EVALUATING ORNAMENTAL SPECIALTY CUT PRODUCTION USING A SUSTAINABLE AGROFORESTRY APPROACH

By

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To my Mother, Sandra Fletcher Whetstone

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Two experiments were conducted in order to examine the performance of shrubs with potential for use as woody cuts. In the first study, shrubs were established in a *Carya illinoinensis* (pecan) grove to quantify the effects of irradiance and root competition on survival and initial growth. Treatments included partial shade without root competition (using trenched plots with root barriers), partial shade with root competition (without barriers), and full sun (no tree/root competition). Species with greater than 50% survival at the end of year 2 were considered to have potential for inclusion in an agroforestry system for the production of woody cuts. Of the nine shrub species, only *Callicarpa americana* L., *Callicarpa americana* F.J. Muell var. *lactea*, *Crataegus marshalii* Eggl., and *Salix matsudana* Koidz. F. *tortuosa* Rehd. maintained high rates of survival throughout both years of the study. *Callicarpa americana* and *Crataegus marshalii* performed equally well irrespective of irradiance or root competition. *S. matsudana* had the highest rates of survival in full sun. The remaining five shrub species suffered high mortality from drought stress in spite of supplemental watering thereby preventing evaluation of the effects of exposure and root competition in the pecan alleycropping system.

Additionally, greenhouse experiments were conducted to evaluate the effects of irradiance and nitrogen and photosynthesis and growth of two plant taxa (*Callicarpa americana* L. and *Morella pumila* Mich. 'Suwannee elf'). Plants were grown in a simple hydroponic system by using a modified Hoagland's solution amended with 0, 70, and 210 mgL^{-1} nitrogen (NH_4NO_3). Irradiance treatments included full irradiance within the greenhouse and 50% of full irradiance. For both species, mean photosynthesis was greater for plants under 100% irradiance and for plants given 70 mgL^{-1} nitrogen. Nitrogen had a greater effect than irradiance on growth of *C. americana*. Application of 210 mgL^{-1} nitrogen did not increase plant growth and photosynthesis proportionally compared to application of 70 mgL^{-1} nitrogen for either species, indicating the higher application rate is unnecessary and may inhibit plant growth.

CHAPTER 1
INTRODUCTION

Smallholder farmers have long been an important part of Florida's historical and cultural landscape. Over the last half-century, these farmers have faced serious competition from large industrial farming operations. Large operations have greater access to both farming subsidies and other forms of capital and can afford to purchase expensive equipment, chemicals, and genetically modified crops that make modern row crop agriculture practicable. Additionally, the environmental problems that are caused by the pollution of groundwater and surface water by excess nutrients from agricultural operations (along with residential lawns, dairy farms and golf courses) constitute one of the greatest threats to environmental quality in the state (Nair and Graetz 2004). In order to maintain profitability in a changing economy, smallholder farmers need to find ways to reduce their dependence on conventional row crop agriculture, while at the same time finding ways to mitigate the environmental pollution generated by their operations.

Agroforestry is defined as the deliberate growing of a tree crop and an agricultural or horticultural crop on the same plot of land (Powers and McSorley 2000). Agroforestry systems, which combine an economically valuable tree or shrub crop with an agricultural or horticultural crop on the same plot of land, could be a viable alternative for some smallholder farmers (Ellis 2001). The market for specialty forest products that are useful for the florist trade is expanding, and there is a demand for new varieties of plants with interesting foliage, fruits, and flowers for use in arrangements (Bachmann 2002). Many of Florida's native shrubs have these qualities, and a sustainable agroforestry system combining certain of these species in an alley cropping arrangement with valuable tree species like *Pinus palustris* or *Carya illinoinensis* could provide a farmer with a sustainable, low maintenance crop year after year. Also, a farmer could establish these shrubs in a marginal area unsuitable for crop production, or as part of a riparian buffer.

Of critical concern when considering the use of an agroforestry system are the interactions between the tree crop and the agricultural or horticultural crop for resources such as water, light and nitrogen (Rao et al. 1998). These interactions have been characterized in many tropical agroforestry systems, but research in temperate agroforestry systems has begun in earnest only in the past two decades. Even so, the vast majority of research in temperate agroforestry systems up to this point in time has focused on characterizing the interactions between trees and agricultural crops (Jose et al. 2000a, 2000b, 2004; Gillespie et al. 2000). Systems combining a tree crop with a horticultural crop are not common, but citrus growers in Florida have had success with intercropping of ornamental plants within young citrus orchards (Workman and Allen 2003, Bachmann 2002).

Biophysical interactions between tree crops and agricultural crops in agroforestry systems are characterized in several ways. First, there is the traditional system of classifying interactions between living things using such terms as commensalism, mutualism, amensalism, and parasitism/predation (Begon, Townsend, and Harper 2006). Within agroforestry systems, the interspecific interactions can be classified as complimentary (positive) or as competitive (negative) (Jose et al. 2004). Competitive interactions between tree and crop are complex, and recent research suggests that the resource–ratio hypothesis (Tilman 1985, 1990) is most appropriate when characterizing interactions in agroforestry systems. This hypothesis states that species that have different resource requirements can co-exist because competitive exclusion does not occur (Tilman 1985). Furthermore, when the right combination of tree crop and agricultural crop is determined, more biomass can be accumulated when the two are grown together (Jose et al. 2004).

Studies that focused on characterizing competition for light within temperate agroforestry systems have found that despite the evidence that for C4 species like maize net photosynthetic rates decrease as photosynthetically active radiation (PAR) decreases, there is little evidence that crop yields decrease in temperate alley cropping systems (Jose et al. 2004). This was supported by a study where maize was grown in an alley cropping system with both *Juglans nigra* L. and *Quercus rubra* L. (Gillespie et al. 2000). The study confirmed that other interactions, mainly below ground interactions like competition for water and nitrogen were more important than above ground interactions for light as a determining factor in crop yields. However, while total crop yields were not reduced despite lower levels of photosynthetically active radiation (PAR), there was some spatial variation in yield for crop rows closest to the tree rows (Jose et al. 2004). This was also seen in an alley cropping system in India where below ground interactions were observed to have a greater impact on yields than light competition (Rao et al. 1998). Competition for light may even represent a positive interaction for some tree/crop combinations (Jose et al. 2004). This finding is important when considering which plants are suitable for inclusion in an alley cropping system for horticultural production. Since many shrubs used in landscaping and for cut foliage production are forest understory species within their native ranges, it seems likely that shade could provide a benefit and might increase yields when they are grown in an alley cropping system. Aside from the impact shade has on rates of photosynthesis, temperature is also moderated under shade (Jose et al. 2004). Many understory plants experience heat stress under full sun conditions, which can inhibit photosynthesis (Taiz & Zeiger 2002; Jose et al. 2004).

In tropical climates, many of the tree species used in agroforestry systems are nitrogen-fixing legumes but in temperate zones, trees are most often selected based on their economic value as timber or fruit/nut producers (Jose et al. 2004). In temperate agroforestry systems the tree crop and agricultural crop therefore must compete for limited nitrogen resources. In an experiment conducted by Jose et al. (2000), the competition for nitrogen between the tree crop and agricultural crop in an alley cropping system in the Midwestern United States was characterized. This experiment was similar in structure to other experiments by the same authors, which characterized the competition for water within a similar agroforestry system (Jose et al. 2000). Treatments were set up with and without root barriers and others were trenched to prune tree roots. Nitrogen fertilizer was applied and the root tissues of both tree and crop were analyzed to determine the percentage of nitrogen derived from fertilizer (Jose et al. 2000). Along with percentage of nitrogen derived from fertilizer, the fertilizer use efficiency was determined (Jose et al. 2000).

The results of the study revealed that the competition between *Juglans nigra* and *Zea maiz* for nitrogen supplied by fertilizer is not significant because the two species do not take up nutrients at the same time during the growing season. However, the competition for mineralized soil nitrogen was significant in treatments without root barriers or trenches in place (Jose et al. 2000). In the treatments without root barriers or trenches, competition for soil moisture was also significant (Jose et al. 2000), so it is reasonable to expect the rates of nitrogen uptake by crops to be reduced along with reduced water uptake because nutrients such as nitrogen are taken up along with soil moisture by the plant's root system (Jose et al. 2000).

Agroforestry systems can also be useful in reducing the amount of excess nutrient input into surface and groundwater due to improved nutrient cycling. Certain tree/crop combinations are more efficient than others, as demonstrated by findings suggesting that systems using *Populus deltoides* Bartram ex. Marsh were highly efficient in cycling nitrogen within the system, requiring less nitrogen input though fertilizer (Das and Chaturvedi 2005). While *P. deltoides* does not fix nitrogen in its roots, the leaf litter has a higher proportion of available nitrogen, which is cycled back into the soil during decomposition (Das and Chaturvedi 2005). Nair and Graetz (2004) investigated the role agroforestry systems can play in reducing the input of phosphorus and nitrogen into water supplies. While the root systems of both tree and agricultural crop can occupy the same soil strata at shallow depths, the trees root system extends much deeper into the soil profile. This allows the tree crop to intercept more nitrogen and phosphorus as it leaches out of the surface layers of the soil (Nair and Graetz 2004).

In an experiment conducted in a pecan (*Carya illinoinensis*)–cotton (*Gossypium hirsutum*) alley cropping system in Jay, Florida where both organic and inorganic nitrogen fertilizers were applied to both trenched (to remove root interaction between tree and crop) and untrenched plots, more nitrate was taken up in the untrenched plots where the root systems of tree and crop interacted freely (Nair and Graetz 2004).

All of the work cited above was in agroforestry systems combining trees with agricultural crops, but it provides a good guide for systems that combine trees with horticultural crops. Horticultural crops, specifically those species with potential for use as specialty woody cuts can be incorporated into agroforestry systems such as alleycropping arrangements, riparian buffers or wind/snow breaks such that they not only provide a source of profit to the grower, but an ecological benefit by increasing biological diversity at both the ecosystem and landscape scale (Josiah, St-Pierre, and Brott 2004).

CHAPTER 2
EFFECT OF ROOT COMPETITION AND SHADE ON SURVIVAL AND GROWTH OF NINE WOODY PLANT TAXA WITHIN A PECAN (*CARYA ILLINOINENSIS* K. KOCH.) ALLEY CROPPING SYSTEM

Introduction

The market for specialty forest products that are useful for the florist trade is expanding, and there is a demand for attractive plant cultivars that have attractive flowers, foliage, berries and seedpods for use in arrangements (Bachmann 2002). Farmers who wish to increase production on marginal lands or within tree plantations could benefit from including woody cuts production in a sustainable agroforestry system.

Studies carried out in Nebraska, USA and Saskatchewan, Canada have shown that temperate agroforestry systems that include woody ornamentals can be a profitable alternative for small farmers, producing up to $15 of income per meter (Josiah, St-Pierre, and Brott 2004; Josiah, Brott, and Brandle 2004). In order to recommend plant species for inclusion in an agroforestry system for the production of specialty woody ornamentals, evaluation of plant growth and survival of various species under field conditions is needed. An ideal plant choice for producing woody cuts in an environmentally benign alleycropping system would be a species that produces attractive stems and that is able to survive and grow with minimal input of fertilizer and water.

In agroforestry systems, yields are sometimes reduced due to the below ground interactions of the tree crop and agricultural crop as they compete for water and nitrogen (Jose et al. 2000). Light is the most limiting factor of plant growth only if there is sufficient water and nitrogen available to the crop (Montieth et al. 1991; Zamora et al. 2008). Below ground interactions, particularly the competition for water resources and nutrients are more likely to occur when the root systems of the plant species in question grow into the same area of the soil profile (Gillespie et al. 2004). Large trees often have the majority of their root systems in the top 30 cm of soil, the same depth as the root systems of most agricultural crops and shrubs (Brady & Weil 2002). The tree canopy will expand over time, and tree roots will extend into the root zone of the horticultural crop, so any tree/crop combination must be supported by proper management techniques including pruning of tree roots (Thevathasan and Gordon 2004). In this study, nine shrub species were established in a *Carya illinoinensis* K. Koch (pecan) grove in northwest Florida. The objectives of this experiment were to determine which shrub species would survive, grow, and produce high quality stems under the conditions present at the study site. Treatments included a full sun treatment (uninterrupted daily irradiance without tree competition) and two partial shade treatments (with and without root competition from the tree crop). At the study site irradiance was never reduced to less than 50% of the full sun treatment by the tree canopy, and the topsoil was enriched with nutrients due to deposition of leaf litter from the pecan trees over many years (Allen et al. 2004). As a result, competition for water was expected to be the most limiting factor in determining plant survival and growth. A previous study carried out in the same location as this study found that growth of *Gossypium hirsutum* L. (cotton) was greatest when competition from tree roots was inhibited by a root barrier (Wanvesraut et al. 2004). We hypothesized that plants grown in the partial shade without root competition treatment (which included a root barrier) would have the highest rate of survival and would grow larger than plants grown with root competition or in full sun.

Materials and Methods

Shrubs were established in a 54-year-old *Carya illinoinensis* (pecan) alley cropping system at the University of Florida Jay Research Farm in Jay, Florida (30°46′20N; 87°09′00W). Soils at the study site are classified as Red Bay sandy loam (Wanvestraut et al.

2004). Rainfall data were recorded at the Jay Research Farm (weather station on site)(Figure 2-1).

The shrub species chosen for evaluation were *Callicarpa americana* L. (American beautyberry), *Callicarpa americana* L. var. *lactea* F.J. Muell. (white beautyberry), *Crataegus marshallii* Eggl. (parsley haw), *Ilex glabra* L. (inkberry), *Ilex myrtifolia* Walt. (myrtle-leaf holly), *Hydrangea paniculata* Seibold var. 'Tardiva' (panicle hydrangea), *Hydrangea quercifolia* Bart. (oakleaf hydrangea), *Lyonia lucida* (Lam.) K. Koch (fetterbush), and *Salix matsudana* Koidz. f. *tortuosa* Rehd. (corkscrew willow).

***Callicarpa americana* L.** (American beautyberry) is a deciduous, multi-stemmed shrub with a range extending from Texas to Florida and as far North as Maryland (Austin 2005). It is deciduous throughout most of its range although some plants keep their leaves all year in the southernmost populations. It prefers full sun to partial shade and moist soils in a wide variety of habitats. This shrub is fast growing and is often an early colonizer of disturbed sites (Austin 2005). It can grow up to 2m in height and up to 2m in width (Nelson 2003). *Callicarpa americana* is commonly used in landscapes and gardens for its attractive foliage and bright purple fruits that are borne in clusters along the stems at the leaf axils. Leaves are opposite and slightly pubescent, and are aromatic when crushed (Nelson 2003). The fruits tend to persist on the stems into the winter months, and this gives this species good potential for use as a woody cut. Foliage is not persistent on cut stems and should be removed at harvest prior to shipping. Fruiting stems may be harvested when fruits at mid-stem are fully colored (Bachmann 2002). If the stems are harvested at this point, the risk of discoloration of the fruits from frost damage can be avoided (Bir and Connor 1997).

***Callicarpa americana* L. var. *lactea* F.J. Muell**. (white beautyberry) is a naturally occurring variety of *Callicarpa americana* which bears white fruits. It is uncommon in the wild but is produced commercially by the nursery industry and is most often encountered as a garden specimen. Flowering and fruiting are typical of the species with fruits in late summer and early autumn. Fruits persist on the stems well into winter and often develop brown blemishes as time passes which can reduce their visual appeal, so it may be appropriate to harvest the stems earlier in the season than for *C. americana* (Nelson 2003).

***Crataegus marshallii* Eggl.** (Parsley Haw) is a shrub or small tree that is found across the southeastern United States as far west as Texas and as far north as Virginia. In Florida, it is found primarily in the Panhandle region but is known to grow as far south as Marion County (Austin 2005). It typically grows in wetland or floodplain habitats but is equally adapted to upland areas (Nelson 2003). Unlike many species in the genus, *C. marshallii* is easily distinguished by its deeply lobed and toothed leaves, which resemble the leaves of parsley, hence the common name of the species. It has straight thorny stems, attractive foliage, white or pink flowers borne in spring, and bright red fruit borne on the stems in the late summer. The stems could be harvested in spring to take advantage of the flowers or in late summer or early autumn to take advantage of the fruits.

***Hydrangea paniculata* Siebold var. 'Tardiva'** (panicle hydrangea) is native to temperate areas of East Asia, but has been introduced to the United States as an ornamental shrub. It can grow as tall as 3 meters from a single main stem and has a treelike growth habit. Clusters of white flowers are borne at the end of long, straight branches in late summer and persist on the branches into early autumn. Stems may be harvested for the fresh flower market in August or September or may be harvested as a dried product in late September or October. After harvesting the stems in autumn, cutting back the plant allows for re-growth of long, straight stems for the following season (Leeson et al. 2004).

***Hydrangea quercifolia* Bart.** (Oakleaf hydrangea) is a stoloniferous, deciduous, multi-stemmed shrub native to the southeastern United States, from Louisiana to Florida and as far north as Tennessee and North Carolina (Austin 2005). This species is most commonly found on slopes and in ravines and is tolerant of shady conditions (Nelson 2003). Plants typically have multiple stems with shaggy bark and large leaves with multiple lobes (Nelson 2003). *H. quercifolia* has become a popular native plant in landscapes in North Florida for use in both sunny and shaded areas due to its attractive foliage, autumn color and clusters of white flowers born on terminal panicles. Like *H. paniculata*, this species could provide stems for both the fresh and dried stem markets. However, this species generally blooms somewhat earlier than *H. paniculata* so harvesting could begin in late summer (Nelson 2003).

***Ilex glabra* L.** (Inkberry) is a common evergreen shrub native to the Atlantic and Gulf Coastal Plain from Texas to Maine. It can grow up to 3 meters tall and has multiple upright stems that bear small black fruits (Austin 2005). This species bears small white flowers in spring and the black fruits are attractive and persist on stems into winter (Halls 1977). This species has potential for season-long harvesting of stems. The leafy stems may be used as filler in arrangements while spring flowers and fall fruits may provide additional uses for the stems. This species is stoloniferous and colonial, forms large thickets and spreads vegetatively (Thetford et al. 2006). New stems are also produced in response to burning or pruning (Tobe 1998). *I. glabra* is often used in landscapes as a hedge and there are several cultivars available commercially. Most commonly found in moist flatwoods habitats, *I. glabra* is tolerant of both full sun and partial shade but is not particularly tolerant of dry conditions (Nelson 2003).

***Ilex myrtifolia* Walt.** (Myrtle-leaf holly) is native to the Atlantic and Gulf Coastal Plain from Texas to North Carolina and is found almost exclusively in wet habitats such as cypress domes (Tobe 1998) but is tolerant of seasonally dry conditions (Nelson 2003). This species is a shrub or small tree and can grow up to approximately 8 meters tall with small leaves and bright red or yellow fruits which ripen from December to January (Nelson 2003). Fruits persist on the stems for a month or more after ripening, so the best time to harvest stems for use as a woody is in late September or early October. Non-fruiting stems could be harvested but this may diminish future availability of fruiting stems.

***Lyonia lucida* (Lam.) K. Koch** (fetterbush) is a common understory shrub in flatwoods and wetlands throughout the coastal plain of the Southeastern United States. It can grow up to 2 to 3 meters tall and forms large colonies by means of underground runners (Osorio 2001). Pink to white blooms appear in late winter and early spring and are borne in showy clusters along the branches (Nelson 2003). These blooms can persist on the stems for up to a month. In addition to flowers, the stems have a characteristic angular pattern of growth providing additional visual interest. Stems may be harvested in early spring when in flower or throughout the remainder of the year if harvested for the foliage.

Salix matsudana Koidz. f. ***tortuosa* Rehd.** (Corkscrew willow) is a shrub or small tree up to 9 meters tall native to East Asia introduced to North America as a landscaping plant for its attractive foliage and yellow fall color (Gillman and Watson 1994). Branches grow in a spiraling, twisting shape, giving this species visual appeal in winter. Stems are also used by florists as woody cuts (Kuzovkina and Quigley 2005). *Salix matsudana* f. *tortuosa* is particularly suited for this purpose because it has been shown to be capable of ample stem production after repeated coppicing (Douglas et al. 1996, Kuzovkina and Quigley 2005).

Callicarpa americana and *Ilex myrtifolia* were grown in a 100% composted pinebark (0.5 inch screened) nursery production mix at the West Florida Research and Education center production area from cuttings collected from private land in Santa Rosa County, Florida. One year old *Ilex glabra* and *Hydrangea quercifolia* (3.9L containers), and 2 year old *Crataegus marshallii* (19L containers) were purchased from Superior Trees, Inc. (P. O. Box 9325 Lee, FL). Plants of all species aside from *Crataegus marshallii* and *Lyonia lucida* were planted on December 22, 2004. *Crataegus marshallii* were planted June 5, 2005, and *Lyonia lucida* were planted March 1, 2006.

Plants were fertilized with controlled-release fertilizer (18N-2.6P-9.9K Osmocote 18-6-12, 8-9 months; The Scotts Co., Marysville, Ohio) at the time of establishment. The study site had no permanent irrigation system, but plants were supplied with supplemental irrigation via tanker truck (4L per plant per week) during the summer months of 2005 and 2006.

The experimental design was a randomized complete block with three blocks and three treatments. Treatments were full sun (uninterrupted daily irradiance without root competition), partial shade with root competition and partial shade without root competition. Root competition from the tree crop was eliminated by trenching the margins of the plots to a depth of 1.2 meters and inserting black plastic to form a barrier to subsequent root growth (Gillespie et al. 2004). All plants were spaced 3 meters apart within and between rows. The shaded treatments consisted of plots situated beneath the canopy of the pecan grove that provided approximately a 50% reduction in irradiance at 12 o'clock noon local time. The shade provided was irregular as a result of hurricane Ivan having damaged the trees within the grove. Mowing and application of herbicides Glyphosate (N-(phosphonomethyl) glycine) (Monsanto Corp., Saint Lois, MO, USA) and Oryzalin (3,5-dinitro-N4, N4-dipropylsulfanilamide) (DowElanco, Indianapolis IN, USA) was used to manage weeds.

Plant survival and shoot growth were recorded once per month in May, June, and July of 2005 and 2006 by measuring plant height (cm), and two perpendicular widths (cm). These widths were averaged to provide one value for mean width for each plant. In order to provide a measure of plant growth, a growth index was calculated for each plant using the following formula: [(Height x mean width)/2] (Norcini and Knox 1989).

The data collected during the study were analyzed using SAS Mixed Procedure (SAS Institute Inc., Cary, NC, USA). Differences among treatments were determined using the LS Means procedure (alpha=0.01).

Results and Discussion

The study site experienced drought conditions during 2006 (Figure 2-1). In December of 2004, when the plants were transplanted into the alley cropping system, there was a total of 132 mm of rainfall, which is very close to the average rainfall (127mm) in December for the years 2002-2006. Total rainfall for 2005 (1.97m) was above the average for 2002-2006 (1.5m) due to tropical storm Arlene (June 11) and Hurricane Dennis (July 10), but during 2006 the total rainfall for the year was down 44% from 2005 and was 26% below the 2002-2006 average.

The performances of the plant species used in the study are detailed below. Plant survival (%) and consistent growth were the primary criteria by which a species was judged to be suitable for inclusion in either a full sun woody cuts production system or an agroforestry system for production of woody cuts.

Callicarpa americana had 100% survival in all treatments at the end of summer 2006, the highest rate of survival in all treatments for any species in this study (Table 2-1). Mean plant heights decreased over the course of the study and were similar for all treatments while mean width increased over time as a result of stems becoming more plagiotropic. There was a significant interaction between treatment and month ($p<0.0001$). Plants in the partial shade treatments showed a 32% increase in width from May 2005 to July 2006, while mean width for plants in full sun increased by 23% over the same time period. Growth indices were similar among all treatments (Table 2-1). *Callicarpa americana* produced stems, survived equally well in sun or shade and grew well even in drought conditions. Although not sufficient to warrant harvest or measurement, this species did produce a minor crop of fruit in year two indicating a minimum of two years to establish sufficient vigor for fruit production in both the open field and alley cropping production systems. With the high rate of survival and consistent growth in full sun and shade both with and without competition and early fruiting, *Callicarpa americana* should be considered as a component of both a full sun and an agroforestry system for the production of woody cuts.

Callicarpa americana var. *lactea* had high rates of survival for all treatments, losing only one plant in partial shade without root competition and two in full sun by the end of the second growing season (Table 2-2). Mean plant height decreased over the course of the study, while mean width increased over time as a result of stems becoming more plagiotropic. From May 2005 to July 2006, mean width increased by 39% in partial shade without root competition and by 37% in partial shade with root competition as compared to a 27% increase in mean width in full sun over the same time period. There was a significant difference in growth index among treatments ($p<0.0001$). Plants in partial shade without root competition showed a 30% increase in growth index from May 2005 to July 2006, compared to an 18% increase in growth index in partial shade with root competition and an 8% increase in growth indices for plants in full sun. These results show that while *Callicarpa americana* var. *lactea* has high rates of survival in both shade and sun, plants grew larger and showed an greater percent increase in size in partial shade and therefore could be considered as a component of an agroforestry system for the production of woody cuts. *Crataegus marshallii* had high rates of survival (92%-100%) under all treatments, losing only two plants, one plant in partial shade without root competition and one plant in the full sun treatment (Table 2-3). There was a significant difference in mean plant height among the treatments over the course of the study ($p<0.0013$). Plants in partial shade showed a slight decrease in plant height (5% for plants in partial shade without root competition; 2% for plants in partial shade with root competition) from May 2005 to July 2006, while plants in full sun showed a 1% increase in mean height over the same time period. While these differences were statistically significant, they were not large enough to be considered biologically significant. No significant differences were found among treatments for mean width and growth index. These results demonstrate that *C. marshallii* can survive equally well in sun or shade, and that despite the lack of growth in partial shade this species may be considered as a component of an agroforestry system for the production of woody cuts. No plants of this species flowered during the course of the study.

Survival of *Hydrangea paniculata* decreased dramatically for all treatments after June 2005 with only 50% of plants surviving in the partial shade without root competition treatment, 25% of plants surviving in the partial shade with root competition treatment, and 42% of plants surviving in the full sun treatment by July 2005 (Table 2-4). Drought stress and deer browse were the primary causes of mortality (Personal observation). Although *H. paniculata* shows moderate drought resistance (Gillman and Watson 1993), plants in this study frequently displayed symptoms of drought stress. Deer browse was contributed significantly to plant death in all three treatments for *Hydrangea paniculata* during 2005. Damage from deer browse killed

41% of the Hydrangea paniculata plants in the full sun treatment and partial shade without root competition treatments, respectively, compared to 16% mortality in the partial shade with root competition treatment. Overall, out of the 36 Hydrangea paniculata plants included in this study, 12 individuals (33%) were killed by deer browse.

A study from Japan showed that *H. paniculata* was preferentially browsed by Sika deer in its native range (Takatsuki 1986), so it is unsurprising that it would be palatable to deer in Florida especially during a time of below normal rainfall. The low survival and vulnerability to deer limit the potential for this species to be included in woody cuts production systems in Florida without supplemental irrigation and some measures to exclude deer from the plots.

Plant survival for *Hydrangea quercifolia* decreased between 2005 and 2006 (Table 2-5). By July 2005, survival was 83% or less and in 2006 survival dropped below 50%. Plant height, width and growth index showed no significant difference in plant size among sun and shade or competition treatments (Table 2-5). As with *H. paniculata*, low survival and vulnerability to deer browse limit the potential for *H. quercifolia* to be included in woody cuts production systems in Florida without supplemental irrigation and some measures to exclude deer. Deer browse contributed significantly to *Hydrangea quercifolia* mortality 16% mortality in both the in the full sun and partial shade with root competition treatments, compared with 8% mortality in the partial shade without root competition treatment. Overall, 14% of the *Hydrangea quercifolia* plants in this study were killed by damage caused by deer browse.

Survival of *Ilex glabra* ranged from 75% to 83% by July 2005 (Table 2-6) and decreased to 20% in April 2006 (data not shown). Mean plant height, mean width, and growth index did not differ among treatments by July 2005 (Table 2-6). After May of 2006, survival of *Ilex glabra* dropped below 50% in all treatments. Drought stress during the second year of the study was likely the cause of mortality. In a study where *I. glabra* plants grown in differently sized containers were planted in a coastal dune environment (sandy, dry and saline soil conditions), those plants grown in standard one-gallon pots had similarly low rates of survival (50% and less) over a similar time span (Thetford et al. 2005). More study is needed to determine if *I. glabra* plants grown in deeper pots or the use of a temporary irrigation system to assist with establishment would contribute to higher rates of survival before this species could be recommended for inclusion in an agroforestry system for the production of woody cuts.

Rates of survival for *Ilex myrtifolia* were high in July 2005, with 100% survival for plants in partial shade without root competition. Only two plants were lost in 2005, one in partial shade with root competition and one in full sun. Rates of survival dropped drastically during the summer of 2006, with only four plants of this species alive by July 2006, two in partial shade with root competition and two in the full sun. This species shows a great deal of drought tolerance in its native habitat and in landscape plantings (Nelson 2003). The plants used in this study were 3 years old at the time of transplanting. Larger transplanted plants generally require longer establishment times compared to smaller plants because of the longer time required for root growth to reach a level similar to non-transplanted plants of the same size (Watson 2005). The water stress experienced by the plants during their establishment was compounded by drought conditions during 2006, resulting in the precipitous drop in survival during that year. As with *I. glabra*, the use of a temporary irrigation system to assist with establishment of *I. myrtifolia* may contribute to higher rates of survival.

Lyonia lucida had very low survival (25% and less) for all treatments. Plants received supplemental water at the time of transplanting and periodically thereafter (one gallon per week per plant). This species was transplanted during March of 2006 during a period of particularly low rainfall (about 50% below the 2002-2006 average). Also, the root system of this species is very fibrous and extends into the native soil very slowly which along with drought stress may have contributed to the high rates of mortality experienced in this trial.

For *Salix matsudana*, a treatment by year interaction (p= 0.0004) was present indicating the effects of treatment on survival differed between 2005 and 2006. Initially exposure and competition had no impact on survival, which was high with only a single plant lost during 2005. However, continued mortality was evident each month in 2006, with the greatest losses in shaded treatments (Table 2-7). Survival for *S. matsudana* f. *tortuosa* was highest in the full sun. Although survival in full sun decreased from 92% in April to 75% in July sufficient plants survived to consider S. *matsudana* f. *tortuosa* for full sun woody cuts production. There is some evidence that growth of *S. matsudana* f. *tortuosa* is enhanced under full sun and suppressed under shade (He and Dong 2001). Since survival was low under both partial shade treatments is not likely that mortality under shade was solely the result of below-ground competition for water. In its native range, this species is noted for its fast growth rate and its preference for sunny sites (He and Dong 2001). Most species in the genus *Salix* are early succession species and are not tolerant of shade, and full sun conditions have been cited as a main requirement for the establishment of *Salix spp*. (Kuzovkina and Quigley 2005). Because of its preference for full sun, this species could be established in an alleycropping system along with a young tree crop. *S. matsudana* f. *tortuosa* could be replaced with more shade tolerant species as the tree canopy grows and develops. More study is needed to assess the performance of this species in an alleycropping system with young trees in order to fully understand the role of root competition in a scenario where light is not the limiting factor.

Conclusion

High rates of survival were evident among *Callicarpa americana*, *Callicarpa americana* var. *lactea*, *Crataegus marshallii*, in both full sun and partial shade and for *Salix matsudana* f. *tortuosa* in full sun. Based on survival and growth under partial shade conditions *C. americana*, *C. americana* var. *lactea*, and *C. marshallii* have potential for inclusion in a low input pecan (*Carya illinoinensis*) alleycropping system like the one in this trial. Of these, *C. americana* and *C. marshalii* survived and grew equally well in sun or shade and neither experienced a reduction in growth due to root competition. *C. americana* var. *lactea* had the greatest increase in growth in the partial shade treatments, although the reason why this species performed differently from *C. americana* despite their similarity is not clear.

No plants produced saleable woody cuts as part of the two year long study. Although many of the plants were old enough to have produced flowers and fruits, only *Callicarpa americana* produced flowers and fruits during the course of the study. The poor survival and growth performance of many of these species is most likely related to drought stress. In order to reduce mortality of plants vulnerable to drought during establishment, it may be appropriate to install a temporary or portable irrigation system. Herbivory (deer browse) had an impact on plant survival during this study, so installing fences or other measures to exclude deer may be appropriate where economically feasible.

Table 2-1. Initial survival (%), height (cm), width (cm), and growth index[z] of *Callicarpa americana* grown in sun or shade with and without root competition 152, 183, 214, 579, 610, and 640 days after planting on December 24, 2004.

	Survival (%)			Mean Height (cm)			Mean Width (cm)			Growth Index		
	Shade		Sun	Shade		Sun	Shade		Sun	Shade		Sun
	Competition			Competition			Competition			Competition		
Date	no	yes	no	no	yes	no	no	yes	No	no	yes	no
May 2005	100	100	100	71.1	71.8	73.9	58.0	54.3	58.1	64.5	63.1	66.0
June 2005	100	100	100	75.2	68.9	66.7	76.3	77.0	72.4	75.7	69.1	70.4
July 2005	100	100	100	64.3	66.0	63.6	77.0	72.4	77.3	70.6	69.2	70.5
May 2006	92	100	100	68.5	70.9	73.7	79.4	75.3	79.5	73.9	73.1	76.6
June 2006	100	92	100	66.5	71.1	71.8	74.5	80.7	74.1	70.5	75.9	72.9
July 2006	100	100	100	65.5	67.2	70.0	84.9	79.6	75.7	75.2	73.4	72.9
Significance												
Year		*ns*			*ns*			*ns*			*ns*	
Month		*ns*			*ns*			*ns*			*ns*	
Month*year		*ns*			*ns*			*ns*			*ns*	
Treatment		*ns*			ns			*ns*			*ns*	
Treatment*year		*ns*			*ns*			*ns*			*ns*	
Treatment*month		*ns*			*ns*			<0.0001			*ns*	
Treatment*month*year		*ns*			*ns*			*ns*			*ns*	

[z]Growth index = (height + mean of two witdths)/2

[y]For each variable, means within a row followed by the same letter do not differ, α= 0.01.

Table 2-2. Initial survival (%), height (cm), width (cm), and growth index[z] of *Callicarpa americana* L. var. *lactea* F.J. Muell. grown in sun or shade with and without root competition 152, 183, 214, 579, 610, and 640 days after planting on December 24, 2004.

	Survival (%)			Mean Height (cm)			Mean Width (cm)			Growth Index		
	Shade		Sun	Shade		Sun	Shade		Sun	Shade		Sun
	Competition			Competition			Competition			Competition		
Date	no	yes	no	no	yes	no	no	yes	no	no	yes	no
May 2005	92	92	100	73.3a[y]	67.1b	62.3c	52.1a	43.3b	41.8c	62.7a	55.2b	52.3c
June 2005	100	92	100	73.0a	66.7b	61.0c	64.3a	55.9b	46.5c	68.7a	61.3b	53.8c
July 2005	100	92	100	71.2a	61.5b	58.3c	65.4a	56.2b	50.5c	68.3a	58.8b	54.4c
May 2006	100	92	100	76.3a	64.8b	54.5c	79.7a	65.3b	54.2c	78.0a	65.1b	54.4c
June 2006	100	92	83	77.3a	67.3b	57.1c	77.8a	66.6b	57.5c	77.9a	67.0b	57.4c
July 2006	100	92	83	78.7a	66.0b	56.6c	84.8a	68.4b	57.4c	81.7a	67.2b	57.0c
Significance												
Year		*ns*			*ns*			<0.0001			<0.0001	
Month		*ns*			*ns*			0.0016			*ns*	
Month*year		*ns*			*ns*			*ns*			*ns*	
Treatment		*ns*			<0.0001			<0.0001			<0.0001	
Treatment*year		*ns*			*ns*			*ns*			*ns*	
Treatment*month		*ns*			*ns*			*ns*			*ns*	
Treatment*month*year		*ns*			*ns*			*ns*			*ns*	

[z]Growth index = (height + mean of two widths)/2

[y]For each variable, means within a row followed by the same letter do not differ, $\alpha = 0.01$.

Table 2-3. Initial survival (%), height (cm), width (cm), and growth index[z] of *Crataegus marshalii* Eggl. grown in sun or shade with and without root competition 152, 183, 214, 579, 610, and 640 days after planting on December 24, 2004.

	Survival (%)			Mean Height (cm)			Mean Width (cm)			Growth Index		
	Shade		Sun	Shade		Sun	Shade		Sun	Shade		Sun
	Competition			Competition			Competition			Competition		
Date	no	yes	no	no	yes	no	no	yes	no	no	yes	no
June 2005	100	100	100	165.3b[y]	182.5a	175.7a	84.6	92.3	89.6	124.9	137.3	132.5
July 2005	100	100	100	152.2b	168.5a	162.5a	102.5	87.7	88.6	127.3	128.1	125.5
May 2006	100	92	92	155.1b	178.8a	179.8a	104.0	95.9	89.4	129.5	136.8	134.1
June 2006	100	92	92	156.0b	171.5a	180.0a	96.8	85.1	89.1	126.4	128.3	134.5
July 2006	100	92	92	157.0b	179.5a	178.3a	99.0	87.7	85.5	128.1	133.6	131.9
Significance												
Year		*ns*			*ns*			*ns*			*ns*	
Month		*ns*			*ns*			*ns*			*ns*	
Month*year		*ns*			*ns*			*ns*			*ns*	
Treatment		*ns*			0.0013			*ns*			*ns*	
Treatment*year		*ns*			*ns*			*ns*			*ns*	
Treatment*month		*ns*			*ns*			*ns*			*ns*	
Treatment*month*year		*ns*			*ns*			*ns*			*ns*	

[z]Growth index = (height + mean of two widths)/2

[y]For each variable, means within a row followed by the same letter do not differ, $\alpha = 0.01$.

Table 2-4. Initial Survival (%) of *Hydrangea paniculata* var. 'Tardiva' grown in sun or shade with and without root competition 152, 183, and 214 days after planting on December 22, 2004.

	Survival (%)		
	Shade		Sun
	Competition		
Date	no	yes	no
May 2005	92a[y]	92a	92a
June 2005	100a	83a	67a
July 2005	50b	25b	42b
Significance			
Month		<0.0001	
Treatment		*ns*	
Treatment*month		*ns*	

[y] For each variable, means within a row followed by the same letter do not differ, α= 0.01.

Table 2-5. Initial survival (%), height (cm), width (cm), and growth index[z] of *Hydrangea quercifolia* Bart. grown in sun or shade with and without root competition 152, 183, and 214 days after planting on December 24, 2004.

	Survival (%)			Mean Height (cm)			Mean Width (cm)			Growth Index		
	Shade		Sun	Shade		Sun	Shade		Sun	Shade		Sun
	Competition			Competition			Competition			Competition		
Date	no	yes	no	no	yes	no	no	yes	No	no	yes	no
May 2005	100	92	83	26.1a[y]	27.8a	28.7a	21.6a	17.0b	15.6b	23.8	22.4	22.1
June 2005	92	83	67	32.5a	35.3a	34.0a	30.4a	20.9b	19.6b	31.4	28.1	26.8
July 2005	75	83	67	29.8a	38.6a	32.8a	35.4a	21.7b	22.2b	32.6	30.2	27.5
Significance												
Month		*ns*			*ns*			*ns*			*ns*	
Treatment		*ns*			*ns*			*ns*			*ns*	
Treatment*month		*ns*			*ns*			*ns*			*ns*	

[z]Growth index = (height + mean of two widths)/2

[y]For each variable, means within a row followed by the same letter do not differ, $\alpha = 0.01$.

Table 2-6. Initial survival (%), height (cm), width (cm), and growth index[z] of *Ilex glabra* L. grown in sun or shade with and without root competition 152, 183, and 214 days after planting on December 24, 2004.

	Survival (%)			Mean Height (cm)			Mean Width (cm)			Growth Index		
	Shade		Sun	Shade		Sun	Shade		Sun	Shade		Sun
	Competition			Competition			Competition			Competition		
Date	no	yes	no	no	yes	no	no	yes	no	no	yes	no
May 2005	100	100	100	42.1	40.1	44.0	25.5	24.9	27.7	33.8	32.5	35.9
June 2005	100	75	92	47.5	48.2	43.6	30.1	33.0	29.4	38.8	40.6	36.4
July 2005	75	67	83	48.6	44.6	48.4	36.6	34.1	32.8	42.6	39.4	40.6
Significance												
Month		<0.0001			*ns*			*ns*			*ns*	
Treatment		*ns*			*ns*			*ns*			*ns*	
Treatment*month		*ns*			*ns*			*ns*			*ns*	

[z]Growth index = (height + mean of two widths)/2

[y]For each variable, means within a row followed y the same letter do not differ, α=0.01.

Table 2-7. Initial survival (%), height (cm), width (cm), and growth index[z] of *Salix matsudana* Koidz. f. *tortuosa* Rehd. grown in sun or shade with and without root competition 152, 183, 214, 579, 610, and 640 days after planting on December 24, 2004.

	Survival (%)			Mean Height (cm)			Mean Width (cm)			Growth Index		
	Shade		Sun	Shade		Sun	Shade		Sun	Shade		Sun
	Competition			Competition			Competition			Competition		
Date	no	yes	no	no	Yes	no	no	yes	no	no	yes	no
May 2005	100a[y]	100a	100a	83.3a	74.7a	91.1a	41.5a	39.3a	39.8a	62.4a	57.0a	65.4a
June 2005	100a	100a	100a	97.7a	91.7a	101a	57.8a	56.0a	62.0a	77.8a	73.9a	81.5a
July 2005	100a	92a	100a	98.0a	98.5a	110a	72.3a	67.3a	96.0a	85.1a	82.9a	103.0a
May 2006	58b	83ab	92a	121ab	102a	134b	78.0a	72.6a	104b	99.4a	87.1a	119b
June 2006	50b	67ab	83a	134ab	110a	150b	102ab	83.6a	113b	118ab	96.8a	131b
July 2006	33b	42a	75a	145ab	139a	152b	122b	117b	97.9a	133b	128b	125b
Significance												
Year		<0.0001			<0.0001			<0.0001			<0.0001	
Month		*ns*			<0.0001			<0.0001			<0.0001	
Month*Year		*ns*			*ns*			*ns*			*ns*	
Treatment		0.0004			<0.0001			*ns*			0.0002	
Treatment*year		0.0004			*ns*			*ns*			*ns*	
Treatment*month		*ns*			*ns*			*ns*			*ns*	
Treatment*month*year		*ns*			*ns*			*ns*			*ns*	

[z]Growth index = (height + mean of two widths)/2

[y]For each variable, means within a row followed by the same letter do not differ, $\alpha = 0.01$.

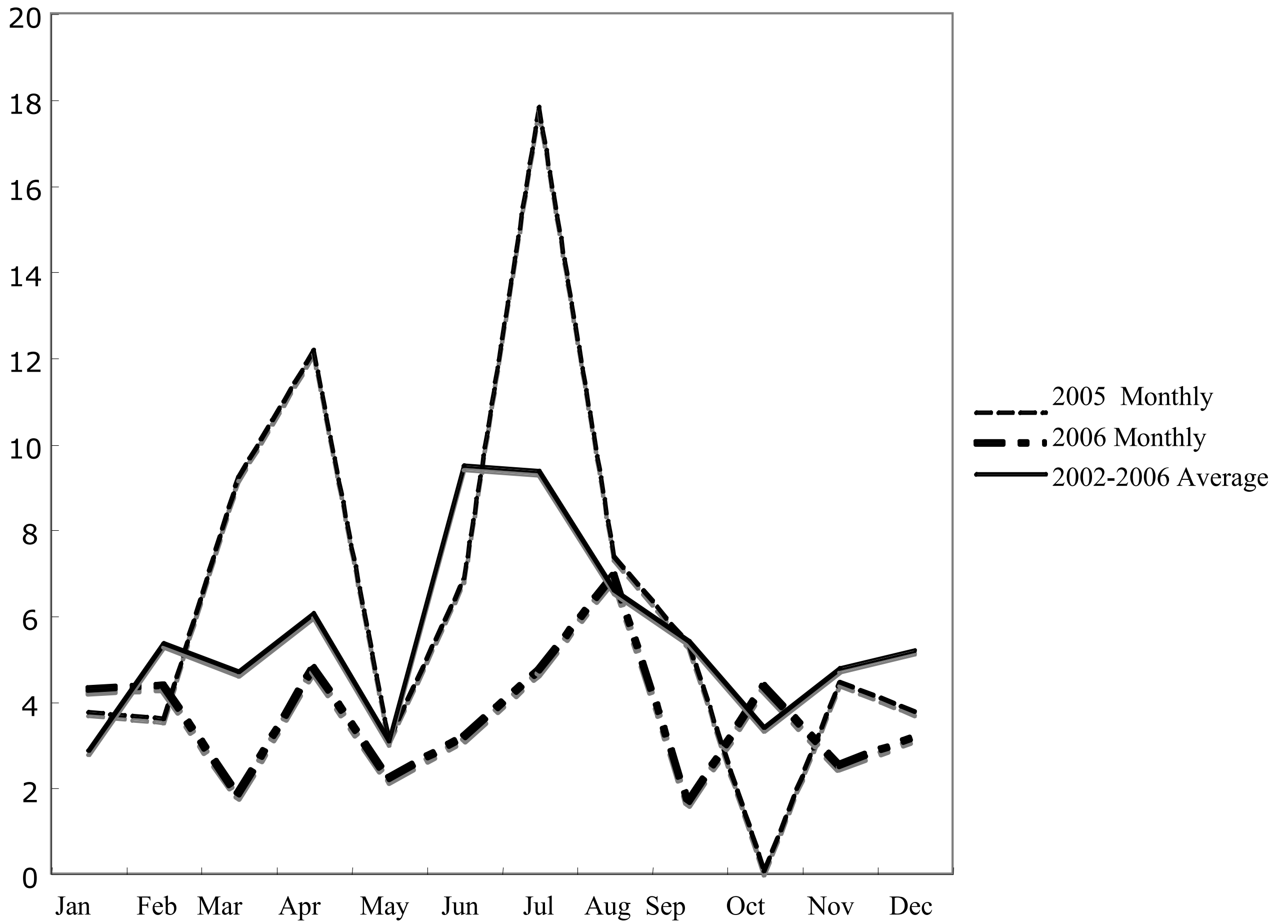

Figure 2-1. Rainfall for 2005 and 2006 (inches) for Jay, FL, USA with five year average (2002-2006).

CHAPTER 3
NITROGEN AND IRRADIANCE AFFECT PHOTOSYNTHESIS AND GROWTH OF TWO NATIVE FLORIDA SHRUBS

Introduction

Changes in plant community structure due to changes in nitrogen availability have been attributed to differences in growth response to nitrogen among plant species (Padgett and Allen 1998). A study was conducted to investigate the role of interactions of irradiance and nitrogen supply on growth and photosynthesis of shrubs native to Florida that have potential for use as woody cuts. We chose *Callicarpa americana* L., a fast growing early succession species (Gillman 1999), and *Morella pumila* Mich. 'Suwannee elf', a slower growing understory taxon (De la Garza 1999). The two most important factors in determining the successful establishment of shade-tolerant shrub species (where water is not limiting) are irradiance and mineral nutrient supply (Grubb et al. 1996). Of these two factors, studies have shown that growth of shrubs and tree seedlings is more limited by nitrogen supply than by light availability (Osmund 1983; Clough et al. 1983). Likewise in *Impatiens parviflora* DC., a shade tolerant species, growth rate responds to variation in nitrogen supply at both low and high irradiance levels (Peace and Grubb 1982). Fast-growing early succession species tend to show a greater photosynthetic response to nitrogen supply under a range of light conditions than understory plants (Riddoch et al. 1991; Grubb et al. 1996; Fetcher et al. 1996).

Based on these findings, we hypothesized that amount of nitrogen would have a greater influence than irradiance on photosynthesis and growth of *C. americana* and *M. pumila*. Quantifying the effects of nitrogen and irradiance for these two species can aid growers to produce higher quality plants using less fertilizer and can help growers make better use of field space by growing the shrubs under shade or in marginal areas. Similarly, this information could be useful when choosing low maintenance, shade tolerant plants to include in a landscape design.

Materials and Methods

For each of the two species, *Callicarpa americana* and *Morella pumila*, a experiment utilizing a randomized complete block design (RCBD) with a factorial arrangement of two irradiance treatments: high irradiance (full exposure to sunlight within the greenhouse) and low irradiance (50% reduction of full exposure to sunlight within the greenhouse), and three nitrogen (NH_4NO_3) concentrations (0 mgL^{-1}, 70 mgL^{-1}, 210 mgL^{-1}) was established by using four blocks and three pseudoreplicates per block. This arrangement resulted in 12 pseudoreplicates (experimental units) for each of the six treatment combinations for a total of 72 plants for each species. One plant planted within a single container was considered an experimental unit. Because the ambient conditions can vary from location to location within greenhouses, we used four separate greenhouse benches as four blocks. Mean daytime temperature inside the greenhouse from April to September 2007 was 27ºC, and mean nighttime temperature over the same period was 20ºC.

C. americana plants were purchased as <1 year old liners (150ml) from Ornamental Plants and Trees, Inc. (Hawthorne, FL). Plants of *M. pumila* were asexually reproduced from cuttings and were purchased from Panhandle Growers, Inc. (Milton, FL) as 1-year-old plants in 3.79L plastic containers.

Fifty percent shade was provided for the low irradiance treatment by constructing four individual frames to cover half of each of the four benches. Frames were constructed by using ¾ inch (19mm) diameter polyvinyl chloride (PVC) tubes with the following dimensions: frames 1.52m wide x 1.83m x long x 1.37m high. Black polyethylene shade cloth (B&T Growers Supply, Inc., Forest Hills, LA) was placed on the frames such that it covered the top and hung down each of the four sides.

Production substrates were washed free from the roots of each plant with tap water and the plants were placed in 5.68L plastic containers (Lerio Corp., Kissimmee, FL) using coarse perlite (The Schindler Company, Methuchen, New Jersey) as the growing medium. Plants within containers were arranged on the benches such that there were 36 plants per bench, with 18 plants of each species. Nine plants of each species were placed in a random arrangement in the shaded and unshaded portion of each bench such that there were three plants of each species for each of the three nitrogen treatments.

To precisely control the nutrient input for each plant, a simple drip-through inorganic medium hydroponic system was used and the nutrient solutions were applied by top irrigation (Jones 2005). A modified Hoagland's solution (Hoagland 1920) was used to supply the three nitrogen concentrations (0, 70, or 210 $mg \cdot L^{-1}$). The nitrogen-free solution was assembled from six stock solutions. Stock solution #1 was made by dissolving one half of the molecular weight of potassium sulfate into one liter of deionized (DI) water. Stock solutions #2, #3, and #4 were made by dissolving one molecular weight worth each of calcium chloride, potassium acid phosphate, and magnesium sulfate to one liter of DI water. Stock solution #5 was a blend of different micronutrients and was made by adding the following in the amounts shown to one liter of DI water: 2.86g boric acid, 1.81g manganese chlorate, 0.22g zinc sulfate, 0.08g copper sulfate, and 0.02g molybdic acid. Stock solution #6 was made by dissolving 3.67g of Fe-EDTA into one liter of DI water.

For this experiment a 25% strength Hoagland's solution was used. Each plant received 400 ml of solution per application, so that a total of 20L was needed per application.

In order to make 20L of 25% strength solution for the 0 $mg \cdot L^{-1}$ treatment, the following was added to 500ml DI water: 25ml Stock solution #1, 25ml of Stock solution #2, 2.5 ml Stock solution #3, 5ml Stock solution #4, 50ml stock solution #5, and 5ml stock solution #6. For the treatments that included Nitrogen, Ammonium nitrate was completely dissolved into the DI water before adding the stock solutions. For the 70 $mg \cdot L^{-1}$ nitrogen treatment, 4g ammonium nitrate (0.2g x 20 b/c making 20L) was added, and for the 210 $mg \cdot L^{-1}$ treatment 12g (0.6g x 20 b/c making 20L) was added.

Each plant received 400ml of 25% strength Hoagland's solution with the appropriate Nitrogen concentration at 48-hour intervals for the duration of the study. *Callicarpa americana* received solution for sixteen weeks, and *Morella pumila* received solution for ten weeks. Data were recorded every two weeks and included measuring photosynthesis, stomatal conductance, and photosynthetically active radiation (PAR) by using the Li-Cor Li 6400 Portable Photosynthesis System (Li-Cor Inc, Lincoln NE). Plant height (cm) was recorded for both species. The number of stems sprouting from the base that were at least one half the length of the main stem was recorded (Callicarpa only). HOBO® dataloggers (Onset Computer Corp., Pocasset, MA) were suspended above the benches to gather temperature and relative humidity data during the study.

At the end of the data collection period, the leaves were removed from each individual plant and placed in a reclosable plastic bag that was pre-labeled with the plant's individual observation number. A moist paper towel was placed in with the leaves to prevent drying. Leaf area (cm^2) was measured using a Li-3100 Leaf Area Meter (Li-Cor Inc, Lincoln NE) and recorded for each plant and the leaves from each plant were placed in pre-labeled paper bags. The paper bags containing the leaves were placed in a dryer at 65ºC for 72 hours and the dry weight (g) for all the leaves of each plant was recorded. The fruits (from those individual plants which had them) were also placed in pre-labeled paper bags, dried at 65ºC for 72 hours, and dry weights were recorded after this time.

While the leaves and fruits were drying, the stems and roots of each plant were removed from their pots and the roots were carefully washed to remove all perlite medium. The roots and stems were separated by severing the stem at the root collar. All stems from each plant were placed in pre-labeled paper bags, dried for 72 hours at 65ºC and weighed (g). Roots were passed through an area meter and the root area (cm^2) for each plant was recorded, along with the length (cm) of the longest root. The roots from each plant were then placed in pre-labeled paper bags and placed in a dryer at 65ºC for 72 hours prior to weighing (g).

After drying, the stems, fruits, and leaves from each plant were weighed together and placed in paper bags pre-labeled with the individual observation number and marked "shoot". The combined shoot tissues from each plant were ground in a mill (2mm sieve) and placed in pre-labeled reclosable plastic bags. The root tissues from each plant were also ground after drying and placed in pre-labeled reclosable plastic bags. After grinding, there were 288 samples, with one root sample and one shoot sample from each of the 144 plants. The samples were then sent to Quality Analytical Laboratories (2355 St. Andrews Blvd. Panama City FL 32405) for full plant tissue analysis. The analysis provided data on the concentration of the nutrients nitrogen (%), potassium (%), phosphorus (%), calcium (%), magnesium (%) sulfur (%), iron (ppm), manganese (ppm), boron (ppm), copper (ppm), zinc (ppm), molybdenum (ppm), sodium (ppm) and aluminum (ppm) in both the root and shoot tissues of each plant.

The data collected during the study were analyzed using SAS Mixed Procedure (SAS Institute Inc., Cary, NC, USA). Differences among treatments were determined using the LS Means procedure (alpha=0.05).

Results and Discussion

Callicarpa americana

The Main effect of nitrogen on photosynthesis was significant ($p=0.0085$) but there was also an interaction between nitrogen and time on photosynthesis for *Callicarpa americana* ($p<0.0001$). Mean photosynthesis for *Callicarpa americana* was higher in plants receiving 70 mgL^{-1} and 210 mgL^{-1} nitrogen than for plants receiving no nitrogen on every date except 9 April, 3 July, and 17 July (Figure 3-1). The much higher values for mean photosynthesis on 23 April may have been the result of a total lack of cloud cover on that date. Mean photosynthesis was higher in plants receiving 70 mgL^{-1} (5.8 µmol $m^{-2}s^{-1}$) and 210 mgL^{-1} (5.7 µmol $m^{-2}s^{-1}$) nitrogen as compared to plants receiving 0 mgL^{-1} nitrogen (4.0 µmol $m^{-2}s^{-1}$). Mean photosynthesis for *Callicarpa americana* on the first two dates was almost twice as high (10.5 µmol $m^{-2}s^{-1}$) as the means on the last two data collection dates (5.11 µmol $m^{-2}s^{-1}$). Interactive effects of time and irradiance were found on mean photosynthesis ($p<0.0001$). Mean photosynthesis for plants in the high irradiance treatment was higher on all dates except 7 May and 17 July (Figure 3-2). Main effect of irradiance on mean photosynthesis was significant ($p<0.0001$), with higher means for plants under high irradiance (5.4 µmol $m^{-2}s^{-1}$) compared to means for plants under low irradiance (4.8 µmol $m^{-2}s^{-1}$). This supports a finding by an earlier study that found significant differences in mean photosynthesis between fertilized and unfertilized *Impatiens parviflora* grown under high irradiance (Peace and Grubb 1982). Studies that examined growth and survival of seedlings of the early succession species *Betula alleganiensis* under varying levels of irradiance found that growth was enhanced under higher irradiance (Walters and Reich 1996). Results for *C. americana,* another early successional species support this finding.

Main effects of nitrogen concentration and of irradiance on stomatal conductance were significant ($p<0.0001$). Stomatal conductance was significantly higher for nitrogen treated plants than for plants receiving no nitrogen (0.08 mol H_20 $m^{-2}s^{-1}$) ($p<0.0001$), but values for mean stomatal conductance in the 70 mgL^{-1} (0.14 mol H_20 $m^{-2}s^{-1}$) and 210 mgL^{-1} (0.13 mol H_20 $m^{-2}s^{-1}$) treatments were not significantly different from each other ($LSD_{(\alpha-0.05)}$=.02). Stomatal conductance was also higher for plants in the low irradiance treatment (0.13 mol H_20 $m^{-2}s^{-1}$) compared to plants in the high irradiance treatment (0.10 mol H_20 $m^{-2}s^{-1}$) ($p<0.0001$)($LSD_{(\alpha-0.05)}$=.02).

Significant interactions were found of time and nitrogen concentration and of time and irradiance on stomatal conductance for *C. americana* ($p<0.0001$). Mean stomatal conductance was higher for nitrogen treated plants on every date aside from April 9, July 3, and July 17 (Figure 3-3). Mean stomatal conductance was higher for plants under 50% irradiance on all dates aside from April 23 (Figure 3-4).

Mean plant height for *C. americana* was affected by a two-way interaction of nitrogen and time ($p<0.0001$). After 7 May, mean height (cm) for plants receiving nitrogen was much greater on all dates than mean height for plants receiving no nitrogen (Figure 3-5). Mean height for plants receiving 70 mgL^{-1} and 210 mgL^{-1} nitrogen were similar. Nitrogen concentration did influence the number of stems per plant ($p<0.0001$) with plants receiving 70mgL^{-1} nitrogen having the greatest mean number of stems (1.7). Plants receiving 0mgL^{-1} and 210mgL^{-1} had similar mean number of stems (1.4 and 1.5, respectively).

Means for selected growth parameters such as leaf area, leaf dry weight, stem dry weight, shoot dry weight, root dry weight, and root area were consistently higher for the plants receiving 70 mgL^{-1} nitrogen (Table 3-1). The plants receiving 210 mgL^{-1} nitrogen had means that were approximately half as large as the means for the plants receiving 70 mgL^{-1} nitrogen, which suggests that application of 210 mgL^{-1} nitrogen had reached a level sufficient to inhibit growth.

Main effect of N on Root:Shoot ratio was significant ($p<0.0001$). Root:shoot ratio was significantly higher for plants receiving 0 mgL^{-1} nitrogen (1.23) as opposed to root:shoot ratio for plants receiving nitrogen (70 mgL^{-1}: 0.51; 210 mgL^{-1}: 0.64). There was no significant difference in root/shoot ratios between the 70 mgL^{-1} treatment and the 210 mgL^{-1} nitrogen treatment (Table 3-2). A study involving two Ericaceous species grown under varying levels of irradiance and three nitrogen application rates showed a similar trend in root:shoot ratio (Hawkins and Gordon 2004). Ericaceous species suffer increased rates of mortality under the highest nitrogen application rates because the surplus nitrogen inhibits root growth, leaving the plants vulnerable to drought stress (Hawkins and Gordon 2004). While root:shoot ratio decreased in nitrogen treated *C. americana* plants, there was no mortality associated with higher nitrogen rate. The mortality seen in Ericaceous species was the result of water stress, which was not a factor in this experiment (Hawkins and Gordon 2004). Based on the results of the earlier study, it is possible that the inhibition in growth of *C. americana* at 210 mgL^{-1} nitrogen could lead to plant mortality under water stress.

Mean concentration of nitrogen (in both root and shoot tissues) was highest in plants receiving 210 mgL^{-1} nitrogen. However, mean concentrations of phosphorus and iron were higher in plants receiving 0 mgL^{-1} nitrogen (Table 3-1). This is likely because the metabolic processes by which plants utilize these nutrients were inhibited by the lack of nitrogen supply in the 0 mgL^{-1} nitrogen treatment (Marschner 1995).

Amount of nitrogen had a greater effect than irradiance on plant growth of *C. americana*. There were no significant differences in growth parameters between the two irradiance treatments, whereas plants that received 70 mgL^{-1} nitrogen showed the greatest growth response and the highest rate of photosynthesis under both irradiance treatments. Plants supplied with 210 mgL^{-1} nitrogen did not show a three-fold increase in photosynthetic rate, and plant growth parameters were approximately half as large as for plants supplied with 70 mgL^{-1} nitrogen. This suggests that this species grows equally well in shade as in unrestricted sunlight and that over-application of nitrogen may inhibit plant growth.

There were no apparent significant differences in growth parameters between the two irradiance treatments. *C. americana* appears to grow well in full sun or shade as long as adequate nitrogen is supplied. Rates of photosynthesis were generally higher under 100% irradiance at a given nitrogen application rate, but growth was not inhibited at 50% irradiance. This species was shown in a field study to be capable of growth and survival under drought conditions in both full irradiance and 50% irradiance, and in plots that were trenched (to remove root competition) and untrenched (Chapter 1).

Morella pumila

A two-way interaction of time and irradiance was found for *M. pumila*. PAR increased until 6 August, and then gradually declined until 7 September.

Mean photosynthesis was higher for *M. pumila* earlier in the study, possibly because of decreasing day length as the study progressed. Nitrogen treated plants had higher values for mean photosynthesis (70 mgL^{-1}: 3.0 $\mu mol\ m^{-2}\ s^{-1}$; 210 mgL^{-1}: 3.2 $\mu mol\ m^{-2} s^{-1}$) as compared to plants receiving 0 mgL^{-1} nitrogen (2.5 $\mu mol\ m^{-2} s^{-1}$), but means for nitrogen treated plants were not statistically different from each other.

Main effect of irradiance on stomatal conductance was significant ($p=0.0053$), with higher means for plants in the low irradiance treatment (0.09 mol H_20 $m^{-2}s^{-1}$) compared to means for the high irradiance treatment (0.08 mol H_2O $m^{-2}s^{-1}$) at all nitrogen application rates ($LSD_{(\alpha\text{-}0.05)}$=0.008). This finding is in contrast to the results of an experiment where *Solanum dulcamara* grown at differing levels of irradiance and with varying nitrogen application rates, where stomatal conductance decreased at low irradiance and at low nitrogen application rates (Osmond 1983).

Mean plant height was affected by an interaction of nitrogen and irradiance ($p<0.0001$), with higher means for plants receiving 100% irradiance for all nitrogen treatments (Figure 3-6). The greatest difference in mean plant height between irradiance treatments was found for plants receiving 70 mgL^{-1} nitrogen. Plants receiving the same amount of nitrogen grew taller under 100% irradiance. This finding is in contrast with earlier studies that found that understory species did not respond to nitrogen application under high irradiance with an increase in growth (Riddoch et al. 1991; Grubb et al. 1996; Fetcher et al. 1996). The differences in height between irradiance treatments was statistically significant ($p<0.0001$) but were not necessarily biologically significant.

A main effect of nitrogen was found on means for selected growth parameters and concentration of nitrogen and phosphorus in both root and shoot tissues (Table 3-3). Means for leaf area, leaf dry weight, and shoot dry weight were higher for plants receiving 70 mgL^{-1} and 210 mgL^{-1} nitrogen as compared to plants receiving no nitrogen, but the means for nitrogen treated plants were not statistically different from each other. Means for root area and root:shoot ratio were similar among the three nitrogen treatments and between irradiance treatments. Mean concentration of nitrogen for both root and shoot tissues was higher for plants receiving 210 mgL^{-1} nitrogen, while mean concentration of phosphorus did not show statistical differences between nitrogen treatments (Table 3-3).

Conclusions

Plants in this study responded more to variations in nitrogen than to differences in irradiance. This finding supports the findings of earlier studies that found that changing irradiance levels change the amount of nitrogen the plants require for optimum growth (Coutinho and Zingmark 1993). Additionally, the inhibition of plant growth at the highest nitrogen application rate observed for *C. americana* has been noted in other plant species such as *Cryptomeria japonica* and *Pinus densiflora*, and *Artemesia californica*, all of which are found in nitrogen deficient habitats (Najaki et al. 2001, Padjett and Allen 1998).

The lack of any definable trend in root:shoot ratio across the nitrogen gradient for *M. pumila* contrasts with the decrease in root:shoot ratio at increasing nitrogen rates observed in *C. americana* in this study, and for many other species in earlier studies (Hawkins and Gordon 2004; Padgett and Allen 1998). Additionally, plant growth was not inhibited at 210 mgL^{-1} nitrogen. Photosynthetic efficiency did not increase for *M. pumila* at the highest nitrogen application rate. Plant growth was similar for both nitrogen application rates, indicating that while plant growth was not inhibited at 210 mgL^{-1} nitrogen, the higher nitrogen application rate was not necessary. Plant growth was not influenced by low irradiance, indicating that this species grows equally well under shade and under unrestricted sunlight. This result was obtained under controlled conditions within a greenhouse, and may not apply to field or forest conditions where below ground interactions between water, and nutrients are more complex and where irradiance is not as uniform (Grubb et al. 1996; Putz and Canham 1992). More study of the nitrogen response of this species is needed before recommendations for growers can be made.

Table 3-1. Main effect of nitrogen was observed on means for selected growth parameters and concentration of selected nutrients in *Callicarpa americana*. Means for growth parameters were highest for the 70 mg·L^{-1} treatment. Mean concentration of nitrogen in roots and shoots was highest for the 210 mg·L^{-1}treatment, while means for all other nutrients were highest for the 0 mg·L^{-1} treatment (n=12).

N treatment (mg·L^{-1})	Leaf area (cm^2)	Leaf dry wt (g)	Stem dry wt (g)	Root dry wt (g)	Shoot dry wt (g)	Root area (cm^2)	Root N (%)	Shoot N (%)	Root P (%)	Shoot P (%)	ShootFe (ppm)
0	296 b^z	0.52 c	0.25 c	72 c	0.90 c	0.77 c	1.17 c	0.86 b	0.39 a	0.32 a	447 a
70	2585 a	9.90 a	6.51 a	341 a	8.48 a	16 a	2.05b	0.88 b	0.09 b	0.07 b	75 b
210	1831 a	5.51 b	3.97 b	189 b	5.88 b	9 b	3.64 a	1.64 a	0.10 b	0.09 b	52 b

^{z}Means with the same letter within a column are similar as determined by Fisher's LSD (α=0.05).

Table 3-2. Interactive effect of time and irradiance on mean photosynthesis ($\mu mol\ m^{-2}\ s^{-1}$) for *Callicarpa americana* (n=36). Mean photosynthesis was highest on earlier dates for both irradiance treatments.

Date	Photosynthesis ($\mu mol\ m^{-2}\ s^{-1}$) (100% Irradiance)	Photosynthesis ($\mu mol\ m^{-2}\ s^{-1}$) (50% Irradiance)
9 April	6.63 a[z]	6.81 a
23 April	14.80 b	13.80 b
7 May	3.17 c	3.87 c
21 May	3.86 c	2.95 de
7 June	3.70 c	2.90 d
21 June	4.90 d	3.70 cd
3 July	3.33 c	2.51 de
17 July	2.13 e	2.25 e

[z]Means followed by the same letter do not differ ($LSD_{(\alpha\text{-}0.05)}$=0.87).

Table 3-3. Main effect of nitrogen was observed on means for selected growth parameters and concentration of nitrogen and phosphorus in *Morella pumila* (n=12). Mean leaf area and stem dry weight were highest for plants receiving 70 mg·L^{-1} nitrogen, while means for leaf dry weight, root area, and concentration of nitrogen in both root and shoot tissues were highest for plants receiving 210 mg·L^{-1} nitrogen.

N treatment (mg·L^{-1})	Leaf area (cm^2)	Leaf dry wt (g)	Stem dry wt (g)	Root area (cm^2)	Shoot dry wt (g)	Root N (%)	Shoot N (%)	Root P (%)	Shoot P (%)
0	302 b^z	6.73 b	7.23 b	153 a	14 b	0.79 c	1.14 a	0.17 a	0.16 a
70	464 a	9.37 a	9.42 a	158 a	19 a	0.99 b	1.23 b	0.18 a	0.15 a
210	440 a	10.3 a	8.85 ab	171 a	19 a	2.00 a	1.61 b	0.18 a	0.15 a

^{z}Means with the same letter within a column are similar as determined by Fisher's LSD (α=0.05).

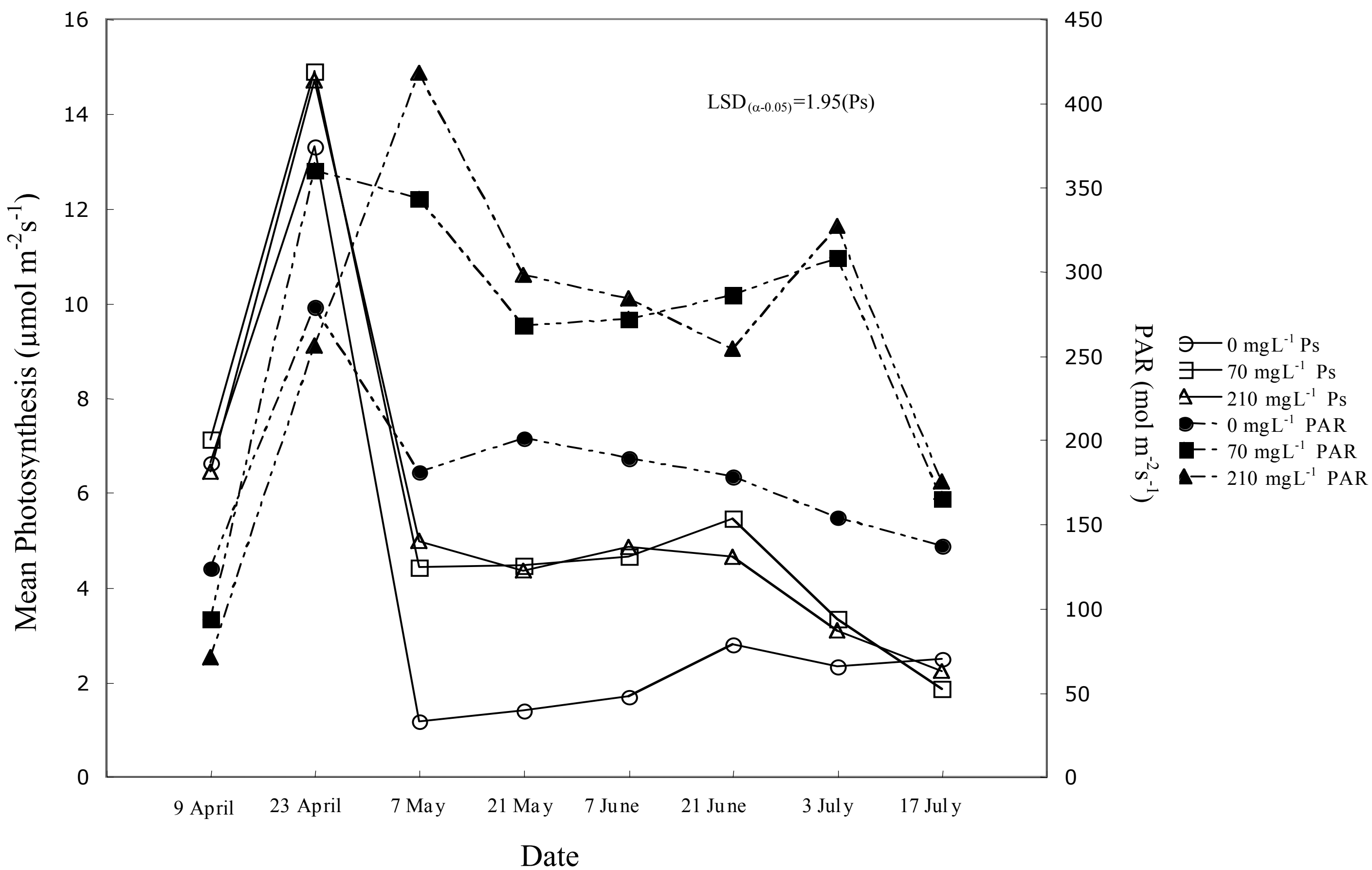

Figure 3-1. Mean photosynthesis (Ps) (µmol m^{-2} s^{-1}) for *Callicarpa americana* was affected by an interaction of amount of nitrogen and time (n=24). Mean Ps was higher on earlier dates and for plants receiving 70 mg·L^{-1} and 210 mg·L^{-1} nitrogen.

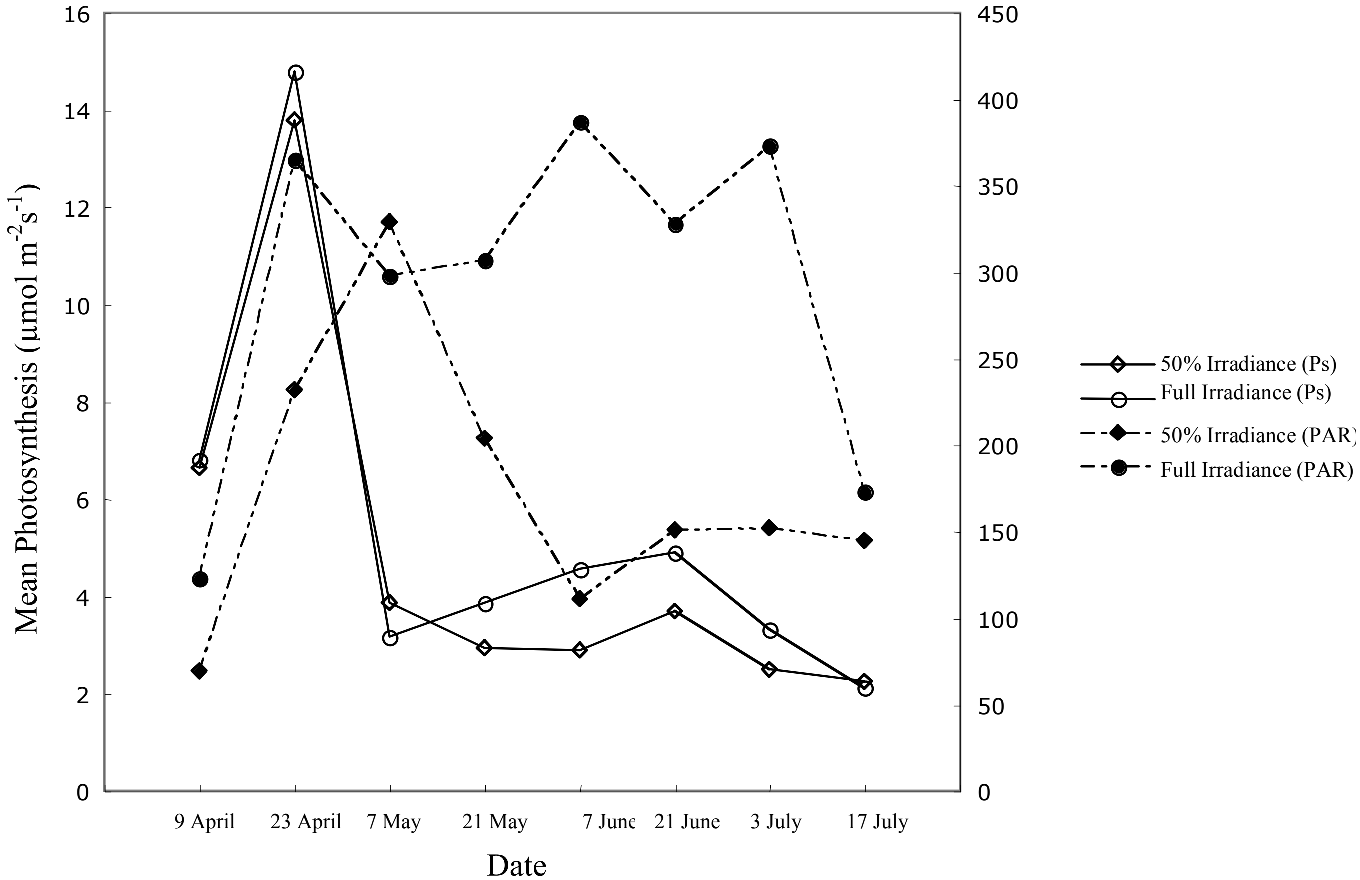

Figure 3-2. Mean photosynthesis (Ps) (μmol m^{-2} s^{-1}) was higher for plants under 100% irradiance on all dates aside from 7 May and 17 July. A two-way interaction of time and irradiance were found on Ps for *Callicarpa americana* (n=36).

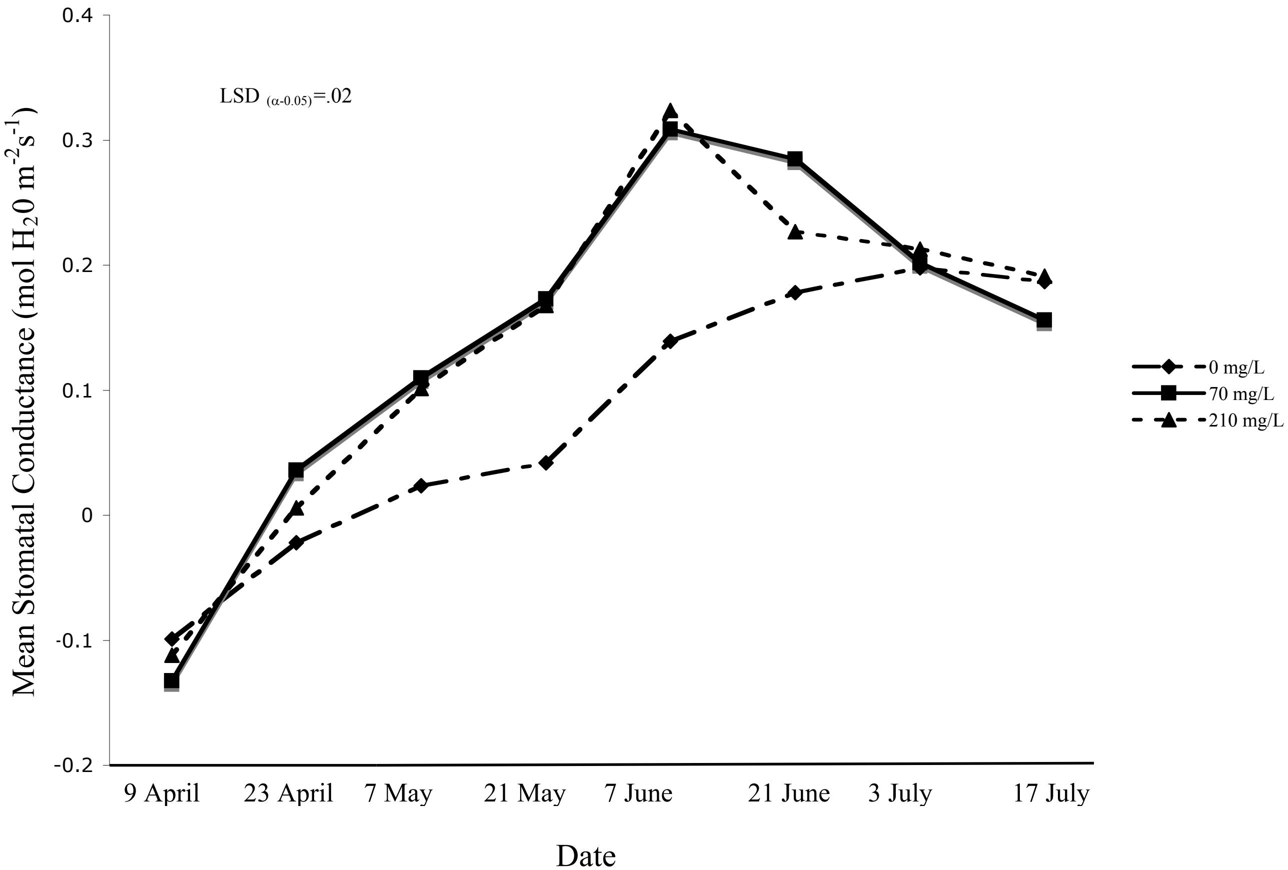

Figure 3-3. Mean stomatal conductance (molH_2O $m^{-2}s^{-1}$) for C. americana was affected by an interaction of time and nitrogen concentration (n=24). Mean stomatal conductance was higher for nitrogen treated plants on every date aside from April 9, July 3, and July 17.

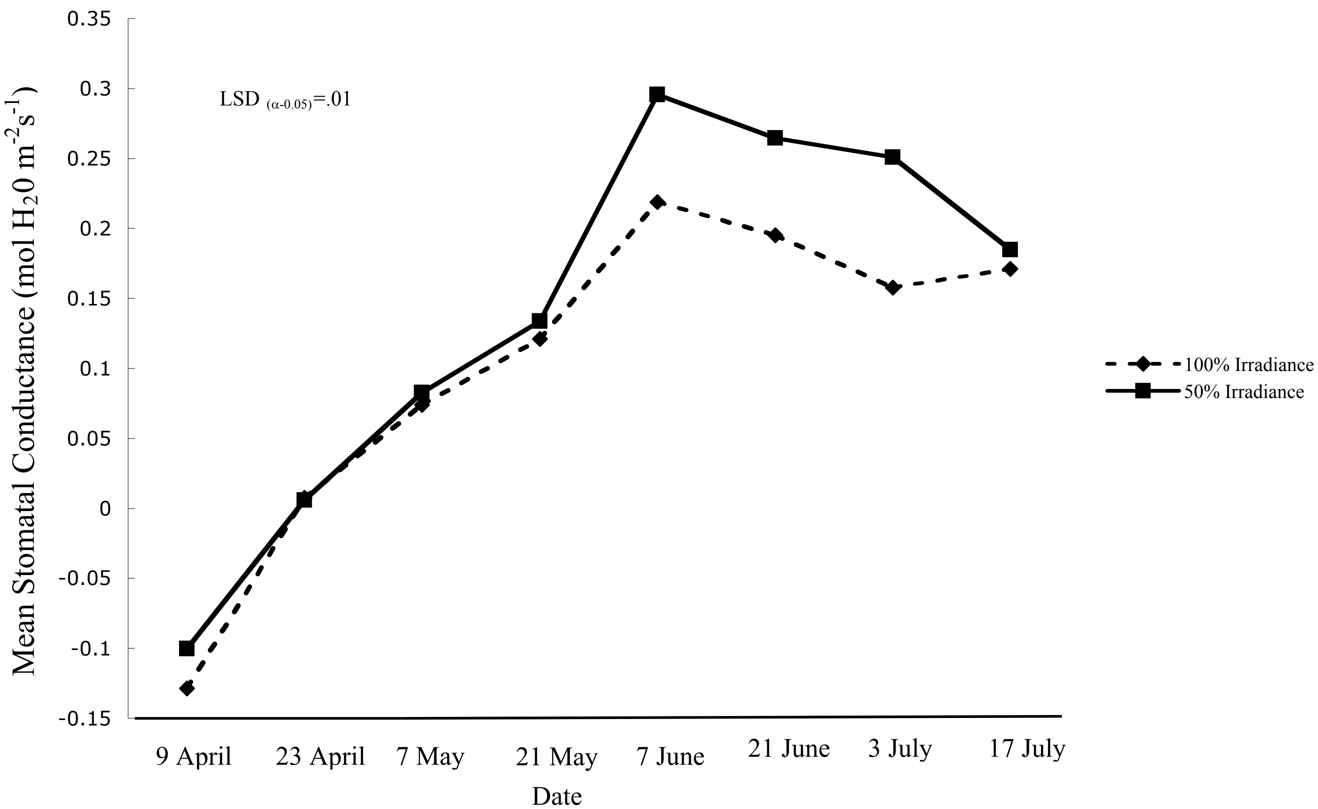

Figure 3-4. Mean stomatal conductance (mol$H_2$0 $m^{-2}s^{-1}$) for *C. americana* was affected by an interaction of time and irradiance (n=36). Mean stomatal conductance was higher for plants under 50% irradiance on all dates aside from April 23.

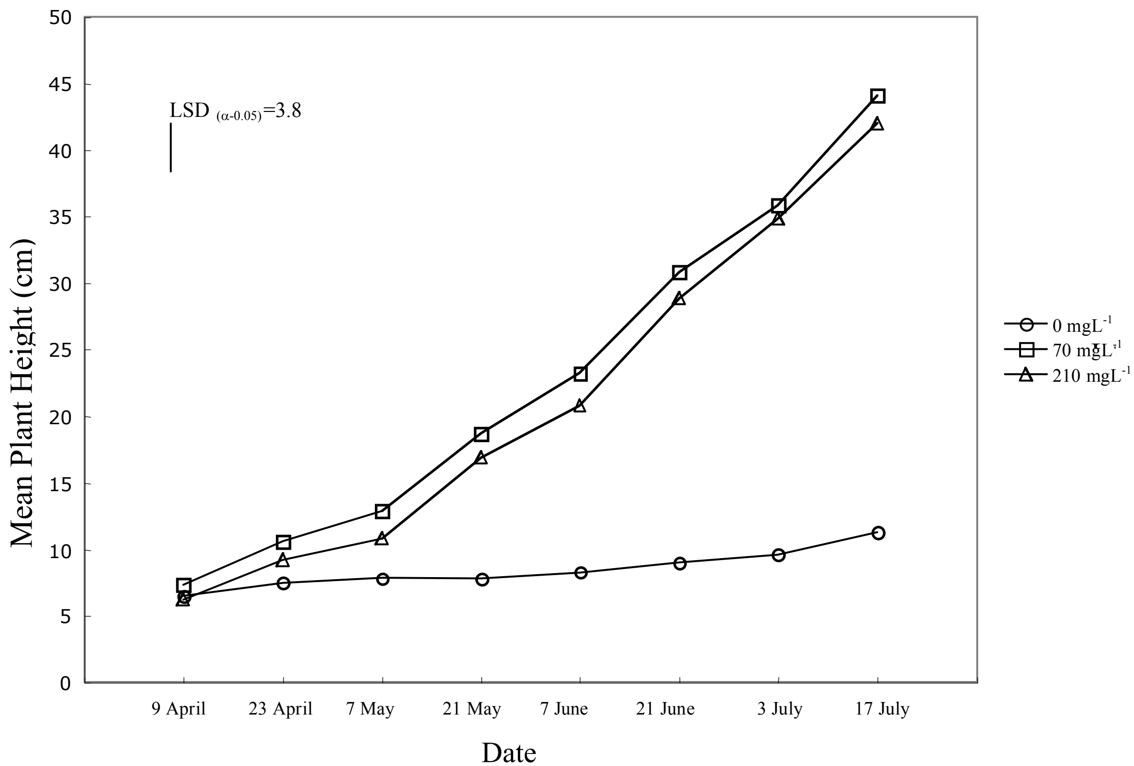

Figure 3-5. An interaction of nitrogen and time was observed on mean plant height (cm) for *Callicarpa americana* (n=24). Increase in mean plant height was much greater in plants receiving nitrogen. Means for plants receiving 70 mg·L^{-1} and 210 mg·L^{-1} nitrogen were similar.

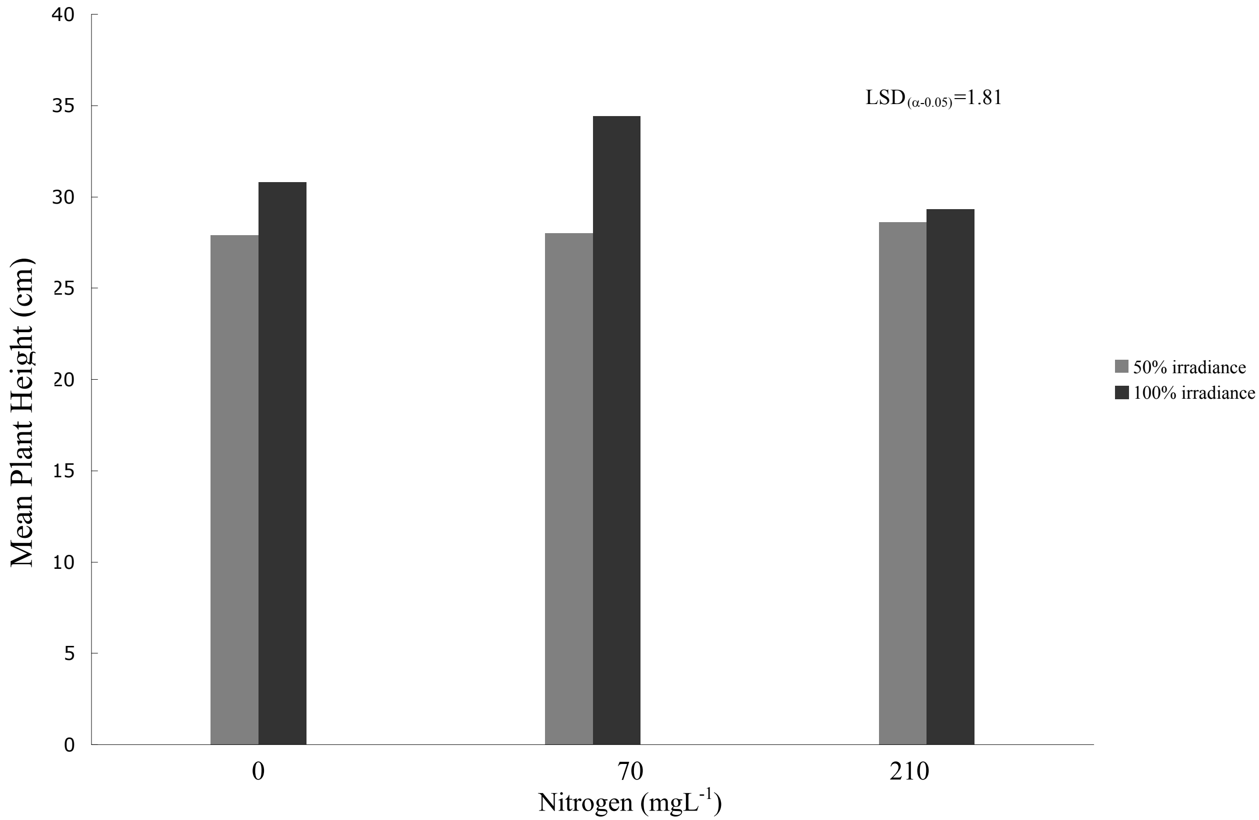

Figure 3-6. Mean plant height (cm) for *Morella pumila* was affected by an interaction of amount of nitrogen and irradiance (n=72). Means were higher for plants under 100% irradiance for all nitrogen treatments. The largest difference between irradiance treatment means was in plants receiving 70 $mg{\cdot}L^{-1}$ nitrogen.

CHAPTER 4
CONCLUSION

The results of both of these experiments indicate support the conclusions of previous studies, which found that below ground competition for resources such as nitrogen and water have a greater influence on plant growth than irradiance (Clough et al. 1983; Montieth et al. 1991; Osmund 1983; Zamora et al. 2008). The only exception to this would be the survival rates of *S. matsudana*, which performed poorly under partial shade irrespective of the presence of root competition. This result is unsurprising considering that this species grows best in full sun conditions in its native range (He and Dong 2002). The performance of *C. americana* in both studies demonstrates that this species is highly versatile and can grow well under a wide range of conditions. It is reasonable to expect that a species that is tolerant of a wide range of environmental conditions in its native habitat would be a good choice for growers to include in a low maintenance agroforestry system or landscape design. In contrast, the closely related *C. americana* var. *lactea* proved to be less tolerant of variations in irradiance and root competition than *C. americana*, which may explain why this species is far less common in the wild. Also, the high rates of survival in all treatments of *C. marshallii* demonstrate that this species is also highly versatile in the range of conditions it can tolerate.

Differences in the way that various species respond to variations in irradiance and supply of nutrients and water are important to understand when considering potential plant choices for inclusion in agroforestry systems or in landscape designs. Based on the results of this study, it is clear that interactions between tree crops and horticultural crops are complex and are challenging to study under field conditions. For example, *Ilex myrtifolia* is known to be resistant to periodic drought conditions in its native habitat, and it has been used in landscapes with some success (Nelson 2003). Nevertheless this species performed very poorly in this trial.

An understanding of how various factors interact to influence plant growth is essential when designing an ecologically sound approach to producing a horticultural crop in a low maintenance agroforestry setting. An agroforestry approach can provide a viable alternative to full sun production of woody cuts stems if growers can make informed decisions about what species are most suitable for inclusion in alley cropping arrangements. These studies provide a basis for further research by quantifying the interactions of the three primary limiting factors to plant growth and survival: light, water, and nutrients on a range of species with potential use as woody cuts. While it is critical to include plants that are capable of survival and growth under field conditions and to further quantify the interaction of the important factors in plant growth under more controlled settings, it is necessary to determine the conditions under which any plant choice will produce commercially valuable stems before final recommendations can be made.

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BIOGRAPHICAL SKETCH

Edward H. Fletcher III was born in 1971 in Tallahassee, Florida, USA. After graduating from Robert F. Munroe Day School in 1989, he attended Santa Fe Community College in Gainesville, Florida and transferred to Tallahassee Community College in Tallahassee, Florida, where he completed an Associate of Arts degree in 1992. He entered Florida State University that same year and completed a Bachelor of Science Degree in anthropology in 1996, and returned in 2002 to complete a bachelor's degree in geology. He then worked as a grower for Fletcher Nurseries, Inc. in Greensboro, Florida until 2004, when he was accepted into the Department of Natural Resources and the Environment at the University of Florida to seek a Master of Science degree in interdisciplinary ecology, which was completed in 2009.