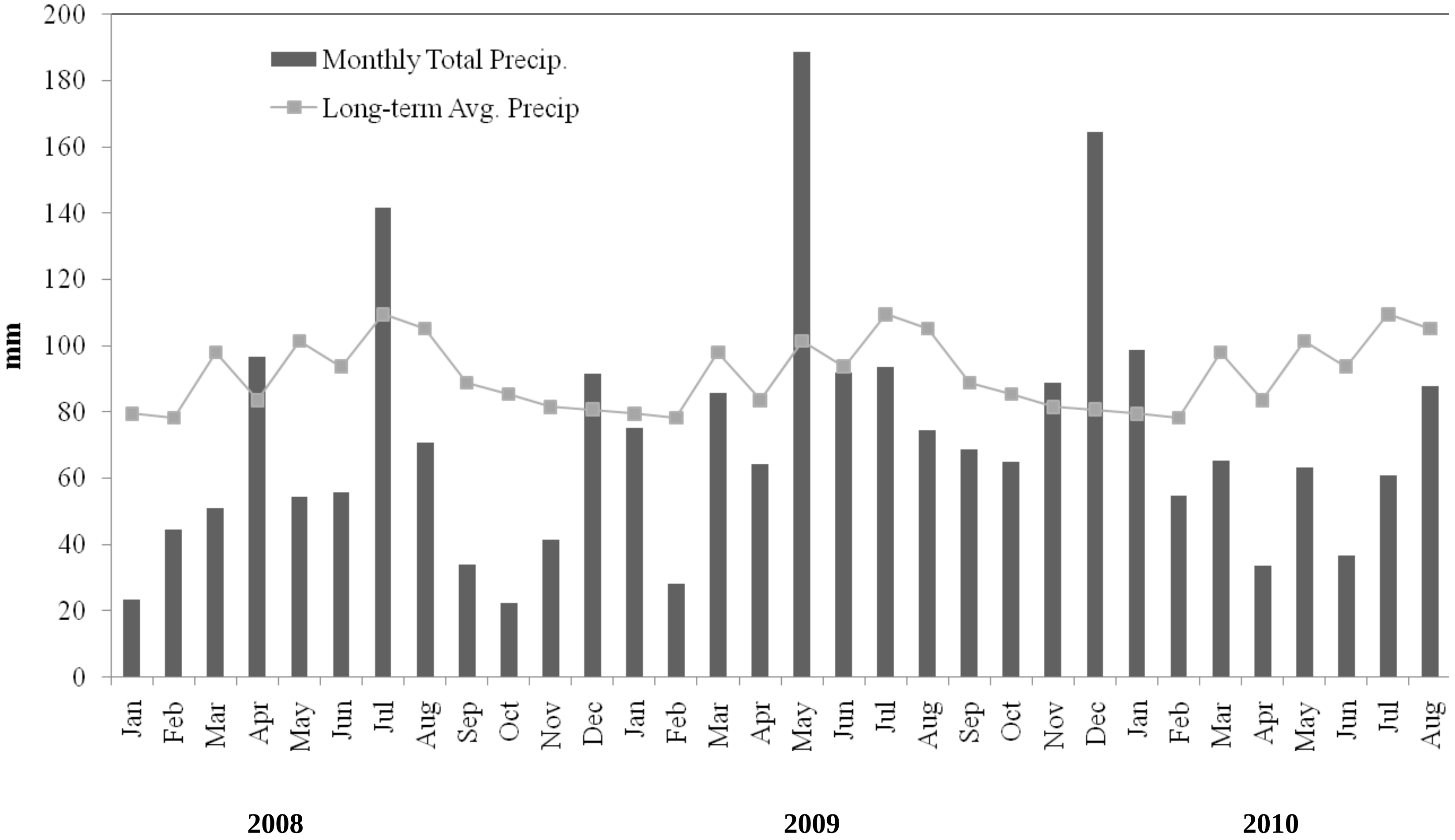

Figure 3.1. Monthly total average precipitation at Kentland Farm research site, Blacksburg VA, during 2008, 2009, and 2010

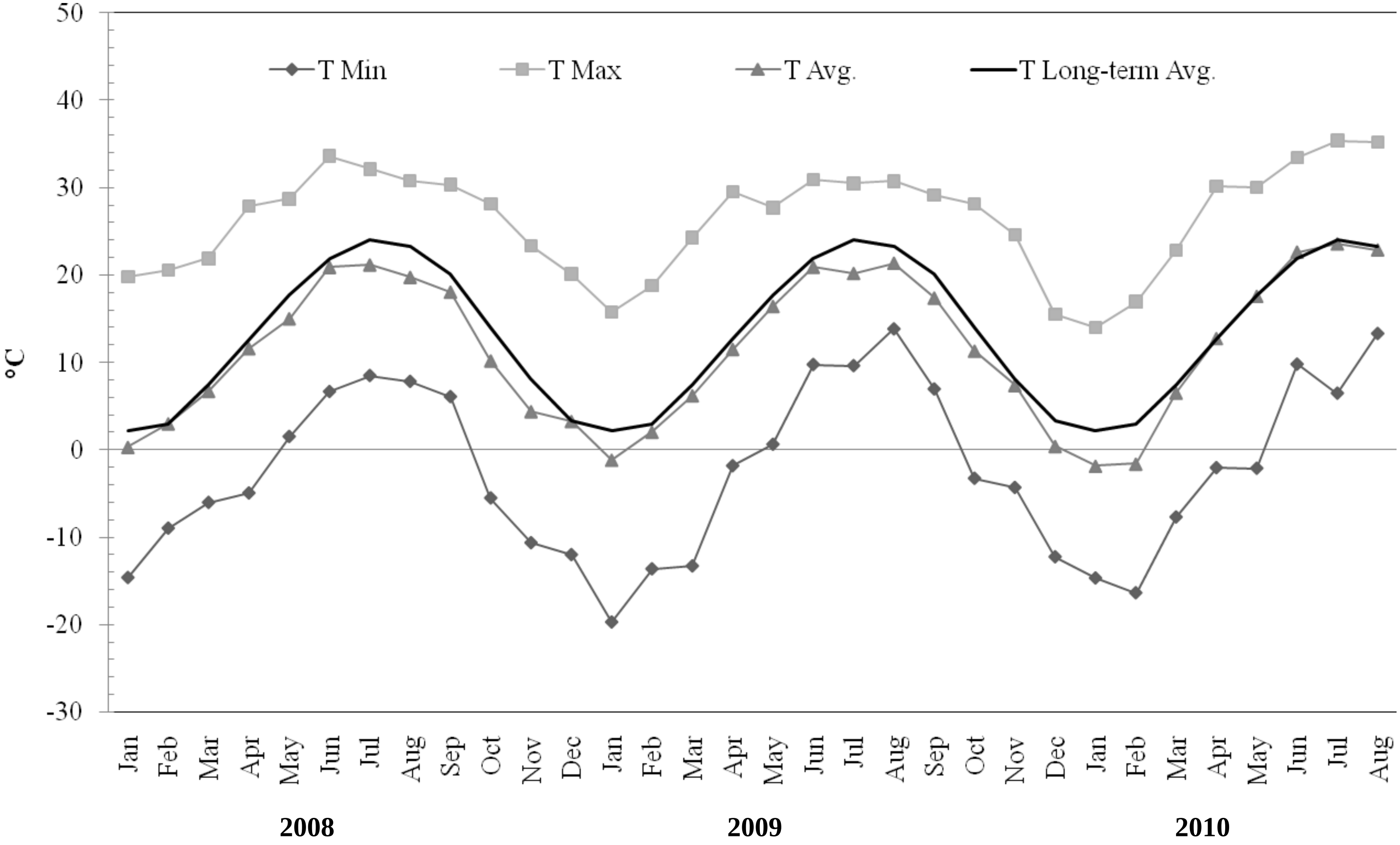

Figure 3.2. Minimum, maximum, and average ambient during 2008, 2009 and 2010, as well as long term average air temperatures at the Kentland Farm research site, Blacksburg VA.

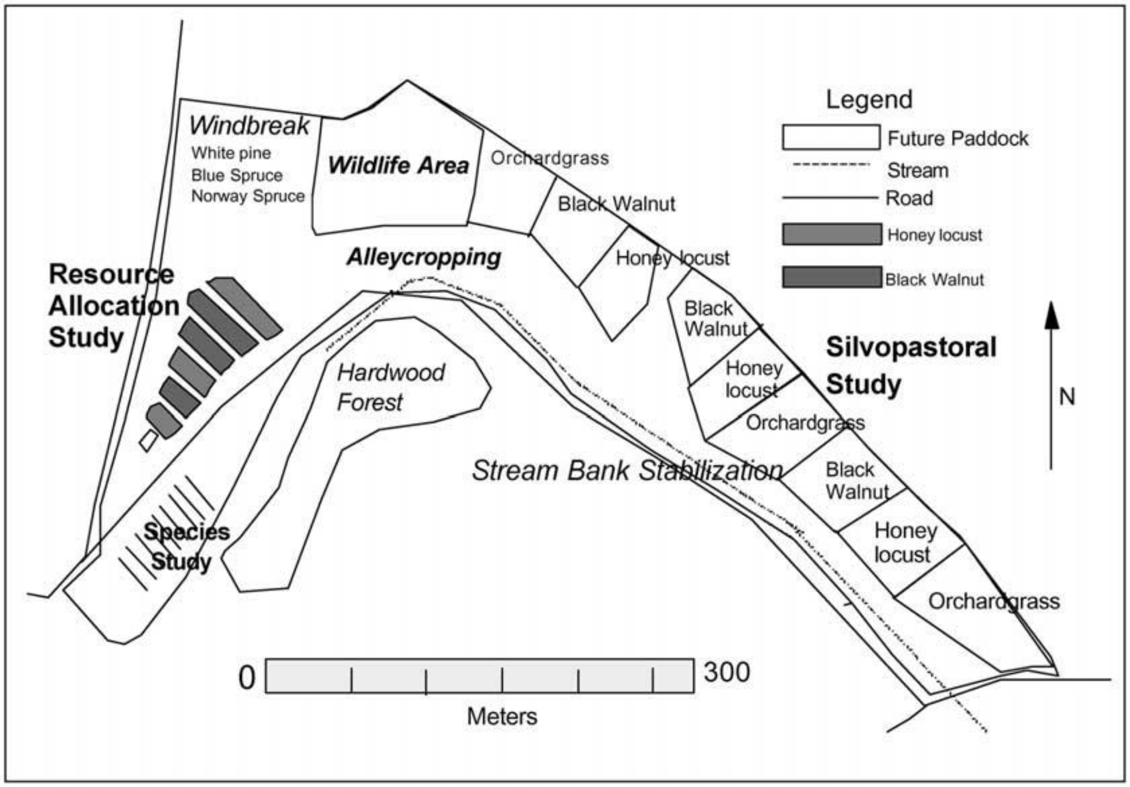

Figure 3.3. Kentland farm agroforestry research and demonstration project area

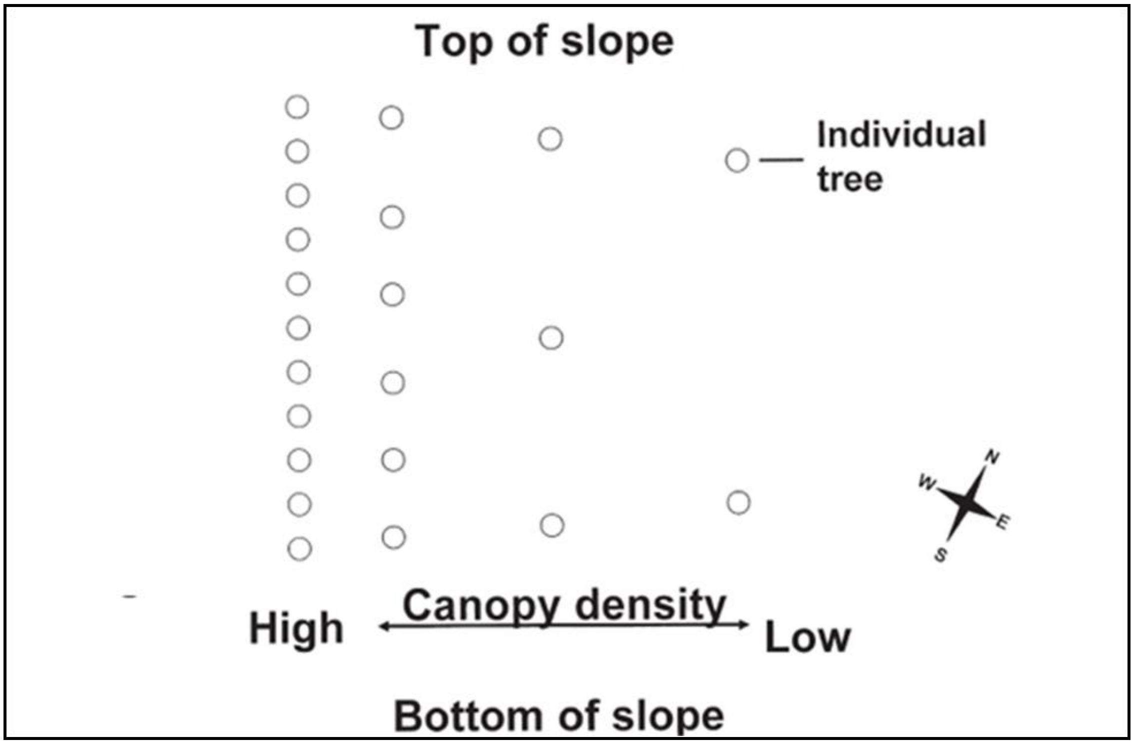

Figure 3.4. Layout of one RAS plot depicting tree placement and tree canopy

Chapter 4: Nutritive Variability of Seedpods and Yield Characteristics of Millwood Honeylocust

Abstract

Selecting appropriate trees is important for optimizing ecological and financial returns of agroforestry systems. Honeylocust (*Gleditsia triacanthos* L.) has gained particular interest for silvopasture systems because its relatively fast growth rate, as well as morphological and phenological characteristics that compliment cool-season grass production (Clason and Sharrow, 2000). Furthermore, honeylocust trees produce edible seed pods that livestock can consume after pod drop (Fowells, 1965). Pods can serve as a supplemental feed over the course of several months in autumn and winter when cool-season grass production is limited or negligible (Gold and Hanover 1993).

Silvopastoral systems that incorporate honeylocust may be designed as widely-spaced "fodder orchards" to supply pods. Improved honeylocust varieties, such as the 'Millwood' cultivar, produce seedpods with high nutritive value and elevated non-structural carbohydrate levels relative to pods from wild honeylocust trees (Scanlon, 1980). In addition, Millwood trees may produce high seedpod yields (Moore, 1948; Papanastasis et al., 1999). Data regarding the nutritive characteristics of seedpods and the fodder yield potential of specific, improved varieties of honeylocust such as Millwood are limited, particularly for the southern Appalachian region.

Two studies were conducted within an active sheep and honeylocust silvopasture to: 1) estimate the nutritional variability of seedpods among Millwood honeylocust trees; 2) determine seedpod yields of Millwood honeylocust trees managed within silvopastures; and 3) estimate seasonal production variation by tree. To determine seedpod nutritive variability, six randomly-sampled pods were harvested from each pod-bearing Millwood in October 2008 and 2009, just

prior to pod drop. Upon retrieval from the field, whole pods were dried then fractionated into seed and pod components. *In vitro* true digestibility (IVTD), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), crude protein (CP) were determined by wet chemistry and near infrared reflectance spectroscopy. To estimate Millwood fodder yields in 2008, 2009, and 2010, field measurements were taken in October and trees were ranked as low-, medium-, or high-bearing trees based on relative yield quantities.

In 2010, three representative trees were selected from each scoring class (9 trees, total). All pods on each representative tree were harvested by shaking pods from trees prior to natural pod drop. Pods from each harvested tree were dried (120 to 168 h at 55°C) and weighed. Pod yield for unsampled trees were estimated based on the relationship between harvest weight from sampled trees and pod yield score.

Both ground pods and seeds were highly digestible (78.7 and 96.3%, respectively). Pod NDF, ADF, and ADL values were generally low and averaged 27.3, 19.3, and 6.3%, respectively. Seeds (collected only in 2008) contained 13.2% NDF and 7.5% ADF, with no measurable concentrations of ADL. Seeds had greater CP concentrations than pods (20.4% vs. 6.2%). Although only 29% of total DM, seeds supplied 60% of total CP within whole seedpods. The nutritional value of whole, ground Millwood seedpods in this study was comparable to that of both ground whole-ear dent corn and oat grain. Nearly all Millwood trees displayed some form of alternate bearing pattern. Those few trees having similar yields from year to year had relatively low pod yields in all years. Of the 72 Millwood trees, 61 (85%), 13 (18%), and 67 (93%) produced pods in 2008, 2009, and 2010 respectively. Average yields of pod-bearing trees were 15.8 kg tree^{-1} in 2008, 4.8 kg tree^{-1} in 2009, and 14.7 kg tree^{-1} in 2010. Millwood trees can produce seedpods of sufficient yield and quality to provide financial benefit for land managers.

Hypothesis

Immature, limited-management Millwood honeylocust silvopasture systems can produce seedpods of sufficient yield and quality to provide financial benefit for land managers.

Objectives

1. To estimate the nutritional variability of seed pods among juvenile Millwood honeylocust trees managed in a temperate silvopasture.
2. To estimate fodder yields of juvenile Millwood honeylocust trees managed within silvopastures and estimate seasonal production variation by tree

Materials and Methods

Nutritive variability

In October 2008 and 2009, just prior to pod drop, 6 randomly-sampled pods were harvested from each pod-bearing Millwood to determine the variability in pod nutritive value among trees. Upon retrieval from the field, whole pods were dried (48 to 72 h at 55°C) then fractionated into seed and pod components. Both pods and seed fractions were ground in with a Wiley mill to pass a 2-mm screen. The pod fraction was then ground again with a coffee mill (La Pavoni Co., Long Branch, NJ, USA), while seeds were ground with a UDY Cyclone Sample Mill (Model 3010-014; UDY Corporation, Fort Collins, CO, USA) to pass through a 1-mm screen. At both stages, pods were ground with dry ice to prevent liberated sugars from adhering to the mill chamber and blades.

Nutritive analysis

Sample NDF, ADF, ADL, CP, and IVTD concentrations were estimated using near infrared reflectance spectroscopy (Foss NIR System 6500M, Silver Spring, MD, USA). Samples were scanned with near infrared radiation from 400 to 2,500 nm, and log (1/reflectance) was recorded. A stepwise multiple regression equation was generated for each fractionated pod and seed 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 fractionated pod and seed 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, which presented a subset of samples to be analyzed using wet chemistry (Table 4.1).

Fiber, ADL, and IVTD concentrations were determined sequentially using batch procedures of the ANKOM fiber analysis and Daisy Incubator systems (ANKOM Technology, Macedon, NY, USA). After initial NDF analysis, seed samples remained gelatinous (rather than fibrous) and had high and inconsistent NDF values. Following advice of ANKOM technical staff, seed samples were pretreated to remove excess lipids and proteins in two stages. Filter bags containing seed samples were first soaked for 60 min in acetone while agitated by hand every 15 min and then air dried. Filter bags were then soaked twice (sequentially) in a fresh, 10% protease solution (2.5 ml protease in 22.5 ml water) at 60°C for 30 min with circular agitation (150 rpm; VWR shaking incubator, Model 1575; Sheldon Manufacturing Inc., Cornelius, OR, USA). Samples were then rinsed thoroughly with warm water prior to standard

ANKOM procedures. Both pod and seed samples were analyzed in duplicate and analysis was repeated if the coefficient of variation between duplicates exceeded 3% for NDF, ADF, and ADL or 4% for IVTD. Ruminal fluid for the IVTD assay was collected from a non-lactating Holstein cow in October 2009 and 2010 housed at the Virginia Tech Dairy Center and maintained in accordance with Virginia Tech's Animal Care and Use Protocol (07-070-CSES). The cow was fed a standard diet of first-cut, mixed, cool-season grass hay ad libitum and 0.45 kg of cracked corn (*Zea mays* L.) once per day (and constituting less than 5% of daily DMI). The cow was fed each morning at approximately 7:00 am and ruminal fluid was sampled at approximately 1:00 pm. Samples were analyzed for CP at the Virginia Tech Soil Fertility Lab by dry combustion using a Vario MAX CNS macro-elemental analyzer, (Elementar, Hanau, Germany).

Seedpod yield estimates

In October of 2008, 2009, and 2010, visual assessment was used to estimate pod yield from Millwood trees. Measures such as percent branches bearing pods, percent cover per branch and relative pod density were collected for all Millwood (MW) trees. Trees were ranked according to the following scoring system:

1= Low pod yield; ≤ 33% pod cover in canopy
2= Medium pod yield; 34-66% pod cover in canopy
3= High pod yield; ≥ 67% pod cover in canopy

In October of 2010, average of field measurements from all three years were used to determine 3 representative trees from each scoring class (9 trees, total). All pods on each representative tree were harvested by shaking pods from trees prior to natural pod drop (Figure 4.1). Pods from each harvested tree were dried (120 to 168 h at 55°C) and weighed. Estimates of pod yield for unsampled trees were based on the relationship between harvest weight from sampled trees and pod yield score (low, medium, and high).

To characterize MW tree size, measurements of tree height and diameter at breast height (DBH) were recorded in August 2010.

Results

Nutritive variability of seedpods among Millwood trees

Variability of Millwood pod nutritive value (Table 4.2) was determined for 2008 and 2009, but nutritive value for seed was possible only in 2008. Seedpod yields in 2009 were relatively low and few of the harvested seedpods contained seed, thus precluding analysis. Seeds in 2009 constituted 3% of total seedpod DM, in contrast to seeds in 2008 which constituted 29% of total seedpod DM. Further, seeds from the 2009 harvest generally were brittle, and diseased or undeveloped, or both.

Both ground pods and seeds were highly digestible (787 and 963 g kg^{-1}, respectively). Pod IVTD values ranged from 649 and 874 g kg^{-1}, and seed IVTD ranged from 900 to 991 g kg^{-1}. Pod NDF, ADF, and ADL values were generally low and averaged 273, 193, and 63 g kg^{-1}, respectively. Pod NDF concentrations ranged from 184 to 438 g kg^{-1}, ADF ranged from 131 to 321 g kg^{-1}, and ADL from 40 to 108 g kg^{-1}. Few trees produced pods with high fiber and low digestibility. Seeds in 2008 contained 132 g kg^{-1} NDF, 75 g kg^{-1} ADF, and no measurable ADL. Seed NDF concentrations ranged from 68 to 160 g kg^{-1} and ADF concentrations ranged from 47 to 101 g kg^{-1}. Seeds had greater CP concentrations than pods; values for the two fractions averaged 204 and 62 g kg^{-1}, respectively. The range of CP values ranged from 155 to 255 g kg^{-1} for seeds and 31 to 101 g kg^{-1} for pods. Estimated values for IVTD, NDF, ADF, ADL, and CP of whole seedpods (pods and seeds together) in 2008 were 833, 235, 161, 63, and 99 g kg^{-1} respectively. Although seeds were only 29% of DM, they supplied 60% of total CP within whole seedpods.

Millwood seedpod production

The 13 to 15-yr-old MW trees averaged 7.4 (± 1.4) m-height and 12.7 (± 2.4) cm DBH. Of the 72 trees in the study, 61 (85%), 13 (18%), and 67 (93%) produced pods in 2008, 2009, and 2010 respectively. Pod yields were the greatest in 2008, when the estimated average yield of pod-bearing trees was 15.8 kg tree^{-1} (Table 4.3). In 2009, when few trees produced pods, yields averaged 4.8 kg tree^{-1}. Trees in 2010 were largely classified as medium-yielding; pod yields averaged 14.7 kg tree^{-1}. Weak positive relationships existed between tree DBH and estimated seedpod yields during the two most productive years and r^2 for 2008 and 2010 were 0.26 and 0.56, respectively.

Over three years, most pod-bearing trees (69 out of 72; 96%) displayed some form of alternate bearing pattern (see Chapter 2). Based on pod scores, about half (32 trees) had relatively high yields in 2008 followed by relatively low yields in 2009 and moderate yields in 2010. Fourteen trees (28% of 72 pod bearing trees) had two consecutive years of no production followed by one year of low to medium pod production. Only 3 trees produced comparable yields over all years, but yields were generally low (4.8 kg tree^{-1}).

Discussion

Nutritive variability of seedpods among Millwood trees

Millwood pods and seeds have high digestibility and nutritive value and could be an excellent supplemental feed. The nutritional value of whole, ground Millwood seedpods in this study was comparable to that of ground whole-ear dent corn or oat grain (NRC, 1989; Table 4.4). Honeylocust seedpods have been compared with oats in past studies (Gold and Hanover, 1993; Papanastasis et al. 1999). The Alabama Experiment Station, as cited by Gold and Hanover (1993), conducted a two year animal feeding trial and found that ground seedpods from Millwood trees could be successfully substituted 1:1 for oats in a dairy ration.

Pod NDF, ADF, and ADL concentrations were lower than those found by Papanastasis (1999; Tables 4.2 and 2.2). Seed fiber values were also lower; however this may be due to differences in analytical methods. Papanastasis (1999) did not use acetone and protease pre-treatments to liberate fats and proteins contained within seed samples.

Pod CP concentrations (62 g kg^{-1}) were generally low (Table 4.2) and comparable to values found in early TVA studies (82 g kg^{-1}; Scanlon, 1980). Papanastasis et al. (1999) reported Millwood trees grown in southern France produced pods with CP concentrations as high as 123 g kg^{-1} (Table 2.2).

Seed CP concentration averaged 204 g kg^{-1} in this study. This was as much as 93 g kg^{-1} lower than values reported for Millwood seeds in other research (Scanlon, 1980; Papanastasis, 1999). Seeds provided the majority of the CP found in whole Millwood seedpods. However, capacity to meet livestock CP needs with Millwood seedpods would be limited by low production years as in 2009. And, even with high seed yields, it is unlikely that Millwood seeds would supply adequate CP to large ruminants given the toughness of the seed coat, although the seeds could be digested by small ruminants (leRoux, 1959b; Small, 1983; Foroughbakhch et al., 2007; Foroughbakhch et al., 2008).

Millwood seedpod production

Nearly all Millwood trees displayed some variation of alternate bearing pattern. Those few trees having similar yields from year to year had relatively low pod yields in all three years. Tree DBH was weakly correlated with seedpod yields during productive years. Honeylocust's irregular fruiting from year-to-year is a commonly occurring phenomenon in many fruit, nut, and mast producing trees. More well-known, economically and ecologically valuable tree species that display alternate bearing include oak, beech, apple, pear, avacoado, walnut, citrus, and pistachio (Hodgson and Cameron, 1935; Jonkers, 1979; Dennis and Neilsen, 1993; Crawley and Long, 1995; Rosecrance et al., 1998; Hilton and Packham, 1997; Maeto, K. and K. Ozaki. 2003; Bukovac et al. 2010). The exact cause of alternate bearing pattern is not known, but research suggests it may be the result of several species-specific and environmental factors (see Chapter 2; Jonkers, 1979; Crawley and Long, 1995; Rosecrance et al., 1998). Several strategies, such as pruning, girdling, fruit thinning, nutrient management, and breeding programs are utilized in fruit/nut orchards to adjust bearing patterns; however yield responses to these techniques are species-specific (Jonkers, 1979; Davie et al., 1995). Past studies focusing on honeylocust pod yields, such as Moore (1948) and Papanastasis et al. (1999), show the tree's tendency to alternately bear; however there is no reported evidence concerning the genetic or environmental causes of such patterns.

Overall, yields were lower than those reported of 5- to 10-yr-old trees by Moore (1948), where the 5-yr average yield was 32.9 kg tree^{-1} yr^{-1} (Table 2.1). However, it is not clear that these figures are on a DM basis. It should be noted that branches of high yielding trees within this study were densely covered by pod clusters and physically stressed under the weight. In 2010, scaffold branches of 3 high-bearing trees sagged and split under the weight of seedpods. Thus, it is unlikely that trees within this study could bear the yields reported by Moore (1948). Yields, averaged over all 72 study trees (including non-bearing trees), were 13.4, 0.9, and 12.3 kg tree^{-1}, for 2008, 2009, and 2010, respectively. A 13-to 15-yr-old Millwood silvopasture planted with 170 trees ha^{-1} and producing yields similar to those in this study would bear approximately 2.3 Mg ha^{-1} of pods (DM basis) in a productive year and 0.14 Mg ha^{-1} of pods in a low-yielding year (Table 4.5). Based on a 3-yr average of 1.51 Mg ha^{-1}, and using an average value of oat grain for 2008 - 2009 (\$3.15 bushel^{-1}; USDA, 2009), Millwood trees could generate over \$325 ha^{-1} yr^{-1} in feed supplement equivalent.

These estimates are very conservative, given that our yield averages include non-bearing trees. Seedpod yields might be further improved through genetic selection, selective thinning, and more intensive management. Pruning strategy is one management factor that may have reduced yields in this study. Trees were managed to maintain a clear 2.4-m bole for future timber harvests. Although seedpod yields may be further improved by allowing canopies to have free-growth structure, this must be balanced with understory forage production.

Conclusion

Millwood pods and seeds have high digestibility and nutritive value and could be an excellent supplemental feed. Further, Millwood trees can produce sufficient yields of seedpods to provide financial benefit for land managers. Since honeylocust trees produce a potential feed resource for ruminants, studies characterizing yield potential and the nutritive value of seedpods may influence management decisions regarding their utilization within silvopastures.

Table 4.1. Calibration and validation statistics for near infrared spectroscopy (NIRS) for determination of pod and seed nutritive value†

	Calibration				Validation	
Item	n	Mean	R^2	SEC‡	1-VR§	SECV¶
IVTD	75	0.7901	0.9828	0.0147	0.9701	0.0195
NDF	72	0.2755	0.9934	0.0782	0.9854	0.0117
ADF	72	0.1871	0.9908	0.0727	0.9833	0.0980
ADL	47	0.0725	0.9230	0.0513	0.8536	0.0709
CP	74	0.0947	0.9973	0.0330	0.9960	0.0402

† IVTD= In vitro true digestibility; NDF= neutral detergent fiber; ADF= acid detergent fiber; ADL= acid detergent lignin; CP= crude protein.

‡ 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 4.2. Nutritive variability of Millwood seedpods.

	IVTD	NDF	ADF	ADL	CP	% of DM
	—————— g kg^{-1} ——————					
Pod†	787 ± 50	273 ± 53	193 ± 40	63 ± 15	62 ± 17	71.2 ± 7.6
Seed‡	963 ± 19	132 ± 13	75 ± 9	–	204 ± 16	28.8 ± 7.6

†Average pod nutritive values determined from two years of production data (2008 and 2009).

‡ Seed nutritive value data determined only with seeds collected in 2008. In 2009, seedpods did not contain enough seed material to conduct lab analyses.

Table 4.3. Millwood seedpod yields from 72 sample trees.

	Pod DM yield, kg tree^{-1}				Number of trees		
Yield Score	Average	Min	Max	Pods tree $^{-1}$	2008	2009	2010
High	26.3	22. 5	29.3	2240	25	0	8
Medium	15.8	11.7	19.0	1340	12	0	36
Low	4.8	3.3	5.8	410	24	13	23

Table 4.4. Conventional feeds with nutritive profile comparable to whole, ground Millwood honeylocust seedpods

	NDF	ADF	ADL	CP
	———— g kg^{-1} ————			
Ground Millwood seedpods	235	161	63	99
Ground whole-ear dent corn†	280	110	20	90
Oat grain†	320	160	30	133

† NRC (1989). Nutritional requirements of dairy cattle

Table 4.5. Estimated yields of 13- to 15-yr-old Millwood trees grown in Appalachian silvopastures

		Estimated yield, Mg ha^{-1}†		
Tree Spacing (m)	Trees ha^{-1}	High-bearing year	Low bearing year	Three-year average
5 × 12.5	170	2.27	0.14	1.51
12.5 × 12.5	68	0.91	0.06	0.61

† High- and low-bearing years derived from estimated average yields per tree in 2008 (13.37 kg tree^{-1}) and 2009 (0.85 kg tree^{-1}). Three-year average (8.9 kg tree^{-1}) included 2010.

Figure 4.1. Method of shaking Millwood pods from canopies prior to natural pod drop

Chapter 5: Change of Millwood and Wild Type Honeylocust Seedpod Nutritive Quality and Mineral Concentrations over Winter

Abstract

Seedpods from high-sugar varieties of honeylocust (*Gleditsia triacanthos* L.) trees have potential as an animal feed supplement from late fall to mid-winter. However, seedpod degradation over time after pod drop, and its effects on pod nutritive value is unreported. Honeylocust pods have potential to supply high-quality feed, and studies characterizing their nutritive value and degradation over time are needed to guide management decisions regarding their utilization within silvopastures. A study was conducted within an active honeylocust silvopasture to determine changes in Millwood (MW) and wild type (WT) seedpod nutritive value when left on the ground over winter.

In October 2008 and 2009, seedpods harvested from representative Millwood and wild type trees were placed into nylon mesh in-situ bags, laid out in wire enclosures within silvopastures, and allowed to decompose over time. At monthly intervals from November to March, pod samples were retrieved, then dried, fractionated into seed and pod components, and analyzed for digestibility and nutritive value.

Pod nutritive value changed very little in 2008, but a general pattern of decreasing digestibility and increasing fiber concentrations with time was observed for both pod types. Decreases in pod IVTD and corresponding increases in pod fiber and lignin concentrations were greater in 2009 than in 2008, most likely due to wetter environmental conditions. Millwood pods were more digestible and less fibrous, despite being more resistant to degradation than pods from WT honeylocust. The decrease in digestibility from November to March was over two-fold greater for WT pods compared to MW pods. In general, pod CP did not change over winter in

either year. Further, differences in CP between tree types, although significant, were usually small. Honeylocust seeds were largely resistant to short-term degradation. Although the differences were minute, ground MW seeds were less fibrous, more digestible, and contained less CP than WT seeds. Ground honeylocust seeds were nearly 5 fold more digestible than whole seeds.

Change in most pod mineral concentrations (Ca, Mg, and Cu), as well as the relative differences between pod types, varied from year to year and no consistent patterns were evident. Concentrations of macro-minerals, such as P and K, decreased over winter in both 2008 and 2009. Whole honeylocust seedpods have greater K and Ca concentrations than more conventional feeds with comparable nutritive quality. Seedpod concentrations of P, S, and Mg fall below the maintenance requirements of a dry pregnant cow.

Hypothesis

Nutritive value of honeylocust seedpods varies by tree type (*i.e.*, by genetic origin) and over time following pod drop. Time of peak nutritional value for Millwood and wild type seedpods can be determined to optimize utilization within silvopasture systems.

Objectives

1. To determine changes in digestibility and nutritive value over winter – after pod drop – in seedpods from Millwood and wild-type honeylocust trees.

Methods and Materials

Sample selection and preparation

In 2008, six trees were sampled from each of the two honeylocust tree types: Millwood (MW) and wild type (WT). Six representative Millwood trees were selected from those trees receiving a pod productivity score of two (2= medium pod yield; 34-66% pod cover) as described in Chapter 4. Six WT trees were chosen randomly. Thirty pods from each sample tree were randomly selected and composited (n=180 for each tree type). In 2009, few Millwood trees produced pods and yields were extremely low, thus pod samples were taken from the six trees with the greatest number of pods.

From the two sets of composited samples, 6 to 8 pods were selected and placed in nylon mesh in-situ bags. Bags had a surface area slightly larger than the surface area of the pods, a 4-mm mesh pore diameter, and 5 pores per cm^2. Pore space ensured sample exposure to sunlight, moisture, insects, and other factors influencing decomposition. Mesh bags were placed flat on the ground surface in wire enclosures and collected at monthly intervals from November to March to determine changes in nutritional value over time. Four replications were used per treatment (2 tree types X 5 months X 4 replications = 40 in-situ bags).

Upon retrieval from the field, whole pods were dried (48 to 72 h at 55°C) then fractionated into seed and pod components. Seeds were inspected for visible signs of cracks, mold growth, or holes caused by boring insects (Figure 5.1). In 2008, the seed fraction was split: half the seeds were ground and used for all analyses, while the remaining whole seeds were used for IVTD analysis only. Both pods and seed fractions were ground in two stages, the first being with a Wiley mill to pass a 2-mm screen. The pod fraction was then ground again with a coffee mill (La Pavoni Co., Long Branch, NJ, USA), while seeds were ground with a UDY Cyclone

Sample Mill (UDY Corporation, Fort Collins, CO, USA) to pass through a 1-mm screen. At both stages, pods were ground with dry ice to prevent liberated sugars from adhering to the mill chamber and blades.

Nutritive analysis

Sample NDF, ADF, ADL, CP, and IVTD concentrations were estimated using near infrared reflectance spectroscopy (Foss NIR System 6500M, Silver Spring, MD, USA). Samples were scanned with near infrared radiation from 400 to 2,500 nm, and log (1/reflectance) was recorded. A stepwise multiple regression equation was generated for each fractionated pod and seed 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 fractionated pod and seed 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, which presented a subset of samples to be analyzed using wet chemistry.

Samples were analyzed for CP at the Virginia Tech Soil Fertility Lab by dry combustion using a Vario MAX CNS macro-elemental analyzer (Elementar, Hanau, Germany). Fiber, ADL, and IVTD concentrations were determined sequentially using batch procedures of the ANKOM fiber analysis and Daisy Incubator systems (ANKOM Technology, Macedon, NY, USA). In initial trials of NDF analysis, ground seed samples taken out of the fiber analyzer were gelatinous and had unexpectedly high and inconsistent NDF values. Under the advisement of

ANKOM technical staff, seed samples were pretreated in two stages to remove excess lipids and proteins.   Filter bags containing seed samples were first soaked for 60 min in acetone while agitated by hand every 15 min. Filter bags were air dried and then soaked twice (sequentially) in 25 ml of 10% protease solution (2.5 ml protease + 22.5 ml H_2O) at 60°C for 30 min, while agitated at 150 rpm in an orbital shaking incubator (VWR, Model 1575; Sheldon Manufacturing Inc., Cornelius, OR, USA). Samples were then rinsed thoroughly with warm water prior to standard ANKOM procedures. Both pod and seed samples were analyzed in duplicate and analysis was repeated if the coefficient of variation between duplicates exceeded 3% for NDF, ADF, and ADL or 4% for IVTD.

Due to high variability, whole seed samples were analyzed in triplicate for IVTD, and all three results were averaged. Ruminal fluid for the IVTD assay was collected from a non-lactating Holstein cow in October 2009 and 2010 housed at the Virginia Tech Dairy Center. The cow was fed a standard diet of first-cut, mixed, cool-season grass hay ad libitum and 0.45 kg of cracked corn (*Zea mays* L.) once per day (and constituting less than 5% of daily DMI). The cow was fed each morning at approximately 7:00am and ruminal fluid was sampled at approximately 1:00pm. Neutral detergent fiber digestibility (NDFd) was calculated from NDF and IVTD values.

Mineral analysis

To determine pod mineral concentrations, samples were dried to a 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, 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.

Data analysis

Data were checked for homogeneity of variance using Levene's test and normality was confirmed using the Shapiro-Wilk W Test. Where these conditions were not met, the data were transformed as appropriate, using log, square root, and multiplicative inverse transformations. Initially, a three-factor analysis of variance (ANOVA) was used to test the effects of study year, tree type, and month on changes in seedpod nutritive and mineral values. However, year X treatment effects existed for almost all nutritional parameters. Therefore, data were analyzed by year using a two factor ANOVA to test the effects of tree type and month on changes in pod nutritive value measures. The least square means Tukey HSD test was used to determine significance among mean values following the ANOVA. All tests were conducted using GLM procedures of JMP software (SAS Institute, Cary, North Carolina).

Results

Nutritive quality

Decreases in pod IVTD and CP and corresponding increases in fiber and lignin concentrations were greater in 2009 than in 2008 and variable by pod type (year × time × treatment interaction; $P < 0.05$). Thus, data were analyzed and are presented by year. Although the ANOVA table is not presented, statements of significant year effects are based on results from the three-factor ANOVA. Probability values for means comparisons of months are derived from Tukey's HSD tables, which are also not presented, but are cited within the results section.

Digestibility

In 2008, MW pod IVTD decreased ($P = 0.0019$) 46 g kg^{-1} from November (800 g kg^{-1}) to March (754 g kg^{-1}), with the largest numeric declines occurring in the first two months of exposure (Table 5.2) In contrast, WT pod IVTD did not differ ($P > 0.50$) over 4 months of exposure, although a general pattern of numerically lower IVTD was observed; values in March were 33 g kg^{-1} less than in November. On average, MW pods were 19% more digestible than WT pods (5-mo. mean IVTD = 766 vs. 643 g kg^{-1}).

The MW pods sampled in November 2009 were more ($P = 0.0001$) digestible than those sampled in November 2008 (864 vs. 800 g kg^{-1}, respectively). However, IVTD declined more in 2009 than in 2008 (79 vs. 46 g kg^{-1}), resulting in a month × year interaction ($P < 0.0001$). Pod IVTD was similar from November to January (mean = 859 g kg^{-1}), with most of the reduction in IVTD occurring during January and February.

For WT pods, initial (November) IVTD did not differ ($P = 0.3889$) between years (mean = 680 g kg^{-1}). However, as with MW, pod IVTD decreased more in 2009 than in 2008 (month × year interaction; $P = <0.0001$). In 2009, WT pod IVTD decreased ($P < 0.0001$) 160 g kg^{-1} from November to March (701 vs. 541 g kg^{-1}). On average, WT pods in 2009 were 25% less digestible than MW pods ($P < 0.0001$). Further, the decrease in digestibility from November to March was over two-fold greater for WT pods compared to MW pods.

The IVTD of ground seeds tended ($P = 0.089$) to decrease from November to March. Over five months, WT seeds had 20 g kg^{-1} lower IVTD ($P \leq 0.0001$) than MW seeds (946 vs.

965 g kg^{-1}), although IVTD was similar ($P > 0.05$) for the two tree types in November and December.

Whole seed IVTD was similar ($P > 0.30$) over time and by tree type. Average IVTD for MW and WT whole seeds was 204 and 214 g kg^{-1}, respectively. Visible damage to seeds increased ($P = 0.0325$) over the 4-mo. exposure period but did not differ by tree type. By March, seeds had 54% more damage than those in November (13.7% vs. 8.9%). The proportion of total damage caused by boring insects increased ($p=0.0009$) over time and by Febuary was nearly three-fold greater than in November (10.9% vs. 4.0%). Seed damage caused by factors other than boring insects was similar across months and by tree types. Changes followed no noticable pattern, suggesting that seed integrity over winter was highly dependant on the prevalance of boring insects, rather than weathering.

NDF, ADF, and ADL

In 2008, MW pod NDF, ADF, and ADL concentrations were similar ($P > 0.50$) from November to March and averaged 296, 214, and 70 g kg^{-1}, respectively. Although similar by month, a general pattern of increasing fiber concentrations was observed and values in March were 29, 21, and 13 g kg^{-1} more than values in November. For WT pods, average NDF (412 g kg^{-1}), ADF (297 g kg^{-1}), and ADL (104 g kg^{-1}) concentrations were greater ($P < 0.001$) than in MW pods, and WT pods were more sensitive to effects of time. WT pod ADF and ADL values in March were 15% (314 vs. 274 g kg^{-1}) and 17% (112 vs. 96 g kg^{-1}) greater ($P < 0.03$) than in November.

The MW pods harvested in 2009 had about 24% less fiber ($P < 0.01$) than those harvested in 2008. However, MW pod fiber concentrations increased more dramatically over the months of exposure in 2009 than in 2008 (year × month interaction; $P = <0.05$). In 2009, MW pod NDF, ADF, and ADL values were 93, 76, and 26 g kg^{-1} greater, respectively, in March than in November, with most of the increase in fiber concentrations occurring during January and February.

Unlike MW, fiber and lignin levels in WT pods at harvest (November) were similar ($P > 0.50$) between years. However, as with MW, WT pod NDF, ADF, and ADL concentrations increased more in 2009 than in 2008 (year × month interaction; $P < 0.05$). From November to March, NDF, ADF, and ADL increased 133, 97, and 48 g kg^{-1} in WT pods.

At no time during 2008 and 2009 were MW pod fiber concentrations similar to those of WT pods ($P = <0.0001$). Further, the magnitude of increase in fiber concentrations from November to March was greater for WT pods when compared to MW pods. Averaged over years, the relative increases of NDF, ADF, and ADL concentrations from November to March were 53%, 88%, and 21%, greater for WT pods than for MW pods.

In 2008, average NDF and ADF concentrations in MW seeds (130 and 72 g kg^{-1}, respectively) were lower ($P < 0.001$) than in WT seeds (142 and 86 g kg^{-1}, respectively). Seed fiber fractions were similar ($P > 0.10$) over the 4-mo exposure period for both tree types.

Fiber digestibility

In 2008, average MW pod NDFd (258 g kg^{-1}) was 58% greater ($P \leq 0.0001$) than that of WT (164 g kg^{-1}). MW pod NDFd decreased ($P \leq 0.0001$) from 324 g kg^{-1} in November to 233 g kg^{-1} in March. Most of the decrease occurred during the first month of exposure, since MW pod NDFd values were similar ($P > 0.05$) from December to March. In contrast, WT pod NDFd remained similar ($P > 0.05$; 164 g kg^{-1}) over time (tree type × time interaction; $P = 0.0025$).

For pods harvested in 2009, average NDFd was nearly 2.5 times greater ($P \leq 0.0001$) for MW than for WT pods (406 vs. 172 g kg^{-1}), and MW pod NDFd declined ($P < 0.05$) from 424 g kg^{-1} in November to 334 g kg^{-1} in March. The WT pods sampled in November 2009 had greater ($P = <0.0001$) NDFd values than those sampled in November 2008 (225 vs. 159 g kg^{-1}, respectively), but NDFd declined ($P < 0.05$) from 225 g kg^{-1} to 104 g kg^{-1} over time (month × year interaction, $P < 0.0001$).

Seed NDFd of both tree types remained similar ($P = 0.0555$) from November to March, however MW seeds displayed a trend of decreasing NDFd. Average MW seed NDFd (868 g kg^{-1}) was 18% greater ($P < 0.0001$) than that of WT seeds (733 g kg^{-1}).

Protein

In 2008, MW pod CP concentrations were unaffected ($P > 0.19$) by exposure time. Initial CP concentrations were similar for WT and MW pods (59 and 54 g kg^{-1}, respectively), but for WT pods, CP concentrations increased over the exposure period (Table 5.2). Average CP concentrations were 67 g kg^{-1} for WT and 52 g kg^{-1} for MW pods.

Average CP concentrations for WT and MW pods were 26% (85 vs. 67 g kg^{-1}) and 81% (94 vs. 52 g kg^{-1}) greater ($P < 0.0001$) in 2009 than in 2008, respectively. In 2009, CP concentrations for MW pods were similar across months (mean = 94 g kg^{-1}). For WT pods, CP concentrations were similar from November to February (mean = 88 g kg^{-1}), but a 26% decrease from February to March (92 vs. 73 g kg^{-1}) resulted in significant tree type × month interaction ($P = 0.0001$). Averaged over 4 months in 2009, CP concentrations in MW pods were 11% greater ($P < 0.0001$) than CP in WT pods (94 vs. 85 g kg^{-1}).

Crude protein concentrations in both WT and MW seeds did not change ($P > 0.76$) from November to March. Monthly differences did not follow a clear pattern (Table 5.3). Crude protein concentrations were about 5% greater ($P < 0.0001$) in WT seeds (214 vs. 204 g kg^{-1}, respectively).

Mineral concentrations

Potassium

Pod K concentrations decreased ($P < 0.0001$) from November to March in both years for both tree types (Table 5.5). However, reductions in K over time were greater in WT pods (tree type × month interaction; $P < 0.05$). In 2008, both WT and MW pods had similar ($P = 0.2841$) K concentrations and average values declined ($P < 0.0001$) from 16.8 g kg^{-1} in November to 12.9 g kg^{-1} in March. In November 2009, pod K concentrations were similar ($P > 0.10$) by tree type (12.6 g kg^{-1}). By March 2010, however, K in WT pods had decreased to 6.0 g kg^{-1} versus 10.0 g kg^{-1} for MW pods. Seed K concentrations did not change ($P = 0.3385$) over time for either tree type. Average K concentrations were less ($P < 0.0001$) in MW (11.3 g kg^{-1}) than in WT seeds (12.6 g kg^{-1}).

Calcium

In both years, MW pod Ca concentration did not change ($P > 0.05$; Table 5.5) over 4 mo of environmental exposure. The 2-yr average was 1.9 g kg^{-1}. Calcium concentrations in WT pods did not change ($P = 0.2523$) from November 2008 to March 2009 (3.1 g kg^{-1}), but increased ($P = 0.0003$) from 2.0 g kg^{-1} in November 2009 to 2.7 g kg^{-1} in March 2010 (tree type

× month interaction; $P < 0.03$; Table 5.8). Averaged over two years, WT pods had 42% greater ($P < 0.01$) Ca concentrations than MW (2.7 vs. 1.9 g kg^{-1}).

Seed Ca concentrations did not change ($P > 0.10$) over time for either tree type (Table 5.6). Differences ($P < 0.0001$; Table 5.8) in seed Ca concentrations were observed, but small. Seed from WT trees had greater Ca concentrations (2.9 g kg^{-1}) than those from MW (2.4 g kg^{-1}).

Phosphorous

There was no significant interaction effect when year was included in a three way analysis, so pod data from 2008 and 2009 were combined. Phosphorus concentrations decreased ($P < 0.0001$) from November to March in pods from both tree types. Values declined from 1.9 to 1.6 g kg^{-1} in MW pods and from 1.5 to 1.2 g kg^{-1} in WT pods. Average P concentration in MW pods (1.8 g kg^{-1}) was 30% greater ($P < 0.0001$) than that of WT pods (1.4 g kg^{-1}).

Seeds had about twice as much P as pods, and seed P concentrations were similar ($P = 0.2485$) for both tree types. Averaged over tree type, seed P concentrations decreased ($P = 0.0002$) slightly from November 2008 (3.7 g kg^{-1}) to March 2009 (3.4 g kg^{-1}).

Sulfur

In 2008, MW and WT pods had similar ($P > 0.10$) S concentrations within each month (Table 5.5); average concentrations decreased ($P < 0.0001$) from 0.50 g kg^{-1} in November to 0.42 g kg^{-1} in March. In 2009, however, S concentrations were greater ($P = 0.0009$) in WT pods (0.43 vs. 0.36 g kg^{-1}) but did not change ($P = 0.2188$) over time.

Sulfur concentrations (0.75 g kg^{-1}) in MW seed did not differ ($P = 0.9998$; Table 5.6) by month. Initial (November) S concentrations in WT seeds (0.84 g kg^{-1}) were greater ($P = 0.0103$)

than in MW but by March, S levels in WT (0.77 g kg^{-1}) seeds were similar ($P = 0.8694$) to that of MW (tree type × month interaction; $P \geq 0.05$; Table 5.6 and 5.8).

Magnesium

In 2008, Mg concentrations (0.73 g kg^{-1}) did not change ($P = 0.3631$) over time in MW pods but tended ($P = 0.0533$) to increase from November (0.44 g kg^{-1}) to March (0.58 g kg^{-1}) in WT pods (Table 5.5). Average Mg concentrations in MW pods (0.73 g kg^{-1}) were 43% greater ($P < 0.0001$) than that of WT pods (0.51 g kg^{-1}; Table 5.8). Over 4 mo in 2009, pod Mg concentrations increased ($P < 0.0001$) from 0.68 g kg^{-1} to 0.78 g kg^{-1} in MW pods and from 0.69 g kg^{-1} to 1.00 g kg^{-1} in WT pods (tree type × month interaction; $P = 0.0020$; Table 5.8). Average Mg concentrations in WT pods (0.85 g kg^{-1}) were greater ($P = 0.0005$) than in MW pods (0.73 g kg^{-1}).

Seed Mg concentrations did not change ($P = 0.1568$) over time with either tree type. Although the difference was small, average Mg concentrations within MW seeds (1.72%) were greater ($P = 0.0180$) than those within WT seeds (1.69 g kg^{-1}).

Copper

From November 2008 to March 2009, Cu concentrations did not change ($P > 0.05$; Table 5.5) in MW pods (0.0031 g kg^{-1}) but increased ($P < 0.05$) from 0.0027 g kg^{-1} to March 0.0035 g kg^{-1} in WT pods (tree type × month interaction; $P = 0.0134$; Table 5.8). Copper concentrations increased ($P < 0.03$) with time for both pod types during 2009-2010 from 0.0036 to 0.0042 g kg^{-1} for MW and 0.0040 to 0.0049 g kg^{-1} for WT pods). Average Cu concentrations were greater ($P = 0.0005$; Table 5.8) in WT pods than in MW pods.

Seed Cu concentrations (0.025 g kg^{-1}) were similar between tree types (*P* = 0.4804) and did not change (*P* = 0.4544) over time (Table 5.8).

Discussion

Nutritive quality

Pod nutritive value changed very little in 2008, but a general pattern of decreasing digestibility in MW pods and increasing fiber concentrations in WT pods was observed. Decreases in pod IVTD and corresponding increases in pod fiber and lignin concentrations were greater in 2009 than in 2008, most likely due to wetter environmental conditions. In 2009, MW and WT pods collected in February and March were visibly more tattered, molded, and/or degraded than those collected in November. Although MW pods were more digestible and less fibrous, they were unexpectedly more resistant to degradation than WT pods. The decrease in digestibility from November to March was over two-fold greater for WT pods compared to MW pods. Likewise, fiber and lignin concentrations increased at a greater rate than that of MW pods. Average MW pod fiber was up to 2.5 times more digestible than that of WT. In general, pod protein did not change over winter in both 2008 and 2009. Relative average differences in pod protein concentrations were inconsistent from year to year, as well as between tree type. Further, differences in CP, although significant, were usually small.

Similar results of increasing fiber and decreasing digestibility in feeds exposed to environmental conditions over winter have been found other studies. Hand et al. (1994) found that legume-grass (*Medicago sativa*/ *Bromis inermis*) round bales stored 10 mo. outdoors without covering had 3.1 and 1.8 percentage unit increases in NDF and ADF fractions, respectively (core samples were taken at the center of each bale, 30 cm from the bale end). Higher moisture content within hay bales may cause faster nutritive degradation over time (Atwal et al., 1984; Buckmaster et al., 1989; Han et al., 2004). Buckmaster et al. (1989) found that after 60 days of barn storage, alfalfa hay bales stored at 40 – 50% moisture had ADF concentrations 13% greater and CP concentrations 19% less than those stored at 10 – 15% moisture.

Given their greater digestibility and lower fiber concentrations, MW pods would be expected to degrade at a faster rate than WT pods, but that was not the case. This may be due to a thicker protective coating or a different molecular arrangement of cutin and/or other waxy polymers on the outside of the pod shell. Further research is needed to determine lipid concentrations in pod material. Generally, since pod nutritive value may decline appreciably after pod drop in wet conditions, it is recommended that producers feeding pods in pastures over winter should do so before January (or two months after pod drop).

Honeylocust seeds were largely resistant to short-term degradation. Fiber and CP concentrations, as well as the digestibility of whole and ground seeds, remained similar over winter. Seed fiber digestibility also remained similar over time. Although the differences were minute, ground MW seeds were less fibrous and more digestible, but contained less CP than WT seeds. Seeds from both tree types contained no observable concentrations of ADL. Ground honeylocust seeds were nearly 5-fold more digestible than whole seeds. Limitations may exist if cattle cannot digest CP sources in whole seeds, since CP concentrations of pod fractions do not meet maintenance requirements.

The integrity of whole seeds over winter was highly dependent on the prevelance of boring insects, rather than weathering over time. Damage to honeylocust seeds increased over time, however whole seed digestibility was not affected. Although boring insects degraded or consumed small amounts of seed material, they may have also made nutrients within the seed more available for digestion. Le Roux (1959) also observed that boring ‘weevils’ were prevalent within honeylocust seeds after wild type seedpods were stored over many years in dry conditions.

Mineral concentrations

Whole honeylocust seedpods have greater K and Ca concentrations than more conventional feeds with comparable nutritive quality. However, seedpod P, S, and Mg concentrations fall below the maintenance requirements of a dry pregnant cow (Table 5.9). Change in most pod mineral concentrations, as well as the relative differences between pod types, were variable from year to year and no consistent patterns were evident. Concentrations of P and K in pods decreased over winter in both 2008 and 2009. Seeds had about twice as much P and Mg as pods; time increased seed P, but had little effect on Mg. Due to overall variability among minerals, no one pattern can be used to conclusively predict mineral responses to environmental exposure over time.

Conclusions

Nutritive value and digestibility of MW and WT honeylocust pods may decline appreciably after pod drop in wet conditions. Producers feeding pods within pastures over winter should do so before January. Although MW pods were more digestible and less fibrous, they were more resistant to degradation with environmental exposure than were WT honeylocust pods. Honeylocust seeds were largely resistant to degradation over winter, but ground seeds are considerably more digestible than whole seeds. Change in seedpod mineral concentrations over winter were variable and may not be affected by environmental exposure. Honeylocust trees have great potential to provide land managers with valuable fodders for livestock production.

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

	Calibration				Validation	
Item	n	Mean	R^2	SEC‡	1-VR§	SECV¶
IVTD	75	0.7901	0.9828	0.0147	0.9701	0.0195
NDF	72	0.2755	0.9934	0.0782	0.9854	0.0117
ADF	72	0.1871	0.9908	0.0727	0.9833	0.0980
ADL	47	0.0725	0.9230	0.0513	0.8536	0.0709
CP	74	0.0947	0.9973	0.0330	0.9960	0.0402

† IVTD= In vitro true digestibility; NDF= neutral detergent fiber; ADF= acid detergent fiber; ADL= acid detergent lignin; CP= crude protein.

‡ 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. Millwood and wild type honeylocust pod nutritive value[†‡] over winter in 2008 and 2009

November 2008 – March 2009

	Millwood Pod					**Wild Type Pod**					
	Nov.	Dec	Jan	Feb	Mar	Nov.	Dec	Jan	Feb	Mar	SE
			$g\ kg^{-1}$					$g\ kg^{-1}$			
IVTD	800a	773ab	758ab	744b	754b	658c	654c	640c	639c	625c	15
NDF	274a	288ab	300ab	315b	303ab	391c	391c	417c	426c	435c	13
ADF	198a	206a	220a	228a	219a	274a	284ab	305ab	307ab	314b	10
ADL	61a	68a	72a	76a	74a	96b	99bc	108bc	107bc	112c	04
NDFd	324a	262ab	241bc	232bcd	233bc	159e	148e	165de	180cde	166de	20
CP	52a	54a	51a	50a	54a	59ab	69bc	68bc	73c	68bc	04

November 2009 – March 2010

	Millwood Pod					**Wild Type Pod**					
	Nov	Dec	Jan	Feb	Mar	Nov	Dec	Jan	Feb	Mar	SE
			$g\ kg^{-1}$					$g\ kg^{-1}$			
IVTD	864a	846ab	867a	825bc	785c	701d	646e	648e	601e	541f	18
NDF	209a	235ab	223a	262b	301c	369d	411de	423ef	467fg	501g	17
ADF	151a	161a	170ab	194bc	226c	270d	302de	309e	344f	367f	12
ADL	46a	51ab	46a	58b	72c	90d	106e	107ef	123fg	138g	05
NDFd	424ab	410ab	474a	390bc	334c	225d	168de	195d	168de	104e	20
CP	92abc	95ab	95ab	96a	94abc	87bc	86c	88abc	92abc	73d	02

† Means within rows, in the same study year, and followed by the same letter are not significantly different ($P < 0.05$)

‡ Where: IVTD= *In vitro* true digestibility; NDF= neutral detergent fiber; ADF= acid detergent fiber; ADL= acid detergent lignin; NDFd= neutral detergent fiber digestibility; CP= crude protein.

Table 5.3. Millwood and wild type honeylocust seed nutritive value[†‡] over winter in 2008

November 2008 – March 2009											
	Millwood Seed					**Wild Type Seed**					
	Nov	Dec	Jan	Feb	Mar	Nov	Dec	Jan	Feb	Mar	SE
	——————— g kg⁻¹ ———————					——————— g kg⁻¹ ———————					
IVTD	965ab	967ab	961abc	965ab	969a	959abcd	946bcd	938d	941cd	941cd	02
WSD	209a	212a	234a	212a	193a	192a	208a	226a	216a	215a	05
NDF	134abcd	130ab	132abc	127a	126a	139bcd	143cd	145d	141bcd	142bcd	01
ADF	75abc	72a	73ab	71a	67a	84bcd	88d	89d	84dc	86d	01
ADL	–	–	–	–	–	–	–	–	–	–	–
NDFd	870ab	876ab	838abc	862ab	895a	827abc	744bcd	691d	703cd	702cd	15
CP	202a	200a	202a	209ab	208ab	213ab	217b	216b	213ab	211ab	02

† Means within rows, in the same study year, and followed by the same letter are not significantly different ($P < 0.05$)

‡ Where: IVTD= *In vitro* true digestibility; WSD= whole seed digestibility; NDF= neutral detergent fiber; ADF= acid detergent fiber; ADL= acid detergent lignin; NDFd= neutral detergent fiber digestibility; CP= crude protein.

Table 5.4. Percent and type of damage in honeylocust seeds over winter in 2008. †

	Nov	Dec	Jan	Feb	Mar	SE
	%					
Total Seed Damage	8.9a	12.1ab	13.6ab	15.6b	13.7ab	0.7
Boring Insect Damage	4.0a	7.0ab	7.4ab	10.9b	7.3ab	0.5
Non-Insect Damage	5.0a	5.1a	6.2a	4.7a	6.4a	0.4

† Means within rows, in the same study year, and followed by the same letter are not significantly different ($P < 0.05$)

Table 5.5. Millwood and wild type honeylocust pod mineral concentrations over winter in 2008 and 2009. †

	2008					2009				
	Millwood Pod		Wild Type Pod			Millwood Pod		Wild Type Pod		
	Nov	Mar	Nov	Mar	SE	Nov	Mar	Nov	Mar	SE
	$g\ kg^{-1}$					$g\ kg^{-1}$				
P	1.9a	1.5b	1.4b	1.1c	0.02	2.0a	1.7b	1.7b	1.2c	0.02
K	15.9a	13.3b	17.7a	12.6b	0.4	13.1a	10.0b	12.2a	6.0c	0.2
Ca	1.9a	2.4ab	3.1b	3.0b	0.1	1.6a	1.8ab	2.0b	2.7c	0.1
S	0.48ab	0.40c	0.52a	0.44bc	0.01	0.35a	0.38ab	0.42b	0.43b	0.01
Mg	0.69ab	0.77a	0.44c	0.58bc	0.03	0.68a	0.78b	0.69ab	1.00c	0.04
Cu	0.0030ab	0.0033bc	0.0027a	0.0035c	0.0001	0.0036a	0.0042b	0.0040ab	0.0049c	0.0001

† Means within rows, in the same study year, and followed by the same letter are not significantly different ($P < 0.05$)

Table 5.6. Millwood and wild type honeylocust seed mineral concentrations over winter in 2008. †

	Millwood Seed		Wild Type Seed		
	Nov	Mar	Nov	Mar	SE
	———————— g kg⁻¹ ————————				
P	3.5ab	3.7c	3.4b	3.7ac	0.03
K	11.3a	11.2a	12.7b	12.5b	0.09
Ca	3.0a	2.8ab	2.5bc	2.3c	0.08
S	0.76a	0.75a	0.84b	0.77a	0.01
Mg	1.7ab	1.7a	1.7b	1.7ab	0.01
Cu	0.025a	0.019a	0.029a	0.025a	0.002

† Means within rows, in the same study year, and followed by the same letter are not significantly different ($P < 0.05$)

Table 5.7. Summary of probability values for nutritive value† analysis of ground pods and seeds, and nutritive value and damage‡ to whole seeds

	2008			2009		
	Tree Type	**Month**	**Tree Type × Month**	**Tree Type**	**Month**	**Tree Type × Month**
DF	**1**	**4**	**4**	**1**	**4**	**4**
	P value					
Pod IVTD	< 0.0001	0.00	0.3	< 0.0001	< 0.0001	0.1
Pod NDF	< 0.0001	0.0004	0.7	< 0.0001	< 0.0001	0.4
Pod ADF	< 0.0001	0.0003	0.7	< 0.0001	< 0.0001	0.2
Pod ADL	< 0.0001	0.0001	0.8	< 0.0001	< 0.0001	0.08
Pod NDFd	< 0.0001	0.0312	0.003	< 0.0001	< 0.0001	0.07
Pod CP	< 0.0001	0.2	0.08	< 0.0001	< 0.0001	0.0001
Seed IVTD	< 0.0001	0.09	0.1	–	–	–
Seed NDF	< 0.0001	0.3	0.2	–	–	–
Seed ADF	< 0.0001	0.2	0.3	–	–	–
Seed NDFd	< 0.0001	0.06	0.1	–	–	–
Seed CP	< 0.0001	0.8	0.05	–	–	–
Seed WSD	1.0	0.3	0.7	–	–	–
Seed TOTD	0.5	0.03	1.0	–	–	–
Seed BID	0.9	0.0009	0.7	–	–	–
Seed OTID	0.2	0.6	0.7	–	–	–

† IVTD= *In vitro* true digestibility; NDF= neutral detergent fiber; ADF= acid detergent fiber; ADL= acid detergent lignin; NDFd= neutral detergent fiber digestibility; CP= crude protein; WSD= whole seed digestibility

‡ TOTD= total seed damage; BID= seed damage caused by boring insects; OTID= damage caused by sources other than insects

Table 5.8. Analysis of variance and source table for change in pod and seed mineral concentrations over winter in 2008 and 2009

	2008			2009		
	Tree Type	**Month**	**Tree Type × Month**	**Tree Type**	**Month**	**Tree Type × Month**
DF	**1**	**1**	**1**	**1**	**1**	**1**
	——— P value ———					
Pod P	<0.0001	<0.0001	0.5	<0.0001	<0.0001	0.5
Pod K	0.3	<0.0001	0.03	<0.0001	<0.0001	<0.0001
Pod Ca	0.0005	0.3	0.10	<0.0001	0.0003	0.03
Pod S	0.01	<0.0001	0.9	0.0009	0.2	0.3
Pod Mg	<0.0001	0.007	0.4	0.0005	<0.0001	0.002
Pod Cu	0.4	<0.0001	0.01	0.0005	0.0001	0.4
Seed P	0.2	0.0002	0.4	–	–	–
Seed K	<0.0001	0.3	0.6	–	–	–
Seed Ca	<0.0001	0.02	0.7	–	–	–
Seed S	0.007	0.04	0.05	–	–	–
Seed Mg	0.02	0.2	0.9	–	–	–
Seed Cu	0.5	0.5	0.6	–	–	–

Table 5.9. Mineral profile of whole Millwood and wild type seedpods†, whole ear dent corn‡, and oat grain‡, as well as mineral requirements of dry pregnant cows‡

	Whole Honeylocust Seedpods†		Conventional feeds with comparable nutritive quality‡ to Millwood		Requirements for dry pregnant cows‡
	Millwood	Wild Type	Whole Ear Dent Corn	Oat Grain	
	——— g kg⁻¹ ———				
P	2.2	2.2	2.7	3.8	2.4
K	13.6	14.1	5.3	4.4	6.5
Ca	2.4	2.8	0.7	0.7	3.9
S	0.53	0.61	1.60	2.30	1.6
Mg	1.01	0.98	1.40	1.40	1.6
Cu	0.0085	0.0126	0.0080	0.0070	0.01

† Calculated from average 2008 pod and seed results. In 2009, MW seeds comprised 28.4% and WT seeds comprised 39.8% of whole seedpod DM. In 2009, seedpods did not contain enough seed material to conduct lab analyses.

‡ NRC (1989). Nutritional requirements of dairy cattle

Figure 5.1. Seed damage caused by boring insects.

Chapter 6: Response of Black Walnut Tree Product Productivity to Density and Slope Changes

Abstract

Black walnut has great potential to offer a variety of short- and long-term income sources for land managers utilizing agroforestry practices. However, since black walnut agroforestry has not been commonly used in the Appalachian region, studies focusing on management strategies are necessary to understand its potential.

Differences in black walnut biomass productivity, nut production, and kernel quality in response to tree stand density and topography were determined within an emulated silvopasture. In the spring of 1995, walnut trees were planted in replicated plots (r =3) into existing tall fescue pastures. Four tree rows were planted down-slope within each tree plot; from west to east, within-row spacings are 1.8, 3.7, 7.3 and 14.6 m, and between-row spacings are 3.7, 7.3, and 14.6 m (Figure 3.4).

In Spring 2009, measurements such as tree height, diameter at breast height (DBH), live crown ratio (LCR), crown width, stem quality, total aboveground biomass (TAB), and timber volume (VOL) were obtained. In October of 2008 and 2009, nut counts were estimated using a standardized sampling procedure. In 2009, nuts were also subsampled and used to estimate nut quality, which was defined by desirable kernel color, weight, and the percent kernel within hulled, dried shells.

Trees planted at toe-slopes had both greater DBH (P = 0.0202) and height (P = 0.0168) than those planted on shoulder slopes. Tree height increased (P = 0.0003) as row spacing decreased. Estimated total aboveground biomass for trees planted on toe-slopes (109.0 kg) was

72% greater (*P* = 0.0162) than at back slopes (63.2 kg) and nearly 3-fold more than at shoulder-slopes (37.6 kg). Tree crown size increased (*P* < 0.0001) as tree spacing increased.

Nut yields ranged from 0 to 7.9 kg of dried, hulled nuts tree^{-1} year^{-1}. All trees displayed alternate nut bearing patterns, with 2008 characterized by relatively high and 2009 by relatively low nut yields. Nut production was marked by high variability even among trees within the same slope and density treatments. Nut yields per tree were similar (*P* = 0.3166) across density treatments, but trees planted on toe-slopes had greater (*P* = 0.0056) average nut yields (69 nuts tree^{-1}) than trees on shoulder-slopes (4 nuts tree^{-1}). Average kernel weight (2.7 g), color (dark), and percent kernel (17.0%) within walnut shells did not change (*P* > 0.05) with tree spacing or topographic position.

Hypothesis

Black walnut timber quality, as well as nut production and kernel quality will vary across tree stand density and topography gradients within an emulated silvopasture maintained with minimal management.

Objectives

1. To determine black walnut biomass productivity and timber quality in response to tree stand density and topography within an emulated silvopasture.
2. To determine black walnut nut production and kernel quality in response to tree stand density and topography within an emulated silvopasture.

Materials and Methods

In the spring of 1995, walnut trees were planted in replicated plots (r =3) into existing tall fescue pastures. All walnut trees were seeded from a single unknown, wild variety chosen for its greater-than-average nut production. Four tree rows were planted down-slope within each tree plot; from west to east, within-row spacings are 1.8, 3.7, 7.3 and 14.6 m, and between-row spacings are 3.7, 7.3, and 14.6 m (Figure 3.4). The resulting density treatments were 1480 trees ha^{-1} (high), 370 trees ha^{-1} (moderately high), 100 trees ha^{-1} (moderately low), and 50 trees ha^{-1} (low).

Total biomass across landscape and planting-density gradients was estimated by measuring tree height and DBH of each walnut tree within the RAS in spring 2009. Tree height was determined with a handheld clinometer (PM-5/PC66 Clinometer, Suunto Oy, Vantaa, Finland). Live crown ratio, crown width, and stem quality also were estimated in spring 2009 to ensure proper canopy and timber quality characterization for each tree. Stem volume estimates were determined from DBH and tree height measurements according to Hahn and Hansen (1991). Equations from Smith (1986) were used to estimate total aboveground biomass. Further, trees were classified as either acceptable or unacceptable growing stock based upon visual observations of growth form, presence of disease, and damage to boles.

A standardized grid system was established in each replicate to determine nut yields across landscape and planting-density gradients in 2008 and 2009. Transect lines for each grid were established from a single, randomly-selected base point in the southwest corner of each replicate to ensure a random sample throughout the sample area. Sampling intervals between and along transect lines (~30 m long) within the grid were two meters in length. At each sample point, a 1-m^2 quadrat was placed on the ground and all walnuts within the quadrat were counted.

In Fall 2008, nuts were allowed to drop without intervention. Nut counts were made in October when approximately half of the nuts had fallen and again in November 2008 after all nuts had fallen. This sampling timing precluded appropriate assessment of nut quality.

In 2009, nuts were shaken from the trees on October 1st. No appreciable downhill nut roll was observed when mid-slope trees were shaken. Nuts were counted within quadrats along transect lines, subsampled (n = 3), and were used to determine nut quality across the landscape. Nuts were hulled by hand, scrubbed clean with a wire brush, and cracked with a lever-operated nut cracker (Duke Pecan Co., West Point, MS, USA). Nut quality was based upon desirable kernel color and the percent kernel within hulled, dried shell. Percent kernel was determined on a dry weight basis by drying at 105°C for 24 to 48 hrs. Kernel color was measured with a colorimeter (Minolta Chroma Meter CR-300, Ramsey, NJ, USA) with a 6-mm diameter aperture and specular light was included. Two kernel fragments were randomly selected from each sample, two readings (L*, chroma, and hue angle) from different locations were taken of each fragment, and all readings (n = 4) were averaged. The L* measure specifies the range of black to white, chroma (C) quantifies brightness, and hue (H) angle quantifies color. Readings were interpreted and classified according to Warmund (2008), in which L*, C, and H values were summed (LCH sum) and separated into a three tier rating system (Figure 6.1):

1. Light-colored (≥ 150 LCH sum);
2. Medium-colored (149 – 126 LCH sum);
3. Dark-colored (≤ 125 LCH sum) kernel classes.

Light-colored walnut kernels are widely considered to be of higher quality (Ried et al 2007).

Tree and nut count data of 2008 and 2009 were each further processed using ESRI's ArcGIS 9.3.1, comprehensive Geographic Information Systems (GIS) software. To attribute nut count points to individual trees, the nut count grid centroid points and tree location points were entered as separate layers. Buffers were created for tree points that were equal to 1/3 of the given tree's canopy width. A nearest distance function (NEAR tool in the Analysis toolbox) was used to determine the tree buffer nearest to each nut count point. Attributes of 2008 and 2009 nut count points were each summarized by tree buffer to estimate nuts produced per tree. Nuts counted per tree were doubled to account for non-sampled regions within the grid.

Data Analysis

The data were checked for normality using the Shapiro-Wilk W Test and, where these conditions were not met, data were transformed as appropriate using log transformations. Variance of data was plotted and visually assessed for homogeneity. Tree growth characteristics, nut quality, and estimates of nuts tree^{-1} were analyzed in a spit plot with subsampling design. Field replicates, slope, and density treatments were considered as main-, sub-, and sub-sub plots, respectively. The analysis of variance (ANOVA) was conducted using JMP software (SAS Institute, Cary, North Carolina). The least squares means Tukey HSD test was used to determine significance among mean values following analysis.

Severely stunted tree growth (DBH < 3.0) was assumed to be a result of competition rather than density or slope effects, and such trees were excluded from analysis. This is justified because such trees would likely be thinned in an actively managed walnut plantation. Further, since all trees displayed some variation of alternate nut bearing pattern, two years of nut count data were added together prior to analysis. Due to low nut yields in 2009 nut quality data were missing from field replicate 3 and all shoulder-slope treatments. Thus, only nut quality data from toe- and back-slopes in reps 1 and 2 were analyzed.

A separate analysis of nut yield was conducted to account for any occurrences of nuts rolling down back-slope treatments – especially in 2008. Average nut yields per tree were calculated as the totals of all nut counts within each treatment area divided by all trees (with DBH > 3) within that given treatment area. Nut yields were analyzed as a spit plot (without sub-sampling); replicates were considered main plots and slope and density treatments were subplots. However, because results (averaged over area) were comparable to analysis of nut production estimates from individual trees, only those data are presented.

Results

Tree growth characteristics

DBH and height

Trees planted at toe-slopes had both greater DBH (P = 0.0202) and height (P = 0.0168; Table 6.1) than those planted on shoulder slopes. However, tree DBH and height on back-slopes were similar (P <0.05) to those at both toe- and shoulder-slopes. Average DBH values for toe-, back-, and shoulder-slopes were 16.0, 13.5, and 11.5 cm, and average height values were 8.5, 7.2, and 5.5 m, respectively (Figures 6.2 and 6.3). Tree DBH did not change (P = 0.1292), but tree height increased (P = 0.0003) as tree spacing decreased. Average tree height for high, moderately high, moderately low, and low density treatments were 7.5, 7.5, 6.5, and 6.8 m, respectively.

Aboveground biomass and timber volume

Total aboveground biomass (TAB) for trees planted on toe-slopes (109.0 kg) was 72% greater (P = 0.0162) than on back- (63.2 kg) and nearly 3-fold more than on shoulder-slopes

(37.6 kg). Tree TAB did not change significantly ($P = 0.1821$) with density, but values had a pattern of gradual increase with wider spacing (Figure 6.4). Timber volume (VOL) followed the same patterns as TAB. Timber volume on toe-slopes (2.6 gross ft^3) was 67% and 164% greater ($P = 0.0193$) than back- (1.6 gross ft^3) and shoulder-slopes (1.0 gross ft^3), respectively. Timber volume did not change significantly ($P = 0.1592$; Table 6.1) with density, but values had a pattern of gradual increase with wider spacing. The proportion of acceptable growing stock of all trees was 91%.

Live crown ratio

The size of tree crowns increased ($P = <0.0001$) as tree spacing increased (Table 6.1). From highest to lowest density, mean crown ratios were 39, 42, 50, and 54%. Trees planted on toe-slopes tended ($P = 0.0990$) to have greater live crown ratio (49%) when compared to trees on back- (47%) and shoulder-slopes (43%; Figure 6.5).

Nut yields

All trees displayed alternate nut bearing patterns; high yields in 2008 were followed by much lower yields in 2009. Further, a high degree of variability in nut production was observed among trees, even within the same slope and density treatments. Nuts per tree did not differ ($P = 0.3166$) with tree stand density. Trees on toe-slopes had more ($P = 0.0056$) nuts (69 nuts $tree^{-1}$) than trees on shoulder-slopes (4 nuts $tree^{-1}$). Nuts per tree on back-slopes (25) did not differ ($P > 0.05$) to those on toe-slopes, but were greater ($P < 0.05$) than on shoulder-slopes. The greatest average nut count (114 nuts $tree^{-1}$) was in moderately low densities at the toe-slope position (Figure 6.6).

Nut yields ranged from 0 to 7.9 kg of dried, hulled nuts tree^{-1} year^{-1}. Data from the 10 trees having the greatest average nut yields per year are displayed in Table 6.5. Of 168 trees assessed for nut yields in 2008, most (101 trees; 60%) produced either no nuts or less than 50 nuts tree^{-1} (Table 6.6). However, 35 trees (21%) produced 50 to 100 nuts tree^{-1}, 22 trees (13%) produced 100 to 200 nuts tree^{-1}, 4 trees (2%) produced 200 - 300 nuts tree^{-1}, and 6 trees (4%) produced more than 300 nuts tree^{-1}. Seven of the 10 trees that yielded over 200 nuts tree^{-1} in 2008 were growing in toe-slope positions and in moderately low and low density treatments. In 2009, the large majority of trees (164 trees; 98%) produced less than 50 nuts tree^{-1}, and of all nut bearing trees, only 5 were situated on shoulder slopes.

Kernel quality

The proportion of kernel to shell in harvested nut samples ranged from 1 to 30%. The percent of kernel DM within walnut shells did not change ($P > 0.30$) with tree spacing or topographic position (Table 6.2). Average kernel-to-shell proportion across all treatments was 17.0% of total nut DM. Kernel mass ranged from 0.1 to 4.7 g nut^{-1} (DM basis).

Treatment effects on kernel weight were obscured by slope X density interaction ($P < 0.0001$; Table 6.2). Kernel weights generally increased as tree density decreased (Table 6.7), but statistical effects were not significant ($P > 0.05$), largely due to extremely low kernel weights from trees at low-density back-slope positions. Trees planted at 100 stems ha^{-1} produced nuts with the highest numerical values for nut weight (3.0 g). Across treatments, kernel weights averaged 2.7 g nut^{-1} and not did not change ($P = 0.3723$) with topographic position.

Kernels had lowest numeric LCHsum values (103.5) with low tree density, but response to spacing varied with slope position (slope X density interaction; $P = 0.0154$; Table 6.2). Trees growing at high densities had the lightest colored nuts (LCHsum = 115.2). Average kernel LCHsum value was 111.1 across all treatments. Kernels from all treatments were dark (LCH sum ≤ 125) colored and unaffected (*P* = 0.5922) by topographic position.

Discussion

Greater total aboveground biomass production observed at back- and toe-slope positions reflects both the site selectivity of and site suitability for black walnut trees. Generally, walnuts that grow on concave upper slopes have shallower rooting depth and reduced access to moisture (Jones and Saviello, 1991) and slopes of 10% or more can decrease the site index (base age 50 years) of black walnut trees by at least 1.3 m (Geyer et al., 1980). Neither total aboveground biomass nor timber volume changed with density, although numeric values had a pattern of gradual increase with wider spacing.

Juvenile trees in this study had insufficient timber volume to obtain reasonable profits from the original investment of tree planting. Highest density plantings would have the greatest value based on current hardwood pulpwood prices (Table 6.3). As trees grow, however, the lower competition for above- and belowground resources at wider spacings on toe-slopes would likely favor the development of greater quality (and higher value) saw logs or veneer (Schlesinger and Funk, 1977; Burde, 1988).

The variable nut production (over years and within stands) observed in this study is common in the literature (Zarger, 1946; Jones et al., 1995; Ares and Brauer, 2004; Reid et al., 2007). Nut yields were similar across density treatments, but greater for trees planted at back- and toe-slope positions.

Tree planting arrangement limited our ability to forecast the economic value of nut production. Tree stand density effects on nut production were confounded by edge effects. Despite having the highest in-row spacing, trees in the first row were completely open on one side (Figure 3.4), allowing half of tree canopies access to nearly full sunlight. It is likely that a 13- to14-yr-old plantation of multiple tree rows, spaced at 1480 trees ha^{-1} would have considerably lower nut yields than those observed in this study. Walnuts planted close together often experience canopy crowding and a loss of lower limbs due to shading effects; this can dramatically decrease nut production and quality (Reid et al., 2007). In contrast, all trees within moderately low and low densities appeared to be in free-growth form.

The highest 2-yr average nut yield (57 nuts tree^{-1}) was found at 100 trees ha^{-1} at the toe-slope position (Table 6.4). However, because of high tree numbers, the greatest estimated yield per ha (359.3 kg ha^{-1}) was observed with the highest density treatment (1480 trees ha^{-1}) at the toe slope. It is unlikely that trees planted at this high density will continue to produce the greatest amounts of nuts per ha, as tree-to-tree competition increases in the future and limits tree growth. Economic estimates from nut yields and timber productivity (Table 6.3 and 6.4) indicate that nut production will generate greater revenues than pulpwood harvesting in a juvenile walnut plantation. The same may be true of mature walnut stands. Financial analyses of black walnut agroforestry systems in Missouri suggested internal rates of return and net present worth were maximized by sacrificing log length for greater crown area for nut production (Garrett and Harper, 1999). Managing walnut trees with free growth canopy structure is generally recommended for maximizing nut production (Reid et al., 2007). However, dense tree plantings in the beginning years optimize nut yields in juvenile walnut plantations (Reid et al., 2007). Depending on the goals of land managers, tree spacing in more mature plantations may be reduced to optimize timber production. Garrett et al. (1996) suggest that a spacing of 3 m X 10 m (276 trees ha^{-1}) is a good compromise between nut and timber production in mature plantations.

Walnut kernel yield and quality generally was not influenced by planting density or topographical position. Total nut and kernel weights averaged 16.0 and 2.7 g, respectively. Comparable nut weights were reported for 130 'select' 17-yr-old walnut trees grown on high quality sites (SI 27.5+) in Missouri (Jones et al., 1995). However, approximately 90% (118) of the trees examined by Jones et al. (1995) produced nuts with a greater percent kernel than found in this study (17.0%). Kernels of all nuts harvested within this study were of a similar dark color. As walnut husks deteriorate, black staining alkaloids soak through the shell and into the kernel meat (Ried et al., 2004). The resulting dark colored kernels are generally characterized by more intense burnt, woody, and/or astringent flavors than more light colored kernels (Warmund et al., 2009). Thus the colors measured were most likely the result of a relatively late harvest date and/or the delayed time between harvest and hulling (7-14 days; Warmund et al. 2008). In Missouri, nuts are traditionally harvested and hulled from early September through early October (Rickman, 1998). Further research would be needed to determine optimal harvest and hulling dates within southwest Virginia.

Estimating economic value of black walnut tree spacings may be further complicated for landscape managers choosing to incorporate these trees into silvopasture production systems. Land managers may prefer to reduce investments in dense tree plantings during early stages of growth in order to maximize annual profits received from grazing livestock, and yet this reduction may be somewhat offset by greater forage production under moderately-spaced immature trees (Buergler et al., 2006).

Conclusions

Individual juvenile walnut trees were more productive when planted in low densities at toe- positions with 10 – 25% concave slopes. However, higher density plantings have economic advantage during the early stages of growth due to overall greater biomass and nut production. As trees mature, wider spacings on toe-slopes would likely favor the development of greater quality (and higher value) saw or veneer logs. Average kernel weight, color, and percent kernel were unaffected by tree spacing and topographic position. Economic estimates from nut yields and timber productivity indicate that nut production will generate greater revenues than pulpwood harvesting in a juvenile walnut plantation. Black walnut has great potential to offer a variety of short- and long-term income sources for land managers utilizing agroforestry practices.

Table 6.1. Summary of probability values for tree productivity indicators†

	DF	DBH	Tree Height	LCR	TAB	VOL	Nut count
		P-value					
Block	2	0.3392	0.6924	0.0668	0.297	0.3161	0.4446
Slope	2	0.0202	0.0168	0.0990	0.0162	0.0193	0.0056
Density	3	0.1292	0.0003	<0.0001	0.1821	0.1592	0.3166
Density*Slope	6	0.9641	0.9255	0.1345	0.979	0.9726	0.0757

† DF = degrees of freedom; DBH = diameter at breast height; LCR = live crown ratio; TAB = total aboveground biomass; VOL = timber volume.

Table 6.2. Summary of probability values for nut quality indicators.

	DF	Kernel Weight	Percent Kernel	Kernel Color
		P-value		
Block	1	0.4000	0.5517	0.6970
Slope	1	0.3723	0.3217	0.5922
Density	3	0.0405	0.8333	0.0345
Density*Slope	3	<0.0001	0.1997	0.0154

Table 6.3. Estimated timber yield and economic value of walnut trees planted in various topographic positions and tree spacings.

Slope Position	Tree Spacing‡ (trees ha^{-1})	Avg. TAB† (kg tree^{-1})	Avg. Timber Volume (ft^3 tree^{-1})	Estimated Timber Yield (ft^3 ha^{-1})	Estimated Pulpwood Value§ (dollars ha^{-1})
Toe	1480	100.5	2.4	3576	473
	370	105.2	2.5	940	124
	100	114.1	2.8	277	37
	50	116.5	2.8	142	19
Back	1480	54.7	1.4	2002	265
	370	69.5	1.8	649	86
	100	60.8	1.5	150	20
	50	68.6	1.7	87	12
Shoulder	1480	30.3	0.8	1165	154
	370	42.4	1.1	421	56
	100	39.2	1.0	104	14
	50	39.1	1.0	52	7

† TAB = total aboveground biomass.

‡ Trees per ha based on spacing of high (1.8 X 3.7 m), moderately high (3.7 X 7.3 m), moderately low (7.3 X 14.6 m), and low (14.6 X 14.6 m) density treatments.

§ Estimated from price values presented in Timber Mart South (2001), where the average value of 128 ft^3 hardwood pulpwood is $16.94.

Table 6.4. Estimated economic value of unshelled nut and shelled kernel yields of walnut trees planted in various topographic positions and tree spacings.

Slope Position	Tree Spacing† (trees ha^{-1})	2-yr Avg. Nut Count (nuts tree^{-1})	Nut Yield (kg ha^{-1} yr^{-1})	Kernel Yield‡ (kg ha^{-1}yr^{-1})	Value of Unshelled Nuts§ (dollars ha^{-1} yr^{-1})	Value of Shelled Kernels§ (dollars ha^{-1} yr^{-1})
Toe	1480	15	358.8	61.1	101	808
	370	43	253.7	43.2	71	572
	100	57	91.0	15.5	26	205
	50	38	30.4	5.2	9	69
Back	1480	11	261.5	44.5	74	589
	370	27	161.9	27.6	46	365
	100	7	10.7	1.8	3	24
	50	12	9.3	1.6	3	21
Shoulder	1480	4	93.3	15.9	26	210
	370	3	15.3	2.6	4	34
	100	2	2.4	0.4	1	6
	50	1	0.9	0.2	0	2

† Trees per ha based on spacing of high (1.8 X 3.7 m), moderately high (3.7 X 7.3 m), moderately low (7.3 X 14.6 m), and low (14.6 X 14.6 m) density treatments.

‡ Nut and kernel yields estimated from average weights and percent kernel values of samples collected in toe- and back-slopes of field replicates 1 and 2.

§ Estimated from price values presented in Thomas and Schumann (1993), where unshelled nuts are valued at \$1.65 kg^{-1} and shelled kernels are valued at \$13.23 kg^{-1}.

Table 6.5. Management, growth, and yield characteristics of walnut trees that produced the most nuts over 2008 and 2009.

	Management		Tree Growth[‡]				Nut Yield[§]		
Tree ID	Tree Spacing[†] (trees ha^{-1})	Topography	DBH (cm)	Height (m)	TAB (kg)	LCR (%)	Nut Count (2-yr Avg.)	2-yr Avg. Nut Yield (kg tree^{-1})	2-yr. Avg. Kernel Yield (kg tree^{-1})
r2t56	100	Back	15.7	7.3	90.5	65	116	1.86	0.32
r1t63	370	Toe	17.0	8.8	126.8	50	120	1.92	0.33
r1t65	100	Toe	16.0	8.2	108.7	50	127	2.03	0.35
r1t85	50	Toe	18.8	8.8	162.5	75	141	2.26	0.38
r1t64	100	Toe	15.7	7.9	104.5	60	168	2.69	0.46
r1t67	100	Back	17.0	9.1	124.5	50	180	2.88	0.49
r2t68	50	Toe	22.1	11.0	241.0	75	182	2.91	0.50
r2t54	100	Toe	21.1	9.4	214.3	70	199	3.18	0.54
r1t66	100	Toe	20.6	10.4	203.6	65	355	5.68	0.97
r1t83	100	Back	16.5	8.5	111.0	65	492	7.87	1.34

[†] Trees per ha based on spacing of high (1.8 X 3.7 m), moderately high (3.7 X 7.3 m), moderately low (7.3 X 14.6 m), and low (14.6 X 14.6 m) density treatments

[‡] DBH = diameter at breast height; TAB = total aboveground biomass; LCR = Live Crown Ratio

[§] Nut and kernel yields estimated from average weights and percent kernel values of samples collected in toe- and back-slopes of field replicates 1 and 2

Table 6.6. Distribution of nut counts per tree in 2008 and 2009.

	Nut Counts per Tree					
Year	0	< 50	50 - 100	100 - 200	200 - 300	>300
	——————————— number of trees observed ———————————					
2008	29	72	35	22	4	6
2009	92	72	4	0	0	0

Table 6.7. Quality characteristics of black walnut nuts in response to topographic positions and density treatments.

Slope Position	Tree Spacing† (trees ha^{-1})	Percent Kernel	Weight (g)	Color‡ (LCHsum)
Toe	1480	18.9	2.53	118.9
	370	19.6	2.78	110.6
	100	16.6	2.78	109.4
	50	22.0	3.28	112.6
Back	1480	17.7	2.46	111.6
	370	14.6	2.76	109.6
	100	15.1	3.26	121.2
	50	11.8	1.70	95.2

† Trees per ha based on spacing of high (1.8 X 3.7 m), moderately high (3.7 X 7.3 m), moderately low (7.3 X 14.6 m), and low (14.6 X 14.6m) density treatments.

‡ Values (LCHsum) represent the sum of L*, chroma (C), and hue angle (H). Color values were interpreted and classified according to Warmund (2008).

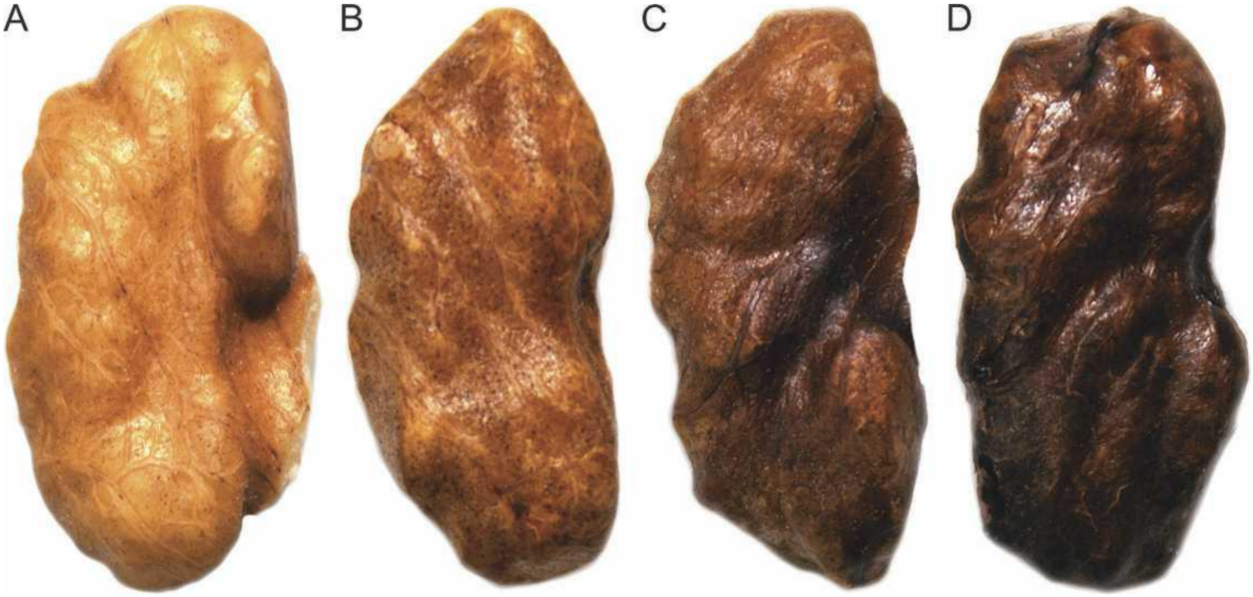

Figure 6.1. Color values for black walnut kernels (adapted from Warmund, 2008): (A) L* = 52.18, chroma = 27.55, hue angle = 72.12, and LCHsum = 151.85; (B) L* = 41.12, chroma = 25.48, hue angle = 66.29, and LCH sum = 132.89; (C) L* = 34.98, chroma = 18.91, hue angle = 56.58, and LCH sum = 110.47; and (D) L* = 30.30, chroma = 11.87 hue angle = 50.00, and LCH sum = 92.17.

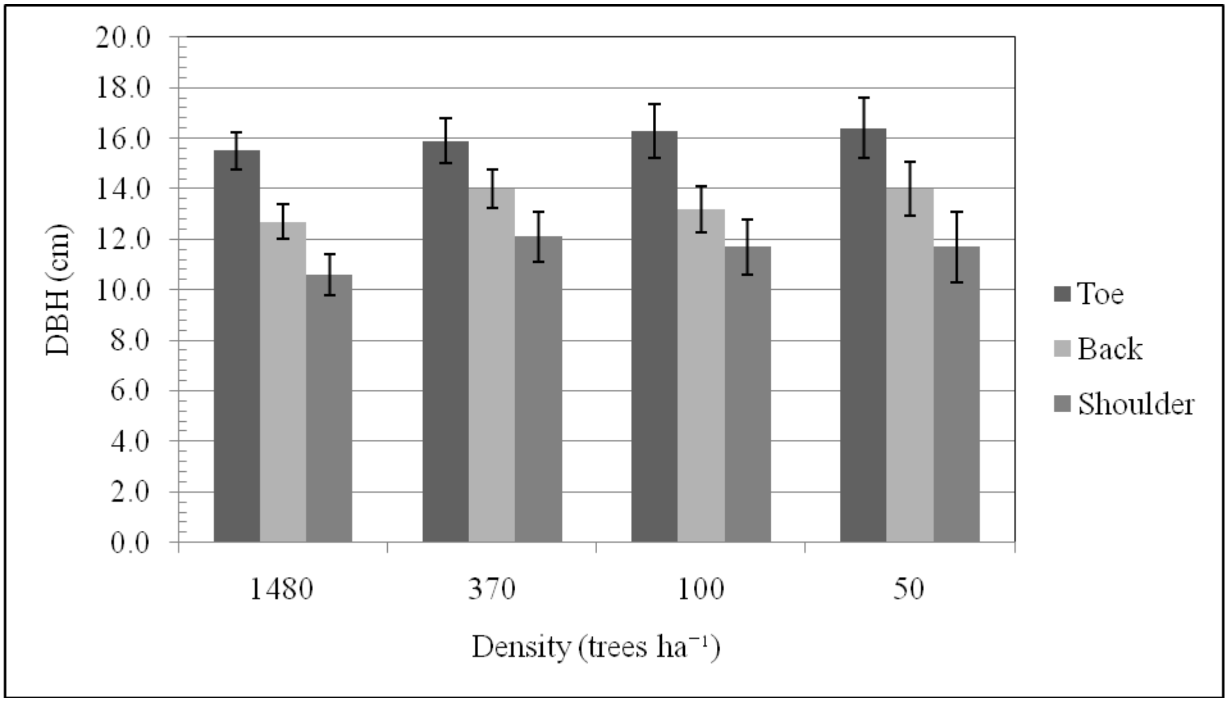

Figure 6.2. Diameter at breast hieght (DBH) of black walnut trees in response to topographic positions and density treatments.

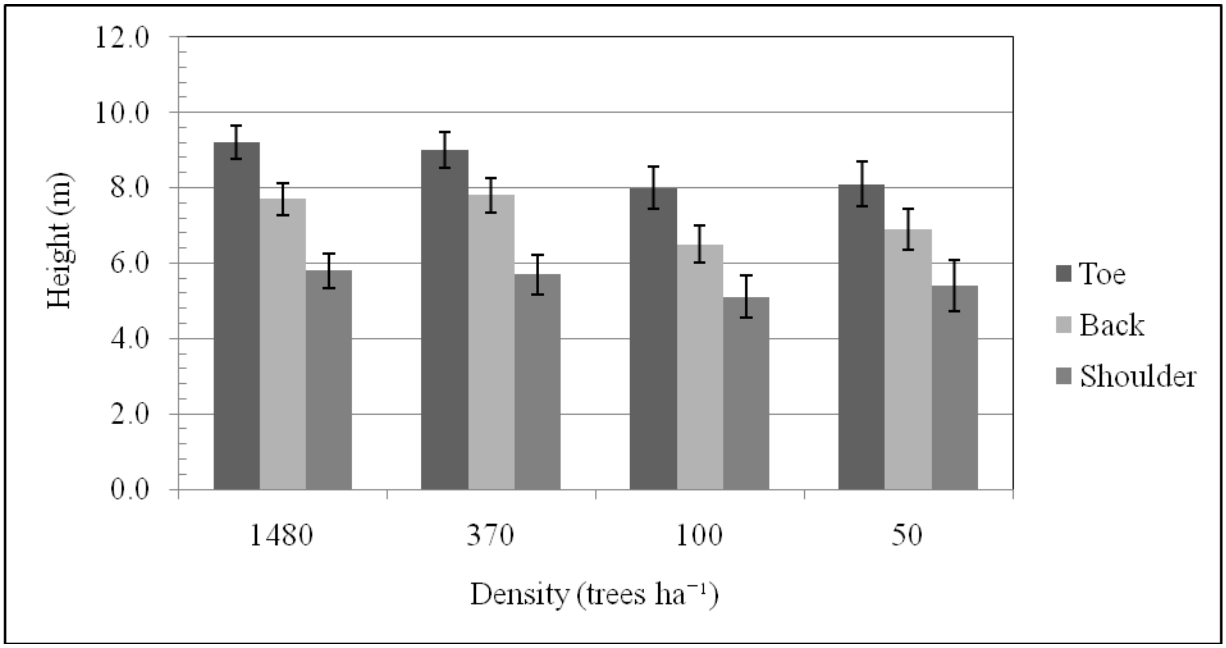

Figure 6.3. Height of black walnut trees in response to topographic position and density treatments.

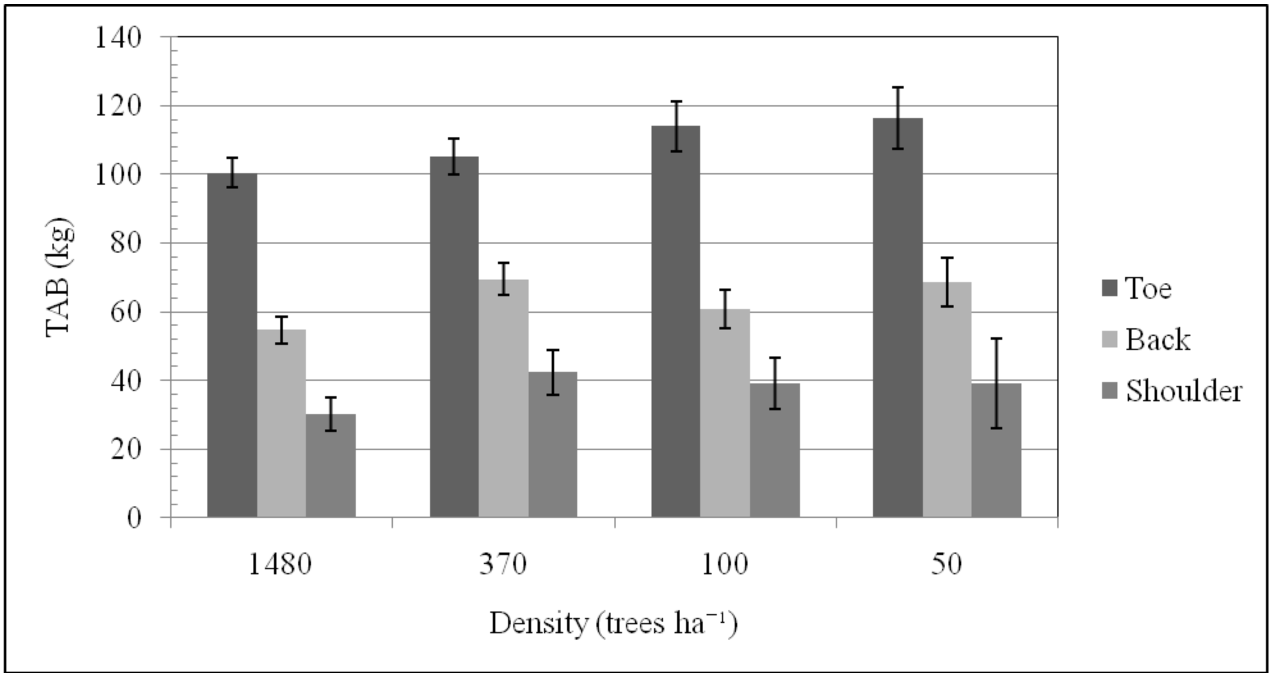

Figure 6.4. Total aboveground biomass (TAB) of black walnut trees in response to topographic positions and density treatments.

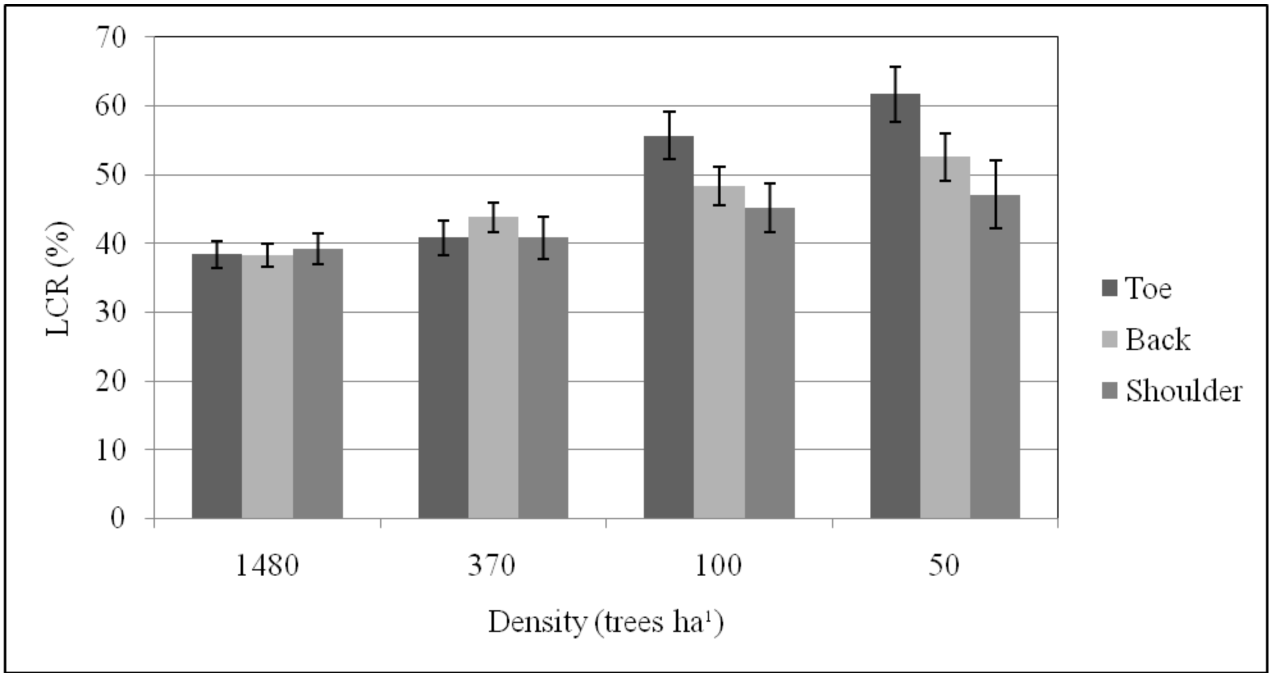

Figure 6.5. Live crown ratio (LCR) of black walnut trees in response to topographic positions and density treatments.

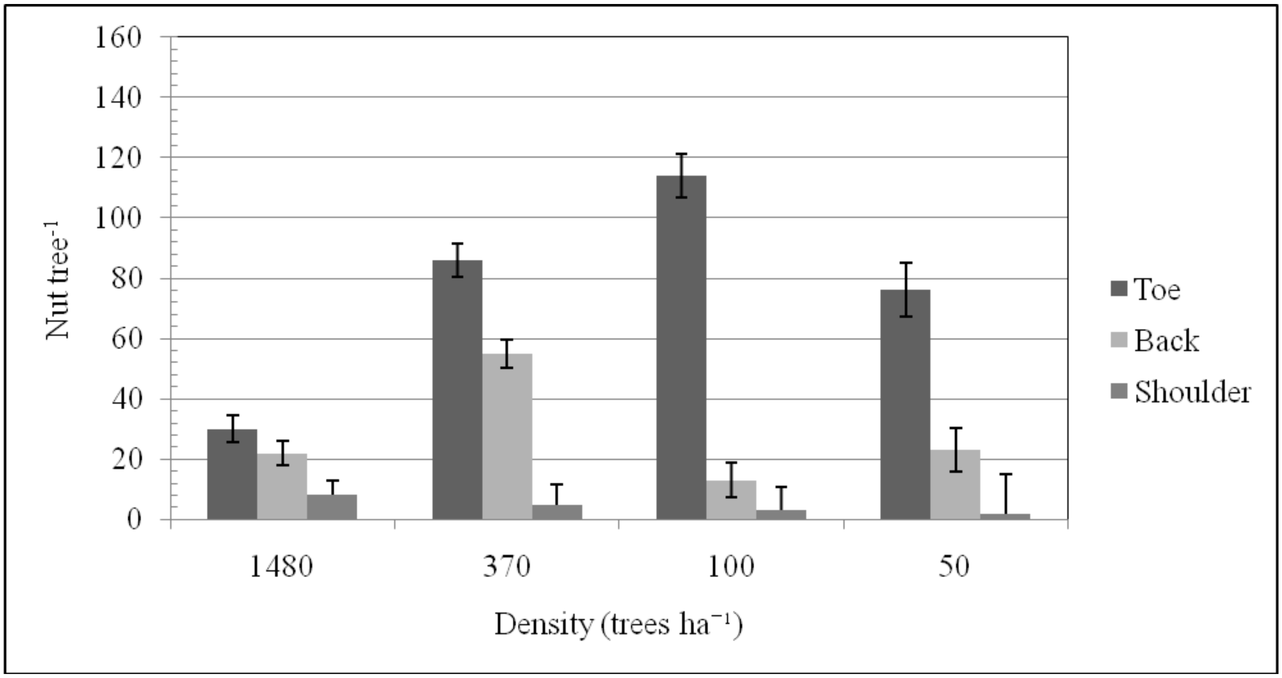

Figure 6.6. Mean nuts tree^{-1} produced by black walnut trees in response to topographic positions and density treatments.

Chapter 7: Conclusions and Considerations for Future Research

Incorporating high-sugar varieties of honeylocust or black walnut trees within pastures may be an effective way to diversify farm incomes and improve biodiversity. Our results suggest that both tree species offer land-managers the ability to generate short-term profit from the harvest of annual tree products (i.e. seedpods and nuts).

Millwood pods and seeds have high digestibility and nutritive value and could be an excellent supplemental feed. However, there are a few limitations that land-managers must consider. Since pod nutritive value may decline appreciably after pod drop in wet conditions, it is recommended that producers feeding pods in pastures over winter do so within the first two months after pod drop. The wetter the weather, the sooner pods should be consumed. Although a good potential energy source, some (e.g., P, S, and Mg) mineral concentrations within whole honeylocust seedpods may fall below the maintenance requirements of cattle.

Millwood seedpods were intriguing in that they were more nutritious yet less degradable than wild type pods with exposure to weathering over time. Research that helps explain this observation would be helpful. In addition, analysis of sugar, lipid, and pectin fractions in pod material would further our understanding of seedpods and their suitability as a feed resource.

Animal performance studies are needed to understand the full potential of honeylocust seedpods as a feed or feed supplement. For example, this study has shown that honeylocust seeds have high CP concentrations, but that ground seeds are considerably more digestible than whole seeds. Also, CP concentrations of pods (without seeds) do not meet the nutritional requirements of cattle. Thus research is needed to determine the ability of various livestock species to digest honeylocust seeds. And, because of such potential differences, ecological research is needed to understand potential invasivity of honeylocust in pastures grazed by cattle vs. small ruminants.

Based on our estimates of pod nutritional value as a feed supplement, Millwood honeylocust trees can produce sufficient yields of seedpods to provide financial benefit for land managers. However, land managers would need to plan for year-to-year yield differences due to alternate bearing patterns, a commonly occurring phenomenon in many fruit, nut, and mast producing trees. Further research on honeylocust may focus on strategies to improve overall yields and bearing patterns through genetic selection, selective thinning, pruning, girdling, and/or more intensive management.

In silvopastures managed to optimize seedpod harvests, land managers likely would allow Millwood pods to fall without intervention and livestock would consume pods freely from the ground. However, since results from this study show pod nutritive value may decline appreciably after pod drop, mechanical harvesting of pods could prove valuable for some land managers. In this context, further research is needed to determine the most efficient means of harvesting, storing, and distributing seedpods to livestock.

Results from the black walnut study found that individual, juvenile trees were more productive when planted in low densities at toe- positions with 10 to 25% concave slopes. Black walnut proved to be a highly site sensitive species and exhibited severe reductions in productivity when planted on sloped sites of poor quality. Thus, black walnuts incorporated into silvopastures would likely be restricted to lowland sites of the highest quality. Higher density plantings were found to have economic advantage during the early stages of growth due to overall greater biomass and nut production. But, as trees mature, wider spacings on toe-slopes would likely favor the development of greater quality (and higher value) saw or veneer logs.

Economic estimates from nut yields and timber productivity indicated that nut production will generate greater revenues than pulpwood harvesting in a juvenile walnut plantation. Since this study was conducted only in 2008 and 2009, future research may focus on a longer-term assessment of nut production and management in Appalachian silvopastures. For example, research is needed to determine optimal harvest and hulling dates for walnuts within southwest Virginia.

The results of our studies suggest that both honeylocust and black walnut trees can provide economic benefit to farmers. However, many challenges exist in the adoption of these methods, since little is known about management considerations unique to the Appalachian region. Research regarding the utilization of these tree species in silvopastures contributes to the larger effort in creating more environmentally, economically, and socially sustainable agricultural systems.

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