RECOMMENDATIONS FOR TREE ESTABLISHMENT IN TALL FESCUE—BASED SILVOPASTURE

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

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ABSTRACT

Silvopasture offers Midwest landowners the opportunity to plant trees in their pastures without significant loss of forage production. However, much of the pasture in the Midwest is dominated by tall fescue (*Schedonorus phoenix* (Scop.) Holub.). Researchers are unsure why, but tall fescue is known to inhibit tree growth. It may be competition for moisture and nutrients, or possibly allelopathy. Tall fescue is also well adapted to and yields better than most forages in the Midwest so it could be that poor tree growth is simply related to tall fescue's growth and the constraints that it puts on shared resources. Additionally, most of the tall fescue in pastures is infected with an obligate fungal endophyte [*Neothyphodium coenophialum* (Morgan-Jones & Gams) Glenn, Bacon & Hanlin] that is known to improve tall fescue's drought tolerance and persistence in the Midwest. The endophyte may also affect mycorrhizal relationships, or possibly be allelopathic.

To improve the adoption of silvopasture, this research was conducted to delineate factors that may affect tall fescue's competitiveness and to create recommendations that minimize the effects of these factors on tree growth. Three experiments were conducted. The first study evaluated the growth of four tree

species [eastern black walnut (*Juglans nigra* L.), northern red oak (*Quercus rubra* L.) black locust (*Robinia pseudoacacia* L.), and pitch x loblolly pine (*Pinus rigida* P. Mill. X *P. taeda* L.) in three grass species [tall fescue , orchardgrass (*Dactylis glomerata* L.), and Kentucky bluegrass (*Poa pratensis* L.). Four tall fescue varieties were used that differed in growth habit and endophyte status [endophyte-infected (E+) forage, not infected (E-) forage, novel endophyte-infected (E++) forage, and (E+) turf-type]. The second study assessed how much weed control is necessary to maximize black walnut growth in tall fescue pasture. And, the third study evaluated three types of black walnut planting stock (containerized, bare-root, and seed) and mycorrhizae inoculation when planting in tall fescue pasture.

In the first study, black walnut, red oak, and black locust growth was reduced up to 90 % when grown with grass competition compared to that in vegetation-free controls while pitch x loblolly pine growth was similar in grasses and in vegetation-free plots. Black walnut growth was less in tall fescue than in Kentucky bluegrass and orchardgrass. Northern red oak growth was greater in Kentucky bluegrass than in the tall fescues or orchardgrass, and growth in orchardgrass was similar to at least two of the four fescues. Black locust height growth was less in ‘Max-Q’ and ‘Houndog 5’ than in the other grasses, but diameter growth was similar across grass species. Pitch x loblolly pine growth was similar across grass species and growth in grasses was similar to that in vegetation-free plots.

Neither dry matter yield of grasses nor tall fescue’s endophyte association affected tree growth. Some of the poorest tree growth occurred in the lowest yielding grass, ‘Houndog 5’ tall fescue. When tree growth was compared in tall fescue differing in endophyte status, no differences in growth of black walnut, red oak, or black locust were attributed to differences in endophyte status of the tall fescue cultivars. Pitch x loblolly pine growth was greater when averaged across E+ ‘KY-31’ and E+ ‘Houndog 5’ than in E- ‘KY-31’ and novel E++ ‘Max-Q’. However, growth was similar in E+ and E- “KY-31’ tall fescue suggesting that these differences were due to differences in fescue variety and not endophyte status.

The effect of grass competition on tree growth could not be alleviated with supplemental irrigation and fertilization. Soil moisture and stomatal conductance measurements during drought suggest that irrigation is affecting black walnut seedlings. Nonetheless, growth was not improved with irrigation suggesting that factors other than competition for moisture reduce growth when black walnut are planted into grass. When fertilizer was applied at twice the standard rate for black walnut, tree growth did not improve. Estimations based on forage yield suggest that at least half of the fertilizer could be lost to herbage removal, and forage growth around fertilized trees was visibly larger than that in the rest of the plot. Fertilizer and irrigation did not improve tree growth in vegetation-free plots suggesting that these factors are not limiting to tree establishment and growth on good sites when weed control is used.

Weed control is the most important management consideration in black walnut plantings. Results from the second study suggest that weed control should extend a minimum of 1.21 m from black walnut seedlings in tall fescue pastures to maximize height and diameter growth. More weed control may not result in greater tree growth and would require greater weed control costs and remove more land from forage production. Soil moisture and stomatal conductance generally increased with increasing amounts of weed control. The most striking difference in soil moisture occurred at the 40 cm depth. Here, soil moisture was greater in 1.21 m and larger zones than in smaller zones through most of the drought period. Diameter growth in larger zones continued through unfavorable conditions in July and August while growth in smaller zones slowed or ceased. Late season diameter growth appeared to be a good indicator of conditions in the different sized zones and suggests that tall fescue competition for resources may be limited beyond a distance of 0.90- 1.21 m.

In the third study, bare-root and containerized seedlings transplanted well and were larger than seeded seedlings after two years in the field. Containerized seedlings had a larger diameter than that of bare-root seedlings at planting and after two years of growth but heights were similar throughout the experiment. There are considerable cost differences between containerized and bare-root stock, and that suggests that bare-root stock may be the best choice. However, producers wishing to plant improved black walnut varieties may be limited to containerized stock because improved bare-root seedlings are not often available. Mycorrhizae inoculants had no effect on the establishment of any stock type.

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CHAPTER 1

INTRODUCTION

Silvopasture

Silvopasture is the intentional combination of trees, forage, and livestock that is managed as a single integrated practice. The most common silvopasture in the United States is forest grazing (Clason and Sharrow, 2000) where undergrowth forages in existing woodlands are grazed. In the southwest USA, grazing within ponderosa pine (*Pinus ponderosa* C. Lawson), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), spruce (*Picea* A. Dietr.), fir (*Abies* Mill.), oak (*Quercus* L.), pinyon-juniper, and mesquite (*Prosopis* L.) woodlands is commonly practiced (Neary and Ffolliot, 2005). In the Pacific Northwest USA, integrated forest grazing is common and grazing in tree plantations is also practiced (Clason and Sharrow, 2000). The most prominent use of silvopastoralism is in the southeast USA where the practice has received considerable attention in the past 25 years (Lewis et al., 1985; Clason, 1995; Clason, 1999). Forest grazing of slash pine (*P. Elliottii* Engelm.), longleaf pine (*P. palustris* Mill.), and loblolly pine (*P. taeda* L.) woodlands is still the most common form of silvopasture (Clason and Sharrow, 2000). However, establishing livestock forage in pine plantations (Clason, 1995; 1999) or adding trees to pastures is being researched and implemented (Nowak et al., 2002; Nowak and Long, 2003).

In the southeast USA, significant economic gains are associated with silvopasture relative to monoculture pasture or forest. In some cases, the returns from silvopasture can be astounding (Dangerfield and Harwell, 1990; Clason 1995). Native pine species such as loblolly, slash, and longleaf pine are compatible with grazing and forage production (Robinson and Clason, 2000). And, guidelines are available for the establishment of plantations with the intent of integrating livestock once trees are established (Robinson and Clason, 2000; Nowak et al., 2002; Nowak and Long, 2003).

In the Midwest USA, forest grazing is being researched as a way to improve millions of acres of existing unmanaged timber (Garrett et al., 2004). And, grazing in pecan (*Carya illinoinensis* (Wangenh.) K. Koch.) plantations has also received attention (Ares et al., 2006). However, silvopasture adoption has been slow.

In Missouri, 24% of the state or nearly 11 million acres are in pasture land (NRCS, 2000). Most of this pasture is owned by family farmers with a herd size of less than 50 head of cattle (USDA, 2004). Adding tree crops to pastures could improve biological diversity (Heitmeyer and Frederickson, 2003), reduce non-point source runoff (Seobi et al., 2005) and improve economic diversity through timber and nut sales. The pasture already exists and there is potential to realize these benefits without sacrificing significant forage production if trees are placed into these settings (Buergler et al., 2004).

Few financial analyses have been conducted on hardwood silvopasture in the Midwest (Garrett et al., 2004). Nonetheless, one of the primary economic issues of silvopasture is the establishment costs of converting the land and planting trees (Nowak et al, 2002). To integrate trees into pastures and make silvopasture a viable land use, financial inputs made early in the investment time period must be minimized.

Tall Fescue

Most of the pasture in the Midwest is dominated by tall fescue ((*Schedonorus phoenix* (Scop.) Holub.). And, most prospective silvopasture in the Midwest would involve planting trees into tall fescue. However, many trees grow poorly with tall fescue (Todhunter and Beineke, 1979). In a review of literature encompassing 93 observations, Van Sambeek and Garrett (2004) found that tall fescue reduced the growth of black walnut (*Juglans nigra* L.) and other hardwood tree species more than other groundcovers. When grown with tall fescue, the average tree growth was only 32% compared to the vegetation-free plots. Black walnut has been suggested as a logical tree species for Midwestern silvopasture because it produces valuable lumber and a nut crop. Understanding why tall fescue exerts this negative effect on trees (particularly black walnut) and how it can be minimized may make landowners less reluctant to implement silvopasture in tall fescue.

Researchers are unclear why tall fescue may be more antagonistic to tree growth than other groundcovers. It may be that tall fescue possesses attributes that differ from other cool-season forages in the Midwest. For instance, tall fescue maintains growth across a wide range of temperatures (Mian, 2003) and withstands both short-term and long-term drought events better than other forages (Qian and Fry, 1997; West et al., 1990; Qian et al.,1997; Huang and Gao, 2000; Volaire and Lelievre, 2001). Co-occuring forages like Kentucky bluegrass (*Poa pratensis* L.) and orchardgrass (*Dactylis glomerat* L.) also withstand drought (Jiang and Huang, 2001; Perdomo et al., 1996; Da Costa et al., 2004) but, their tolerance to heat is less than tall fescue (Hannaway and McGuire, 1981; Baker and Jung, 1968). For this reason, Kentucky bluegrass and orchardgrass are better adapted to cooler regions of the upper Midwest and northeastern US (Hall, 1996; NRCS, 2002) while tall fescue is well adapted to the warmer climate of Missouri. One reason that tall fescue may be more antagonistic to tree growth than other forages is that it maintains growth for a greater portion of the growing season and yields more than other forages. This would place more constraints on moisture and nutrients and reduce the availability of these growth factors for tree uptake.

Another aspect of tall fescue that may affect tree growth differently than other forages is its obligate endophytic fungus [*Neotyphodium coenophialum* (Morgan-Jones & Gams) Glenn, Bacon & Hanlin]. Other grasses possess endophytes as well, but their effect on other organisms has not received the attention that *N. coenophialum* has. Orchardgrass is infected with the sexual anamorph of *Epichloe typhina*, that causes choke disease and reduces seed yield. In 2007, choke disease was responsible for reducing US orchardgrass seed production by 30% (Pratt, 2008). This endophyte is related to its asexual anamorph *Neoptyphodium*, however, no allelopathy or toxicity to livestock from orchardgrass' endophyte has been reported. Kentucky bluegrass, on the other hand, has no natural endophytes; however, turfgrass researchers are attempting to integrate them into this grass species (Brilman, 2005).

The *Neotyphodium* endophyte in tall fescue may affect tree response indirectly through enhancing tall fescue's vigor and growth. The endophyte confers numerous competitive benefits that enhance its host's physiological response to drought (Belesky et al., 1987; Elbersen et al., 1994; Bacon, 1993; Elmi and West, 1995; Elmi et al., 1990; Richardson et al., 1993; Malinowski et al., 1997b; Malinowski et al., 1997a; Crush et al., 2004; Malinowski et al., 1999) and may help tall fescue maintain photosynthesis at temperatures above 35 ºC (Marks and Clay, 1996). These attributes may cause tall fescue to grow during hot, dry periods and place demands on soil moisture and nutrients when these resources are scarce.

Tall fescue's endophyte may affect tree growth directly via allelopathy. Although the effect of tall fescue's endophyte on soil ecology is at best undefined, Springer (1996) showed that extracts from endophyte infected tall fescue seed inhibited clover root hair length and density to a greater extent than extracts from endophyte free tall fescue seed. Also, autotoxicity was cited by Matthews and Clay (2001) who showed that endophyte infected tall fescue had reduced growth in soil that was previously inhabited by endophyte infected tall fescue.

Endophyte-infected tall fescue may also interact with the soil microfauna. It appears to affect mycorrhizal associations (Chu-Chou et al., 1992; Guo et al., 1992), fungal population dynamics (Guo et al., 1993; An et al., 1993), soil invertebrate diversity and abundance (Bernard et al., 1997) and it has been investigated for use in a rotation system to suppress pathogenic fungi in tobacco (Guo et al., 1992) and nematodes in succeeding soybean (Pedersen et al., 1988).

Additionally, tall fescue, regardless of endophyte infection, may be allelopathic. Chung and Miller (1995) showed that tall fescue extracts could inhibit the germination of alfalfa—although other grasses in the study affected germination similarly. Tall fescue and other grass species appear to be quite autotoxic (Stowe, 1979) and allelopathy may vary with tall fescue genotype (Peters and Zam, 1981). Allelopathy has been cited as a reason for tall fescue affecting mycorrhizal relationships in loblolly pine (Wheeler and Young, 1979) and sweetgum (*Liquidambar styraciflua* L.) (Walters and Gilmore, 1976). And, tall fescue herbage also reduced infection of black walnut roots by *Glomus mosseae* (T.H. Nicolson & Gerd.) Gerd. & Trappe (Ponder 1986). These studies suggest that allelopathy may be partly responsible for inhibiting tree growth. However, it is difficult to quantify these effects in field settings where numerous other factors such as soil physical, chemical, and biological properties affect plant-plant interactions. Further, many of the substances that are found to be allelopathic in tall fescue (Luu et al., 1989) are ubiquitous in the plant kingdom and therefore may indicate that tall fescue is no more allelopathic than other plant species found in Midwestern pastures.

Grass Competition and Weed Control

When establishing silvopasture, limiting grass competition is one of the most important considerations because grass competition can severely reduce tree growth. Trees that are affected by grass competition typically have reduced height, diameter, root, and overall biomass growth. This has been witnessed in European beech seedlings (*Fagus sylvatica* L.) (Coll et al., 2004), grape (*Vitis vinifera* L.) (Celette et al., 2005), apples (*Malus sylvestris* L.) (Baugher et al., 1995), peach (*Prunus persica* L.) (Parker et al., 1993; Tworkoski and Glenn, 2001), pecan (Smith et al., 2002), black walnut (Dey et al., 1987) and English walnut (*Juglans regia* L.) (Picon-Cochard et al., 2001). Competition for moisture and nitrogen are most often cited as the reason for reduced growth and some studies have confirmed these observations (Celette, et al, 2005; Coll et al., 2004; Cheng and Bledsoe, 2004).

Rooting characteristics are most likely responsible for both moisture and N competition. Most grasses possess a dense, fibrous root system with root densities in the upper 30 cm of soil that can exceed 800 g m^{-3} (Erusha et al., 2002; Gulick et al., 1989; Garcia et al., 1988; Gentile et al., 2003). With this type of architecture, grass roots proliferate upper soil horizons and out compete trees for moisture and N. Celette et al. (2005) implicated rooting density when tall fescue significantly reduced soil moisture beneath grapes and Coll et al. (2004) showed that grass rooting density was responsible for reducing soil moisture when grasses were grown with European beech. In studies with perennial rye (*Lolium perenne* L.) and Kentucky bluegrass, Hodge et al. (1999) correlated root length density (RLD) to N uptake and found that RLD was more important than altering N inflow mechanisms in the root—they cite root proliferation as an important strategy for N acquisition. Cheng and Bledsoe (2004) showed that this acquisition strategy allowed wild oat (*Avena barbata* L.) to extract 8.5 times more applied N than blue oak (*Quercus douglasii* Hook. and Arn.) despite blue oak being more efficient at N uptake. In another study, root density was positively correlated with 15N uptake at variable depths with Italian ryegrass (*Lolium multiflorum* Lam.) and winter rye (*Secale cereale* L.) (Kristensen and Thorup-Kristensen, 2004).

Many grasses also exhibit root plasticity that allows roots to rapidly respond to changes in soil moisture and nutrient status and allocate root growth accordingly. This allows grasses to maintain growth when moisture and nutrients become scarce. Ash et al. (1975) discovered that tall fescue rooting increased from a depth of 76-90 cm in spring to 150 cm in summer as soil moisture declined in upper soil horizons.

As moisture and temperatures became more favorable in the fall, root growth shifted back to the 95-105 cm range. In general, the number of roots decreased in the upper 15 cm and increased below 15 cm during the summer. A similar response to changes in soil moisture occurs in Kentucky bluegrass (Da Costa et al., 2004) and orchardgrass (Volaire and Lelievre, 2001). Plasticity also allows grasses to quickly respond to changes in nutrient status, especially in competitive environments (Robinson et al., 1999) where plants can invest up to 150% more biomass in roots relative to non-competitive situations (Maina et al., 2002). Craine (2006) suggests that this response is necessary for acquisition of limited moisture and key to optimal allocation of resources in grasses.

Control of grasses (weeds) in tree plantings is necessary to minimize competition. However, weed control is expensive and the amount of weed control required to maximize tree growth is uncertain. Often, weed control research results are confounded by other experimental treatments such as tillage, poor choice of weed control zone sizes, and differing weed control strategies such as percent-area treated, spraying strips, or spraying circular zones. This is unfortunate because it is difficult to determine adequate weed control needs from these works.

For instance, Smith et al. (2002), working with pecan, gives the best information concerning sizes of vegetation-free zones when planting into tall fescue. However, their work only suggests that zones 1.8 m in diameter are better than zones 1.0 m in diameter. In Illinois, Carlisle et al. (2003) looked at the percentage of tall fescue sod (on an area basis) that was sprayed or ‘controlled’ in a 4-yr old black walnut plantation. In their study, they found that black walnut height growth corresponded to: 100% competing vegetation removal > 0.6-m wide strip > no control > 0.9-m diameter circles. In Canada, Von Althen (1981) found that there were few statistical differences between the height growth of black walnut seedlings grown for five years in 1.21-, 1.80-, and 2.3-m wide strips compared to a vegetation-free control, but the size of the vegetation-free zone is somewhat confounded by differing site preparation treatments. Garrett et al. (1996) suggest a minimum diameter of 1.8 m around black walnut trees. But, Schlesinger and Funk (1977) suggest diameter or strip widths do not need to be greater than 0.90 m. Further, Baughman and Vogt (1996) recommend 0.61-0.90 m diameter vegetation-free zones.

Although there is no consensus, 0.90-1.80 m appears to be the recommended diameter. There are considerable differences in input costs and land use associated with these recommendations. Clearly, more defined guidelines need to be established for black walnut plantings into tall fescue.

Type of Black Walnut Stock and Mycorrhizae Inoculants

A considerable amount of research has been conducted to determine prescriptions for the successful establishment of black walnut and other hardwoods. However, data concerning the type of planting stock necessary for successful establishment of new plantings in tall fescue is either poorly documented or is not as inclusive as needed for producers to make wise financial decisions.

Much emphasis has been placed on nursery-run bare-root stock due to the favorable economics of large-scale seedling production and planting (Reitveld and Williams, 1981; Reitveld and Van Sambeek, 1989; Melichar et al., 1986; Hammitt, 1989). While nursery-run bareroot seedlings are the primary source for black walnut seedlings, other planting materials such as seed and containerized stock have been investigated (McQuilken, 1974; Von Althen, 1975; Von Althen and Prince, 1986). These works indicate that after several years of growth, bareroot seedlings performed only marginally better than seedlings from direct seeded nuts. And, while containerized seedlings do give some early growth advantages by not succumbing to transplant shock as readily as bareroot seedlings, planting year survival can be problematic.

Unfortunately, these research efforts were conducted in northern climates and are not readily transferable to the humid transition zone of the Midwest. Currently, walnut plantings in the Midwest rely on bareroot stock and some large container stock. Typically, black walnut seed has been avoided as a planting stock because of losses associated with predation – predominantly squirrels. But, prospective tall fescue silvopasture is an environment where squirrel habitat is sparse so predation may not be a limiting factor to direct seeded nuts.

There are considerable differences in cost between these stock types. Black walnut seed costs approximately $0.13 per seed, bare-root seedlings cost approximately $0.44 per seedling, and containerized stock range from $8.00 to $11.00 per seedling. Because of these differences, producers could save money by planting cheaper stock if it performs similar to more expensive types.

Mycorrhizal inoculation of black walnut has been studied extensively (Melichar et al., 1986; Kormanik, 1985; Ponder, 1984). And, while some of the research showed promising results in controlled greenhouse environments, tree growth responses in field settings have not been conclusive. One explanation for this is that effective mycorrhizae are ubiquitous in natural forests and fields. However, on disturbed sites, like reclaimed mining lands, mycorrhizae are absent and positive growth responses have been reported when inoculations are used (Wolf et al., 1981). Many tall fescue pastures have been void of trees for 50 – 100 years or more and may be deficient of effective black walnut mycorrhizae. In these settings, mycorrhizae inoculants may decrease the amount of colonization by unwanted indigenous mycorrhizae (Abbot and Robson, 1981). But, inoculation with non-native mycorrhizae may not result in the best symbiosis. Ponder (1984) showed that black walnut growth following outplanting into a field previously dominated by tall fescue was greater when the seedlings were inoculated with indigenous mycorrhizae than when they were inoculated with a non-indigenous *Glomus fasciculatum* (Thaxt.) Gerd. & Trappe [as '*fasciculatus*']. In this case, mycorrhizae strains may have evolved with the local site conditions and may be better at producing growth responses. Also, tall fescue's endophyte may affect how inoculations perform in tall fescue pastures. *Glomus microcarpum* Tul. & C. Tul. [as '*microcarpus*'] may be less prevalent in endophyte infected tall fescue pastures whereas *G. fasciculatum* may be nonexistent in the same pastures (Chu-Chou et al., 1992). If black walnut seedlings are placed into association with tall fescue, a lack of effective mycorrhizae may limit the ability of black walnut to compete and survive.

Dissertation Goals and Objectives

The goal of this research is to develop recommendations for planting trees, specifically black walnut, in tall fescue pastures to create silvopasture. To do this, several experiments were conducted with specific objectives designed to address questions concerning tree establishment in tall fescue.

Experiment 1: The first experiment was designed to investigate why tall fescue competes with trees. This study evaluated the growth of black walnut, northern red oak (*Quercus rubra* L.), black locust (*Robinia pseudoacacia* L.), and pitch x loblolly pine (*Pinus rigida* P. Mill. X *P. taeda* L.) in competitive settings with tall fescue, Kentucky bluegrass, or orchardgrass compared to growth with no competition. Differences in tree growth in the forages could determine whether tall fescue is more antagonistic than orchardgrass or Kentucky bluegrass. Also, four tall fescue varieties differing in endophyte status were used to assess whether tree growth differences could be contributed to tall fescue's endophyte status. Forage harvests were taken to evaluate whether differences in tree growth could be attributed to differences in forage yield. Supplemental irrigation and/or fertilization were also evaluated to determine whether these treatments improve tree growth in grasses and whether they improve growth in vegetation-free plots. This experiment has 4 objectives.

Objective 1: Determine if tall fescue affects tree growth more than Kentucky bluegrass or orchardgrass and whether dry matter yield of the grasses has a significant effect on tree growth.

Rapid growth rate and high biomass yield can place high demands on moisture and nutrients and increase plant uptake of these growth factors (Cheng and Bledsoe, 2004). By comparing the response of trees to grass yield the role of grass vigor and biomass accumulation on tree growth can be delineated. Tall fescue has a pronounced effect on the growth of some trees. However, this may be the result of tall fescue's yield and the constraints that it puts on resources. The six different grass varieties represent a range of plant growth habits and biomass yields. Orchardgrass, 'KY-31' E+ and E- tall fescues, and the novel endophyte E++ 'Max-Q' are tall growing forages that tend to yield more than the shorter turf-type 'Houndog 5' fescue and Kentucky bluegrass. This broad range of yields will compare the different groundcovers based on plant vigor and growth.

Objective 2: Determine whether the endophyte is responsible for some of the negative affects on tree establishment attributed to tall fescue.

Three of the four tall fescue varieties planted are endophyte infected (E+) and one of these three is 'Max-Q' that is infected with a non-toxic endophyte that does not produce some chemical compounds associated with poor animal performance. The endophyte may affect tree response directly via allelopathy or indirectly through enhancing tall fescue's vigor and growth. By comparing tree responses and grass yields in E+ and E- tall fescue plots the impact of the endophyte in these competitive relationships can be assessed.

Objective 3: Determine if irrigation or fertilization can alleviate some of the negative effects of tall fescue on tree establishment and which management factor has the greatest affect on tree growth.

Weed mat squares (60 cm x 60 cm) were placed around each tree. The area approximates a 0.61 m diameter vegetation-free zone and is small enough to allow the grass roots to interact with the developing tree root system thus creating an environment where the grass' competitiveness for moisture and nutrients can be expressed. By examining the growth of trees in these plots, we can determine whether moisture and/or nutrients are limiting tree growth.

Objective 4: Determine the effects of irrigation and fertilization on the growth of four tree species in vegetation-free plots.

The vegetation-free plots allow us to compare irrigation and fertilization treatments when little or no competition from grasses for these resources occurs. This condition would be similar to silvopasture settings where trees are placed in vegetation-free strips or circles wide enough to negate plant-to-plant competition. During the establishment years, the effect of irrigation and fertilizer on tree growth in tall fescue are not known. This experiment will tell us which of these tree species respond to irrigation and fertilization when grass competition is minimal. This information can be applied to results from Experiment 3 to develop fertilizer and irrigation prescriptions for use in the optimum size of vegetation-free zone.

Experiment 2: The second experiment evaluated the growth of black walnut in different-sized vegetation-free zones in tall fescue pastures. This research determined the minimum distance at which tall fescue needs to be from black walnut to not inhibit growth. The experiment was conducted at two locations differing in soil characteristics. One location has a defined argillic horizon that impedes moisture and root penetration and the other location has a deep, well-drained soil with no argillic horizon. The growth of black walnut was suspected to be different between the sites. An argillic horizon may impede root access to deeper soil moisture and force tree roots to spread laterally. This difference may require more weed control if an argillic horizon is present.

Experiment 3: This experiment evaluated the type of black walnut stock to use when establishing silvopasture in tall fescue and whether applying mycorrhizae inoculants are beneficial to black walnut growth in tall fescue pastures. This experiment has two objectives.

Objective 1: Determine the type of planting stock (seeded nuts, bareroot seedlings, containerized stock) to use when establishing black walnut in tall fescue pastures.

Three types of planting stock are available to producers: seed, containerized seedlings, and bareroot seedlings. Reforestation efforts typically utilize bare-root seedlings but, containerized stock has also been planted. Another method, seed, has not been practiced due to predation. However, fescue pastures provide a setting where seed predation may not be significant and producers could realize cost savings if seeded black walnut establishes and grows well.

Objective 2: Determine whether producers might benefit from applying mycorrhizal inoculum when planting black walnut seedlings into tall fescue pastures

Typically, trees planted in fields and forests become infected with indigenous mycorrhizae and mycorrhizae inoculants have little effect on tree growth. However, the use of inoculants in tall fescue pastures may be warranted because these settings have been void of trees for extended periods and may lack effective mycorrhizae for black walnut. Knowing whether inoculants improve black walnut growth is important because they are expensive and time consuming to apply.

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CHAPTER 2

The effect of forage yield, tall fescue's endophyte, and supplemental moisture and nutrients on the growth of four tree species identified for use in silvopasture establishment.

ABSTRACT

Missouri pastures are dominated by tall fescue (*Schedonorus phoenix* (Scop.) Holub.)– a fierce competitor known to inhibit tree growth. Researchers are unsure why tall fescue is so competitive but competition for moisture and nutrients, and possibly allelopathy are suspected. This study was conducted to determine whether tall fescue is more competitive than orchardgrass (*Dactylis glomerata* L.) or Kentucky bluegrass (*Poa pratensis* L.), whether differences in tree growth could be attributed to forage yield or tall fescue's endophyte, and whether irrigation and fertilizer can alleviate grass competition. Black walnut (*Juglans nigra* L.), northern red oak (*Quercus rubra* L.), black locust (*Robinia pseudoacacia* L.), and pitch x loblolly pine (*Pinus rigida* P. Mill. x *taeda* L.) seedlings were planted into sods of orchardgrass, Kentucky bluegrass, or tall fescue. There were four entries of tall fescue differing in endophyte status and growth habit ['KY-31' endophyte infected (E+), 'KY-31' non-infected (E-), 'Max-Q' novel endophyte infected (E++), and 'Houndog 5' turf-type (E+)]. Black walnut, red oak, and black locust growth was reduced when grown with grasses. Pitch x loblolly pine growth was similar when grown with grass compared to without grass. Differences in tree growth did not correspond to differences in grass dry matter yield or tall fescue endophyte status.

Black walnut and red oak height and diameter growth and pitch x loblolly diameter growth were greater in Kentucky bluegrass and orchardgrass compared to the forage tall fescues (‘KY-31’ (E+), ‘KY-31’ (E-), and ‘Max-Q’). Irrigation and/or fertilizer did not alleviate grass competition on black walnut, red oak, or black locust, nor did these treatments improve growth of any tree species when grown without grass competition.

INTRODUCTION

Most pasture in the Midwest USA is dominated by tall fescue (*Schedonorus phoenix* (Scop.) Holub.) and much of this land is unsuitable for row crop production. Establishing trees to create silvopasture on these lands could provide benefits to landowners without sacrificing forage production (Buergler et al., 2004). However, tall fescue inhibits the growth of some tree species more than other forages (Alley et.al., 1999; Todhunter and Beineke, 1979; Van Sambeek and Garrett, 2004).

Researchers are unsure why tall fescue is so antagonistic towards trees, but competition for moisture and nutrients are suspected (Messenger, 1976; Glenn and Velker, 1993). However, other factors may be involved. For instance, most tall fescue in pastures is infected with an endophyte [*Neothyphodium coenophialum* (Morgan-Jones & Gams) Glenn, Bacon & Hanlin] that confers numerous competitive benefits—i.e., it enhances its host's physiological response to drought and heat (Belesky et al., 1987; Bacon, 1993; Elmi and West, 1995; Elmi et al., 1990; Richardson et al., 1993; Malinowski et al., 1997a, 1997b, 1999; Crush et al., 2004; Mark and Clay, 1996) and may be implicated in allelopathy (Springer, 1996; Walters and Gilmore, 1976). Also, tall fescue yields better than most cool-season forages in the Midwest and much of its growth occurs when deciduous tree growth occurs. It could be that poor tree growth in tall fescue is the result of grass growth and the constraints that it puts on moisture and nutrients (Cheng and Bledsoe, 2004) rather than something inherent to tall fescue.

Irrigation and fertilization are two management practices that might reduce the impact of these factors on tree growth. However, in the initial years after planting, fertilizers may enhance the growth of competing vegetation and burn the roots of trees (Braun and Byrnes, 1982; Beineke, 1994), and contribute to shoot dieback (Mooter et al., 2004). Irrigation can improve growth (Ponder, 1983), but irrigating trees grown with grass competition may reduce soil moisture by fostering a vigorous grass crop that transpires more than non-irrigated grass (Dey et al., 1987). These practices require significant financial inputs and it is uncertain whether they can alleviate forage competition and improve tree growth.

To evaluate these factors, this study assessed the growth of four tree species in Kentucky bluegrass, orchardgrass, and four tall fescues differing in endophyte status and growth habit. The trees were chosen based on their prospective use in silvopasture. Also, these trees differ in their tolerance to different soil and environmental conditions. Pitch x loblolly pine (*Pinus rigida* P. Mill. X *P. taeda* L.), is tolerant to poor soil moisture and nutrient availability, eastern black walnut (*Juglans nigra* L.) is intolerant of drought, northern red oak (*Quercus rubra* L.) is tolerant of a wide range of soil moisture conditions, and black locust (*Robinia pseudoacacia* L.) is an N-fixing tree. The objectives of this study were to: 1) determine if tall fescue is more competitive than other common forages in the Midwest (Kentucky bluegrass and orchardgrass), 2) determine whether differences in tree growth correspond to differences in grass dry matter yield, 3) determine whether differences in tall fescue endophyte status corresponds to differences in tree growth, and 4) determine whether irrigation and/or fertilization can alleviate competitive interference associated with grass competition.

MATERIALS AND METHODS

Study site and layout

This experiment was conducted at the University of Missouri—Horticulture and Agroforestry Research Center (HARC) located in New Franklin, Missouri (39º 00 N 92º 46' W). The study area was previously in mixed pasture species and the existing vegetation was treated with glyphosate and disced to prepare the seedbed in August 2002. In September 2002, seven groundcover treatments: [endophyte infected (E+) 'KY-31' tall fescue, non-infected (E-) KY-31' tall fescue, (E+) 'Hounddog 5' turf-type tall fescue, 'Max-Q' novel endophyte (E++) tall fescue, orchardgrass, Kentucky bluegrass, and vegetation-free bare soil] were each seeded in four plots within each of six replications (Figure 2.1). Each plot measured 5.18 x 5.18 m with a 0.91 m buffer between each plot. In October 2003, four tree species were planted (black walnut, red oak, black locust, and pitch x loblolly pine) at the corners of a 2.13 x 2.13 m square centered in the middle of each plot. During One of four cultural treatments (irrigation , fertilizer, irrigation and fertilizer, or neither) were applied to each of the trees within one of the four plots established to each of the groundcover treatments within each replication.

Neotyphodium immunoassay (Agrinostics Ltd., Watkinsville GA, USA) was conducted to determine the level of tall fescue endophyte infection in September 2004. Ten tillers were randomly selected from two of the four plots seeded to the same fescue cultivar within each replication, except E- 'KY-31' tall fescue for which all four plots in each replication were sampled. Infection levels were 82, 85 and 83

%, respectively for ‘Max-Q’, ‘Houndog 5’, and E+ ‘KY-31’ tall fescues and 17% for E- ‘KY-31’ tall fescue.

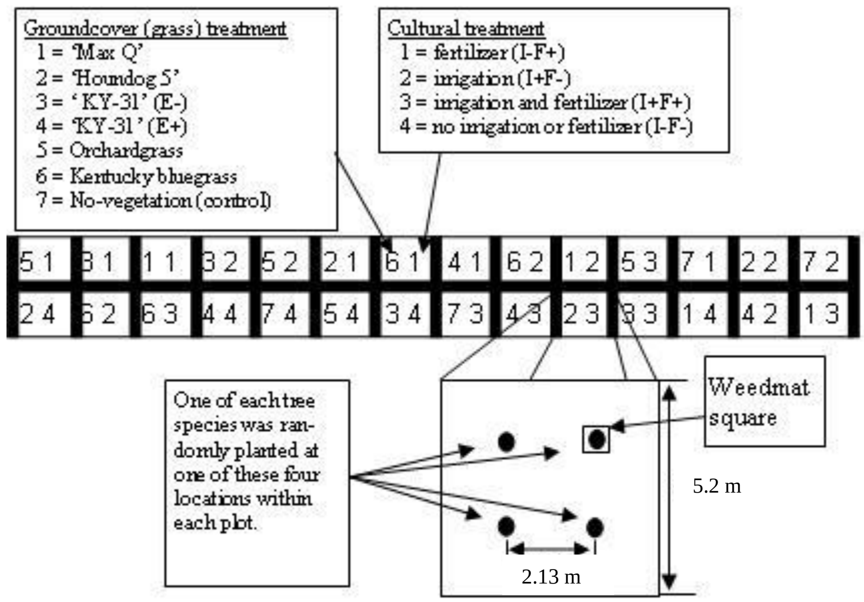

Figure 2.1 Layout of one replication displaying groundcover treatment, cultural treatment, and tree location within a plot.

The following seeding rates were used for each groundcover species (tall fescue varieties and orchardgrass 13.5 kg ha^{-1}, Kentucky bluegrass 7.3 kg ha^{-1}). The red oak, black walnut, and black locust were planted as 2-gallon containerized trees. Pines were planted as 1-0 bareroot seedlings. Weed mat Tree Squares® (Pak Unlimited, Decatur GA, USA) measuring 61 x 61 cm were placed around each tree. This size mat facilitates treatment applications and forage herbage removal, yet allows tree and grass roots to intermingle and be in direct competition with the trees. Drip irrigation was applied with two, 0.5 gph, emitters per tree. Fertilizer was applied as Osmocote® slow release 13-13-13 placed beneath weed mat squares at a rate of 55 g tree^{-1} in March of 2003-2007. In April 2003-2007, an additional 25 g N, 12.5 g of P, and 12.5 g of K was applied to each tree as NH_4NO_3, triple superphosphate, and muriate of potash, respectively.

Forage yield was measured in 2005-2007 when forage height reached approximately 35 cm. Three to four cuttings were taken per year on each grass groundcover except 'Houndog 5' turf-type tall fescue which was cut twice per year. A 1.0 x 0.5 m random sample was taken within each 5.2 x 5.2 m plot at each harvest and all herbage within the rectangle was cut 5 cm above the soil surface with a knife. Two samples were taken from each plot and air dried in a solar drying room (60º C). Samples were combined for yield calculations. Following forage harvesting, the plots were mowed and all herbage removed.

Height and diameters of the trees were measured in November 2003 and in October 2004, 2005, 2006, and 2007. Stretched height was measured on all trees. After the second growing season, most trees in no-vegetation control plots exceeded a reachable height for stretched measurements, so height was measured to the tallest point. Diameter was measured 10 cm above the soil line. Tree growth after planting was assessed as a four-year height and diameter increment where:

Four-year growth increment = (height or diameter in 2007 minus height or diameter when planted)

= (cumulative height or diameter growth during study period)

Due to exceptional growth of black locust trees in the vegetation-free plots in 2004 and 2005, they were removed from all plots in February 2006. Their growth suggested that they would have impacted growth of the other trees had they not been removed. For black locust, two-year increment and aboveground biomass yield is reported. Aboveground biomass of each black locust tree was determined by cutting all trees at ground level and weighing all stems and twigs. Dry weight of the material was determined by oven drying 26 random subsamples at 70º C for 7 days.

In May 2005, Watermark® soil moisture sensors (Irrometer Co., Riverside CA, USA) were installed in three randomly chosen irrigated plots throughout the experimental site to aid in irrigation timing. In the first week of June 2006, ECH2O® soil moisture sensors (Decagon Devices, Pullman WA) were installed in the root zone of irrigated (I+F+) and non-irrigated (I-F+) black walnut trees in three of the six replications. Soil moisture measurements were taken periodically and irrigation was implemented when 50 % of the irrigated plots had volumetric soil water content between 20 and 23%. The year 2004 was wet and cool through the growing season so irrigation was not needed (Table 2.1). Irrigation was used six times in 2005 (June 1 and 25; July 11, 20 and 28; Aug 9), three times in 2006 (July 26, Aug 3 and 11), and five times in 2007 (June 15, July 11, Aug 2, 10, and 18). Irrigation was applied for 3.5 - 4.5 h each event. During drought events in 2006 and 2007 (mid-July – August), measurements were taken periodically to compare volumetric soil moisture content in irrigated plots to those in non-irrigated plots. Also during this time, midday (1100 – 1330 hrs) stomatal conductance measurements were taken with a SC-

1® steady state diffusion porometer (Decagon Devices, Pullman WA, USA) on three of the most recently expanded black walnut leaves in each plot in which volumetric soil water content measurements were taken to determine if the irrigation could be linked to higher stomatal conductance.

Table 2.1. Monthly precipitation and average daily high temperature at the Horticulture and Agroforestry Research Center, New Franklin, MO (2004 – 2007).

	Precipitaion					Temperature				
Year	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.
	mm					°C				
2004	145	56	134	192	26	24.5	26.3	28.3	26.4	26.6
2005	45	184	19	205	72	24.0	29.9	32.5	31.3	27.8
2006	75	102	97	69	45	24.2	29.1	32.6	32.8	24.9
2007	117	156	48	42	31	26.3	28.2	29.8	33.8	28.6
52-yr avg	121	106	95	95	99	24.5	28.9	31.6	31.0	26.8

Experimental design and statistical analysis

The experiment was arranged as a randomized complete block design with six replications. Each replication consisted of seven grass treatments by four cultural treatments completely randomized. Statistical Analysis Software (SAS institute, 2001) was used for all analyses. Prior to analysis of variance, covariance between beginning height and diameter and final height and diameter for each species was analyzed using PROC CORR. Pearson correlation coefficients for each species indicate that growth differences were not confounded by initial seedling size. Further analysis by PROC MIXED indicated that there was no significant difference in beginning height or diameter of the trees among any of the groundcover or cultural management treatments. Four-year (cumulative) height and diameter growth of black walnut, red oak, and pitch x loblolly pine, and two-year height and diameter growth, and biomass yield of black locust was subjected to Analysis of variance (ANOVA) and analyzed individually by PROC MIXED with replication as the random effect. If treatment effects were significant, mean separation using Tukey's Studentized Range Test ($P < 0.05$) was conducted. To meet normality assumptions of the statistical model, square root transformations of height, diameter, and black locust biomass data were conducted. Values mentioned in tables, figures, and text are non-transformed.

Forage yield from 2005, 2006, 2007 and cumulative yield were subjected to Analysis of Variance and analyzed by PROC MIXED with replication specified as the random effect. To assess forage yield on tree growth, linear regression analysis was conducted by PROC REG. Regression equations were developed using linear models comparing black walnut, red oak and pitch x loblolly pine height and diameter growth in 2005, 2006, 2007, and cumulatively with each forage species growth during these years and cumulatively.

For endophyte effects on tree growth, CONTRAST statements were used in PROC MIXED to contrast tree growth in 'Ky-31' (E-) to that in 'Ky-31' (E+), to contrast tree growth in 'Max-Q' (E++) and 'Ky-31'(E-) to that in 'Houndog 5' (E+) and 'Ky-31' (E+), and to contrast tree growth in the forage fescues ('Ky-31' (E-), 'Ky-31' (E+), 'Max-Q' (E++) to that in Kentucky bluegrass and orchardgrass.

RESULTS AND DISCUSSION

Grass competition

During the four years after planting, grass competition reduced black walnut, red oak, and black locust height and diameter growth, and reduced aboveground biomass of black locust compared to growth in vegetation-free plots (Table 2.2). Pitch x loblolly pine was unaffected by grass treatments. There were no interactions between forage species and cultural treatment. Averaged across all grasses, height and diameter was reduced 87 and 67 %, respectively, for black walnut, 72 and 75 %, respectively, for red oak, and 55 and 90 %, respectively, for black locust. Additionally, black locust biomass was reduced 85 %.

Forage species affected black walnut and red oak height and diameter growth, and black locust height growth (Table 2.2). Black walnut generally grew best in Kentucky bluegrass and orchardgrass. Height and diameter growth was 66 and 88% greater, respectively, in Kentucky bluegrass than when averaged across the tall fescues. In orchardgrass, height and diameter growth was 35 and 57 % greater, respectively, than in the fescues. Red oak grew best in Kentucky bluegrass. Height and diameter growth in Kentucky bluegrass was 89 and 92 % greater, respectively, than when averaged across the other grasses. Height growth in orchardgrass, and 'Max – Q' and 'Houndog 5' tall fescues was similar and 24 % greater than that in 'Ky – 31' E+ and E- tall fescue. Red oak diameter growth in orchardgrass was 47% greater than that in 'Ky – 31' E+, but similar to that in the other fescues. Black locust growth in Kentucky bluegrass and orchardgrass was always similar to that in 'KY-31 E+ and 'KY-31' E-. Height growth was greatest in Kentucky bluegrass, orchardgrass, and 'Ky – 31' E+ tall fescue. Black locust height growth in these grasses was 36% greater than that in 'Max – Q' and 'Houndog 5' tall fescues, but similar to that in 'Ky – 31' E- tall fescue. Black locust diameter growth and biomass was similar in all grasses; however means were always smallest in ‘Max-Q’ and ‘Houndog 5’ tall fescue.

Grass competition reduced growth of all trees except pitch x loblolly pine. Similar growth reductions have been reported in beech seedlings (*Fagus sylvatica* L.) (Coll et al., 2004), grape (*Vitis vinifera* L.) (Celette et al., 2005), apples (*Malus sylvestris* L.) (Baugher et al., 1995), peach (*Prunus persica* L.) (Parker et al., 1993; Tworkoski and Glenn, 2001), pecan (*Carya illinoensis* (Wangenh.) K. Koch) (Smith et al., 2002), black walnut (Dey et al., 1987) and English walnut (*Juglans regia* L.) (Picon-Cochard et al., 2001).

Black walnut and red oak grew best in Kentucky bluegrass. Kentucky bluegrass was anticipated to be less competitive as its rooting habit is known to be shallower than the tall fescues and orchardgrass (Erusha et al., 2002; Ash et al., 1975; Weaver, 1926), and its intolerance to heat that forces late-summer dormancy most years. Tree growth in orchardgrass was often similar to that observed in at least one of the fescue varieties suggesting that the competitive differences between these grass species may be difficult to distinguish. Like tall fescue, orchardgrass tolerates drought, but instead of growing deeper root systems, it relies on its ability to tolerate lower leaf water potentials and extract moisture when water content is low (2 -15%) (Volaire and Lelievre, 2001). This difference may result in less competition for moisture deeper in the soil profile and result in greater tree growth than seen in some of the fescue plots.

Table 2.2. Four-year (2004-2007) cumulative height and diameter growth of black walnut, red oak, and pitch x loblolly pine and two-year (2004-2005) cumulative height, diameter, and biomass growth of black locust when grown in seven grass treatments.

	Mean cumulative height growth				Mean cumulative diameter growth				Biomass
Treatment	Black walnut	Red oak	Black locust	Pitch x loblolly pine	Black walnut	Red oak	Black locust	Pitch x loblolly pine	Black locust
	------------------------ cm ------------------------				---------------------- mm -------------------				-- g --
'KY-31' (E-) tall fescue†	15.5 d‡	30.1 d	68.9 bc	104.0 a	5.9 c	7.7 cd	14.5 b	32.7 a	1348 b
'KY-31' (E+) tall fescue	15.0 d	32.6 d	77.8 b	128.4 a	5.3 c	7.2 d	15.7 b	39.7 a	1629 b
'Houndog 5' tall fescue	14.0 d	38.9 c	57.3 c	134.8 a	5.7 c	10.2 c	13.5 b	40.6 a	1263 b
'Max-Q' tall fescue	16.5 cd	39.4 c	58.4 c	102.0 a	5.7 c	8.8 cd	12.6 b	31.2 a	1338 b
Orchardgrass	20.7 bc	38.3 c	85.7 b	117.9 a	8.8 b	10.6 c	16.4 b	38.9 a	1748 b
Kentucky bluegrass	25.4 b	67.6 b	73.3 b	124.5 a	10.5 b	17.1 b	14.7 b	41.6 a	1637 b
Vegetation-free	141.6 a	148.8 a	155.5 a	127.2 a	21.6 a	41.3 a	146.0 a	44.4 a	10381 a

† Refers to tall fescue infected (E+) and non-infected (E-) with the *Neotyphodium coenophialum* endophyte.
‡ Within column means followed by the same letter are not statistically different according to Tukey's Studentized Range MSD (0.05).

Black walnut and red oak height and diameter and black locust height were always lowest in one of the fescue varieties. However, growth in the fescue varieties was not consistent among tree species. Black walnut growth was always similar in the tall fescues and was always poorest in this grass species. However, red oak growth in ‘KY-31’ E+ was always different from that in ‘Houndog 5’ and black locust height in ‘Max-Q’ and ‘Houndog 5’ was different than that in ‘KY-31’ E+.

Growth of the tree species appears to follow their tolerance for poor site conditions. Black walnut requires moist, well-drained soil and avoids drought by accessing soil moisture deep in the soil profile (Pallardy and Rhoads, 1993). With grass competition, aboveground growth was reduced. This appeared to reduce leaf area and likely reduced assimilate production for root growth and limited black walnut’s ability to reach adequate soil moisture deeper in the soil profile. Red oak grew better than black walnut in grass and this is likely due to its tolerance of a range of site conditions (Shreeg et al., 2005). As a nitrogen fixer, black locust grows well in a broad range of site conditions and tolerates unfertile soils (Degomez and Wagner, 2001). However, grass competition reduced black locust growth by over 90% so N-fixation does not appear to provide any significant benefits to black locust when grown in grasses. Pitch x loblolly pine growth was not reduced in grasses and this may result from characteristics of the parental species. Pitch pine and loblolly pine are early successional species of droughty, nutrient poor soils of the Piedmont plain (Schultz, 1997) and the pine barren region of New York (Rundel and Yoder, 2000). Due to their tolerance of poor site conditions, pitch pine and loblolly pine are used for surface mine reclamation (Burger and Zipper, 2002). This inherent ability to compete on poor sites likely contributes to responses seen here.

Grass yield

Few differences in tree growth could be attributed to differences in grass yield. When yield was regressed against tree height and diameter growth, low coefficients of determination resulted. Adjusted r^2 values ranged from 0.0 to 0.24 for cumulative, annual, or early season forage yield and tree growth models. Responses were inconsistent and variable. A broad range of tree height and diameter growth occurred at any given forage yield.

In each year and cumulatively, 'Houndog 5' turf-type tall fescue yielded less than other grasses (Table 2.3). This was not surprising as the cultivar was selected for turf attributes and not forage growth. The only yield differences among the other grasses occurred in 2005 when 'Ky – 31' E+ tall fescue yielded more than Kentucky bluegrass and orchardgrass, and cumulatively, when 'Ky – 31' E+ yielded more than orchardgrass. Forage tall fescue, Kentucky bluegrass, and orchardgrass yields were similar to those reported by others (Lauriault et al., 2006; Hill et al., 2002; Durr et al., 2005; Henning and Risner 1993) so competition in these grasses would likely be similar to that in other pasture settings. Although black walnut, red oak, and black locust often grew less in the highest yielding forages ('Ky-31' E+, 'Ky-31' E-, 'Max-Q' tall fescue) they also grew poorly in the lowest yielding grass ('Houndog 5' tall fescue). When there was no forage yield (vegetation-free plots), black walnut, red oak, and black locust grew well. However, at forage yields realized in the grass plots, growth was reduced up to 90 %. Therefore, much of the reduction in tree growth

Table 2.3. Mean dry matter yield of six grasses in plots with trees at HARC in 2005, 2006, 2007, and cumulative over the three years of study.

Grass species	2005		2006		2007		Cumulative	
	------------------------------------- Mg ha^{-1} ---------------------------------							
'KY-31' Tall Fescue (E+)†	6.09	A ‡	5.09	A	5.70	A	16.8	A
'Max-Q' 'Jesup' Tall Fescue	5.88	AB	4.80	A	5.38	A	15.9	AB
'KY-31' Tall Fescue (E-)	5.80	AB	4.71	A	5.27	A	15.7	AB
Kentucky Bluegrass	5.38	B	4.49	A	5.03	A	15.0	AB
Orchardgrass	5.31	B	4.51	A	5.05	A	14.8	B
'Houndog 5' Tall Fescue	4.20	C	3.63	B	4.09	B	11.8	C

‡ Refers to tall fescue infected (E+) and non-infected (E-) with the *Neotyphodium coenophialum* endophyte.
† Means within a column followed by the same letter are not different according to Tukey's Studentized Range MSD (0.05).

occurs when these forages yield less than that in this study. Thus, competition in Midwest pastures may be too great for adequate black walnut, red oak, and black locust growth regardless of forage management activities that might increase grass yield. On the other hand, pitch x loblolly growth was unaffected by grass and it is uncertain whether any level of grass yield would reduce growth of this species.

Tall fescue endophyte status

Differences in tall fescue's endophyte status did not correspond to differences in black walnut, red oak, and black locust height and diameter growth or black locust biomass (Table 2.4). Growth of the three tree species was inconsistent and variable when planted into 'KY – 31' E+ or E- tall fescue and there were no differences in tree growth in the grasses. Growth averaged across the non-ergot alkaloid producing 'Max – Q' and 'KY – 31' E- was similar to that averaged across 'KY – 31' E+ and 'Houndog 5'. Lack of tree growth differences in these comparisons further indicates that there is no effect of tall fescue's endophyte on these tree species. Pitch x loblolly pine responded to some endophyte differences in tall fescue. Pitch x loblolly height and diameter growth averaged across the E+ tall fescues ('KY – 31' E+ and 'Houndog 5') was greater than that averaged across the non-ergot alkaloid producing tall fescues ('Max – Q' and 'KY – 31' E-). This response was interesting because one would expect tree growth reductions instead of growth improvement if there were any differences associated with tall fescue's endophyte status. Despite this, pitch x loblolly pine height and diameter growth in the same cultivar differing in endophyte status ('KY – 31' E- and E+) was similar and suggests that differences in pine growth are the result of tall fescue variety differences and not endophyte infection. Also, black walnut, red oak, and black locust height and diameter growth, and pitch x loblolly pine diameter growth was less when averaged across the forage fescues ('KY – 31' E+ and E- and 'Max – Q') than when averaged across orchardgrass and Kentucky bluegrass. This further suggests that poor tree growth in tall fescue results from tall fescue and not its endophyte.

Irrigation and fertilizer

Across and within grasses, irrigation and/or fertilizer did not alleviate grass competition on black walnut, red oak, or black locust relative to growth in vegetation-free plots (Table 2.5). Neither did these treatments improve the growth of pitch x loblolly pine. Irrigation plus fertilizer (I+F+) improved black walnut mean diameter growth 45 % relative to applying nothing.

Table 2.4. Four-year (2004-2007) cumulative height and diameter growth of black walnut, red oak, and pitch x loblolly pine and two-year (2004-2005) cumulative height, diameter, and biomass growth of black locust when compared in orthogonal contrasts to evaluate endophyte status effect on tree growth.

	Height				diameter				biomass
Orthogonal Contrast	Black walnut	Red oak	Black locust	Pitch x loblolly pine	Black walnut	Red oak	Black locust	Pitch x loblolly pine	Black locust
	------------------------ cm ---------------------------				------------------------ mm ------------------------				--- kg ---
‘KY-31’ (E-)	15.6	46.9	68.7	112	5.9	9.2	14.8	33.0	1349
‘KY 31’ (E+)	15.0	50.6	75.9	136	7.7	8.6	15.6	38.9	1629
significance†	ns	ns	ns	ns	ns	ns	ns	ns	ns
‘Max Q’ & ‘KY-31’ (E-)	16.0	52.7	63.7	111	6.1	9.8	13.7	32.0	1343
‘KY-31’ (E+) & ‘Houndog 5’	14.4	54.6	67.4	140	5.8	10.2	14.6	39.7	1446
significance	Ns	ns	ns	*	ns	ns	ns	*	ns
Forage fescues	16.1	52	68.4	119	5.7	9.4	14.3	34.3	1438
Orchardgrass and Kentucky bluegrass	22.6	75	79.2	131	10.1	15.5	15.5	40.4	1678
significance	*	***	*	ns	***	***	ns	*	ns

† *, **, *** Significant at the 0.05, 0.01, and 0.001 probability level, respectively.

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However, growth was still 59 % less than that in vegetation-free plots. Fertilizer reduced pitch x loblolly height and diameter growth relative to applying both fertilizer and irrigation, but trees receiving these treatments were similar to those receiving no irrigation or fertilizer. When grown without competing vegetation, irrigation and/or fertilizer had no effect on tree height or diameter growth (Table 2.6).

Reasons for a lack of response to these inputs in grassed plots are unclear. Grasses are known to compete more vigorously than trees for soil moisture and nutrients because of their dense, fibrous root system that proliferates soil (Celette et al., 2005; Coll et al., 2006). Because of this rooting architecture, grasses likely intercepted much of the fertilizer and irrigation inputs. Grass nearest to irrigated or fertilized trees grew larger than grasses near trees that did not receive these treatments. The supplements may have increased resource demands of competing grasses as suggested by Cheng and Bledsoe (2004) and may partly explain the lack of response from these inputs. However, during drought events in July and August 2006 and 2007, soil moisture was consistently greater in irrigated plots than in non-irrigated plots, and stomatal conductance conductance was greater in irrigated plots than in non-irrigated grassed plots indicating that soil moisture is available. and seedlings are benefiting from it (Figure 2.1 and 2.2). Trees likely were affected similarly at other times during the growing season when irrigation was applied also.

Table 2.5. Four-year (2004-2007) cumulative height and diameter growth of black walnut, red oak, and pitch x loblolly pine and two-year (2004-2005) cumulative height, diameter, and biomass growth of black locust when grown in six grasses and supplied with four cultural treatments.

	Mean cumulative height growth				Mean cumulative diameter growth				Biomass
Treatment	Black walnut	Red oak	Black locust	Pitch x loblolly pine	Black walnut	Red oak	Black locust	Pitch x loblolly pine	Black locust
	------------------------ cm ------------------------				--------------------- mm -------------------				---- g ----
No fertilizer or irrigation	16.4 a‡	38.6 a	67.1 a	112.5 ab	5.5 b	8.8 a	14.2 a	36.5 ab	1404 a
Fertilizer	20.3 a	34.9 a	69.4 a	103.8 b	6.9 ab	9.6 a	14.6 a	33.3 b	1426 a
Irrigation	16.4 a	44.1 a	71.2 a	119.6 ab	6.6 ab	10.8 a	14.7 a	40.1 ab	1581 a
Fertilizer plus Irrigation	19.0 a	45.3 a	70.5 a	141.8 a	8.0 a	10.4 a	14.8 a	43.0 a	1656 a

‡ Within column means followed by the same letter are not statistically different according to Tukey's Studentized Range MSD (0.05).

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Table 2.6. Four-year (2004-2007) cumulative height and diameter growth of black walnut, red oak, and pitch x loblolly pine and two-year (2004-2005) cumulative height, diameter, and biomass growth of black locust when grown in vegetation-free plots and supplied with four cultural treatments.

	Mean cumulative height growth				Mean cumulative diameter growth				Biomass
Treatment	Black walnut	Red oak	Black locust	Pitch x loblolly pine	Black walnut	Red oak	Black locust	Pitch x loblolly pine	Black locust
	------------------------ cm ------------------------				--------------------- mm -------------------				--- kg ---
No fertilizer or irrigation	155 a‡	173 a	157 a	171 a	49.4 a	43.7 a	142 a	55.7 a	109.5 a
Fertilizer	143 a	130 a	169 a	99 a	46.9 a	35.2 a	134 a	42.3 a	120.8 a
Irrigation	142 a	124 a	141 a	101 a	38.6 a	38.3 a	157 a	39.8 a	108.2 a
Fertilizer plus Irrigation	160 a	180 a	176 a	138 a	55.4 a	49.4 a	148 a	39.7 a	120.6 a

‡ Within column means followed by the same letter are not statistically different according to Tukey's Studentized Range MSD (0.05).

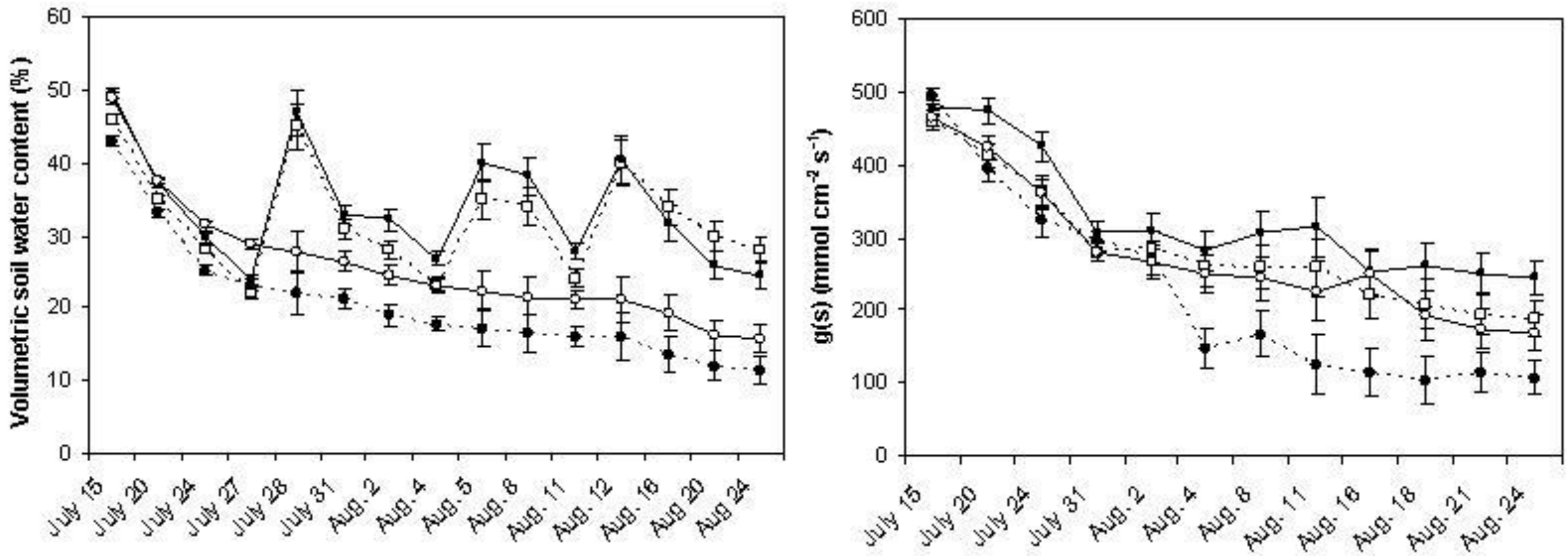

Figure 2.2. Volumetric soil water content (left) and black walnut seedling stomatal conductance (right) during drought in July and August 2006 in vegetation-free plots with irrigation (■), in vegetation-free plots without irrigation (○), in grass plots with irrigation (□) and, in grassed plots without irrigation (●). (vertical bars represent mean +/- std. error).

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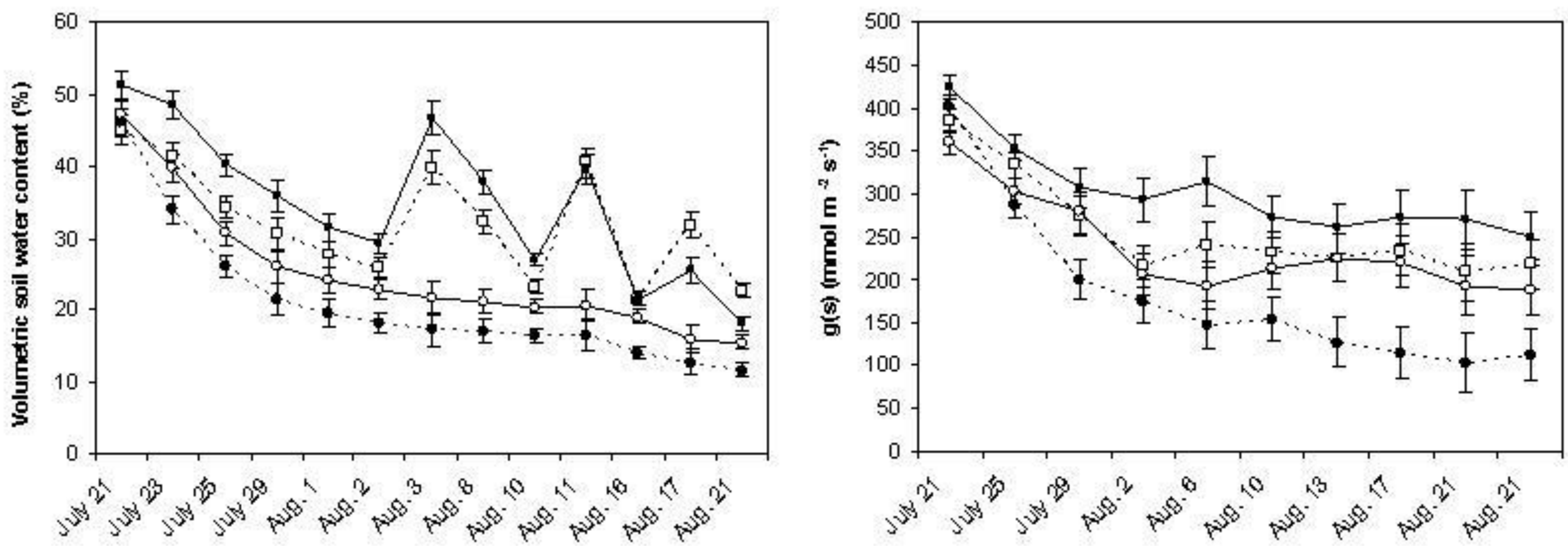

Figure 2.3. Volumetric soil water content (left) and black walnut seedling stomatal conductance (right) during drought in July and August 2007 in vegetation-free plots with irrigation (■), in vegetation-free plots without irrigation (○), in grass plots with irrigation (□) and, in grassed plots without irrigation (●). (vertical bars represent mean +/- std. error).

Higher stomatal conductance should lead to higher photosynthesis and greater growth. It is unclear why irrigation did not result in greater growth. In vegetation-free plots, black walnut height and diameter growth was greater than that in the grasses. As expected, soil moisture and stomatal conductance in vegetation-free plots, regardless of whether they were irrigated, was consistently greater than in non-irrigated grass plots. But, stomatal conductance of non-irrigated trees in vegetation-free plots was similar to irrigated trees in grass plots suggesting that seedlings were affected similarly by soil moisture conditions. However, growth differences between trees in grass and vegetation-free plots were large suggesting that factors other than competition for moisture may be reducing tree growth in grassed plots.

Fertilizer was applied at a rate equivalent to 32.2 g N, 19.7 g P, and 19.7 g K m^{-2} yr^{-1} and was more than twice that recommended for black walnut when weeds are controlled (Beineke, 1994). At this rate, trees did not show signs of over fertilization such as tip dieback so it is not likely that this rate was too high for the growing conditions at the site. Some of the lack of response to fertilizer could be attributed to uptake by grasses. Forage grass yield averaged 5.21 Mg ha^{-1} yr^{-1} in 2005, 2006 and 2007. At this yield level, forage would remove approximately 5.21 – 15.6 g N m^{-2} yr^{-1}, and corresponding amounts of P and K, if grass N concentration ranged between 1 and 3%. This estimated removal would only be half the amount of N applied, but, as mentioned earlier, grass nearest fertilized and irrigated trees grew noticeably larger than grass in the rest of the plot so actual nutrient removal may have been greater than the estimated 5.21 – 15.6 g N m^{-2} yr^{-1}.

Fertilizer and irrigation had no effect on tree growth in vegetation-free plots. In these plots, stomatal conductance of non-irrigated black walnut seedlings was often similar to that of irrigated seedlings despite differences in soil moisture. Trees in these plots grew well, and roots may have grown deep enough to access soil moisture below the depth of the sensors. This would explain similar stomatal conductance despite differences in soil moisture. Often, native fertility is sufficient for young black walnut trees and adding fertilizer can reduce growth (Mooter et al., 2004). For these reasons, many suggest not applying fertilizer to black walnut in the first few years of growth. However, there is little information available to suggest that these inputs would not improve growth of the other tree species. Although tree growth was not reduced from these inputs, it appears that fertilizer and irrigation are not necessary to improve the growth of these tree species in the initial years after outplanting when weed control is used.

CONCLUSION

Grass competition reduced black walnut, red oak, and black locust growth, but had little effect on pitch x loblolly pine. Tree growth in tall fescue was often less than that in Kentucky bluegrass or orchardgrass, but responses to different grass species was tree species dependent. Tree growth differences were not attributed to differences in grass yield or tall fescue's endophyte status suggesting that these factors have little effect on tree growth in pastures. Other properties of tall fescue such as heat and drought tolerance that allow it to maintain growth for a greater part of the year and differentiate tall fescue from orchardgrass and Kentucky bluegrass may be responsible. Irrigation and fertilizer did not alleviate grass competition on black walnut, red oak, or black locust neither did these treatments improve pitch x loblolly pine growth in grass. Their use to alleviate competition does not appear warranted. Soil moisture and stomatal conductance measurements indicate that black walnut trees benefit from irrigation, but lack of differences in growth between irrigated and non-irrigated trees suggest that factors other than moisture competition are reducing tree growth when planted into grass. On good sites such as the one in this study, applying irrigation and fertilizer to trees without grass competition does not result in improved growth either. Pitch x loblolly pine growth was similar in grass plots and vegetation-free plots and appears well suited for silvopasture establishment in tall fescue pastures with minimal weed control inputs. Red oak, black walnut, and black locust would require greater weed control than pitch x loblolly pine to maintain adequate growth. Red oak would grow better and may not require as much weed control in pastures dominated by Kentucky bluegrass compared to tall fescue or orchardgrass. Black walnut would grow better and may not require as much weed control in Kentucky bluegrass and orchardgrass as in tall fescue. Black locust would grow similarly and may require similar amounts of weed control in each forage.

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CHAPTER 3

How much weed control is necessary for establishment of eastern black walnut seedlings in tall fescue silvopasture?

ABSTRACT

Silvopasture – the integration of trees, forage, and livestock, can be established by thinning existing forested stands or by planting trees in existing pastures. In Missouri, successful tree establishment and acceptable growth in tall fescue pastures requires chemical weed control. Current recommendations vary widely with some suggesting weed control zones should extend as much as 2.4 m from tree seedlings. More defined guidelines are necessary to minimize weed control costs and optimize land use. This study was conducted to determine how much weed control is necessary for the establishment of black walnut (*Juglans nigra* L.) in tall fescue (*Schedonorus phoenix* (Scop.) Holub.) pastures in Missouri. Half-sib black walnut seeds were planted in six different sized vegetation-free zones (0.30, 0.61, 0.90, 1.21, 1.52, and 1.80 m in radius) in tall fescue pastures created and maintained by applying glyphosate. A no-herbicide control was also included. The study was planted two consecutive years at two locations in central and north-central Missouri differing in soil types. The forage in the study areas was mowed to a height of 10 cm prior to planting and twice during the growing season. Data were taken on tree seedling height and diameter. Height of trees was greatest in zones that were 0.90 m or larger. Diameter growth was greatest in 1.21 m zones and larger. These results suggest that weed control should extend a minimum of 1.21 m from black walnut

seedlings in tall fescue pastures to maximize tree height and diameter growth. More weed control may not result in greater tree growth, but would require greater weed control costs and remove more land from forage production.

INTRODUCTION

Silvopasture – the integration of trees, forage, and livestock, can be established by thinning existing forested stands or by planting trees in existing pastures. In the Midwest USA, black walnut has received consideration for silvopasture because it produces both a timber and nut crop. To ensure successful establishment and acceptable growth in tall fescue pastures, black walnut requires chemical weed control (Van Sambeek and Garrett, 2004). Removing unwanted vegetation minimizes competition for moisture and nutrients (Messenger, 1976; Glenn and Velker, 1993) and allelopathy (Hunter and Menges, 2002). The minimum size of vegetation-free area that would result in optimum tree growth likely differs with changing climatic and soil environments. In cool climates, suggested vegetation-free zones are typically smaller than in climates where heat and drought are common (Baughman and Vogt, 1996; Smith et al., 2002). Additionally, variations in soil morphology, notably argillic horizons, can impede downward root growth and restrict access to soil moisture deeper in the soil profile (Sudmeyer et al., 2004). This may cause black walnut seedling roots to spread laterally instead of downward, thus requiring a greater area of weed control.

Grasses, particularly tall fescue (*Schedonorus phoenix* (Scop.) Holub.), limit tree growth more than other herbaceous species (Van Sambeek and Garrett, 2004). However, research on the extent of weed control necessary to alleviate tree growth inhibition is difficult to interpret due to differences in location, treatments, and experimental design (Smith et al., 2002; Carlisle et al., 2003; Von Althen and Prince, 1986; Garrett et al., 1996; Baughman and Vogt, 1996). Many recommendations for the amount of weed control are the result of knowledge gained through communications, unpublished research, and personal observation. Currently, a 1.2 m wide strip (J. Van Sambeek, personal communication, 2005), 0.90 m radius circle (W. Reid, personal communication, 2005), or 1.8-2.4 m strip (Van Sambeek et al., 1998) is considered adequate for tree establishment in tall fescue.

All of these experiments and observations indicate that vegetation-free zones from 1.2-2.4 m wide are acceptable. However, there are considerable differences in land use and chemical inputs between these suggested vegetation-free zones. Relative to a 1.2 m-wide strip, 1.8 m- and 2.4 m-wide strips would require 50 and 100% more weed control inputs and would remove this extra amount of land from pasture production. These differences suggest that more defined recommendations are needed. This research was conducted to determine the minimum distance needed between black walnut seedlings and tall fescue sod to ensure successful establishment and optimum growth of black walnut.

MATERIALS AND METHODS

Study Sites

This study was conducted at two locations: the Forage Systems Research Center (FSRC) near Linneus, Missouri (39º 51' N; 93º 08' W) and the Horticulture and Agroforestry Research Center (HARC) in New Franklin, Missouri (39º 00' N; 92º 46' W). The FSRC site is underlain with a somewhat poorly drained Lagonda silt loam (fine, montmorillonitic, mesic, aquertic argiudoll) that has a defined argillic horizon (40% clay) starting at 20 cm. The HARC site is underlain with a well-drained Menfro silt loam (Fine-silty, mixed, superactive, mesic typic hapludalf) with a less pronounced zone of clay accumulation (27% clay) developing at 20 cm.

Project layout, planting, and maintenance

Seven different sizes of vegetation-free zones in tall fescue pastures were created by applying glyphosate [4.7 l ha^{-1} + ammonium sulfate (1.1 kg ha^{-1})] to circular areas (zones) measuring 0.0 (no herbicide), 0.30, 0.61, 0.90, 1.21, 1.52, and 1.80 m in radius. Each zone was centered 6.1 m apart. One of each zone size was randomly assigned within each of six blocks at each location. Germinated, half-sib, 'Thomas' black walnut seed was planted in the center of each zone in late April of 2005 and 2006. Seedlings were watered at planting and 55 g of Osmocote® 13-13-13 was applied to each seedling at planting and in March of each year after planting. In early May of each year an additional 12.5 g N, 6 g of P, and 6 g of K was applied to each tree as NH_4NO_3, triple superphosphate, and KCl, respectively. The vegetation in the study areas was mowed prior to planting and twice during the growing season to a height of 10 cm. Herbicide applications using the initial rate were made as needed when weed seedlings became noticeable; seedlings were protected by herbicide drift by using a spray shield attached to the sprayer wand. Four applications were made at each location during in the establishment years. In the second year at each location, three applications were applied with the first one being made in early April to eliminate winter annual weeds. Weeds that were unaffected by glyphosate treatments were removed manually.

Data Collection

Data were taken on seedling height and diameter (10 cm above root collar) every two weeks during the growing season (April-August) and at the end of season in October. For each planting, data were taken in the first and second year of growth. For the HARC location only, EC-5 volumetric soil water content sensors (Decagon Devices, Pullman WA, USA) were installed in 2006 in the plot area where seedlings were established in 2005. Sensors were placed at depths of 20 and 40 cm in three replications. Sensors were checked every few weeks during June and July to determine when drought was affecting soil moisture so that a more comprehensive data set could be collected during drought events. Drought conditions were present during July and August in 2006 and 2007. During this time, soil moisture and stomatal conductance were measured periodically. The last significant rainfall events prior to the onset of drought occurred on July 14, 2006 and July 20, 2007 and the drought event lasted a similar number of days each year. Stomatal conductance measurements were taken midday (1100 – 1330 hrs) with a SC-1 steady state diffusion porometer (Decagon Devices, Pullman WA, USA) on three of the most recently fully expanded leaves of seedlings in each plot in which volumetric soil water content measurements were taken.

Experimental design and statistical analysis

The experiment was arranged as a split-plot randomized complete block design with locations as main plots and vegetation-free zones as subplots within each location (Steel and Torrie, 1980). There were six replications and the study was initiated in 2005 and repeated in 2006.

Volumetric soil water content measurements and stomatal conductance measurements taken at HARC were arranged as randomized complete blocks with three replications. If homogeneity of variance was established across years or locations, data were pooled for analysis. Seedling height and diameter at each sampling date during the growing seasons were subjected to analysis of variance (ANOVA) by PROC MIXED (SAS Institute, 2001) with year, location, and vegetation-free zone size specified as random effects. If treatment effects were significant, mean separation using Tukey's Studentized Range Test ($P < 0.05$) was conducted. Stomatal conductance and soil volumetric water content taken at sampling dates during drought periods was subjected to analysis of variance by PROC MIXED with year, location, and vegetation-free zone size specified as random effects. Variance was homogeneous between years for volumetric soil water content and stomatal conductance measurements so data were pooled across years. Mean separation using Tukey's Studentized Range Test ($P < 0.05$) was conducted on these means.

RESULTS AND DISCUSSION

After the first year of growth, seedling diameter, but not height, was affected by zone size (Figures 3.1, 3.2). Diameter was often significantly less in smaller zones (0.0 to 0.61 m) than in larger zones (0.90 to 1.80 m), but few differences within these groupings resulted. As early as the July 8 sampling date, seedling diameter in the smallest zone (0.0 m) was less than that in 1.80 m zones at HARC and less than that in 0.61 m and larger zones at FSRC (Figure 3.1). During July, diameter growth in 0.0, 0.30, and 0.61 m zones slowed. And, after the August 3 sampling date, diameter growth in these smaller zones averaged across locations was only 1 to 12 % of the season's diameter growth. In contrast, diameter growth in larger zones (0.90 to 1.80 m) ranged from 17 to 30% across both locations after this date.

After the first year of growth, seedling height was not affected by zone size. One possible explanation for the lack of height difference is that initial height flushes from seed result from stored energy in the embryo. All seed came from the same seed lot, so one would expect seedlings to grow similarly after germination. Another reason is that most first-year height growth occurred during May, June, and July each year when growing conditions are more favorable for growth and competition is likely less than when moisture and temperature become limiting to growth later in the season. Also, while seedling height tended to increase with increasing zone size height varied greatly in any zone size resulting in a high coefficient of variation both establishment years (CV = 32 % in 2005; 38 % in 2006). This variable height growth led to non-significant differences between means at $P < 0.05$. However, after the second year of growth means were different at $P < 0.05$.

After the first year, there were differences in diameter growth between locations, and height growth between planting years. These location and planting year differences were difficult to interpret because one would expect both parameters to interact with location or planting year similarly. Instead, height was greater in 2006 than in 2005 while diameter was similar in both years, and diameter was greater

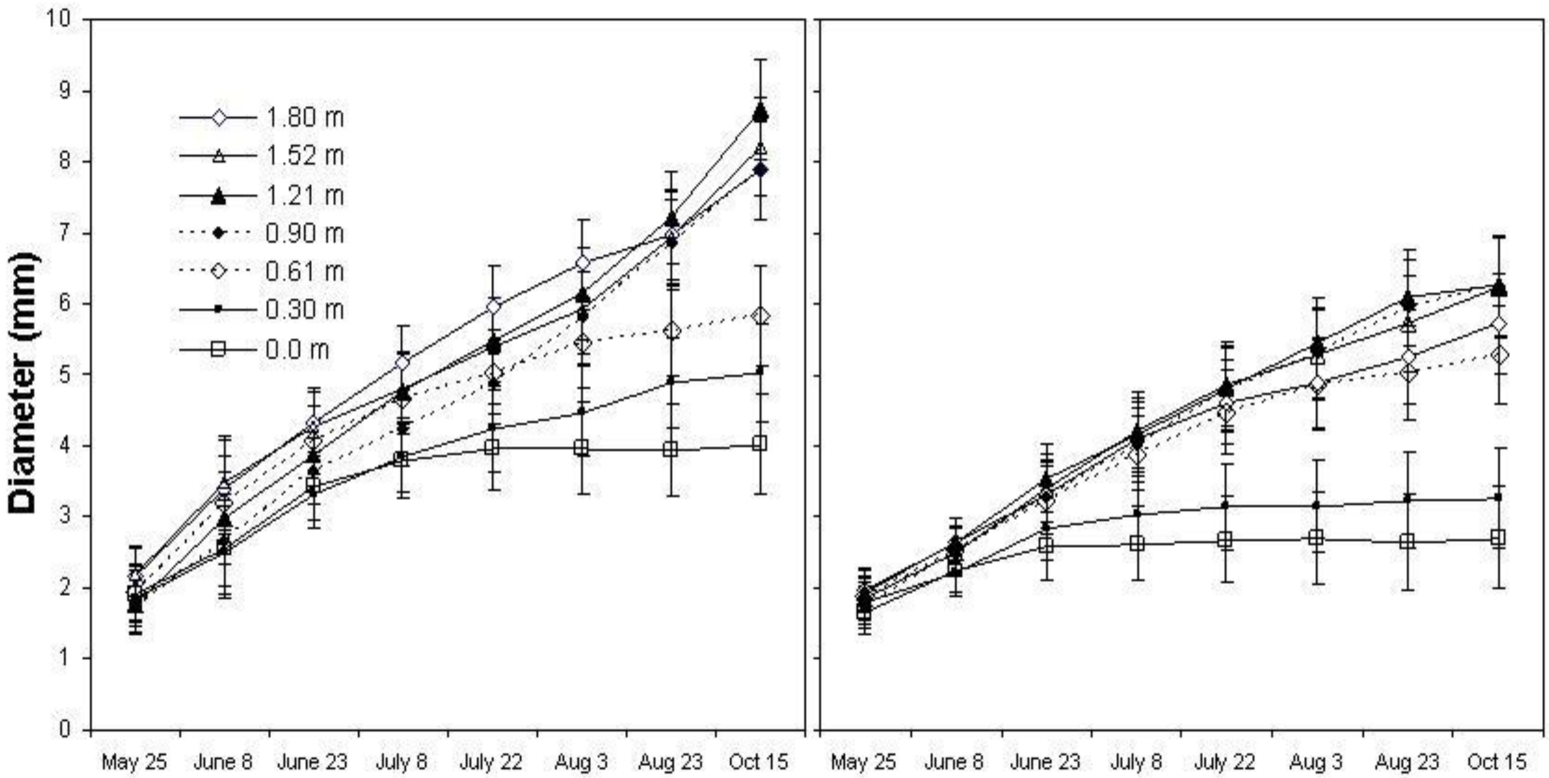

Figure 3.1. Black walnut seedling diameter during the first growing season when grown in vegetation-free circles varying in radii from 0.0 to 1.80 m at HARC (left) and FSRC (right). (vertical bars represent mean +/- std. error; $n = 6$).

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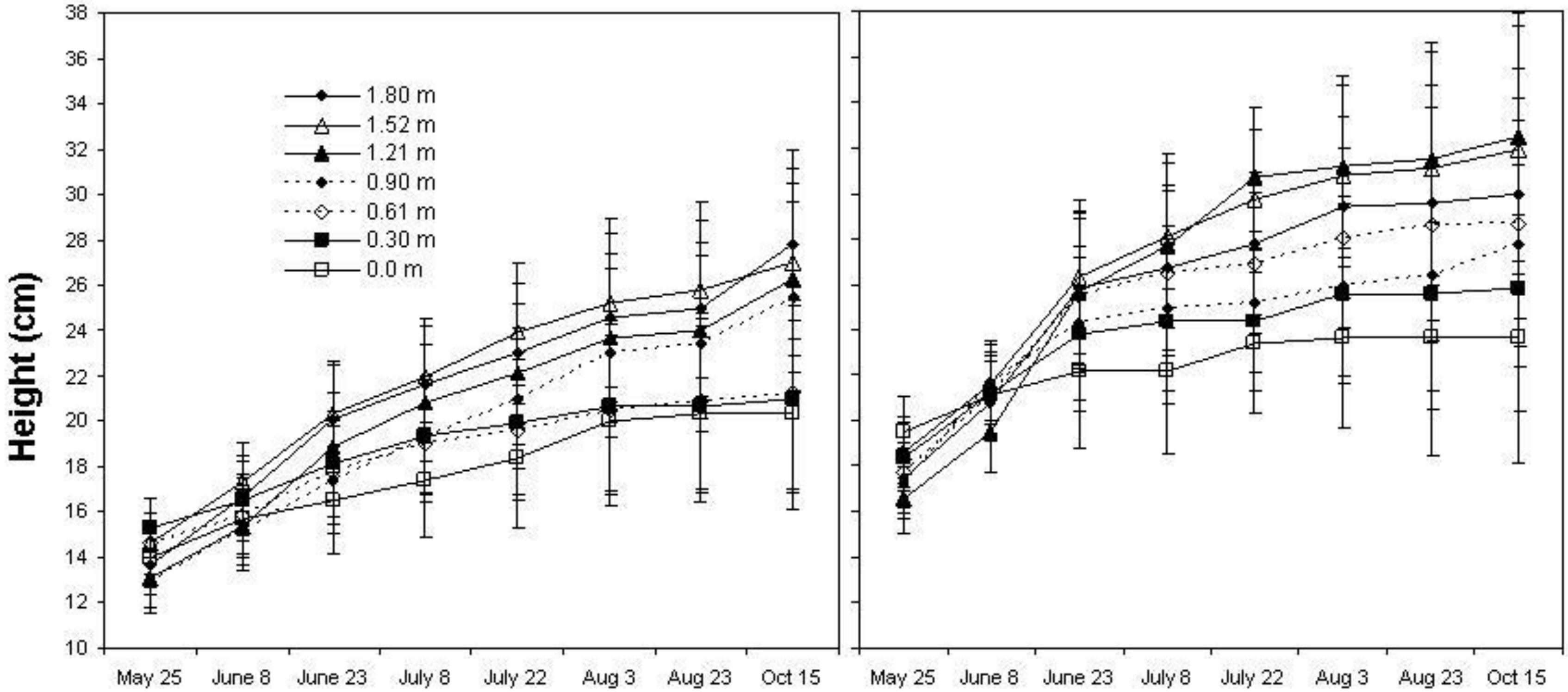

Figure 3.2. Black walnut seedling height during the first growing season when grown in vegetation-free circles varying in radii from 0.0 to 1.80 m at HARC and FSRC in 2005 (left) and 2006 (right). (vertical bars represent mean +/- std. error; *n* = 6).

at HARC than FSRC while height was similar at both locations. In September 2005 and 2006, precipitation was greater at HARC than at FSRC and this may have contributed to greater diameter growth at HARC (Table 3.1; Figure 3.1). July rainfall was considerably less in 2005 than in 2006. However, height growth in 2005 does not appear to be reduced during July so height differences could not be explained by differences in weather between years. After two growing seasons, location and planting year differences were not apparent, so it is possible that these disparities resulted from planting and establishment variability that did not affect growth in the second year of growth.

Table 3.1. Monthly precipitation (May – Sept.) and average daily high temperature at FSRC and HARC in 2005 - 2007.

	Precipitation					Temperature				
Site	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.
	mm					ºC				
2005										
FSRC	65	133	17	99	21	23.1	29.7	32.1	31	27.8
HARC	45	184	19	205	72	24.0	29.9	32.5	31.3	27.8
2006										
FSRC	63	96	99	119	25	23.5	28.9	31.9	30.1	24.1
HARC	75	102	97	69	45	24.2	29.1	32.6	32.8	24.9
2007										
FSRC	135	135	35	99	49	25.0	27.8	30.4	32.9	27.9
HARC	117	156	48	42	31	26.3	28.2	29.8	33.8	28.6
Historical avg.										
FSRC	136	113	114	114	98	22.8	27.9	30.8	29.7	25.6
HARC	121	106	95	95	99	24.5	28.9	31.6	31.0	26.8

After two growing seasons, zone size affected black walnut seedling diameter and height (Figure 3.3). Mean diameter ranged from 4.9 to 19.8 mm in 0.0 - 0.90 m zones. In zones 1.21 m and larger, diameter was similar and averaged 22.6 mm. Diameter increased as zone size increased to 1.21 m indicating a decline in competition as more weed control was implemented. Weed control greater than 1.21 m in radius did not result in greater growth and suggests that zones larger than 1.21 m are unnecessary for black walnut establishment in tall fescue pastures.

Similar to the first year, diameter growth in smaller zones slowed or ceased earlier in the growing season than in larger zones. In the four largest zones, diameter growth continued until the last sampling date, while little growth occurred in smaller zones (0.0 – 0.61 m zones) after the July 22 sampling date. Growth during mid- to late-season has lasting effects on seedling fitness because carbohydrate production exceeds growth demands and reserves used for the following early season's growth are established (Kozlowski and Pallardy, 1997). This is important because as much as 66% of the carbohydrate used in early season growth is stored in the latter part of the previous season (Hansen, 1977). Less diameter growth in smaller zones in the planting year in mid- to late-season likely contributed to less early season growth in the second year.

After two growing seasons, black walnut seedling height was affected by zone size (Figure 3.3). Mean height ranged from 34 to 64 cm in 0.0 and 0.61 m zones, respectively. Like diameter, height increased with increasing zone size indicating a decline in competition with more weed control; however, differences between smaller zones were not always significant. Height was similar in 0.90 m and larger zones and averaged 85 cm suggesting that tall fescue competition does not affect height beyond a distance of 0.90 m from the sod edge. Diameter increased in zones up to 1.21 m in

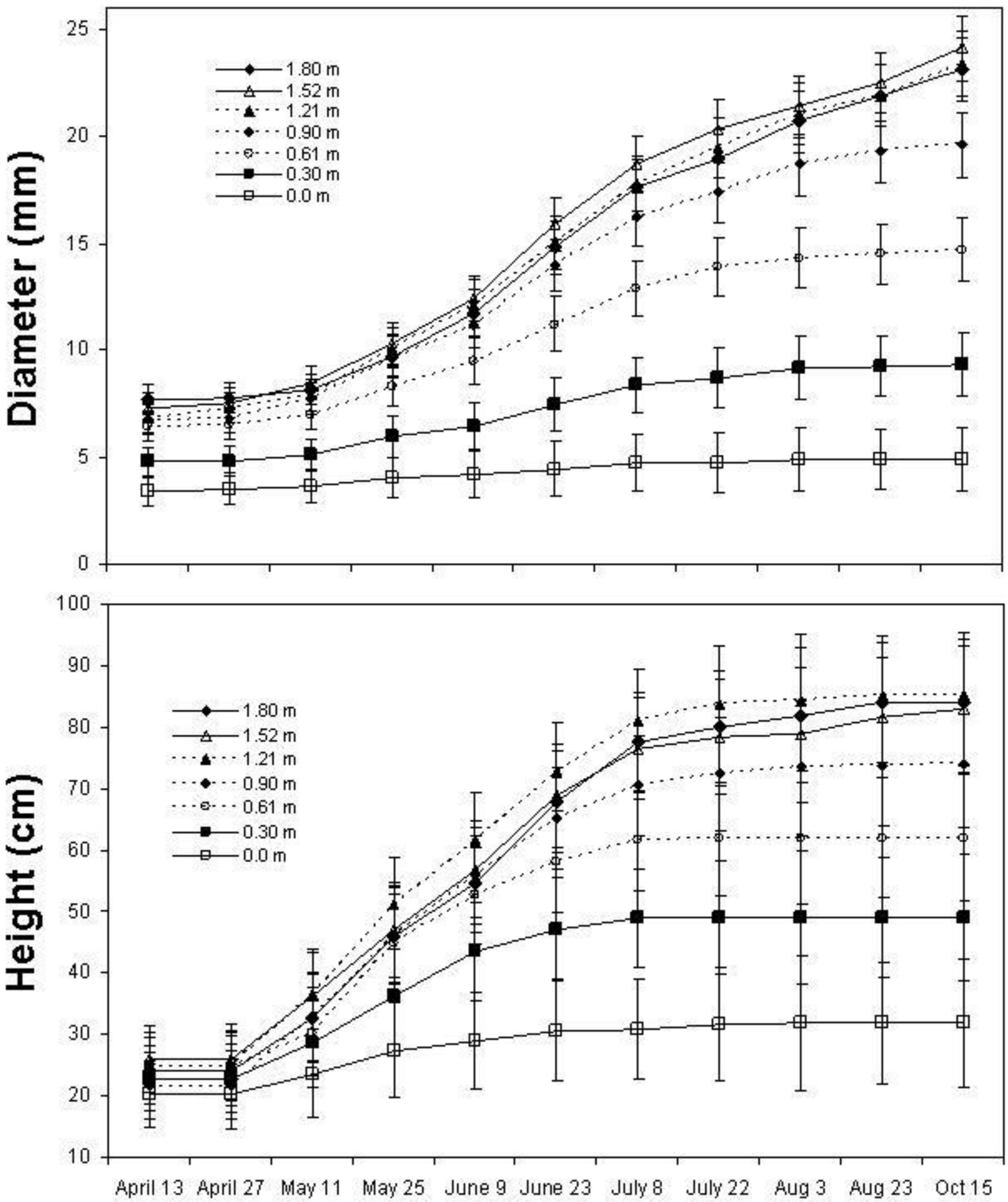

Figure 3.3. Black walnut seedling diameter (top) and height (bottom) during the second-growing season when grown in vegetation-free circles varying in radii from 0.0 to 1.80 m. Data is combined across locations and planting years. (vertical bars represent mean +/- std. error; n = 24).

radius suggesting that this parameter is more sensitive than height to tall fescue competition. These differences in zone size requirements appear to be due to the duration of the season in which diameter and height growth occur. In the first and second year of growth, most height growth slowed near the beginning of July in all zones and little growth occurred after the July 22 sampling date. In contrast, diameter growth in many of the zones continued through the end of the growing season. This accounted for up to a 10 to 15 week longer growth period and allowed for a longer period in which competition could affect diameter growth.

Volumetric water content (soil moisture) and stomatal conductance measurements taken at the HARC location were similar both years so data were pooled across years for analysis. Soil moisture at 20 and 40 cm depths and stomatal conductance ($g_{(s)}$) during summer droughts were affected by zone size (Figures 3.4 and 3.5). Differences were not always significant, but means declined with decreasing zone size at most sampling periods. One day after the last precipitation event in July of each year, soil moisture ranged from 36 to 39 % and 28 to 31 % at 20 and 40 cm depths, respectively, and stomatal conductance averaged 490 mmol cm^{-2} s^{-1} across the zones. Daytime temperatures were above 33 ºC at this time and soil moisture at 20 cm and stomatal conductance rapidly declined during the first seven days.

By day seven, soil moisture at 20 cm declined to 16 % in 0.0 m zones and this was less than that in all other zones which averaged 24 %. Soil moisture at 40 cm averaged 22 % in 0.00 to 0.90 m zones and was less than that in 1.21 m and larger zones which averaged 25 %. By day seven, seedlings were affected and $g_{(s)}$ declined

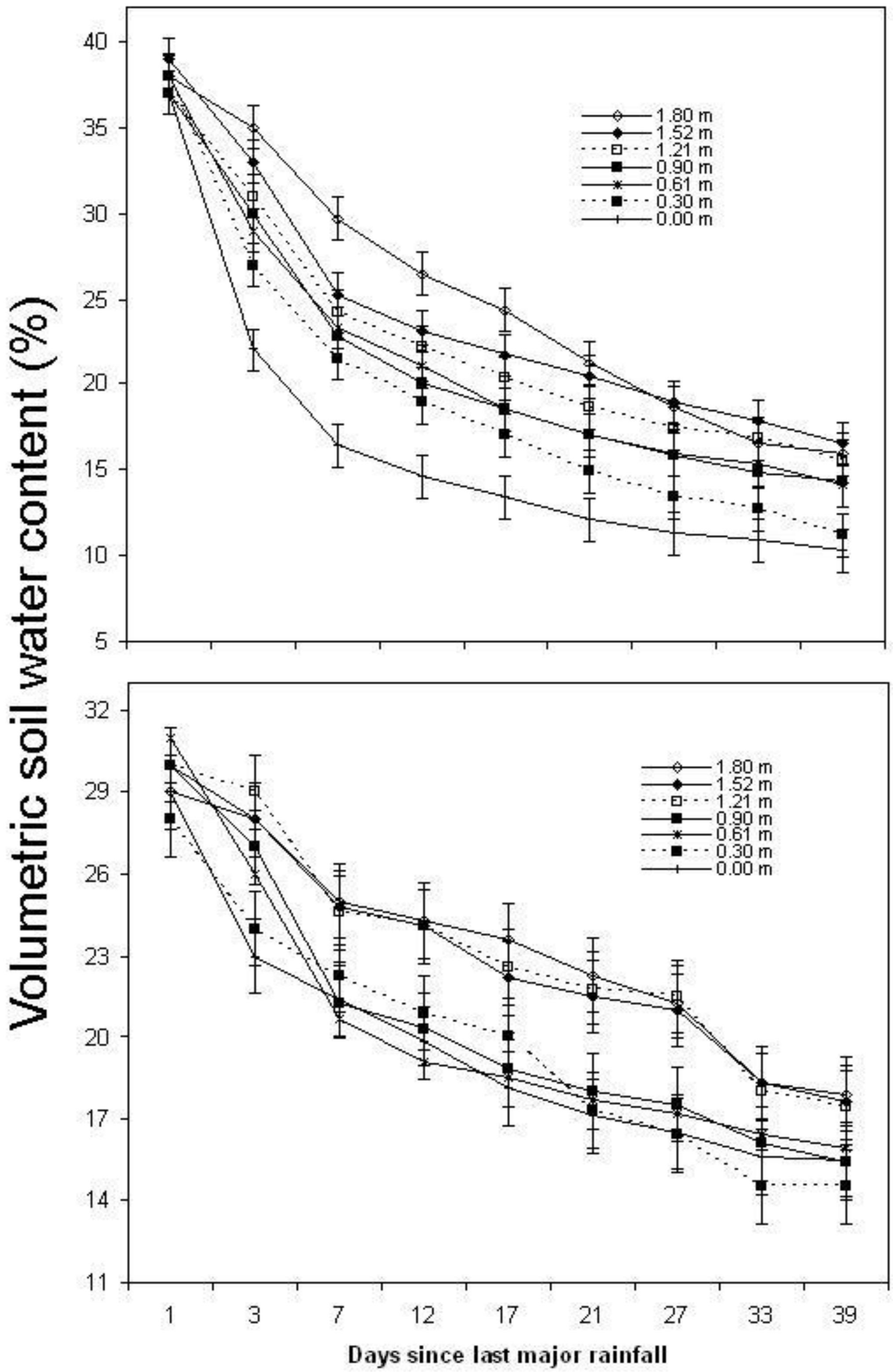

Figure 3.4. Volumetric soil water content in vegetation-free zones varying in radii from 0.0-1.80 m following the last major rainfall event in July at 20 cm depth (top) and 40 cm depth (bottom). Data were similar each year and were combined. (vertical bars represent mean +/- std. error; n = 3).

in all zones. In 0.0 m and 0.3 m zones $g_{(s)}$ averaged 84 mmol cm^{-2} s^{-1} and was similar despite soil moisture being greater in 0.3 m zones. In larger zones, $g_{(s)}$ averaged 246 mmol cm^{-2} s^{-1} and was greater than in 0.0 and 0.3 m zones.

After day 7, soil moisture at both depths continued to decline as daytime high temperatures remained above 33 C. In the smallest zone, soil moisture at 20 cm remained less than that in other zones except that in 0.30 m zones after day 27. At the end of the period, soil moisture at 20 cm averaged 11% in the two smallest zones and was less than that in other zones. Soil moisture at 20 cm in the three largest zones remained greater than that in the two smallest zones throughout the remainder of the study period and averaged 17.5 % at day 39. The most noticeable moisture differences between zones occurred at the 40 cm depth where soil moisture in the three largest zones averaged greater than 20 % and was greater than that in all other zones until the day 33 sampling. By day 39, soil moisture at 40 cm ranged from 15 to 19% and there were few differences between any zones. Average $g_{(s)}$ in zones larger than 0.30 m declined from 249 mmol cm^{-2} s^{-1} at day 7 to 175 mmol cm^{-2} s^{-1} at day 33. Daytime high temperatures declined to 29-30 ºC after day 33 and seedlings in 1.21 m zones appeared to respond to these changes and by day 39 had higher $g_{(s)}$ than in 0.00 – 0.61 m zones.

Black walnut seedlings grew best in 1.21 m radius and larger vegetation-free zones. This is more weed control than others recommend for similar conditions (Smith et al., 2002; Garrett et al., 1996) and twice as much as that recommended in northern climates (Baughman and Vogt, 1996). Soil water content measurements taken at the HARC location indicate that the zone size has an effect on soil moisture. Stomatal conductance measurements during drought events also indicate that lower

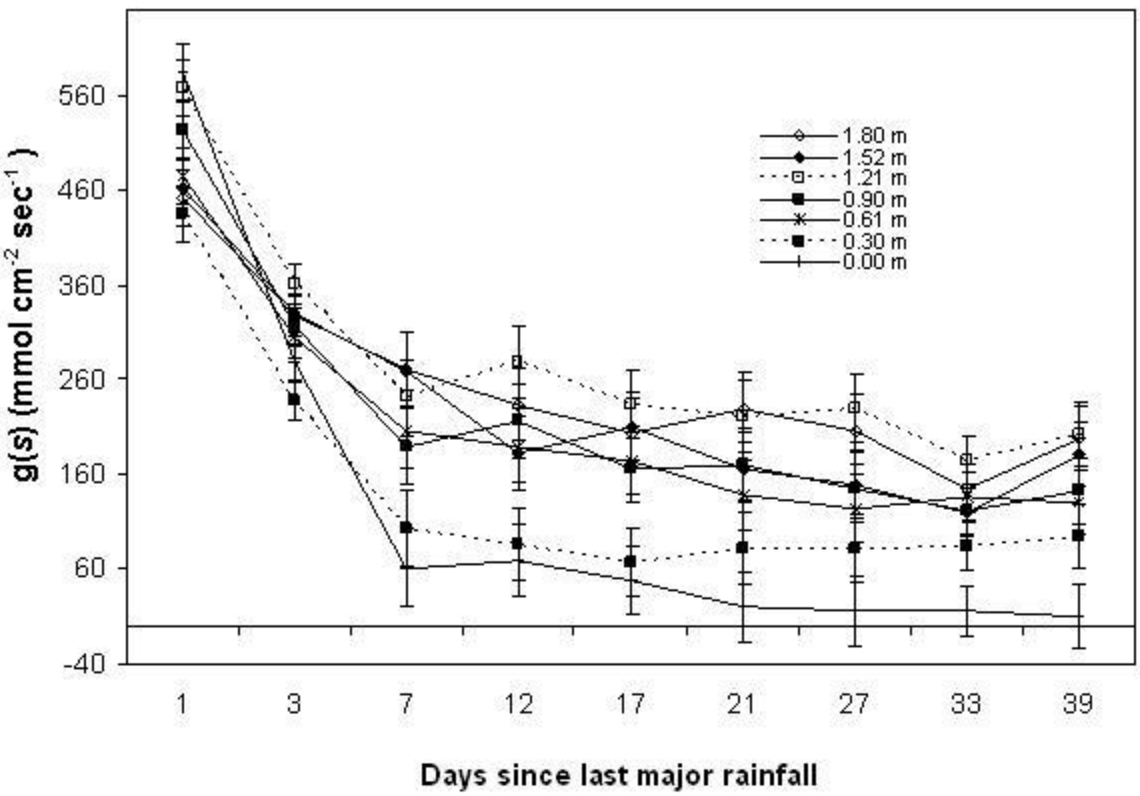

Figure 3.5. Black walnut seedling stomatal conductance (g_s) following the last major rainfall in July when grown in vegetation-free circles varying in radii from 0.0 to 1.80 m. Data were similar each year and were combined. (vertical bars represent mean +/- std. error; n = 6).

soil moisture associated with smaller zones affects seedling physiology. Lower stomatal conductance would reduce gas exchange and photosynthesis and result in the reduced growth seen in smaller zones. Differences in soil moisture and stomatal conductance developed rapidly during drought events and it is likely that differences in these parameters develop among the different zones at other times of the year also.

CONCLUSIONS

Results from successive planting years at two locations in Missouri suggest that weed control should extend a minimum of 1.21 m from seedlings when establishing black walnut into a tall fescue sod. Weed control greater than 1.21 m in radius did not result in greater growth, but would result in greater weed control costs and loss of forage production in silvopastures. Diameter was more sensitive than height to differences in zone sizes and requires a larger zone for maximum growth. Improved growth in the larger zones was likely due to less competition that results in better physiological status of seedlings. In the latter part of the growing season, this may be critical for energy storage used in the following early-season growth. In general, soil moisture during drought events declined with decreasing zone size at both depths. At the 40 cm depth, soil moisture was greater in 1.21 m radius and larger vegetation-free zones than in most other zones through most of the drought period. Greater moisture at this depth may partly explain why diameter growth in 1.21 m and larger zones continued through July and August both years. The presence of an argillic horizon at FSRC had no effect on the response of the seedlings after two years of growth and suggests that in the initial years after planting, competing vegetation is the primary factor influencing black walnut seedling growth. Although site selection is critical for the long term productivity of black walnut planted into a tall fescue pasture, initially, site characteristics may not be as important as weed control for seedling growth.

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CHAPTER 4

An evaluation of planting stock and mycorrhizae inoculum on black walnut establishment and growth in tall fescue-based silvopastures.

ABSTRACT

Creating silvopasture in existing pastured settings offers the opportunity to plant eastern black walnut (*Juglans nigra* L.) seed because predation by animals may be discouraged due to a lack of proximity to habitat. In these environments, seeded seedlings may offer a lower-cost alternative to bare-root and containerized stock that often suffer from transplant shock and poor survivability. Many Midwest pastures have been void of trees for extended periods and may lack effective mycorrhizae for black walnut. Adding effective mycorrhizae in these environments may improve tree growth. To evaluate these factors 'Sparrow' bare-root, containerized, and seed stock were planted in April 2005 at two locations in Missouri. Weed control was used to eliminate tall fescue competition and seedlings were grown for two seasons after outplanting. Bare-root and containerized seedlings transplanted well and were larger than seedlings from planted nuts after two years in the field. Containerized seedling diameter was larger than that of bare-root seedlings at planting and after two years while heights were similar throughout the experiment. There are considerable cost differences between containerized and bare-root stock that suggest that bare-root stock is the best choice. However, producers wishing to plant improved black walnut varieties may be limited to containerized stock because improved bare-root seedlings

are often not available. Mycorrhizae inoculants did not affect growth of any stock type.

INTRODUCTION

When establishing silvopasture, producers have three types of eastern black walnut (*Juglans nigra* L.) planting stock to choose from: bareroot seedlings, containerized seedlings, and seed. Nursery-run bareroot seedlings are the primary source for black walnut stock due to the economics of large-scale seedling production, shipping, and planting (Reitveld and Williams, 1981; Reitveld and Van Sambeek, 1989; Melichar et al., 1986; Hammitt, 1989). This stock is easily available, but seedling survival and performance after transplanting can be poor if seedlings have not been properly cared for during production, shipping, and pre-plant storage (Webb and Von Althen, 1980).

Containerized seedlings are typically larger than bareroot stock, and are often not affected by transplant shock as readily as bareroot seedlings. However, planting year survival can be problematic (Von Althen and Prince, 1986) and within a few years after planting, containerized seedlings may not perform better than bareroot seedlings or seeded nuts (McQuilken, 1974; Von Althen, 1975).

Direct seeding of walnut seed is not recommended because of predation by animals. However, pastures present a setting where predation may be discouraged because of the lack of proximity to habitat. Direct seeded seedlings can grow as well as or better than bareroot or containerized stock (Hammitt, 1989; McQuilken, 1974). Unlike other stock, seedlings develop taproots naturally at the planting site (Van Sambeek 1988) and this may be why this material can perform as well as other choices (Geyer and Deneke, 2005). Seed is easier to handle than other stock choices and it can be planted quickly with a hand trowel. For these reasons, direct seeding could offer considerable cost savings to landowners.

Arbuscular mycorrhizae (AM) fungi of the genus *Glomus* and *Gigaspora,* have been shown to improve black walnut growth (Kormanik et al., 1982; Kormanik, 1985; Melichar et al., 1986, 1982). In the Midwest, many tall fescue pastures were converted from forests many years ago. And, although tall fescue forms mycorrhizal associations with some of the same AM fungi that black walnut does, Guo et al., (1993) showed that some *Glomus* and *Gigaspora* propagules were nonexistent in tall fescue plots and could not be bioassayed with tall fescue. Thus, tall fescue pastures may not have effective indigenous mycorrhizae for black walnut and inoculating seedlings with proper AM fungi may improve tree growth. However, studies under similar circumstances resulted in conflicting conclusions. For instance, Abbot and Robson (1981) suggest that adding effective mycorrhizae may decrease the amount of colonization by unwanted indigenous mycorrhizae. But, Ponder (1979) suggests that indigenous mycorrhizal strains may limit the colonization of inoculated AM fungi and may be better acclimated to local site conditions and provide more benefits than introduced inoculants (Ponder, 1984). Applying mycorrhizae inoculants take time and they are expensive. While black walnut growth can be improved with proper mycorrhizae, the value of inoculants in many settings is questionable because mycorrhizae already inhabit most soils.

To evaluate the effect of introduced mycorrhizae, we chose planting sites in tall fescue pastures that have been void of trees for more than 40 years. One site in central Missouri has been in pasture since before 1953 when the University of

Missouri took ownership of the property. The other site in north-central Missouri has been a University of Missouri forage research farm since 1965. This property was homesteaded in the 1880's and may have been in pasture since then.

The goal of this study was to create recommendations for planting stock type and mycorrhizae inoculations for silvopasture establishment in tall fescue pastures. To do this, two objectives were adopted: 1) to compare growth of black walnut from seed, bare-root stock, and containerized stock two years after outplanting and, 2) to evaluate growth of these stock types with and without mycorrhizae inoculants.

MATERIALS AND METHODS

Study sites

This study was conducted at two locations: the University of Missouri, Forage Systems Research Center (FSRC) near Linneus, Missouri (39º 51' N 93º 08' W) and the Horticulture and Agroforestry Research Center (HARC) near New Franklin, Missouri (39º 00' N 92º 46' W). The FSRC site is underlain with a somewhat poorly drained Lagonda Silt Loam (fine,montmorillonitic, mesic, Aquertic Argiudoll) that has a defined argillic horizon (40% clay) starting at 20 cm. The HARC site is underlain with a well-drained Menfro silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalf) with a less pronounced zone of clay accumulation (27% clay) developing at 20 cm.

Project layout, planting, and maintenance

At each location, three types of black walnut planting stock (seed, containerized seedlings, and one-year old bareroot seedlings) were planted in 2.4 m-wide, vegetation-free strips created by applying glyphosate (41% a. i.) at a rate of 4.7 l ha^{-1} + Ammonium Sulfate (1.1 kg ha^{-1}) in tall fescue pastures in April 2006. Seed and bare-root stock were acquired from the George O. White State Nursery in Licking, MO. Both seed and bare-root seedlings were 'Sparrow' progeny. To produce the bareroot seedlings, seed were sown from mid-October – early December and grown for one season in nursery beds and lifted the following winter (early December – March). After lifting, seedlings were graded, packaged, and stored in coolers at 1.1 ºC prior to shipping. Prior to sowing, nursery beds are fumigated with methyl bromide (448 kg ha^{-1}) and seedlings are not inoculated with mycorrhizae in the nursery. Containerized stock were 'Sparrow', two-gallon seedlings from Forrest Keeling Nursery in Elsberry, MO. Seed for this stock, were sown in early spring and grown for one season using the Root Production Method® that includes mycorrhizae inoculations. Seed were surface sterilized prior to planting by soaking in 10% bleach and rinsing with distilled water, the process was repeated three times.

Bareroot and containerized seedlings were graded by height and diameter and analyzed by PROC mixed (SAS Institute, 2001) prior to planting to determine if these stock types differed in size. Height of containerized and bareroot seedlings were similar, but containerized seedling diameter was greater than bareroot seedlings. Two of each planting stock were randomly planted 2.4 m apart in a line running lengthwise through the middle of each strip. Seedlings at each strip end were planted 1.2 m from the sod edge. Each strip was separated by 3 m of tall fescue sod and replicated six times. Mycorrhizae inoculant (MycorrhizaROOTS ®, Roots Inc., Independence, MO, USA) was mixed with distilled water (42.3g L^{-1}) and applied at planting as a soil drench at the rate of 1.9 L per seedling. Inoculant was randomly applied to one of two seedlings of each stock type in each replication. Non-inoculated seedlings received 1.9 L of distilled water at planting also. The 2.4 m-wide vegetation-free strips were maintained with glyphosate.

Data, Experimental design, and statistical analysis

Height and diameter of the seedlings were measured in April and October of 2006 and October 2007. The experiment was arranged as a split-plot randomized complete block design with locations as main plots and combinations of three stock type and two mycorrhizal treatements as subplots within each location (Steel and Torrie, 1980). Seedling height and diameter at the end of each growing season was subjected to analysis of variance (ANOVA) by PROC MIXED (SAS Institute, 2001) with location specified as a random effect. If homogeneity of variance was established, data were pooled for analysis. Pairwise comparisons were made to determine the effect of mycorrhizae treatment within each stock type using ADJUST=TUKEY in the LSMeans statement of PROC MIXED. If treatment effects were statistically significant, mean separation using Tukey's Studentized Range Test ($P < 0.05$) was conducted.

RESULTS AND DISCUSSION

Stock types

All seedlings established well and survival was similar among stock type and mycorrhizae treatment. Survival averaged 91 % after the first growing season and no seedlings perished in the second season. Seedlings grew similarly at both locations so data were pooled across locations.

After two growing seasons, height growth was similar for containerized and bareroot seedlings (165.4 and 150.3 cm, respectively) and both of these stock types were more than twice as tall as seeded stock (71.8 cm) (Table 3.1). Height of containerized and bare-root stock was similar at planting and remained so throughout the experiment. Both types grew well and averaged a 96 % increase in height during the experiment. In contrast, seeded stock mean height after two years of growth was about the same as the other two stock types were when they were planted at the beginning of the study. Two years after outplanting, mean diameter of containerized seedlings (28.2 mm) was greater than that of bare-root seedlings (21.4 mm) and mean diameters of both stock types were greater than that of seeded seedlings (15.9 mm). Containerized seedling diameter was greater than bare-root diameters at planting and remained so throughout the experiment.

Table 4.1. Containerized, bare root, and direct seeded black walnut seedling height and diameter in spring 2006 and at the end of each growing season (October) averaged across two planting locations (HARC and FSRC) when inoculated with (Myc (+)) and without (Myc (-)) a mycorrhizae inoculant.

	Spring 2006				October 2006				October 2007			
Stock type	height	mean	diameter	mean	height	mean	diameter	mean	Height	mean	diameter	mean
	------ cm------		----- mm ----		-------cm------		----- mm -------		------ cm-------		------ mm ------	
Containerized												
Myc (+)	79.7	81.4 a†	9.6	9.4 a	95.7	96.1 a	14.3	13.9 a	167.2	165.4 a	28.8	28.2 a
Myc (-)	81.4		9.2		97.2		13.4		164.7		27.0	
Bare root												
Myc (+)	79.9	79.6 a	7.7	7.6 b	91.5	90.2 b	11.6	11.2 b	151.1	150.3 a	21.2	21.4 b
Myc (-)	79.6		7.5		89.3		10.8		147.3		21.8	
Direct seeded												
Myc (+)	0	0 b	0	0 c	29.8	31.4 c	4.4	4.7 c	71.5	71.8 b	16.4	15.9 c
Myc (-)	0		0		32.9		4.9		73.2		16.7	
Significance	ns	*‡	ns	*	ns	*	ns	*	ns	*	ns	*
Tukey's MSD		4.57		1.4		5.34		1.1		15.9		3.9

† Means followed by the same letter in a column are not different (P < 0.05)
‡ * significant at 0.05 probability level

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Two years after outplanting, seeded stock was smaller than containerized and bare-root seedlings. This was not surprising because containerized and bare-root seedlings were larger than seeded seedlings at planting and did not suffer any noticeable transplant shock or mortality. Transplant shock can cause tip dieback, leaf loss, and poor growth in nursery stock after outplanting (Reitveld and Van Sambeek, 1989) and has been cited as a reason why direct seeded seedlings can outperform nursery-grown seedlings after outplanting to the field (Von Althen and Prince, 1986). When transplant shock is minimal, these stock types appear to perform better than seeded stock.

Bare-root seedlings were similar in height but had smaller diameters than containerized seedlings when planted and two years after planting. In the nursery, bare-root seedlings are grown at higher densities relative to containerized stock and thus, typically have taller, thinner stems. Bare-root stem diameter was 19 % less than containerized stock at planting and 24 % less after two years of growth in the field and suggests that both stock types grew similarly in the field.

There are considerable differences in costs associated with these stock types. Containerized stock used in this study range from $8.00 to $11.00 per seedling while bareroot stock cost $0.44 per seedling and walnut seeds cost $0.13 each. Although seeded stock is the lowest cost alternative, planting more than one seed per tree location is often suggested, thus the total cost of seeded stock may range from $0.26-$0.39 per established tree. Also, the growth of seeded stock after two years likely would not justify their use relative to bare-root seedlings that are handled and transplanted properly. Containerized seedlings had the largest diameter at planting and after two years; however, height was similar to bare-root seedlings throughout the experiment and suggests that both stock types grew similarly after outplanting.

Mycorrhizae inoculant

After the first and second growing seasons, the mycorrhizae inoculant did not improve growth of any seedlings. Each year means were inconsistent and variable. Because containerized stock was grown in the nursery with mycorrhizae inoculations the lack of response was not surprising in this stock type. Roots were likely well colonized prior to planting and inoculant spores may not have had any infection sites available for colonization. Bare-root nursery beds are typically fumigated and AM fungal spores are not wind disseminated so colonization of bed-grown seedlings usually requires inoculants. Inoculants are not used at the George O. White State Nursery so the status of mycorrihizae infection in bare-root stock was unknown. Nonetheless, no response was found in bare-root stock either. However, seeded nuts were sterilized prior to planting. Because of sterilization, seeded seedlings offered the best opportunity for inoculant mycorrhizae to infect the germinating seedlings. If there was an obvious effect from the mycorrhizae inoculant, it would have been likely in the seeded seedlings. But, we still did not see a response in seeded seedlings so using inoculants in tall fescue pastures is unwarranted.

The lack of response to mycorrhizal inoculation could be due to many factors. One possibility is that inoculant strains were ineffective at colonizing the roots of these trees. This seems unlikely because the inoculant contains seven species of *Glomus* and *Gigaspora* and similar inoculants are used in commercial nurseries. A more likely possibility is that they could not compete with indigenous mycorrhizae for infection sites as suggested by Abbot and Robson (1981) or were no more effective than indigenous mycorrhizae at improving growth as suggested by Ponder (1984). At these sites, indigenous mycorrhizae have evolved over time and would be better acclimated to local conditions. As such, applying growth promoters that enhance the activity of indigenous mycorrhizae has been suggested for use in tall fescue pastures instead of inoculants (Don Marx, personal communication, 2006).

CONCLUSION

Due to transplant shock being minimized, bare-root and containerized black walnut stock were larger than direct seeded black walnut two years after outplanting. There were few differences in growth and survival between bare-root and containerized stock so the price of containerized stock likely is not justified by growth alone. However, other factors such as improved cultivars selected for early nut production or specific fruiting characteristics may be desired by landowners. Because the supply of improved seed is limited, few nurseries offer improved black walnut bare-root stock. If improved characteristics are desired, containerized stock may be the only choice available. Applying mycorrhizae inoculant at planting did not improve growth of any seedlings. Tall fescue pastures may have indigenous mycorrhizae that compete with inoculant species or are as effective as inoculants at colonizing black walnut. It is unclear whether inoculation may help tree growth over a longer assay period.

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CHAPTER 5

SUMMARY AND CONCLUSIONS

Tall fescue is a competitive grass; however, its effect on tree growth depends upon the tree species. Black walnut was the most sensitive of the trees evaluated to different grass species and grew better in Kentucky bluegrass, and in most cases orchardgrass, than in tall fescue. Northern red oak was less sensitive to grass species than black walnut, but growth in Kentucky bluegrass was always greater than that in orchardgrass and tall fescue. Black locust height growth in two of the four tall fescues was less than in Kentucky bluegrass and orchardgrass, but diameter and aboveground biomass growth were similar in all grasses. Pitch x loblolly pine was least sensitive to grass species and grew similarly in all grasses and vegetation-free plots.

Tree growth differences between grass species were not related to biomass yield as most grass species yielded similarly. Also, black walnut, red oak, and black locust growth was often least in the lowest yielding grass—'Houndog 5'turftype tall fescue. Cheng and Bledsoe (2004) showed that competition for moisture and nutrients increase as grass growth and vigor increase. However, the lack of tree response to grass yield differences suggests that competition is too great in Midwestern pastures for increased forage management intensity to have an adverse affect on tree growth.

No differences in tree growth could be attributed to tall fescue's endophyte. Although pitch x loblolly pine growth was greater in 'Ky-31' E+ and 'Houndog 5' E+ than in 'Ky-31' E- and the novel E+ 'Max-Q', there were no differences in growth when ‘Ky-31’ tall fescue varieties differing in endophyte status were compared (‘Ky-31’ E+ ; ‘Ky-31’ E-). Thus, tall fescue’s endophyte association does not appear to affect tree growth via allelopathy or indirectly by enhancing tall fescue growth. Landowners wishing to establish trees into endophyte-infected tall fescue pastures do not need to take any precautions regarding tall fescue’s endophyte.

Supplemental irrigation and fertilization did not improve tree growth in the grasses. Black walnut diameter growth improved in the grasses when both irrigation and fertilizer were applied, but this growth was still much less than that in vegetation-free plots. These treatments were implemented to determine whether tall fescue’s effect on tree growth was due to competition for moisture and/or nutrients. When irrigated, black walnut responded to higher soil moisture with improved stomatal conductance. Despite this, irrigation did not improve black walnut growth suggesting that factors other than moisture competition are responsible for poor growth. Nitrogen, P, and K were applied at twice the normal rate for black walnut fertilization. At these rates, growth of all tree species except pitch x loblolly pine was still considerably less than when grown in vegetation-free plots. Estimates of forage N removal suggest that almost half of the applied fertilizer could be lost with forage harvests and this may partly explain the lack of response from fertilization.

Supplemental irrigation and fertilization did not improve growth in vegetation-free plots either. Although not significant, tree growth means were often less in vegetation-free plots when only irrigation or fertilizer was applied suggesting that these treatments were not necessary for good growth. This was not surprising as research suggests that trees may not respond to or can be adversely affected by these treatments on good growing sites such as the one used for this study (Van Sambeek and McBride, 1991; Ponder, 1997). On good sites, soil moisture and nutrients are typically present in quantities that are not limiting to tree growth in the first few years after planting.

Weed control is necessary when establishing trees in tall fescue pastures. Black walnut growth in tall fescue was greatest in vegetation-free zones with a radius of 1.21 m and larger. Maintaining zones greater than 1.21 m would result in greater weed control costs without increasing tree growth. This zone size is larger than current recommendations that suggest zones with a radius of 0.61 to 0.90 m (Reid et al., 2007; J. Van Sambeek, personal communication, 2005; Van Sambeek et al., 1998; W. Reid, personal communication, 2005). Diameter growth was more sensitive than height growth to differences in zone size. Differences in diameter growth between zones could partly be attributed to less competition in the larger zones in mid- to late-summer. During this time of the year, diameter growth continued in the largest zones while growth slowed or ceased in smaller zones. Soil moisture and stomatal conductance generally increased with increasing zone size. And, soil moisture at the 40 cm depth remained greater in 1.21 m and larger zones for a greater portion of the sample period in July and August of both years. Access to deeper soil moisture during this time of the year may partly explain why diameter growth continued in larger zones during July and August. There were no growth differences across locations after two years suggesting that site differences such as argillic horizons have little effect on the size of tall fescue-free zones in the initial years of growth.

However, as trees grow larger, site differences may have a greater effect on tree growth.

Containerized and bare-root seedlings transplanted well and were larger than seeded seedlings after two years of growth in field settings. This result was not necessarily due to poor growth of seeded seedlings, but rather a lack of mortality and transplant shock in the larger stock types. Mortality and transplant shock are reasons that seed may perform as well as larger stock types (Webb and Von Althen, 1980; Von Althen and Prince, 1986). However, if these problems are minimized, nursery-grown seedlings should remain larger than seeded seedlings in the first few years following outplanting. Cost considerations make bare-root seedlings the likely choice for most landowners that want to establish silvopasture. However, landowner objectives must be considered when deciding the type and source of stock used. Improved cultivar use is emphasized as a way to increase both yield and nut quality. Most bare-root nurseries do not produce improved cultivars and thus grafting must be considered. Improved cultivars are being produced in containerized nurseries. If improved cultivars are desired, the cost and expertise associated with grafting may make containerized stock the better choice for landowners.

Mycorrhizae inoculants did not improve growth of containerized, bare-root, or seeded seedlings during the two growing seasons. Both sites used for this study have been void of trees for extended periods of time, so adding mycorrhizae seemed justified. The lack of response in containerized seedlings was not surprising as this stock type received may receive mycorrhizae inoculants during the nursery production phase. Bare-root seedling infection status was unknown prior to planting, but no response was seen from field inoculation either. If mycorrhizae inoculation was going to cause a response it likely would have occurred in seeded seedlings that were sterilized prior to planting. However, no response was seen in these seedlings either. It could be that mycorrhizae that infect black walnut are available in pastures and quickly colonize available sites on seedling roots. These mycorrhizae would be adapted to local site conditions and may be more effective for black walnut as suggested by Ponder (1984) or may be more aggressive at colonizing roots than introduced fungi as suggested by Abbot and Robson (1981). Also, a longer study period may be necessary for inoculated trees to fully express any improvements in growth resulting from mycorrhizae inoculation.

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