Effects of Shortleaf Pine Seedling Stock (Bareroot vs Containerized) On Growth and Survival in The Absence and Presence of Fire

By

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ABSTRACT

The survival and growth of containerized and bareroot shortleaf pine seedlings were compared in this study at 3 and 4 years of age (2 years and 3 years in the ground respectively). The following questions were the focus of this study:

1. Which stock type has higher survival in the absence of fire?
2. Which stock type has higher survival in the presence of fire?
3. Which stock type has greater ground-line diameter in the absence of fire?
4. Which stock type has greater ground-line diameter in the presence of fire?
5. Which stock type has greater height in the absence of fire?
6. Which stock type has greater height in the presence of fire?
7. Which stock type has the greater volume in the absence of fire?
8. Which stock type has the greater volume in the presence of fire?
9. Which stock type has the greater growth in ground-line diameter between the time of planting and the burn?
10. Which stock type has the greater growth in height between the time of planting and the burn?
11. Which stock type has the greater growth in volume between the time of planting and the burn?

From this study, containerized had the higher survival at 93% in the absence of fire. The bareroot seedlings had a survival of 87% in the absence of fire. When fire was introduced to the site, the bareroot seedlings had the higher survival at 70%. The containerized seedlings had a survival rate of 61% after the end of the first growing season following the prescribed burn. The average ground level diameter (GLD) for containerized was 11.3 mm and 14.5 mm for bareroot before the burn. The p-value was <0.00001. The average GLD after the burn was 5.1 mm for containerized and 6.1 mm for bareroot. The p-value was 0.000257. The average height before the burn was 62.1 cm for containerized and 73.5 cm for bareroot. The p-value was <0.00001. The average height after the burn was 42.0 cm for containerized and 46.6 cm for bareroot. The p-value was 0.000407. The average volume before the burn was 107.7 cm^3 for containerized and 205.2 cm^3 for bareroot. The p-value was 0.000798. The average volume after the burn was 17.1 cm^3 for containerized and 40.0 cm^3 for bareroot. The p-value was 0.008943. Before the burn, containerized seedlings had a

higher survival, likely due to the lack of root disturbance at time of planting. The bareroot seedlings had a greater average GLD, height, and volume. After the burn, the bareroot seedlings had the higher survival and average GLD, height, and volume. The higher survival of bareroot seedlings after the burn is likely explained by their larger diameters, heights, and biomass volume.

BIOGRAPHY

Dominic Chirico was born on August 19, 1991 in Norfolk, Virginia and raised in Suffolk, Virginia. He graduated summa cum laude with an Associate of Arts and Science in Science from Paul D. Camp Community College in May 2012. In August 2012, he moved to Starkville, Mississippi to pursue a Bachelor of Science in Wildlife, Fisheries, and Aquaculture with a concentration in conservation law enforcement from Mississippi State University. After graduating cum laude in May 2015 he served two terms in Virginia Service and Conservation Corps (AmeriCorps), volunteering with Virginia State Parks. Between terms, he volunteered to assist in the reintroduction of Red-cockaded Woodpeckers in the Great Dismal Swamp National Wildlife Refuge. Shortly after ending his second term in summer 2017, he matriculated into graduate school at North Carolina State University, pursuing a Master of Forestry degree.

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1. Purpose

The purpose of the study is to measure the growth and survival of shortleaf pine seedling stock, comparing bareroot and containerized seedlings. Additionally, the survival and growth of the seedlings will be measured after the presence of fire. The study will aid in the decision making of which seedling stock will likely perform better on sites affected by fire. I hypothesize that there will be no significant difference in the growth and survival between the two stock types following a burn.

2. Introduction

Shortleaf pine (*Pinus echinata* Mill.) covers a broad range across the southeastern United States and has the largest range of the southern pines (Carey, 1992). It grows naturally in 22 states from New York southward to Florida and westward into Missouri and Texas. Shortleaf pine has many uses; it is one of the species used for cavity nesting by the endangered red-cockaded woodpecker. It is a shade intolerant species commonly found growing with oaks (Kabrick et al., 2015). They grow on a variety of soil types and can grow in regions with average temperatures ranging between 50° F and 70° F ("*Pinus echinata* Mill. Range and Habitat", n.d.). It is a fire adapted species but cannot flourish on sites with frequent fires or fires of high intensity.

Shortleaf pine has developed many characteristics which allow it to survive fire events. The bark is relatively thick, and the trees develop dormant buds at the base and along the trunk which allow for resprouting after a damaging fire or other damaging events. If damaged, young trees about 30 years of age or less are capable of resprouting (Carey, 1992). They have needles that are typically 7 to 11 cm in length with 2 or 3 needles in each fascicle, persisting for 2-5 years (*Pinus echinata* Mill. Leaves and Buds", n.d). The bark can be reddish, yellow-brown, or dark brown in color with furrowed scaly plates ("*Pinus echinata* Mill. Bark", n.d.). On occasion, resin pores can be found on the plates. Many of the seedlings of shortleaf pine have a characteristic basal crook, which is an adaptation to fire. A study was conducted to study the growth rates and survival rates of shortleaf pine seedlings in Missouri (Gwaze et al., 2006). The study focused on comparing growth and survival of bareroot and containerized seedlings. According to Gwaze et al., the survival was greater among the containerized seedlings, but the bareroot seedlings exhibited greater growth compared with containerized (2006). In addition to its ecological benefits, shortleaf pine is economically important as well.

According to Lilly et al. (2011), shortleaf pine is one of the most important pine timber species, particularly within the southeastern US. Shortleaf pine produces high wood quality and is of higher quality than loblolly pine, resulting in top grade lumber given its straightness, smaller branches, and slow growth ("Silvics of Shortleaf Pine", 2016). Shortleaf has many commercial uses including lumber, pulpwood (including the taproot), plywood, and ornamental vegetation ("*Pinus echinata* Mill. shortleaf pine", n.d.). Shortleaf has a longer rotation than loblolly due to its slower growth rate. Additionally, shortleaf is less prone to damage from ice storms than the other commercially important southern pine species and is more resistant to fusiform rust (Self, 2014).

Following decades of fire suppression, land use change, and a preference for planted loblolly pine has resulted in a decrease in shortleaf pine populations (Bradley et al., 2016) and continues to decline (Stewart et al., 2015). The southern pine beetle (*Dendroctonus frontalis*) is another factor that has contributed to the decline of shortleaf pine (Elliott et al., 2012). Fire is an important component of shortleaf pine ecosystems and has a fire interval ranging between 2 and 20 years (Lilly et al., 2012). The absence of fire and the increase in planted loblolly pine have led to an introgression resulting from the hybridization of shortleaf pine and loblolly pine (Bradley et al., 2016). Bradley et al. (2016) found that shortleaf pine seedlings are able to resprout and persist following a fire while loblolly and shortleaf x loblolly hybrids had little to no resprouting. Returning frequent fire to the landscape can be beneficial when restoring and managing shortleaf pine ecosystems by ensuring that shortleaf pine seedlings persist while loblolly pine, hybrid pine, and other seedlings will likely be killed by fire (Stewart et al. 2015).

3. Methods

3.1 Site History

The site where the study was conducted is 16.6 hectares located within Durham County, NC. The study site is set in UF_26 at the Umstead Research Farm, which was converted from agriculture land to planted loblolly pine in 1963 (Olanin, 2017). The site was later commercially thinned in 2007 and ultimately clear-cut in 2013 (Olanin, 2017). In 2014, the site was treated with herbicide at 56.8 liters per acre (Olanin, 2017).

3.2 Site Description

The location of the study site is situated within North Carolina's piedmont region. The soil type (Fig. 2) on the site is Mecklenburg loam (MuB), 2 to 6 percent slopes ("Web Soil Survey", n.d.). The Mecklenburg series consists of well-drained and deep soils with slow runoff and drainage ("MECKLENBURG SERIES", 2006). These soils result from weathered crystalline rocks on upland sites ("MECKLENBURG SERIES", 2006). The land uses on this soil are typically agriculture land and forested with various tree species including, but not limited to, loblolly pine, shortleaf pine, and Virginia pine ("MECKLENBURG SERIES", 2006).

3.3 Seedling Information

The seedlings planted on the site were one-year old at the time of planting in March 2016 and originated from western NC seed sources (Olanin, 2017). The seedlings were germinated at Claridge Nursery, NC Forest Service in Goldsboro, NC (Olanin, 2017). The containerized seedling plugs were 3.81 cm in width and 11.43 cm in length, and the bareroot seedlings had gel placed on the roots in preparation for packaging (Olanin, 2017).

3.4 Experimental Design

One-year-old shortleaf pine seedlings were planted in March 2016 within an area of 0.186 hectares (Olanin, 2017). The first row of pine seedlings was planted with 10 bareroot and then 11 containerized. The next row was planted with 10 containerized and then 11 bareroot in that order. The rows ranged between 20 and 21 seedlings per row. This alternating planting technique was continued until a total of 856 seedlings were planted within a grid of 1.52 x 1.52 meters (Olanin, 2017). The site is composed of 41 rows that run from north to south. Each seedling was tagged with a unique number for identification purposes. Pin flagging of two different colors was placed next to each planted seedling for easier identification of stocking type and to serve as a place holder for the numbered tags.

3.5 Measurements

Measurements began for the seedlings on December 22, 2017 and continued until January 5, 2018. Measurements of the seedlings began after the first freeze to end the growing season occurred. The diameter of each seedling was measured in millimeters using a micrometer. The height of each seedling was measured in centimeters using a meter stick and measuring tape. The basal diameter measurements were measured at ground level or just above the basal crook on seedlings where present. The condition of each seedling was recorded as either dead or alive. Naturally regenerated loblolly pines (*Pinus taeda* L.) were removed from the stand via machete.

Fire was introduced to the site by a controlled burn, via a backing fire, was completed by the NC Forest Service on May 2, 2018. Jennifer Roach of NCFS's District 11 office was responsible for the burn. Beginning on May 25, 2018, the seedlings were tallied as either dead or alive. Of the dead seedlings, they were determined as either dead before (D) or top-killed (K) after the burn. The live seedlings were recorded in the survival survey to be either burned or not burned. Live seedlings were determined by the presence of green foliage from the previous year. Seedlings were determined to be dead or top-killed if no green needles could be found. While surveying the seedlings on the site, it is important to note that 17 of the seedlings were mechanically damaged (Fig. 3 & 4) from machinery used to create a fire line around the site pre-burn. These seedlings were recorded as having mechanical damage and were recorded as "M". Most of these seedlings and their tags could not be located and were either scraped away with the soil and/or covered in the piles of soil formed from creating the fire line.

In January 2019, the seedlings were measured, and a survival survey was performed to tally the dead and the number of seedlings that resprouted following the burn. Live seedlings were determined by the presence of resprouting from the stem or at ground-level. Dead seedlings were determined by the absence of resprouting. The diameter of each seedling was measured in millimeters using a micrometer and the height was measured in centimeters using a meter stick. For seedlings with multiple stems, the tallest of the stems for each seedling was measured.

Variables that were calculated include: seedling mean diameter, mean height, and mean volume for each measurement year. The survival percentage in 2018 was calculated using formula (1):

Formula 1: Survival in Year 2018 (Before Burn)

$$S = \frac{N1}{N2}$$

S = survival
N_1 = living seedlings January 2018
N_2 = living seedlings March 2016

The survival in year 2019 was calculated using formula (2):
Seedlings that were mechanically damaged were excluded from this formula

Formula 2: Survival in Year 2019 (After Burn)

$$S = \frac{N3}{N4}$$

S = survival
N_3 = living seedlings January 2019
N_4 = living seedlings January 2018

Volume was calculated using formula (3):

Formula 3: Volume

$$V = GLD^2 * H$$

V = Volume
GLD = ground line diameter
H = Height

4. Methods for Statistical Analysis

4.1 Quantitative Analysis

To compare the sample means of bareroot and containerized seedlings, a t-test was performed and focused on mean diameter, mean height, and mean volume. Social Science Statistics was used to calculate the p-values (Stangroom, 2019). The answers to questions 3-11 were found by calculating the sample mean of each stock type. If the resulting p-value was <0.05, the statistical analysis was considered significant.

4.2 Categorical Analysis

To answer hypotheses 1 and 2, comparing survival of shortleaf pine seedlings by stock type, a contingency table was created. A Chi-Square statistic was used to test if stock type and survival are independent. A normal approximation to binomial distribution was used to analyze the survival of the stick types. To determine if a Z-test could be performed, the normal approximation had to be considered suitable using the following variables:

N = sample size
S = stock type survival
1 – S = probability of mortality

The normal approximation was considered suitable if $N(1-S) \geq 5$ and $NS \geq 5$ (Schoening, 2012). If suitable, the Z-test would be performed to determine differences in the stock types.

5. Results

The average ground line diameter (GLD), height, and volume are outlined in Table 1 for both seedling stock types.

Table 1: the table depicts the average diameter, height, and volume for seedlings by stock type both pre-burn and post-burn.

	Bareroot	Containerized
Jan. 2018 – average GLD (mm)	14.5	11.3
Jan. 2019 – average GLD (mm)	6.1	5.1
Jan. 2018 – average height (cm)	73.5	62.1
Jan. 2019 – average height (cm)	46.6	42.0
Jan. 2018 – average volume (cm^3)	205.2	107.7
Jan. 2019 – average volume (cm^3)	40.0	17.1

Hypothesis 1.1: Ho: Survival before fire is independent of stock type. Ha 1.1: Survival before fire is dependent of stock type.

The survival of bareroot and containerized seedlings before the burn are depicted in Table 2. Assuming survival is independent of stock type, the expected values were calculated as shown in Table 3. The Chi-Squared value was calculated using the Chi Square calculator by Social Science Statistics (Stangroom, 2019). With 1 degree of freedom, $X^2 = 7.0295$ with a $\alpha \leq 0.001$ level of significance. Therefore, I reject the null hypothesis that survival in the absence of fire is independent of stock type and choose the alternative hypothesis that survival before fire is dependent upon stock type.

Table 2: Observed values of survival for bareroot and containerized shortleaf pine seedlings before the introduction of fire in 2018

Observed Values		Stock Type		
		Bareroot	Containerized	Total
Survival after 3 years	Live	373 48%	398 52%	100%
	Dead	54 64%	31 36%	100%
	Total	427 50%	429 50%	100%

Table 3: Expected values of survival for bareroot and containerized shortleaf pine seedlings before the introduction of fire in 2018

Expected Values		Stock Type		
		Bareroot	Containerized	Total
Survival after 3 years	Live	384.6	386.4	771
	Dead	42.4	42.6	85
	Total	427	429	856

Hypothesis 1.2: Ho: Sbr = Sco, there is no difference in survival between the two stock types in the absence of fire. Ha: Sbr ≠ Sco, there is a difference in survival between the two stock types in the absence of fire.

The sample size (N) was 427 for bareroot and 430 for containerized. Bareroot had a survival rate of 87% and containerized had a survival rate of 93%. N(1-S) was calculated to be 54 for bareroot and 32 for containerized seedlings. Since N and N(1-S) are both ≥ 5 (Table 4), the Z-test can be performed. The Z-score and p-value were calculated using a Z-score and p-value calculator (Stangroom, 2019). With a calculated p-value of 0.01108, it is significant at $p < 0.05$. Containerized seedlings have a significantly higher survival than bareroot before the introduction of fire.

Table 4: Survival and calculated p-value of the shortleaf pine seedlings by stock type

	Bareroot	Containerized	
N	427	430	
# survived (μ)	373	398	
Survival rate (S)	0.87	0.93	
Z score			-2.5354
P value			0.01108
N(1-S)	54	32	

Hypothesis 2.1: Ho: Survival after a fire is independent of stock type. Ha: Survival after a fire is dependent of stock type.

The survival of the seedlings after the burn are depicted in Table 5. Assuming that survival is independent of stock type, the expected values are depicted in Table 6. The X^2 value was calculated using a Chi Square calculator by Social Science Statistics (Stangroom, 2019). With 1 degree of freedom, $X^2 = 6.2226$ with a $0.05 > \alpha > 0.01$ level of significance. Therefore, I reject the null hypothesis that survival after a fire is independent of stock type and choose the alternative hypothesis that survival is dependent upon stock type.

Table 5: Observed values of survival for bareroot and containerized shortleaf pine seedlings after the introduction of fire (2019)

Observed Values		Stock Type		
		Bareroot	Containerized	Total
Survival after 3 years	Live	254 52%	237 48%	100%
	Dead	111 42%	152 58%	100%
	Total	365 48%	389 52%	100%

Table 6: Expected values of survival for bareroot and containerized shortleaf pine seedlings after the introduction of fire (2019)

Expected Values		Stock Type		
		Bareroot	Containerized	Total
Survival after 3 years	Live	237.7	253.3	491
	Dead	127.3	135.7	263
	Total	365	389	754

Hypothesis 2.2: Ho: Sbr = Sco, there is no difference in survival between the two stock types after the introduction of fire. Ha: Sbr ≠ Sco, there is a difference in survival between the two stock types after the introduction of fire.

The sample size (N) of bareroot seedlings was 365 and containerized was 389. Bareroot had a survival rate of 70% and containerized had a survival rate of 61%. N and N(1-S) were both greater than 5 (Table 7), therefore, a Z-test could be performed. The Z-score and p-value were calculated using Social Science Statistics (Stangroom, 2019). With a calculated p-value of 0.01278, it is significant at $p < 0.05$. After fire, the bareroot seedlings had a significantly higher survival than containerized.

Table 7: Survival and p-value by stock type after the introduction of fire

	Bareroot	Containerized	
N	365	389	
# survived (u)	254	237	
Survival rate (S)	0.70	0.61	
Z score			2.4945
P value			0.01278
N(1-S)	111	152	

Hypothesis 3: Ho: There is no difference in ground line diameter between bareroot and containerized seedlings in the absence of fire. Ha: There is a difference in ground line diameter in the absence of fire between bareroot and containerized seedlings.

The average ground line diameter for bareroot shortleaf pine seedlings was estimated at 14.5 mm in the absence of fire when measured in January 2018. The average diameter of containerized seedlings was estimated at 11.3 mm. From Table 8, 25% of the bareroot seedlings were at or less than 10.9 mm in GLD and 75% of the bareroot seedlings were at or less than 17.7 mm in GLD. Containerized had 25% of its seedlings at or less than 8.5 mm at GLD and 75% of its seedlings at or less than 13.9 mm in GLD. The resulting p-value from the t-test was calculated at <0.00001, which is significant at $p < 0.05$. Bareroot seedlings resulted in a greater average GLD than containerized at 3 years of age in the absence of fire.

Table 8: Average ground line diameter of containerized and bareroot seedlings. Diameter values are in millimeters (mm).

Column	N	Mean	Variance	Std. dev.	Std. err.	Median	Q1	Q3	IQR
GLD - CO	399	11.3	16.797	4.098	0.205	10.8	8.5	13.9	5.4
GLD - BR	373	14.5	24.412	4.941	0.256	14.1	10.9	17.7	6.8

Hypothesis Test and 95% CI results

Difference	Sample Diff.	Std. err.	DF	T-stat	P-value	L. Limit	U. Limit
μ1 - μ2	3.186	0.173	770	-9.775	<0.00001	2.847	3.525

Hypothesis 4: Ho: There is no difference in ground line diameter between bareroot and containerized seedlings after the introduction of fire. Ha: There is a difference in ground line diameter between bareroot and containerized seedlings after the introduction of fire.

The average ground line diameter of bareroot seedlings was 6.1 mm and the average for containerized was 5.1 mm after introducing fire to the site. From Table 9, 25% of bareroot seedlings were at or less than 4.2 mm in diameter and 75% were at or less than 7.1 mm in diameter. For containerized, 25% of the seedlings were at or less than 3.5 mm in diameter and 75% were at or less than 6.7 mm in diameter. There was a difference in means of 1.03. The p-value was calculated at 0.000257, which is significant at $p < 0.05$. Bareroot seedlings had a greater average diameter after the prescribed burn than containerized.

Table 9: Average ground line diameter of containerized and bareroot seedlings after fire. Diameter values are in millimeters (mm).

Column	N	Mean	Variance	Std. dev.	Std. err.	Median	Q1	Q3	IQR
GLD - CO	237	5.1	5.41	2.33	0.15	4.6	3.5	6.7	3.2
GLD - BR	254	6.1	15.57	3.95	0.25	5.4	4.2	7.1	2.9

Hypothesis Test and 95% CI results

Difference	Sample Diff.	Std. err.	DF	T-stat	P-value	L. Limit	U. Limit
µ1 - µ2	1.03	0.15	489	-3.497	0.000257	0.74	1.32

Hypothesis 5: Ho: There is no difference in height between bareroot and containerized seedlings in the absence of fire. Ha: There is a difference in height between bareroot and containerized seedlings in the absence of fire.

The average height of containerized seedlings was 62.1 cm and 73.5 cm for bareroot. From Table 10, 25% of containerized seedlings were at or less than 49.8 cm and 75% were at or less than 74.4 cm in height. For bareroot, 25% of seedlings were at or less than 57.9 cm and 75% of seedlings were at or less than 89.1 cm in height. The sample difference was calculated to be 11.46. The p-value was calculated at <0.00001, which is significant at $p < 0.05$. Bareroot seedlings had a greater average height than containerized in the absence of fire.

Table 10: Average height bareroot and containerized seedlings in the absence of fire. Height values are in centimeters (cm).

Column	N	Mean	Variance	Std. dev.	Std. err.	Median	Q1	Q3	IQR
Height - CO	399	62.1	336.09	18.33	0.92	61.7	49.8	74.4	24.7
Height - BR	373	73.5	480.66	21.92	1.14	72.1	57.9	89.1	31.2

Hypothesis Test and 95% CI results

Difference	Sample Diff.	Std. err.	DF	T-stat	P-value	L. Limit	U. Limit
μ1 - μ2	11.46	0.75	770	-7.900	<0.00001	10.0	12.9

Hypothesis 6: Ho: There is no difference in height between bareroot and containerized seedlings after the introduction fire. Ha: There is a difference in height between bareroot and containerized seedlings after the introduction of fire.

The average height for containerized seedlings was 42.0 cm and 46.6 cm for bareroot shortleaf pine seedlings. From Table 11, 25% of the containerized seedlings were at or less than 32.4 cm in height and 75% of the seedlings were at or less than 49.5 cm in height. For bareroot, 25% of seedlings were at or less than 36.0 cm in height and 75% of seedlings were at or less than 55.2 cm in height. The sample mean difference was calculated at 4.65. The p-value was calculated at 0.000407, which is significant at $p < 0.05$. The bareroot seedlings had a greater average height compared with containerized after the prescribed burn.

Table 11: Average height of bareroot and containerized seedlings after the introduction of fire. Height values are in centimeters (cm).

Column	N	Mean	Variance	Std. dev.	Std. err.	Median	Q1	Q3	IQR
Height - CO	237	42.0	182.91	13.52	0.88	40.2	32.4	49.5	17.1
Height - BR	254	46.6	279.89	16.73	1.05	44.2	36.0	55.2	19.2

Hypothesis Test and 95% CI results

Difference	Sample Diff.	Std. err.	DF	T-stat	P-value	L. Limit	U. Limit
μ1 - μ2	4.65	0.70	489	-3.369	0.000407	3.28	6.01

Hypothesis 7: Ho: There is no difference in volume between bareroot and containerized seedlings in the absence of fire. Ha: There is a difference in volume between bareroot and containerized seedlings in the absence of fire.

From Table 12, the average volume of containerized seedlings in the absence of fire was 107.7 cm^3 and 205.2 cm^3 for bareroot. For containerized, 25% of seedlings were at or less than 32.4 cm^3 and 75% were at or less than 143.7 cm^3 in volume. For bareroot, 25% of seedlings were at or less than 68.8 cm^3 and 75% were at or less than 277.6 cm^3 in volume. The sample difference was calculated to be 97.55 cm^3. The p-value was calculated at 0.000798, which is significant at $p < 0.05$. The bareroot seedlings had a greater average volume than containerized in the absence of fire.

Table 12: Average volume of bareroot and containerized seedlings in the absence of fire. Volume values are in cubic centimeters (cm^3).

Column	N	Mean	Variance	Std. dev.	Std. err.	Median	Q1	Q3	IQR
Volume - CO	399	107.7	11930.55	109.23	5.47	72.0	35.9	143.7	107.8
Volume - BR	373	205.2	38893.93	197.22	10.21	143.3	68.8	277.6	208.8

Hypothesis Test and 95% CI results

Difference	Sample Diff.	Std. err.	DF	T-stat	P-value	L. Limit	U. Limit
μ1 - μ2	97.55	5.95	770	3.168	0.000798	85.86	109.24

Hypothesis 8: Ho: There is no difference in volume between bareroot and containerized seedlings after the introduction of fire. Ha: There is a difference in volume between bareroot and containerized seedlings after the introduction of fire.

From Table 13, the average volume after the prescribed burn was 17.1 cm^3 for containerized and 40.0 cm^3 for bareroot. For containerized, 25% of seedlings were at or less than 4.0 cm^3 and 75% were at or less than 21.9 cm^3. For bareroot, 25% of seedlings were at or less than 6.4 cm^3 and 75% were at or less than 27.8 cm^3. The calculated sample difference was 22.90 cm^3 and the p-value was calculated at 0.008943, which is significant at $p < 0.05$. Bareroot seedlings resulted in a greater average volume than containerized after the resprouting following the prescribed burn in May 2018.

Table 13: Average volume of bareroot and containerized seedlings after the introduction of fire. Volume values are in cubic centimeters (cm^3).

Column	N	Mean	Variance	Std. dev.	Std. err.	Median	Q1	Q3	IQR
Volume - CO	237	17.1	755.85	27.49	1.79	8.5	4.0	21.9	17.9
Volume - BR	254	40.0	21302.71	145.95	9.16	12.9	6.4	27.8	21.5

Hypothesis Test and 95% CI results

Difference	Sample Diff.	Std. err.	DF	T-stat	P-value	L. Limit	U. Limit

µ1 - µ2	22.90	4.84	489	-2.376	0.008943	13.39	32.40

Hypothesis 9: Ho: There is no difference in ground line diameter growth between bareroot and containerized seedlings before the introduction of fire. Ha: There is a difference in ground line diameter growth between bareroot and containerized seedlings before the introduction of fire.

From Table 14, bareroot seedlings had an average diameter growth of 9.81 mm since the time of planting and containerized had an average diameter growth of 8.07 mm. For containerized, 25% of seedlings were at or less than 5.1 mm of growth and 75% were at or less than 10.7 mm of growth. For bareroot, 25% of seedlings were at or less than 6.3 mm of growth and 75% were at or less than 13.3 mm of growth. There was a sample difference of 1.74 mm between containerized and bareroot diameter growth with a p-value of <0.00001, which is significant at $p < 0.05$. Bareroot resulted in a greater average diameter growth compared with containerized seedlings.

Table 14: Average ground line diameter growth of bareroot and containerized seedlings from the time of planting to before the burn. Diameter values are in millimeters (mm).

Column	N	Mean	Variance	Std. dev.	Std. err.	Median	Q1	Q3	IQR
Diameter - CO	399	8.07	16.74	4.09	0.21	7.63	5.1	10.7	5.53
Diameter - BR	373	9.81	24.97	5.00	0.26	9.57	6.3	13.3	7.01

Hypothesis Test and 95% CI results

Difference	Sample Diff.	Std. err.	DF	T-stat	P-value	L. Limit	U. Limit
µ1 - µ2	1.74	0.17	770	5.314	<0.00001	-0.22	3.71

Hypothesis 10: Ho: There is no difference in height growth between bareroot and containerized seedlings before the introduction of fire. Ha: There is a difference in height growth between bareroot and containerized seedlings before the introduction of fire.

From Table 15, containerized seedlings had an average growth in height of 49.72 cm and bareroot had an average growth of 49.19 cm since planting. For containerized, 25% of seedlings were at or less than 39.0 cm of growth and 75% were at or less than 62.9 cm of growth. For bareroot, 25% of seedlings were at or less than 34.3 cm of growth and 75% were at or less than

64.2 cm of growth. There was a sample difference of 0.53 cm between containerized and bareroot seedlings with a p-value of 0.264688, which is not significant at $p < 0.05$.

Table 15: Average height growth of bareroot and containerized seedlings from the time of planting to before the burn. Height values are in centimeters (cm).

Column	N	Mean	Variance	Std. dev.	Std. err.	Median	Q1	Q3	IQR
Height - CO	391	49.72	329.63	18.16	0.92	49.91	39.0	62.9	23.9
Height - BR	364	49.19	498.03	22.32	1.17	48.85	34.3	64.2	29.9

Hypothesis Test and 95% CI results

Difference	Sample Diff.	Std. err.	DF	T-stat	P-value	L. Limit	U. Limit
μ1 - μ2	0.53	0.74	753	-0.629	0.264688	-2.49	1.43

Hypothesis 11: Ho: There is no difference in volume growth between bareroot and containerized seedlings before the introduction of fire. Ha: There is a difference in volume growth between bareroot and containerized seedlings before the introduction of fire.

From Table 16, containerized seedlings had an average growth in volume of 101.18 cm^3 and bareroot had an average volume growth of 192.16 cm^3 since the seedlings were planted. For containerized, 25% of seedlings were at or less than 40.8 cm^3 of growth and 75% were at or less than 146.7 cm^3 of growth. For bareroot, 25% of seedlings were at or less than 74.7 cm^3 of growth and 75% were at or less than 287.6 cm^3 of growth. There was a sample difference of 90.99 cm^3 with a p-value of <0.00001, which is significant at $p < 0.05$. Bareroot seedlings resulted in a greater growth in volume compared with containerized seedlings.

Table 16: Average volume growth of bareroot and containerized seedlings from the time of planting to before the burn. Volume values are in cubic centimeters (cm^3).

Column	N	Mean	Variance	Std. dev.	Std. err.	Median	Q1	Q3	IQR
Volume - CO	382	101.18	10498.40	102.46	5.24	68.4	40.8	146.7	105.9
Volume - BR	355	192.16	32665.50	180.74	9.59	144.0	74.7	287.6	212.8

Hypothesis Test and 95% CI results

Difference	Sample Diff.	Std. err.	DF	T-stat	P-value	L. Limit	U. Limit
μ1 - μ2	90.99	5.64	735	8.537	<0.00001	89.02	92.95

6. Discussion

From this study, containerized shortleaf pine seedlings have a higher survival than bareroot in the absence of fire. If fire is introduced to the landscape, this study predicts that bareroot will have a higher survival than containerized seedlings. Measurements from 2018 and 2019 show that bareroot seedlings have a greater average diameter, height, and volume compared with containerized seedlings both before and after the prescribed burn. This might explain the reason for the higher survival seen in bareroot seedlings after the presence of fire. Further research might be needed to determine if container-grown seedlings result in less-developed basal crooks. It is not known if or how many of the basal crooks were exposed above the soil surface at the time of burn. Bradley et al. (2016) conducted a study that resulted in decreased survival when the basal crooks were exposed. Also, it is important to note that broomsedge was present on the site (Figure 5) and there was hardwood regeneration towards the southern edge of the site (Figure 6). According to Carey (1992), broomsedge (*Andropogon virginicus*) have shown to inhibit the growth and survival of loblolly pine seedlings due to the possibility of allelopathic effects. These are factors to consider for future experiments to study their effects, whether absent or present, on survival and growth of containerized and bareroot shortleaf pine seedlings. When planning restoration projects for shortleaf pine, bareroot is likely the better stock type to choose if fire is introduced to a site while in the seedling stage. This is important to consider, since shortleaf pine numbers have declined by 60% since 1990 in North Carolina ("Shortleaf Pine", 2016).

7. Conclusion

In the absence of fire, containerized had the highest survival and bareroot had the greatest average ground level diameter, height, and volume. After a fire, bareroot had the highest survival and average ground level diameter, height, and volume. In the absence of fire, containerized seedlings are the better of the two for highest survival. If fire is to be included in the management, bareroot seedlings are better for the highest survival and growth of shortleaf pine. Additionally, bareroot is likely the better choice when considering the cost of seedlings.

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Figures

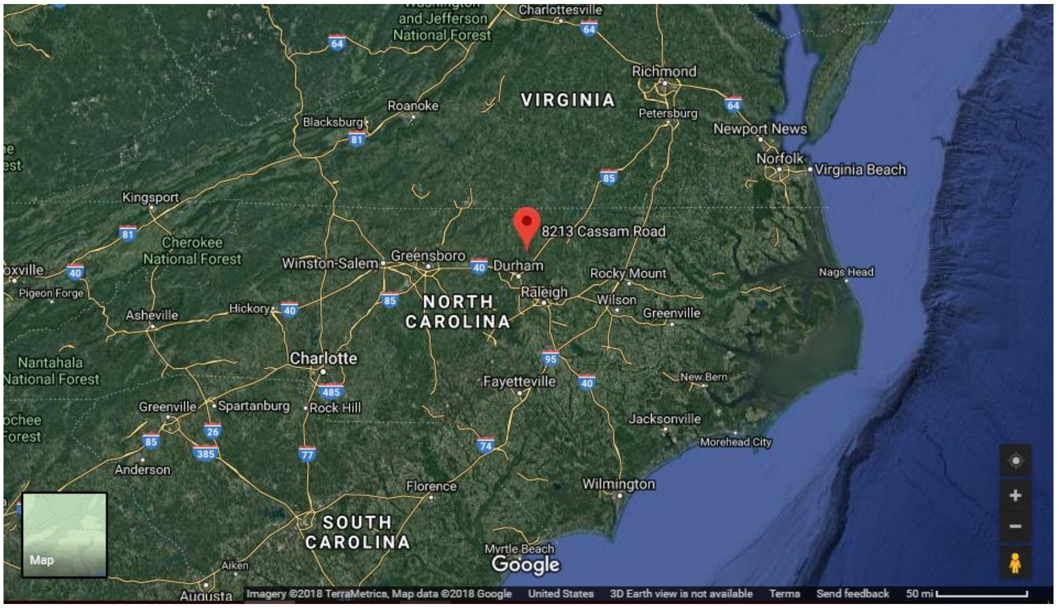

Figure 1. Location of shortleaf pine research site within Umstead Research Farm, Bahama, NC. Map Source: Google Maps

Map Unit Legend

Durham County, North Carolina (NC063)

Durham County, North Carolina (NC063)

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
MuB	Mecklenburg loam, 2 to 6 percent slopes	2.0	100.0%
Totals for Area of Interest		**2.0**	**100.0%**

Figure 2. Site soil map with legend. Mecklenburg loam, 2 to 6 percent slopes. Map source: websoilsurvey

Figure 3: Soil (Mecklenburg loam, 2 to 6% slopes) covering shortleaf pine seedlings at the corner of the research site. May 25, 2018.

Figure 4: Fire line where seedlings were mechanically scraped from the site; pink flagging in foreground indicates where a seedling was once present. January 19, 2019.

Figure 5: Broomsedge at the study site. January 19, 2019.

Figure 6: Hardwood regeneration. January 19, 2019.