

# **GROWTH, BROWSING AND MORTALITY IN MIXED OAK AND PINE PLANTINGS**

A Thesis Presented for the  
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## ABSTRACT

The purpose of this project was to determine if different oak/pine arrangements elicited potential beneficial interactions that affected seedling growth, mortality and overall protection from deer browsing. Northern red oak (*Quercus rubra* L.) and shortleaf pine (*Pinus echinata* Mill.) were planted together and alone in six different planting patterns and spacings, replicated over three blocks in recent clearcuts in east Tennessee, USA. Each block consisted of two monocultures planted at a 3.0 by 3.0 meter (m) spacing and four multi-cropped treatments planted at varying spatial arrangements (0.3 m, 1.0 m, 1.5 m, and 3.0 m) from neighboring shortleaf pine seedlings that were planted on a 3.0 m X 3.0 m grid. Each block was located on a distinct site with its own aspect and slope position. Seedlings were planted in late winter in 2018 and measured in the spring of 2019 and 2020. Height in centimeters (cm), root-collar diameter (cm), and presence of deer browsing were collected for live seedlings. In general, differences in these variables among treatments were not statistically significant except for deer browsing analyzed in the first-year measurements. The 1.0 m treatment appeared to have an influence on the level of deer browsing observed on the northern red oak seedlings. The lack of significant differences in nearly all areas of interest can also suggest there may be minimal negative effects to tree species in multi-cropping systems. This study was designed to build from previous research that investigates if multi-cropping treatments can improve the overall health and resiliency of a forest from the adverse effects of a shifting climate or increasing stress from insects or diseases. This study is also the first installment of a multi-year research project focused on detecting possible synergistic trends between northern red oaks and shortleaf pines.

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# CHAPTER ONE

## INTRODUCTION AND OBJECTIVES

The curiosity surrounding how to improve the overall health and vigor of a forest has been present and persistent for generations. Gifford Pinchot said that trees in a forest both compete for resources such as light and water and work with each other to create the best conditions for growth and fighting power. Each tree contributes in its own way to the general welfare of the forest (Pinchot, 1899).

Many studies have been conducted to find scientific evidence that this synergistic effect occurs and to study the “community” effect that Pinchot wrote about over one hundred years ago (Bordron et al., 2021; Granger & Buckley, 2021; Kelty, 1992; Tilman et al., 1997). The same concept is present in agriculture systems as in forested systems. For centuries, Native Americans have cultivated crops based on synergistic effects one plant has on another as observed in the “Three Sisters” technique in which maize, beans and squash are planted together (Landon, 2008). The science of agro-forestry is founded on this very concept that multi-cropped systems can produce a higher yield and provide greater resiliency to stressors than single species systems (King, 1987).

Competition between species is observed when at least two species interact, and one exerts a negative impact on the other. Conversely, facilitation occurs when there is a positive impact observed (Forrester, 2014). In order to maximize stand resiliency and growth, species differing in characteristics such as height growth rate, shade tolerance or intolerance, root phenology and crown structure should be planted together (Kelty, 1992). These differences can lead to more efficient capture of site resources, resulting in a positive impact on the stand (Kelty, 2006). Previous research has demonstrated that mixed species plantings can have improved tree and overall stand growth through enhanced resource supply, uptake and utilization (Erskine et al., 2006; Pretzsch et al., 2013).

Different species demonstrate different strategies for responding to environmental stressors such as drought, insects, or disease. In forestry, enhanced stand diversity and spatial arrangement can prevent or provide protection against devastating high populations of damaging insects or diseases (Jactel & Brockerhoff, 2007). Diverse species forests may provide natural enemies with complementary habitat or feeding resources thus enhancing naturally occurring biological control (Ramsfield et al., 2016). For decades, foresters have prepared for southern pine beetle (*Dendroctonus frontalis* Zimmermann) infestations in plantations of loblolly pine (*Pinus taeda* L.) by executing stress reducing, growth promoting silviculture prescriptions such as thinning and prescribed burning (Nowak et al., 2015).

In addition to forest level characteristics, more specific dendrological characteristics of certain trees are also known to benefit the growth of other tree species. For example, oak root systems can create hydraulic lift that provides soil moisture from deep in the soil profile to neighboring trees, thereby facilitating their growth and survival during droughts (Pretzsch et al., 2013). This type of beneficial interaction could prove to be useful when managers are searching for ways to better manage forests in the face of climate change. In the southeastern region of the United States, climate change is predicted to manifest as increased temperatures and prolonged dry events, resulting in drought conditions (Ingram et al., 2013). A potential strategy for addressing increased drought could be to interplant tree species possessing characteristics that promote stand resiliency to drought and bolster overall stand health.

A diverse community of trees can also provide protection from animal herbivory. Herbivory can be higher in stands with greater concentrations of desirable forage species than in stands with lower concentrations of desirable species. Kern et al. (2012) reported that deer browsing on tree seedlings may have been lower in larger gaps sizes with higher densities of shrubs because there were greater distances between individual seedlings and greater visual obstruction. Therefore, multi-cropped systems containing some species that are not desirable for deer foraging can create a spatial arrangement that may deter heavy, concentrated browsing behavior.

European foresters in the late nineteenth century began advocating for a departure from single species or monoculture forestry and adopting an approach that mimics the facilitation that occurs in naturally occurring mixed stands (Matthews, 1989). Granger et al. (2018) reported results from a 25-year study suggesting that oak regeneration is more successful in oak-pine mixtures perhaps because these mixtures mimic natural succession patterns. Research conducted by Schubert et al. (2020) found that planting or cultivating small-leaved tree species such as black cherry (*Prunus serotina* Ehrh.) may create favorable diffused light conditions that enhance cherrybark oak (*Quercus pagoda* Raf.) regeneration. At a given level of basal area, Buckley et al. (1999) measured greater understory light levels beneath red pines (*Pinus resinosa* Aiton) than northern red oaks. Pines may also benefit oaks by shielding them from deer browsing and frost damage. Observations in a Michigan oak planting in which red pines were accidentally planted between the oaks in certain rows included better oak survival, form, and height growth in rows interplanted with pine. Oaks were either missing or short in stature with multiple stems in rows without pines (Buckley, unpublished data).

The three objectives of this study were to test the hypotheses that mixing northern red oak and shortleaf pine seedlings in various multi-cropped planting arrangements would (1) produce a positive interaction on seedling height and root-collar diameter; (2) reduce seedling mortality; and (3) deter browsing from

deer. Levels of success within each planting treatment in the first five years will inform follow-up research on thinning and release treatments that could be employed to favor oak, favor pine, or different mixtures of the two. As it relates to this study, shortleaf pine is generally shade intolerant (Burns & Honkala, 1990) but is able to persist in shade. The root system of shortleaf pine is usually larger than that of other southern pines and has a deep taproot (Harlow et al., 1996). It has a well formed, narrow pyramid shaped crown. Its seed is dispersed by prevailing winds in a V-shaped pattern from the parent tree (Siggins, 1933). Oswalt et al. (2012) stated that shortleaf pine dominated forest have declined by 52% between 1980 and 2010. The decline in shortleaf pine population can be attributed many variables including preferential planting of loblolly pine, urbanization, natural hardwood succession facilitated by southern pine beetle outbreaks and lack of canopy disturbances such as wildfire (Clabo & Clatterbuck, 2005; South & Buckner, 2004). Without active management such as artificial regeneration, shortleaf pine forests may continue to decline (Clabo, 2018).

Northern red oak can be classified as intermediate in its preference to shade. Its root system often lacks a well-developed taproot that grows slower than lateral roots at the seedling stage. The crown of northern red oak trees can be widespread if allowed to grow in open settings or can be smaller, more rounded crown in a forested setting (Harlow et al., 1996). Similar to shortleaf pine, northern red oak has challenging regeneration issues. Due to the suppression of wildfire since European settlement in the United States, more shade tolerant species such as sugar maple (*Acer saccharum* Marsh.) and red maple (*Acer rubrum* L.) have become more competitive (Buckley et al., 1998). Northern red oak regenerates more readily from sprouting than from germination of acorns. According to Burns (1990), 95% of northern red oak in a new stand are from sprouts either from advanced regeneration or from stumps of the parent tree.

Shortleaf pine and northern red oak have complimentary silvical characteristics. Both can persist in shade but respond well when released; the rooting characteristics complement each other; the needle size and crown density of a shortleaf pine could create a favorable diffused light environment for northern red oak regeneration; and both species have the ability to sprout after a disturbance.

Establishment of oak-pine mixtures would enhance mast production for wildlife, potentially confer greater resilience to pests, diseases, and extreme weather, and allow managers and landowners to hedge against unforeseen threats to pines, oaks, and overall forest health. These two tree species grow well in naturally mixed forests and provide similar desirable ecosystem values such as wildlife habitat and valuable timber quality.

## CHAPTER TWO

### METHODS

#### **2.1. Study sites**

This study was established in 2018 in Chuck Swan State Forest in the Southern Appalachian Ridge and Valley province in Tennessee (Fig. 2.1). Three blocks of treatments were established in three recently harvested clearcuts. In all blocks, stumps and slash were removed and the site was smoothed with a bulldozer. No additional management treatments such as fertilization or vegetation control was conducted in the blocks prior to study site establishment. The closest weather station to the study sites was located in Tazewell, TN. Average annual high temperature is 19.7°C and average annual low temperature is 5.9° C. Annual precipitation is 128.8 cm (WorldClimate, 2021).

Soils in block 1 are Fullerton gravelly silt loam well drained soils with 5-12% slopes and parent material derived from cherty limestone (NRCS, 2021). Aspect of block 1 was north and west. Block 1 was clearcut (all stems removed or downed) in 2018 and contained primarily residual hickory (*Carya* spp.) and yellow-poplar (*Liriodendron tulipifera* L.) with a site index of 72. The understory contained significant amounts of autumn olive (*Elaeagnus umbellata* Thunb.).

Soils in block 2 are Dewey silt loam well drained soils with 12-25% slopes and parent material derived from clayey residuum weathered from limestone. Additional soil types in block 2 are Fullerton and Bodine gravelly silt loams that are well drained with 25-45% slopes and parent materials derived from clayey residuum from weathered cherty limestone (NRCS, 2021). Aspect of block 2 was south and east. Block 2 was clearcut (all stems removed or downed) in 2018 and contained primarily low quality yellow-poplar with a site index of 81. The understory contained significant amounts of autumn olive.

Soils in block 3 are Clarksville cherty silt loam with rolling phase and 24.5% slopes. A second soil type in block 3 is the Clarksville cherty silt loam with steep phase and 30-40% slopes. Both of these soils are somewhat excessively drained with parent material derived from gravelly colluvium residuum weathered from cherty limestone (NRCS, 2021). Aspect of block 3 was north and west. Block 3 was clearcut (all stems removed or downed) in 2017 and contained a mixed species composition of poor and small sawtimber sized trees with a site index of 72.

#### **2.2. Study design**

The experimental design for this project was a randomized complete block design with three blocks measuring 30.4 X 115.8 meter (m) (0.3 hectare) in size. Six treatments, or spacing arrangements, were randomly assigned to six 9.0 X 30.4 m plots. Two treatments were monocultures of northern red oak and shortleaf pine planted at 3.0 X 3.0 m spacing. The remaining four treatments consisted of shortleaf pine seedlings planted at 3.0 X 3.0 m spacings and

northern red oak seedlings inter-planted 0.3 m, 1.0 m, 1.5 m or 3.0 m away from an anchoring shortleaf pine seedling. All treatments contained forty (40) northern red oaks and forty (40) shortleaf pine seedlings except for the 1.0 m spacing treatment, which contained eighty (80) northern red oak seedlings and forty (40) shortleaf pine seedlings. Treatments were randomly assigned in each block and differentiated by a single row of shortleaf pine to act as a visual buffer to differentiate the treatments (Fig. 2.2). Before measurement each year, the rows in between the plantings were bushhogged to facilitate data collection. The spacing arrangements were designed to fit within the traditional artificial planting specifications of pine at 3.0 m X 3.0 m spacing. The various northern red oak spacings from the anchor shortleaf pine seedling were designed to force interactions between the oaks and the pines. Furthermore, the trees per hectare resulting from this design are similar to trees per hectare in naturally regenerated stands in this geographic region. The northern red oak seedlings were from known genetic families provided by the Tree Improvement Program at the University of Tennessee. The shortleaf pine seedlings were provided by the Tennessee Department of Agriculture, Division of Forestry East Tennessee State Nursery in Delano, Tennessee.

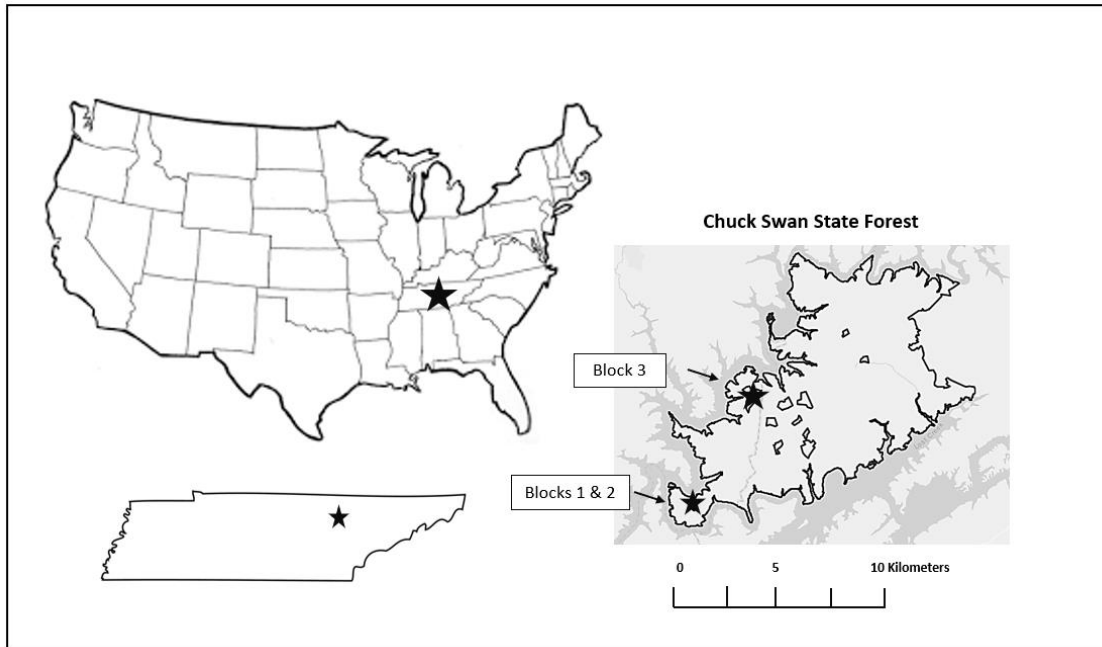


Fig. 2. 1. This study was established in 2018 in recent clearcuts on Chuck Swan State Forest, Campbell and Union Counties, Tennessee USA.

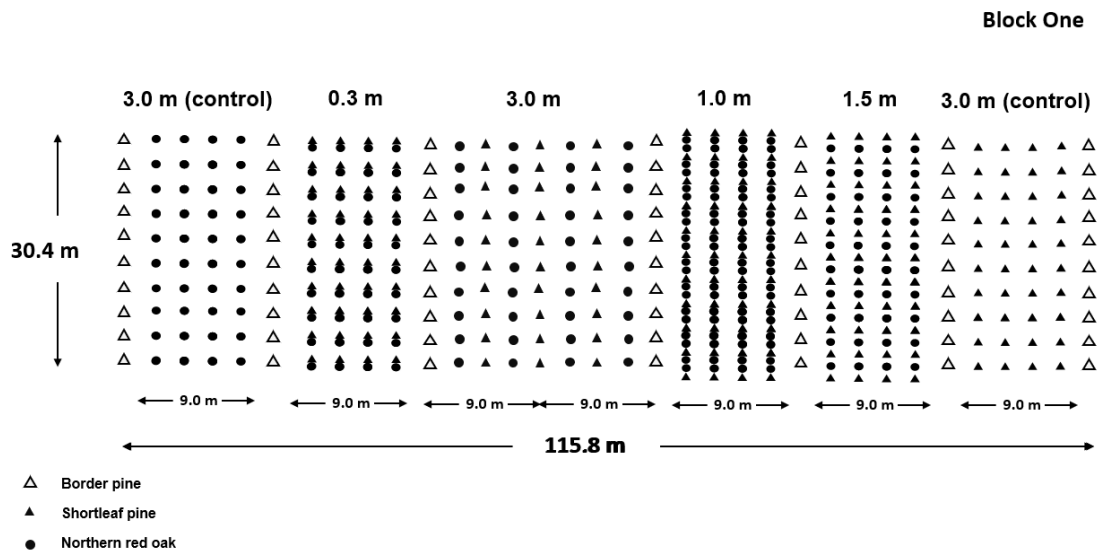


Fig. 2. 2. Arrangement of randomly assigned multi-cropped treatments and controls within the study area.

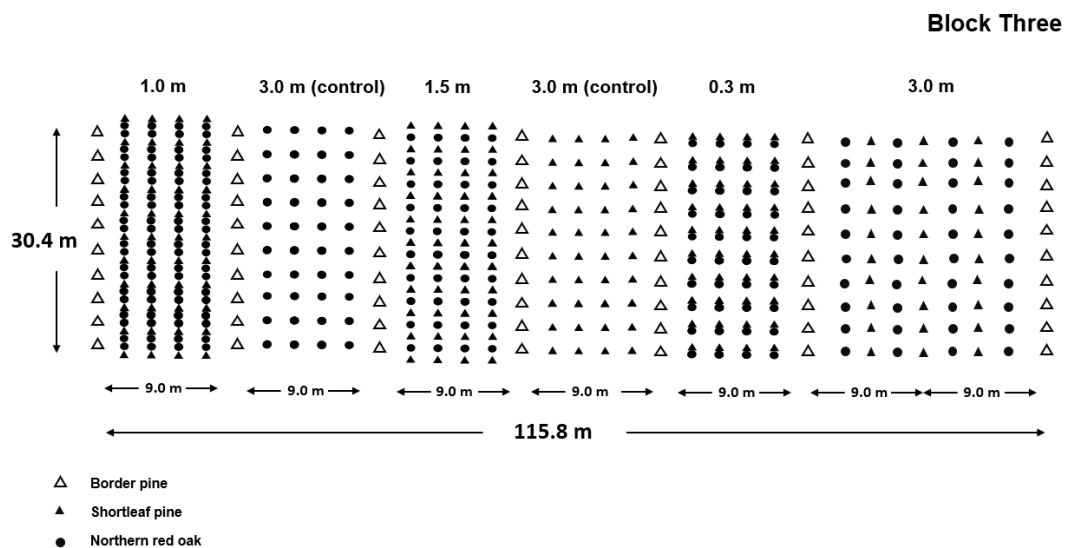
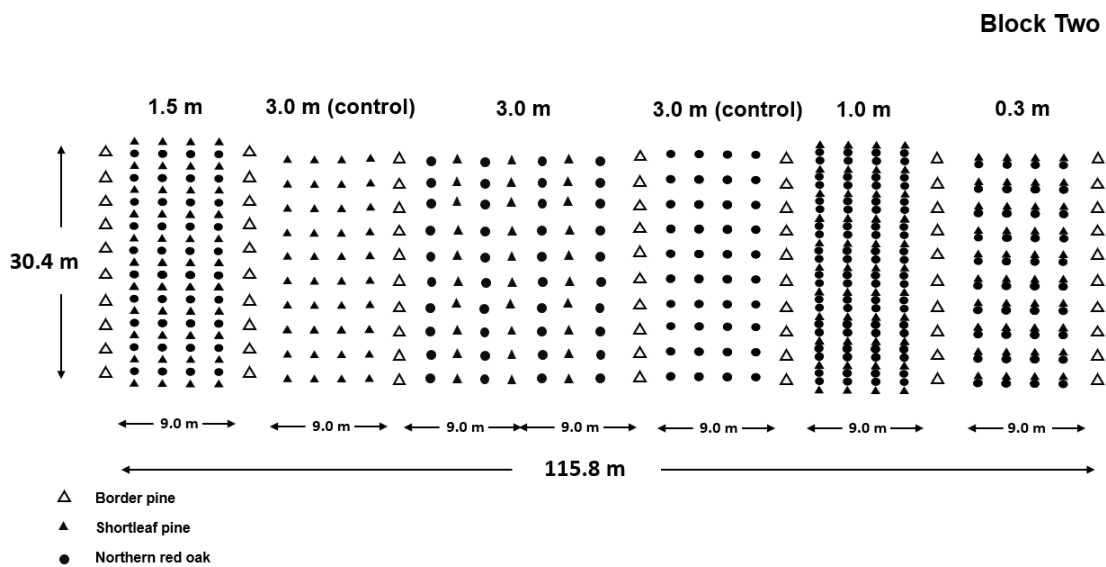


Fig. 2.2. Continued

### **2.3. Measurements**

One year old pine seedlings were planted on March 16, 2018 and one year old oak seedlings were planted on March 20, 2018. Over the first growing season, many pine seedlings died and were replanted on March 15, 2019. The first measurement occurred in April 2019. Second-year performance of the seedlings was measured in May 2020. In both years, total seedling height in centimeters (cm) and root-collar diameter (cm) were recorded. Binary data (yes/no) of deer browsing and mortality were also noted. Height was measured to the nearest hundredth of a centimeter from the ground level to the tip of the previous winter's overwintering terminal bud and was taken using a telescoping measuring rod in metric increments. Root-collar diameter was measured to the nearest hundredth of a centimeter and was taken at ground level using a sliding caliper ruler.

### **2.4. Analysis**

Statistical analysis appropriate for a randomized complete block design was conducted using JMP Pro 15 software. Mean height (cm), mean root-collar diameter (cm) and percent mortality and browsing were analyzed using an analysis of variance (ANOVA) model. Growth was determined by calculating the difference between mean height (cm) and root-collar diameter (cm) by species between the two growing seasons and analyzed using an ANOVA model. Pairwise comparisons of means were carried out using Tukey's Honestly Significant Difference (HSD) test. Extreme deer browsing was observed in block 1, therefore analysis was conducted on all blocks and with block 1 removed to ensure no masked treatment significance was present. Statistical significance for all analysis were determined at the  $\alpha = 0.05$  level. Results of analysis of all blocks modeled are presented in this paper. The following ANOVA model was used to examine the effects of spacing configurations on oak and pine mean height, mean root-collar diameter, mean growth, percent mortality and percent deer browsing:

$$y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij}$$

where:

$y_{ij}$  = response variable for either oak or pine seedlings (mean height, mean root-collar diameter, mean growth, percent mortality, percent deer browsing)

$\mu$  = overall mean

$\alpha_i$  =  $i$ th treatment effect

$\beta_j$  =  $j$ th block effect

$\varepsilon_{ij}$  = random error

$i = 1, 2, 3, 4, 5,$

$j = 1, 2, 3$

## CHAPTER THREE

### RESULTS

#### ***3.1. Seedling height and root-collar diameter plot level means***

The treatments had no significant effect on seedling height or root-collar diameter plot level means after the 2018 or 2019 growing season for either oak or pine. Differences in oak mean height (cm) and mean root-collar diameter (cm) were not significantly different across treatments after the first growing season with  $p = 0.581$  and  $p = 0.854$ , respectively. Differences in height and root-collar diameter for pine also were not significant across treatments after the first growing season with  $p = 0.826$  and  $p = 0.979$  (Fig. 3.1 and 3.2). Differences in the second-year height and root-collar diameter measurements for oak were not significant across treatments with  $p = 0.566$  and  $p = 0.752$ , respectively. Differences in the second-year height and root-collar diameter measurements for pine were also not significantly different across treatments, with  $p = 0.209$  and  $p = 0.689$  (Fig. 3.3 and 3.4).

Differences among blocks were found to be significant for both pine and oak height and root-collar diameter after the first and second year growing seasons, except for pine height in the first-year measurement ( $p = 0.077$ ). Further exploration of this analysis by conducting a pairwise comparisons of means using Tukey's Honestly Significant Difference (HSD) test indicated that block 1 was significantly different from block 2 and 3.

#### ***3.2. Seedling growth***

The difference between mean height (cm) and root-collar diameter (cm) by species between the two growing seasons was analyzed and it was determined that the six treatments had no significant effect on oak height growth ( $p = 0.435$ ), pine height growth ( $p = 0.402$ ), oak root-collar diameter growth ( $p = 0.352$ ), or pine root-collar diameter growth ( $p = 0.651$ ) (Fig. 3.5 and 3.6).

Differences in blocks were found to be significant for pine and oak height growth and oak root-collar diameter growth after the two growing seasons. Further exploration of this analysis by conducting a pairwise comparisons of means using Tukey's Honestly Significant Difference (HSD) test indicated that blocks 2 and 3 were significantly different in terms of oak height growth ( $p = 0.023$ ). For oak root-collar diameter growth and pine height growth, block 1 was significantly different from blocks 2 and 3 ( $p = 0.002$  and  $p = 0.002$ ). Blocks were not significantly different for pine root-collar diameter growth.

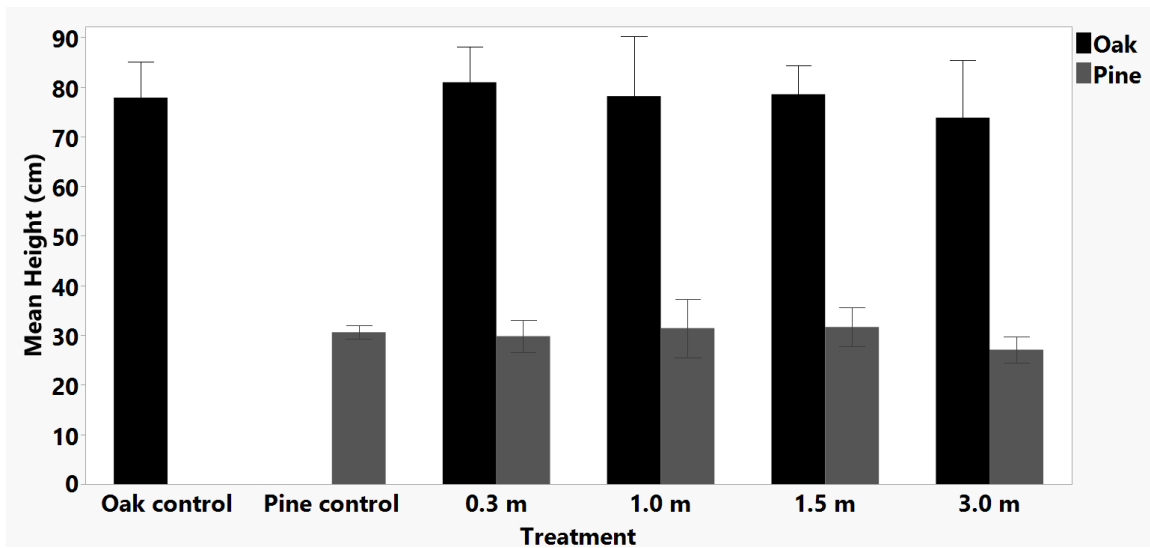


Fig. 3. 1. First year plot-level mean height (cm) for oak and pine by treatment. Differences in means between treatments were not statistically significant. Error bars represent one standard error.

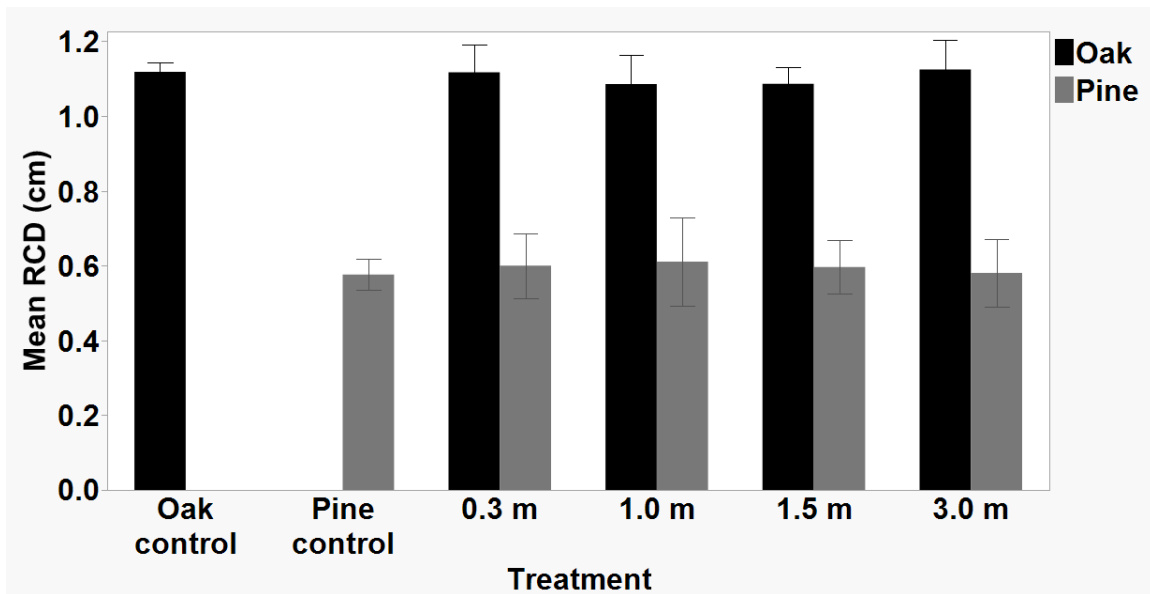


Fig. 3. 2. First year plot-level mean root-collar diameter (RCD) (cm) for oak and pine by treatment. Differences in means between treatments were not statistically significant. Error bars represent one standard error.

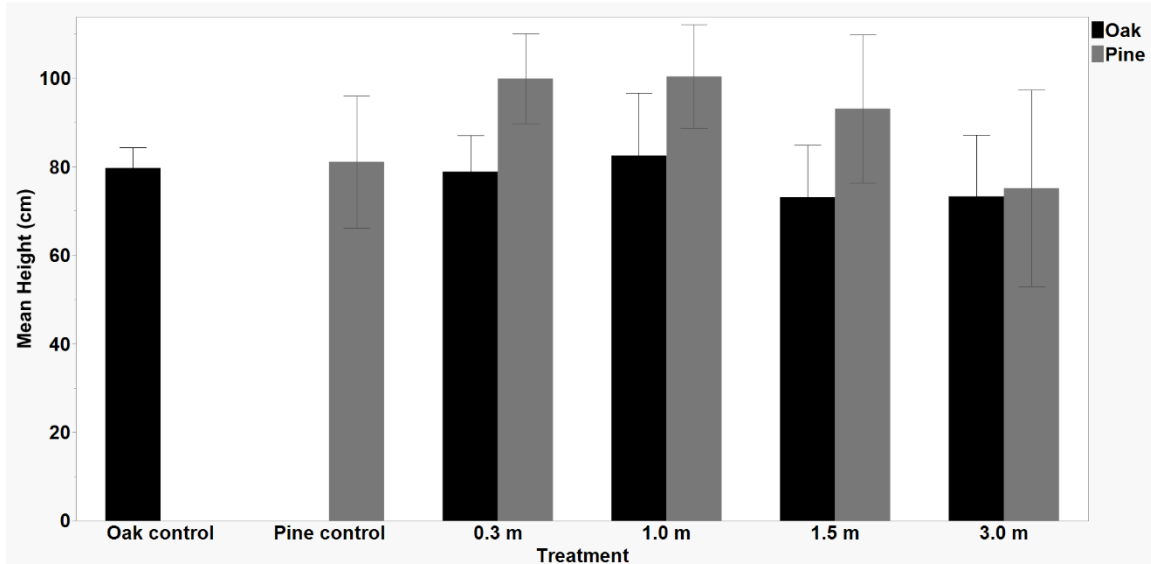


Fig. 3. 3. Second year plot-level mean height (cm) for oak and pine by treatment. Differences in means between treatments were not statistically significant. Error bars represent one standard error.

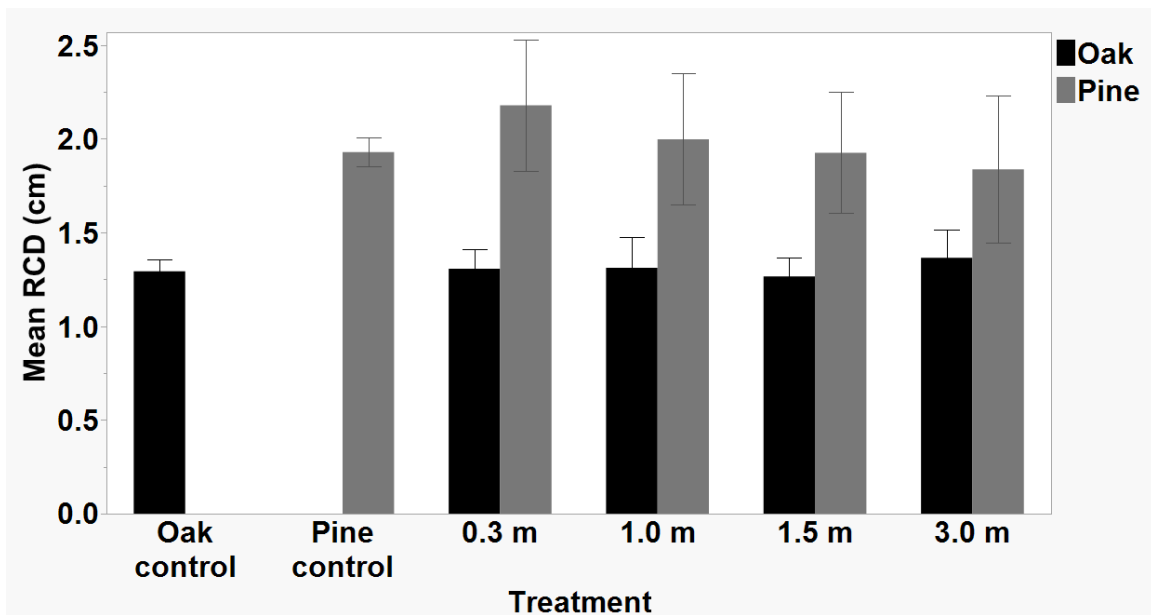


Fig. 3. 4. Second year plot-level mean root-collar diameter (RCD) (cm) for oak and pine by treatment. Differences in means between treatments were not statistically significant. Error bars represent one standard error.

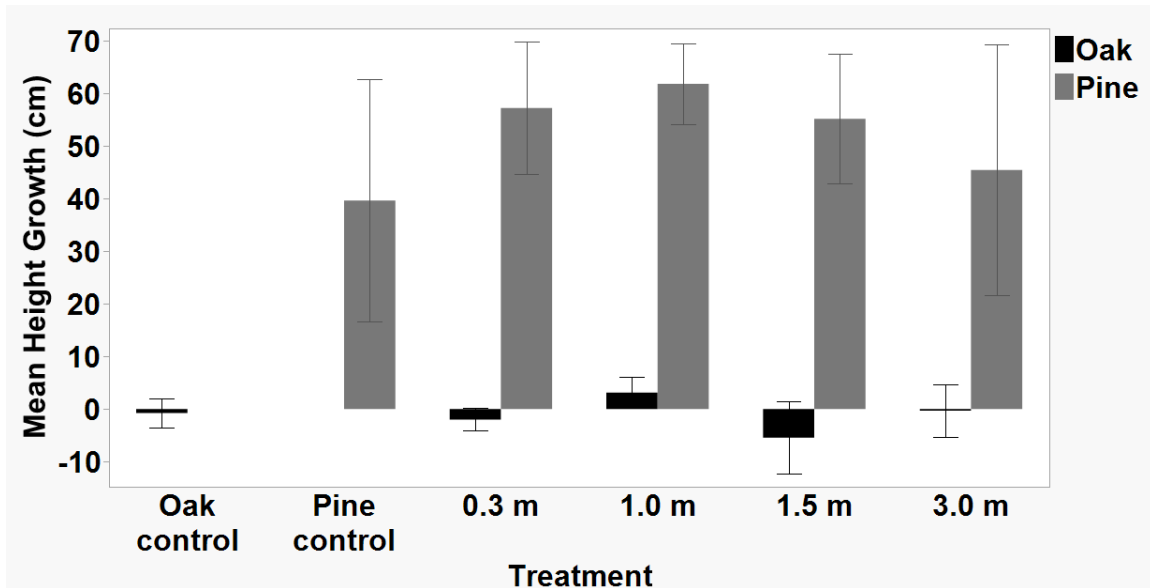


Fig. 3. 5. Mean height growth (cm) for oaks and pines calculated from measurements taken in 2019 and 2020. Differences in means between treatments were not statistically significant. Error bars represent one standard error.

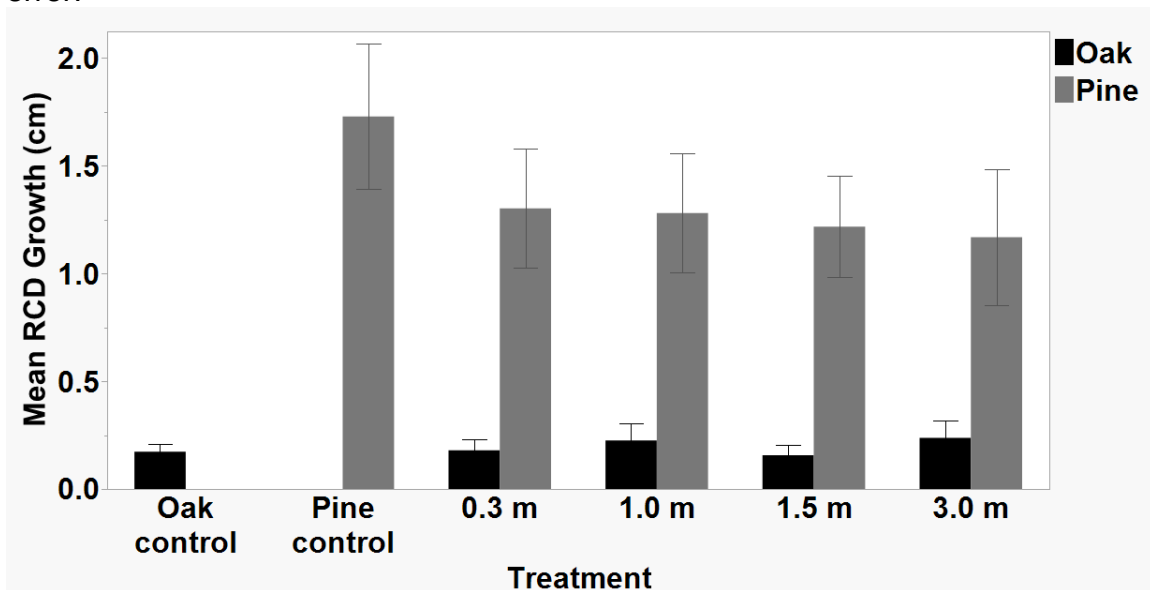


Fig. 3. 6. Mean root-collar diameter (RCD) growth (cm) for oaks and pines calculated from measurements taken in 2019 and 2020. Differences in means between treatments were not statistically significant. Error bars represent one standard error.

### **3.3. Seedling mortality**

Treatments had no significant effect on northern red oak seedling mortality in either the first or second year. The percent increase in percent mortality is highest in the 1.5 m spacing treatment (Table 1) at +48.0%. Block 1 was found to be significantly different from Blocks 2 and 3 in both years ( $p < 0.0001$ ).

Treatments had no significant effect on shortleaf pine seedling mortality in either the first or second year. The percent increase in percent mortality is highest in the 1.5 m spacing treatment (Table 2) at +157.0%. Differences in all three blocks were found to be significant in both years with  $p < 0.001$  and  $p = 0.006$ .

### **3.4. Seedlings browsed by deer**

Seedling damage from deer browsing was collected as a yes/no binary variable after the flush of growth occurred each spring. The presence of browsing damage was not collecting in block 3 of the 2019 dataset because these seedlings had not flushed prior to the time of measurement. Analysis of the 2019 data (Fig. 3.7) indicated that the treatments had a significant effect on percent browsing ( $p = 0.005$ ). A pairwise comparisons of means using Tukey's Honestly Significant Difference (HSD) test indicated that the 1.0 m spacing treatment differed from the remaining treatments ( $p = 0.001$ ). Block 1 also differed from blocks 2 and 3 in browsing ( $p < 0.001$ ). Deer browsing on shortleaf pine seedlings was noted on less than 3.0% of pine seedlings. Therefore, the pine browsing data was not analyzed. The differences among treatments or blocks in percent browsing in the second year were not found to be significant at  $p = 0.793$  (Fig. 3.8).

Table 1.

| Percent mortality of northern red oak seedlings by treatment and year. |                |                |
|------------------------------------------------------------------------|----------------|----------------|
| Treatment                                                              | Mean Mortality | Mean Mortality |
|                                                                        | (%)            | (%)            |
|                                                                        | 2019           | 2020           |
| Control                                                                | 33.3           | 38.3           |
| 0.3                                                                    | 28.3           | 33.3           |
| 1.0                                                                    | 25.8           | 28.8           |
| 1.5                                                                    | 27.5           | 40.8           |
| 3.0                                                                    | 25.0           | 27.5           |

Table 2.

| Percent mortality of shortleaf pine seedlings by treatment and year. |                |                |
|----------------------------------------------------------------------|----------------|----------------|
| Treatment                                                            | Mean Mortality | Mean Mortality |
|                                                                      | (%)            | (%)            |
|                                                                      | 2019           | 2020           |
| Control                                                              | 26.0           | 57.0           |
| 0.3                                                                  | 28.0           | 62.0           |
| 1.0                                                                  | 33.0           | 63.0           |
| 1.5                                                                  | 23.0           | 59.0           |
| 3.0                                                                  | 33.0           | 68.0           |

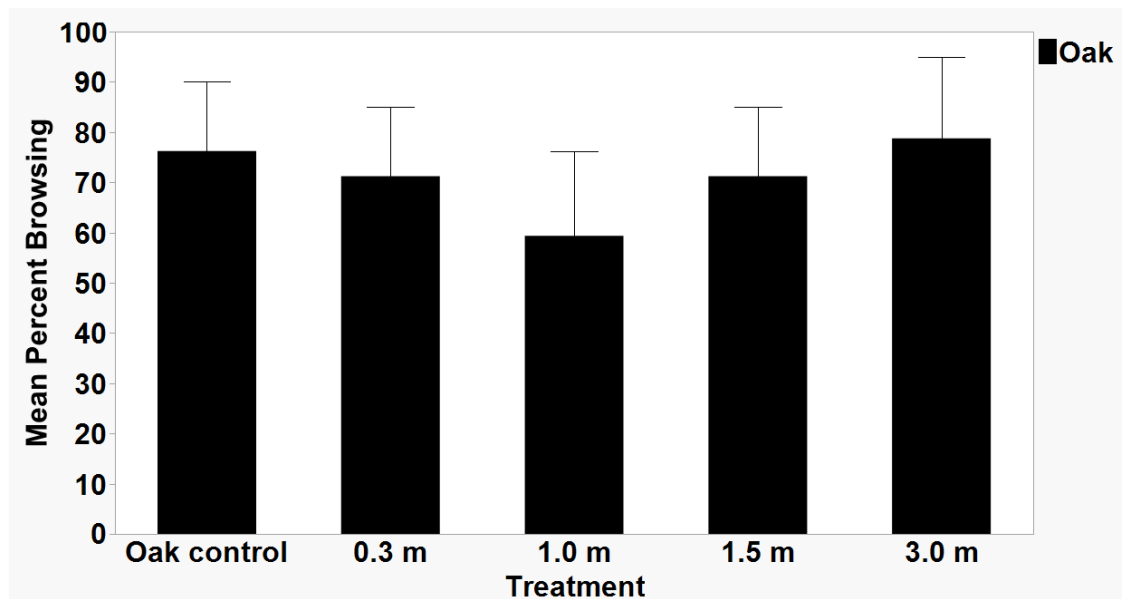


Fig. 3. 7. First year mean percent browsing by treatment for northern red oak. 1.0

m spacing treatment was significantly different from the other treatments. Error bars represent one standard error.

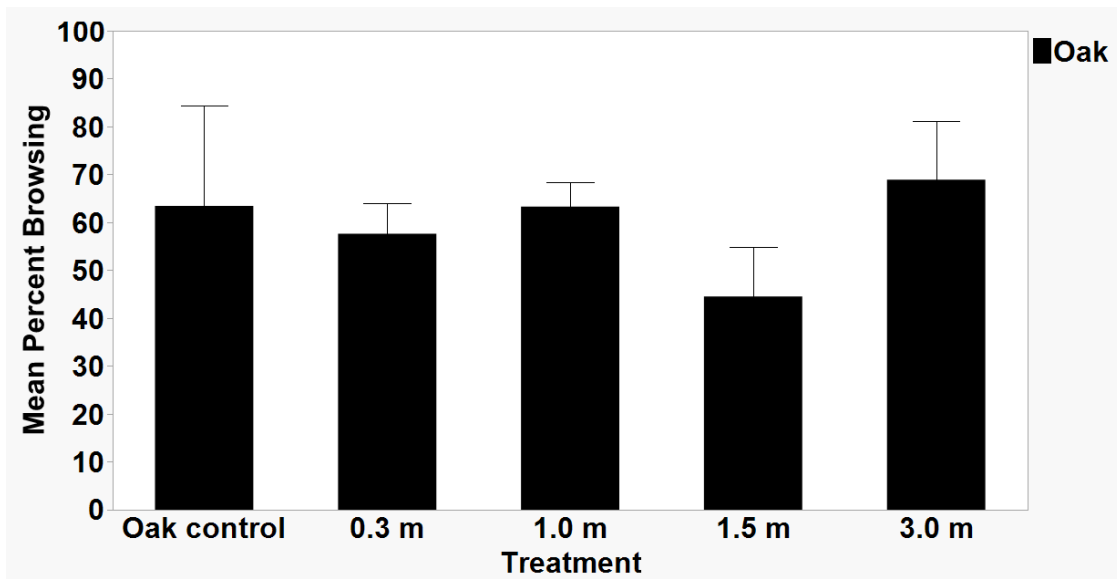


Fig. 3. 8. Second year mean percent browsing by treatment for northern red oak. Differences in means between treatments were not statistically significant. Error bars represent one standard error.

## **CHAPTER FOUR**

### **DISCUSSION AND CONCLUSIONS**

Overall, the results of this study do not support the three hypotheses that mixing northern red oak and shortleaf pine seedlings in various multi-cropped planting arrangements would (1) produce a positive interaction on seedling height and root-collar diameter; (2) reduce seedling mortality; and (3) deter browsing from deer. Spacing arrangements did not have any significant impact on the results of plot level means of seedling height and root-collar diameter or percent seedling mortality. As found in an earlier study by Granger et al. (2021), the lack of any significant differences suggests that the multi-cropping treatments did not have any negative impacts on growth and mortality. The negative mean height growth in northern red oak seedlings shown in Figure 3.5 can be attributed to measurement error or dieback due to deer browsing or the seedlings adjusting to the characteristics of different microsites. Even though the differences in mean percent mortality were not found to be statistically significant across treatments, the greatest percent increase in mean percent mortality between the first and second-year measurements for both oak (48.0%) and pine (157.0%) occurred in the 1.5 m spacing treatments. It is difficult to postulate what variable(s) interactions produced this effect as confounding factors can often be a challenge to detect. It could be the result of microsite interactions, seedlings being planted at such a spacing that neither of the species could become established or perhaps, despite its lack of statistical significance, this could be a spacing arrangement that was detrimental to both shortleaf pine and northern red oak. Future research could be conducted to explore this result.

It should be noted that perhaps some of the hypothesized influences that were the focus of this study have yet to manifest. At the time of planting, the oak seedlings were substantially taller and larger than the pine seedlings. Observations from subsequent site visits since these data were collected indicate that positive relationships, such as pine seedlings protecting oak seedlings from deer browsing and frost damage on an individual seedling basis, are beginning to appear now that the pine seedlings have grown to equal or slightly greater heights next to the oak seedlings. Since it is early in this multi-year study, more evidence may appear regarding the presence of synergistic influences. If this type of study were to be implemented in future research, it may be beneficial to plant pine seedlings first and allow them to grow for at least two years before planting the oak seedlings. However, it should be cautioned that in doing so, oak seedlings could be put at a greater risk of being overtopped, thus influencing height, root-collar diameter and growth data in different, unanticipated ways. Additionally, perhaps facilitation is in fact occurring but very difficult to measure such as less susceptibility to disease, or greater stability against wind, or unanticipated competition control. Facilitation can change on both spatial and

temporal scales and positive effects can counterbalance the negative effects thus resulting in a perceived net zero.

The only statistical significance found between treatments was observed in year 1, in which the percentage of seedlings browsed in the 1.0 m spacing treatment was significantly lower (59.0%) than in the other treatments (71.3% - 78.8%). This treatment contained the highest number of northern red oak seedlings planted in close proximity to each other, eighty (80), compared to forty (40) in the oak control, the 0.3 m spacing, the 1.5 m, and 3.0 m spacing treatments. This result appears to be contrary to research that indicates deer prefer to browse on new growth that occurs after the spring flush in recently clearcut areas (Campbell et al., 2006; Ford et al., 1994). The 1.0 m spacing treatment not only contained a higher number of northern red oak seedlings, which is a preferred forage species, but it also showed positive height growth in comparison to all other treatments, as illustrated in Figure 3.5. However, with the more compact spacing arrangements, deer movement intra-plot could have been deterred, thus resulting in less browse. Ruzicka et al. (2010) found that low density stands that contain desirable forage species may be more attractive to deer, allowing for better mobility and visual detection of predators.

Local deer population estimates were not measured in this research. Therefore, further investigation to more fully explore the influence of deer population dynamics as it relates to multi-cropping systems needs to be conducted. This research could include taking a GPS point at each seedling that displayed evidence of deer browse and mapping the points in order to determine patterns. These patterns could inform managers as to how to use various spacing arrangements to maximize seedling protection from deer browse. Furthermore, more detailed individual seedling data such as distance from a pine tree to an oak tree that has been browsed could illuminate possible relationships not considered when analyzing plot level data.

In nearly every analysis, blocks significantly impacted the results of the study. In all but one of those results (oak height growth), block 1 was statistically different from the other blocks. Block 1 was located directly adjacent to an established wildlife food plot that had been planted in corn. Bonner and Fulbright (1999) found that deer graze on plants in food plot perimeters as they spend diurnal hours in dense shrub areas bedding down before entering food plots for nocturnal feeding. Block 1 contained a significant amount of autumn olive, which provided quality cover and protection for the deer to wait until nightfall before safely entering the food plot. Local deer density can be highly influential in predicting tree seedling abundance and can pose a considerable challenge to seedling survival (Parker et al., 2020; Russell et al., 2017). Each block in this study measured 30.4 X 115.8 meter (0.3 hectare) in size and were located adjacent to an open area. Block 1 was adjacent to a wildlife food plot and blocks 2 and 3 were adjacent to clearcuts that were harvested concurrently with the block establishment. Additionally, the blocks were surrounded by mature forests. Given the small size of each block juxtaposed to the mature forests, it can be

speculated that this study artificially and unintentionally created its own “edge effect”. In researching deer browsing behavior in Vermont, Williamson and Hirth (1985) found that deer will travel to centers of clearcuts for desirable forage, as much as 100 m, if the energy and risk expended to obtain the forage is worth the decision. Otherwise, deer will browse more along the edges of the clearcuts given there is desirable forage present. In this research project in eastern Tennessee, the study design provided both options: smaller clearcuts with desirable forage in the interior and along the edges of clearcuts. This could explain the high percentage of browse throughout all plots. According to Tennessee Wildlife Resources Agency managers, the average amount of deer browse measured in this study appears to be higher than in other deer browse observations in the area (personal communication, Jordan Nanny). Incorporating deer population and behavior into multi-cropping reforestation plans could be prudent for forest managers to increase seedling survivability and growth in regions where high deer pressure is known to be an issue.

Multi-cropping plantings that mimic more naturally occurring mixed forests could be more appealing to today’s forest landowners. A growing trend of parcelization in the eastern United States has resulted in a change of forest landowner demographics, objectives, and economies of scale regarding forest management. According to Willis et al. (2019), changing biological, social and economic conditions, particularly in the southeastern United States, are making traditional single species plantations more difficult to maintain. The authors go on to suggest that even-aged mixed species plantings may provide a compromise between maintaining forest productivity, minimizing management complexity, and maximizing forest resilience. Despite forestland trending towards growing on smaller parcels and landowner objectives shifting from industrial production to multiple ecosystem services, actively managed forests continue to play a crucial role in the conversation of ecological sustainability, climate resiliency, and demand for forest products.

The argument between providing fast growing, economically harvestable fiber (i.e. greater amount of product for less input of energy) and creating long term stand resiliency through mixed plantings has a rich history. There is a long-held misconception that industrial forests must only contain those species that are desirable for products and are the only way to maximize rate of return. Mixed plantings or polycultures have an equally long-standing place in history, yet have been generally misunderstood or underrepresented in this discussion.

It appears that evidence, education and demonstration may be the limiting factor (Nichols et al., 2006) to forest managers adopting mixed species management as a way to both provide fiber for consumption and intentionally manage for long term resiliency. True, it is difficult to research the intricacies such as soil nutrient interactions, synergistic tree health promotion, and pest deterrence at a large scale. However, in the face of changing climate, increased pressure from non-native pests and diseases and the demand for more sustainable systems, the need for this research has never been greater.

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## **VITA**

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