IMPACT OF THINNING ON SOIL PROPERTIES AND BIOMASS IN APALACHICOLA NATIONAL FOREST, FLORIDA

Kelechi James Nwaokorie, Odemari Stephen Mbuya, Johnny McFero Grace III[1]

Abstract—The effect of a silvicultural operation, row thinning at two intensities (single row, SR, and double row, DR, thinning), on soil properties and biomass were investigated in selected 28 year-old slash pine (*Pinus elliotti*) plantations in the Apalachicola National Forest. Stands were thinned in May 2011 and burn regimes were executed during dormant seasons. Indicators of changes in soil physical properties and biomass were evaluated in this work. Response variables included soil bulk density, stand basal area, and biomass. Stand basal area was consistently highest across locations in the control treatments ranging from 21 to 31 m^2 ha^{-1}. In two locations, SR treatment had the greatest DBH and DGL values and was significantly different ($p > 0.05$) in location 2. The average soil bulk density at two depths, 0 and 15 cm were 1.51 g cm^{-3}, 1.49 g cm^{-3}, and 1.44 g cm^{-3}, and 1.62 g cm^{-3}, 1.64 g cm^{-3}, and 1.62 g cm^{-3} for the SR, DR and control treatments, respectively with no significant treatment effects observed. Varying results in understory biomass was detected with as much as 30 percent and 24 percent reduction for SR and DR respectively at location 2 while there was a 3 percent and 15 percent increase for SR and DR respectively at location 1. Aboveground biomass had significant reduction ($p > 0.05$) due to treatment effects with a range of 12 percent to 36 percent for SR and 42 percent to 51 percent for DR across locations.

INTRODUCTION

Southern forests have an increased timber productivity in recent years that is attributed to increased utilization of intensive management (Grace and others 2006), but broad concern has been expressed related to the potential productivity decline and long term adverse impacts in intensively managed forests (Eisenbies 2006, Haywood and Tiarks 1990, Miwa and others 2004, Powers and others 2010). Intensive forest management practices include site preparation, thinning, harvesting, and fertilization with the majority of these management practices performed by heavy machinery (Grace and others 2006). Previous studies have shown that intensive management operations can cause a myriad of effects ranging from alteration of soil physical properties and lowering of site productivity (Eisenbies 2006, Gent and others 1984, Powers and others 2004), increase in the risk of erosion (Carter and others 2006), change in the rate of transpiration and water table dynamics (Bliss and Comerford 2002; Skaggs and others, 2008), and change in soil moisture (Gent and others 1984; Grace and others 2006; Kozlowski, 1999).

The present management plan for the Apalachicola National Forest (ANF) is the regeneration of long-leaf (*Pinus palustris*) pine as the forest's dominant species as was in pre European settlement times and in the early 1950's (US Forest Service Management Plan 1999). Thinning and prescribed burning are two management techniques used by the US Forest Service in actualizing the pre-specified management goal for ANF (US Forest Service Management Plan 1999). Thinning, a silvicultural practice that selectively removes poorly performing trees and leaves a healthy vigorous stand, increases growth of residual trees, develops structural characteristics needed for wildlife habitats, and generally produces healthy, vigorous forests with less risk of insect infestation, destructive fire, and wind damage (Bradford and Palik 2009, Demers and others 2013, Harrington 2001). Whereas, prescribed burning is the deliberate application of fire to forest fuels to achieve site preparation, reduction of woody understory competition, and restoration, or maintenance of fire-dependent ecosystems (Carter and Foster 2004, Fernandes and Botelho 2003).

The objective of this study is to quantify the impact of two levels of thinning (single row (SR) and double row (DR) thinning) in conjunction with prescribed burning on soil bulk density in forest watersheds in the panhandle region of Florida, specifically, the Apalachicola National Forest (ANF). Additionally, the study also investigates the combined influence of these two silvicultural treatments (i.e. thinning with prescribed burning) on

[1]Kelechi James Nwaokorie, Graduate Research Assistant, Florida A & M University-Center for Water & Air Quality, Tallahassee, Florida, 32307; Odemari Stephen Mbuya, Professor, Agronomy/ Soils and Water Science; J. McFero Grace III, General Engineer, USDA-Forest Service, Southern Research Station, Center for Forest Watershed Research, SRS-4353, Tallahassee, Florida. 32307.

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stand characteristics, and, aboveground and understory biomass.

MATERIALS AND METHODS

Study Site

The study area was located in compartment 246 in the Northeastern portion of the Apalachicola National Forest approximately 30° 18' latitude and 84° 27' longitude in Leon County, FL (fig. 1). The site is poorly drained and has a shallow water table with a depth to water table between 0 to 46 cm. Soils are primarily Leon hydric sands and the vegetation in the study area predominantly consists of a 28 year-old slash pine (*Pinus elliotti*) plantation with small cleared patches planted with longleaf pines (*Pinus palustris*) in 2012.

Experimental Design

The experimental design superimposed on this study was a split-plot design with locations as the main plots and management practices as the sub-plots. Three experimental locations were randomly selected to give an unbiased representation of the forest stand properties and watershed characteristics of compartment 246. Nine '7.3 m radius' sub-plots within each location were randomly created using a Microsoft® Excel© program listing directions and bearings from a physical landmark. The random program was designed so that treated plots and corresponding control plots within a location had similar soil types so as to limit the influence of soil variability on treatment effects.

The subplots consisted of two treatments namely; double row thinning with prescribed fire (DR), single row thinning with prescribed fire (SR) and, a no thinning with prescribed fire (C). The DR treatment consisted of thinning two rows for every two rows of pine trees, whereas SR treatment consisted of thinning one row for every two rows, and C treatment had no thinning. All treatments had controlled burning during the dormant season of 2014. A split-plot design was chosen for this study because the treatments and locations had already been implemented according to existing Forest Service management plans for that compartment. Locations

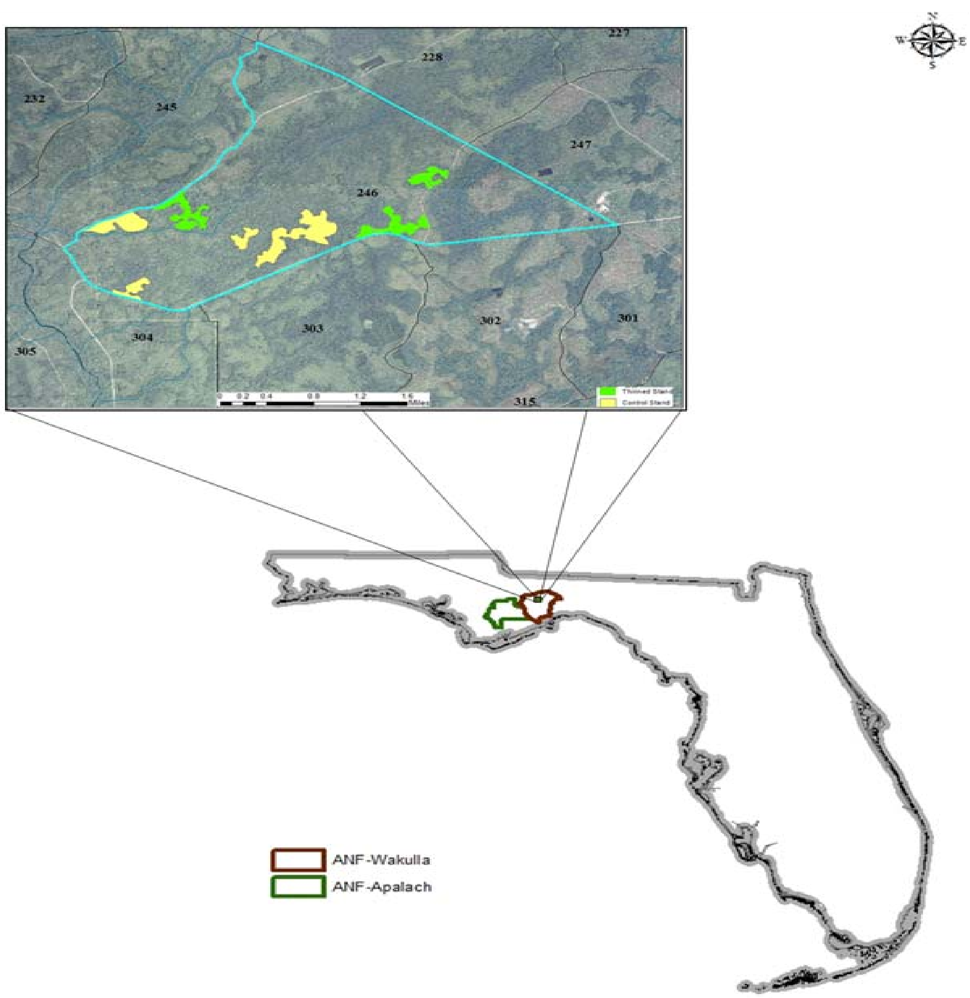

Figure 1—Location of the study area in compartment 246 of the Wakulla District of the ANF within the panhandle region of Florida. Thinned stands are indicated in green and control stands are indicated in yellow.

1 and 3 consisted of nine '7.3 m radius' sub-plots whereas location 2 had six sub-plots with a randomly located "1 m radius" destructive sampling plot within each sub-plot. The disparity in plot number in location 2 was due to the fact that only two management practices had been implemented on that location and this difference would serve as another means of comparing the different treatments. Plot boundaries were surveyed and measured with a compass and logger's tape, and corners or plot centers were marked with flags.

Bulk Density

Soil cores were collected using an AMS 1000 core sampler (5.2 cm diameter by 6 cm length) during two extensive field expeditions in July to September and November to December, 2014. Three core samples were randomly collected from each sub-plot at two depths (0 - 15, and 15 – 30 cm). Collected cores were trimmed in the field, sealed in plastic bags, labelled, and transported to the lab for subsequent bulk density determination. A total of 108 soil cores were collected from the twenty-four sub-plots to describe baseline and post - treatment soil conditions.

Biomass

Overstory biomass (consisting of all standing pine trees) and understory biomass (all living understory biomass) were quantified in all twenty-four sub-plots. Variables used to estimate overstory biomass included: Diameter at Ground Level (DGL), Diameter at Breast Height (DBH), Total Height (TH) and Total Height to first Living Branch (THLB) of the slash pine plantation. The data were used to calculate stand basal area, and, estimate the biomass of slash pine trees within each plot using allometric equations. Understory biomass was quantified in each of the randomly located "1 m radius" destructive sampling plots within each sub-plot. All living understory biomass was severed in the destructive sampling plots, weighed in the field, and ground into a homogenous mixture of all biomass components. Subsequently, a representative sub-sample of the mixture was collected, labelled, and transported to the lab for further nutrient analysis in a separate future study.

Data Analysis

The general model for each treatment response variable was:

$$Y_{ijk} = \mu\ldots + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma k(i) + \varepsilon_{ijk}$$

where: Y_{ijk} is the dependent variable; μ is a constant; α_i is the treatment effects; β_j is the sub-plot effects; $(\alpha\beta)_{ij}$ is the treatment-subplot interaction; $\gamma k(i)$ is the treatment errors; ε_{ijk} is treatment errors.

Response variables in the investigation; bulk density, total biomass, and stand basal area, were tested by the ANOVA. The null hypothesis is that thinning treatment will have no effect on response variables. Tukey multiple range tests, alpha = 0.05, were used to separate means where ANOVA detected significant differences.

RESULTS AND DISCUSSION

Stand Characteristics

The slash pine density in locations 1, 2 and 3 were 2,518, 1,666, and 2,360 trees ha $^{-1}$, respectively. The average tree density for SR, DR and C treatments, respectively were 720, 654 and, 1018 trees ha $^{-1}$. The estimated aboveground biomass for the plantation pine was 97, 74, and 123 tonnes ha $^{-1}$ for the SR, DR, and C conditions, respectively. The estimated biomass contained in the understory vegetation was 2.7, 3.3, and 3.3 tonnes ha $^{-1}$ for the SR, DR, and C treatments, respectively. The similarity in the distribution of the various locations' slash pine trees shows that although the locations and sub-plots were randomly located, the sites gave a fairly unbiased accurate representation of compartment 246 (fig. 2).

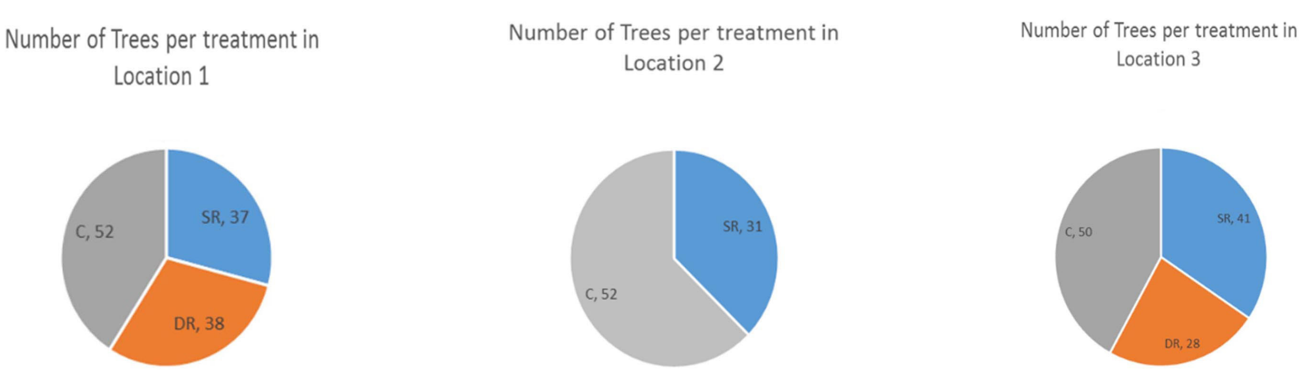

Figure 2—Pie-chart showing distribution of trees amongst the treatments in each location (SR – Single Row thinning; DR – Double Row thinning; C – Control).

Stand Basal Area, Diameter at Breast Height and Diameter at Ground Level

Average stand basal area (SBA) was calculated from measurements of all slash pine trees in each of the three locations using the standard equation;

Basal area = (pi / (4 * 144)) × $(DBH)^2$

* where pi = 3.14, DBH = diameter breast height (Barlow and Elledge 2012).

The range of average SBA ranged from 12 to 31 m^2 ha^{-1} with location 1 having the largest average SBA (table 1). The control had the greatest stand basal area followed by the single row and the double row thinning in that order. Although statistically significant differences were only observed in location 1, the other locations had evident differences in SBA with the double row treatment always having the lowest. This can be explained by the fact that more trees were removed in the DR treatment (two rows) as compared to the SR treatment (one row). The level of differences in similar treatments among locations could probably be attributed to intrinsic location characteristics and variations.

DBH at 1.4 m was measured for all plantation slash pine within inventory plots at each location. With the exception of location 1, DR had the lowest average DBH amongst the treatments while SR always had the greatest DBH ranging from 17.4 to 18.7 cm. Significant differences ($p > 0.05$) were observed between SR and C with SR having an average DBH of 18.7 cm compared to C having an average of 15.2 cm in location 2. SR, DR, and C, respectively, had an average DBH of 17.5, 16.7. and 18.6 cm in location 1, and 17.4, 15.6 and 16.6 cm in location 3. Presumably, SR having the greatest DBH with the exception of location 1 was a result attributed to it having the closest stand basal area to the intended management basal area of 16 m^2 ha^{-1} coupled with the fact that diameter growth is significantly affected by stand density (Bradford and Palik, 2009; US Forest Service Management Plan, 1999). It can also be as a result of reduced disturbance in the form of compaction, or less competition in the SR plots in comparison to the DR plots which had more mechanical disturbances per similar unit area.

An identical trend was also observed in the DGL data. SR had the greatest average DGL in location 1 and 2 but was slightly lower than DR in location three. Similar to the case in the DBH data significant differences between the two treatments, SR and C were detected in location 2.

Bulk Density

Soil bulk densities (Db) in the 0 - 15 cm averaged 1.48 g cm^{-3}, 1.48 g cm^{-3}, and 1.49 g cm^{-3} for the SR, DR, and C treatments, respectively in location 1 (table 2). Whereas in location 3, Db increased from 1. 39 g cm^{-3} for C to 1.49 g cm^{-3} for DR and 1.54 g cm^{-3} for SR. At the 15 – 30 cm depth, Db averages were 1.63 g cm^{-3}, 1.66 g cm^{-3} and 1.64 g cm^{-3} for the SR, DR, and C treatments, respectively in location 1. Db averages at that same depth were 1.60 g cm^{-3}, 1.61 g cm^{-3}, and 1.59 g cm^{-3} respectively for the SR, DR, and C treatments in location 3.

There were no statistical significant differences in Db ($p > 0.05$) among the treatments in the different locations at both depths but at the 0 – 15 cm depth in location 3, SR>DR>C. A plausible explanation for the observation of no treatment effects on Db may be ascribed to the inherent soil properties of the sites, primarily consisting of sandy soils, which has the property of being less compactable than other soil types (Gent and others 1984). Additionally, considering thinning was implemented in 2011 the detection of no treatment effects may be as a result of natural rejuvenation of the soils from specific site activities such as increase in organic matter from thinning residues, root growth, micro-organism activities and environmental conditions (Da-Lun and others 2010, Powers and others, 2004).

Table 1—Calculated stand basal area (m^2 ha^{-1}), average diameter at breast height (cm), and average diameter at ground level (cm) across treatments per location

	SBA (m^2 ha^{-1})			DBH (cm)			DGL (cm)		
	SR	DR	C	SR	DR	C	SR	DR	C
Location 1	20a	18a	31b	17.5a	16.7a	18.6a	22.8a	20.9a	22.8a
Location 2	18a		21a	18.7b		15.2a	24.8b		19.8a
Location 3	21a	12a	24a	17.4a	15.6a	16.6a	21.6a	21.7a	21.5a

*[Means in same row followed by different letters are significantly different at $P < 0.05$, using Tukey's]

Understory Biomass

Understory biomass ranged from 2.1 to 3.7 tonnes ha^{-1} varying on the treatment and location (table 3). The control treatment had the most biomass with 3 tonnes ha^{-1} and 3.7 tonnes ha^{-1} in location 2 and 3, respectively. While in location 1, the control had the least biomass with 3.2 tonnes ha^{-1} whereas DR had the greatest with 3.7 tonnes ha^{-1}. This goes contrary to the expectation of thinning opening up treated stands to more effective burn regimes (Carter and Foster 2004) generally resulting in unthinned (control) forest stands having the most understory biomass. Probably, this deviation can likely be attributed to a less severe or intense burn regime in location 1, environmental conditions during burn schedule or native site characteristics (e.g. high water table, ephemeral ponds).

Aboveground Biomass Estimation

An allometric equation from Gonzalez-Benecke and others (2014) was used to estimate standing whole tree biomass (including trunk, stems, barks, limbs and foliage) for each plot in this study. The equation in its simplified form is:

$[T = b_1 . (DBH^{b2}). (AGE^{b3})]$

* where T = total above stump biomass; DBH = diameter at breast height; AGE = age of tree; b1, b2, and b3 = empirical coefficients dependent on tree species and geographical location.

The biomass estimates (table 4) show that control as hypothesized always had the most aboveground biomass. DR always had the lowest biomass estimates with as much as a 42 percent and 51 percent decrease in biomass compared to the control treatments in location 1 and location 3. Significant treatment effects were observed in location 1 although noticeable differences were also observed in locations 2 and 3. In location 3, there was a huge difference in the biomass estimates between SR and DR treatments which may be due to two sites in the DR treatments having relatively smaller number of trees, 6 and 9, compared to the average number of 13 trees per DR plot.

Table 2—Average soil bulk density (Db) at 0 cm and 15 cm for the three treatments at the different locations

	Db at 0cm (g cm^{-3})			Db at 15cm (g cm^{-3})		
	SR	DR	C	SR	DR	C
Location 1	1.48a	1.49a	1.49a	1.63a	1.66a	1.64a
Location 3	1.54a	1.49a	1.39a	1.60a	1.61a	1.59a

*[Means in same row followed by different letters are significantly different at $P < 0.05$, using Tukey's]

Table 3—Understory biomass (i.e. all living herbaceous plants) for SR and DR treatments showing percentage change with respect to the control

	Understory biomass (tonnes ha^{-1}) (% change w.r.t Control)		
	SR	DR	C
Location 1	3.3a (3%)	3.7a (15%)	3.2a
Location 2	2.1a (-30%)		3a
Location 3	2.6a (-30%)	2.8a (-24%)	3.7a

*[Means in same row followed by different letters are significantly different at $P < 0.05$, using Tukey's]

Table 4—Aboveground biomass estimates for SR and DR treatments showing percentage change with respect to the control in all locations

Aboveground biomass (tonnes ha^{-1}) (% change w.r.t Control)			
	SR	DR	C
Location 1	98.5a (-36%)	89.3a (15%)	154.4b
Location 2	87.9a (-9%)		96.8a
Location 3	104.3a (-12%)	58.2a (-51%)	118.9a

*[Means in same row followed by different letters are significantly different at P < 0.05, using Tukey's]

CONCLUSION

The effect of thinning combined with prescribed burning was investigated on stand characteristics, soil bulk density, and biomass. Management practices resulted in decrease in SBA and stand density in the SR and DR treatments with significant differences (p > 0.05) in location 1. No significant differences were detected in soil bulk density across the treatment. This observation may be attributed to the sandy nature of the soils in majority of the sites. The opening of forest stands due to thinning and the application of prescribed burns resulted in an effective understory control with the no thinning (control) treatment always having the greatest understory biomass except in location 1. The unthinned treatment, C, had the most aboveground biomass with SR and DR having significant reduction (p > 0.05) as much as 36 percent and 51percent reduction, respectively.

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