IMPACTS OF SILVICULTURAL TREATMENTS ON HARDWOOD DEVELOPMENT AND TOTAL STAND PRODUCTIVITY IN LOBLOLLY PINE (*Pinus taeda*) PLANTATIONS IN THE UPPER COASTAL PLAIN AND PIEDMONT

by

M. RYAN MAYO

(Under direction of Michael Kane)

ABSTRACT

I examined the impacts of six site preparation and post-planting silvicultural regimes on hardwood species composition, growth and total productivity index (pine plus hardwood biomass) at 19 locations through plantation age 21. Age 21 hardwood basal area was greatest in the Burn Only treatment plots (42.6 ft^2/acre), followed by the Herbicide and Burn treatment (11.0 ft^2/acre), Chop and Burn (9.3 ft^2/acre), Chop, Herbicide, and Burn (8.8 ft^2/acre), and Shear, Pile, and Disk (8.1 ft^2/acre). Over all treatments, the most common genera present at age 21 was *Liquidambar* (50.0 % of hardwood basal area, BA), followed by *Quercus* (27.0 %), *Carya* (5.0 %), *Prunus* (4.6 %), and *Nyssa* (2.9 %). I classified sites into four hardwood abundance classes (Very Low, Low, Moderate, and High). Total productivity index (pine plus hardwood biomass) was greatest on sites classified as Low hardwood abundance for each treatment excluding Burn Only. Stands with greater pine to hardwood ratios tended to contain more total aboveground biomass than stands that contained more hardwoods.

INDEX WORDS: Competition, hardwood development, hardwood species composition, loblolly pine, site preparation, stand productivity

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INTRODUCTION

Loblolly pine (*Pinus taeda*) is the most widely planted pine in the southeastern United States (Wear and Greis 2002). On many sites where loblolly pine is planted or that was formerly forested, hardwood competitors will be present and if not controlled, can constitute a significant and highly-competitive portion of the stand. The abundance of hardwood competition depends on site characteristics including preexisting hardwoods, the seed bank, neighboring communities, soil type, climate conditions, as well as silvicultural treatments. With traditionally strong markets and economics for southern pine stumpage, the emphasis of land managers and researchers has been on enhancing pine productivity. A key aspect to the enhancement of pine production is successfully controlling competition. The more complete understanding of significant competition effects on pine productivity (Bacon and Zedaker 1987, Creighton et al. 1987, Fredericksen et al. 1991, Jokela et al. 2000, Lauer and Glover 1998, Miller et al. 2003a, Shiver and Martin 2002, Shiver and Shackleford 1996) has prompted the use of various vegetation management regimes in pine plantations.

Understanding hardwood and pine responses to silvicultural practices is important to describe plantation attributes and total production. In current markets, hardwoods may provide economic value because of evolving hardwood pulpwood markets and developing energy/biomass markets as well as ecological value as a component of overall biodiversity. Because the pulp industry requires both the long fibers present in softwoods such as pines as well as the short fibers present in hardwoods, any standing timber of merchantable size regardless of species has some pulpwood stumpage value in most wood basins (Baker 1995). Similarly, energy wood/biomass is beginning to transform valueless residuals of harvesting into a more highly valued commodity. Some coal-operated energy production facilities are beginning to lower their dependence on fossil fuels through the co-firing of wood products along with coal. In some specific cases, such as with Georgia Power's conversion of Plant Mitchell, facilities are converting to the burning of solely wood products (Austin 2009). Because of the growing market for energy production, the value of this formerly unused biomass material is expected to increase. Lastly, overall species diversity has become a point of emphasis in pine plantations. Single-species dominated stands may reduce habitat features for various species of wildlife (Wear and Greis 2002). Understanding total productivity and potential yield can provide managers with the tools and information to manage pine plantations in ways that can more fully meet their land management goals.

The objective of this research project was to determine how differing site preparation practices and post-planting competition control affect hardwood development and total stand net productivity index of loblolly pine (*Pinus taeda*) plantations in the Upper Coastal Plain and Piedmont.

LITERATURE REVIEW

The southeastern United States is comprised of diverse and productive natural forest communities. Much of this area was once dominated by natural pine stands that experienced frequent fires of natural or Native American origin (Wear and Greis 2002). Following land clearing for cotton farming and subsequent land abandonment in the early 1900's, loblolly pine (*Pinus taeda*) successfully pioneered these "old-field" areas. Natural succession generally exhibited a pattern of initially pine forests, followed by mixed forests, and ending with mature hardwood forests. Currently, these natural stands that developed following agriculture are composed of mixed pine and hardwood, and if they are left unmanaged they likely will convert into pure hardwood stands. Successional change to hardwoods was favored by the suppression of wildfire during much of the 20^{th} century. Naturally occurring fires favored the more resistant pines and helped produce many pristine pine forests reported by early explorers and settlers. We see the results today of fire suppression as longer-lived more shade tolerant hardwoods generally replace pines in mixed stands over time (Wear and Greis 2002, Allen et al. 2005).

The area of interest for this study is the Upper Coastal Plain and the Piedmont of Georgia and Alabama. The climate is temperate with warm to hot summers and cool winters that include freezing temperatures. Dominant tree components of the area on well-drained upland sites include pine (*Pinus* spp.), oak (*Quercus* spp.), hickory (*Carya* spp.), and sweetgum (*Liquidambar styraciflua*) (Wear and Greis 2002). The soils have a long history of use by humans, are generally highly weathered and well-aerated. There is little available information for looking at long-term changes in soil characteristics over the past 200 years although we are able to see some short-term changes based on forest management practices. These include the effects on soil bulk density and organic matter of practices such as burning, site preparation, and harvesting. Extensive usage of heavy machinery during site preparation and harvesting leads to varying levels of soil compaction and can alter soil bulk density. Although current forestry methods attempt to limit machine passes on forested lands, earlier common practices utilized multiple passes during site preparation and harvest. These multiple pass regimes coupled with prescribed fire also led to decreased levels of organic matter, either by pushing it away from planting areas or by over-burning the areas (Trettin 2004).

Following pine plantation establishment, various types of vegetation compete with the planted pines for water, sunlight, space, and nutrients. This competing vegetation typically is controlled by various site preparation techniques before planting or by competition control methods carried out during the rotation. Miller et al. (2003b) reported that herbaceous plants reoccupied planted areas quickly after site preparation and may comprise 60% to 80% of cover in the first growing season. However, coverage by herbaceous species declined significantly between years 5-8 due to shading when pine and hardwood canopies reached 50-60% canopy closure. They also found that early woody control (age 3-5) resulted in greater cover of forbs, semi-woody plants, and grasses at age 15. Conversely, early herbaceous control treatments (age 3-5) resulted in less herbaceous cover at age 15 due to a smaller contingent of vines and small semi-woody cover. Understory regrowth of herbaceous cover occurred more on woody control sites than on woody and herbaceous control sites, although all sites with control averaged less than 40% ground cover at age 15.

Bacon and Zedaker (1987) tested the response of loblolly pine to differing levels of competition control. They examined eight competition control treatments consisting of the removal of all, two-thirds, one-third, or none of the hardwood stems before planting, each in combination with or without complete herbaceous weed control. They reported that an intensive treatment (two-thirds stem removal) coupled with herbaceous weed control resulted in the most significantly increased pine growth. Hardwood basal area and rootstocks decreased with increasing intensity of the treatment. They also reported increased hardwood basal area in the treatments receiving herbaceous weed control and plots receiving herbaceous weed control averaged about half of the herbaceous biomass compared to plots with no herbaceous weed control.

The Consortium for Accelerated Pine Production Study (CAPPS) examined the effect of complete competition control and annual fertilization on loblolly pine productivity (Borders and Bailey 2001). The CAPPS study consisted of 10 replicated sites throughout Georgia each containing control plots, annual fertilization plots, complete competition control plots, and combination annual fertilization and complete competition control plots. While complete control of competition increased pine growth, the annual fertilization treatments resulted in more sustained pine growth increases. Treatments that consisted of both competition control as well as annual fertilization more than doubled the stem biomass when compared to the control treatment in later ages. However, the fertilization treatment led to decreased wood quality through lower specific gravity in the latewood.

Previous research has generally evaluated the impact of competition control and fertilization on pine productivity rather than on total site productivity. However, South and Miller (2007) characterized potential total stand growth response patterns (pine plus hardwood) to competition control in loblolly pine plantations as Type 1, Type 2, Pseudo Type 1, Type E, and Type F. A Type 1 response does not increase the total carrying capacity (pine plus hardwood) of a stand, however it does lead to a shortened establishment phase, allowing the pine component to reach maturity earlier ("age-shift"). Herbaceous weed control on an old field pine plantation typifies a treatment producing a Type 1 growth response. A Type 2 growth response shows an increased maximum carrying capacity (pine plus hardwood) as well as a shortened establishment phase. In this case, pine growth response exceeds hardwood growth loss due to treatment. A Pseudo Type 1 response is characterized by an increase in pine growth but no change in the total amount of pine plus hardwood growth or carrying capacity ("species shift"). A Type E response shows a negative pine growth response throughout its rotation and decrease in maximum carrying capacity. Lastly, a Type F response shows no change in maximum carrying capacity coupled with negative pine response after establishment but positive pine volume gain at harvest. South and Miller (2007) tested the hypothesis that hardwood control always resulted in a Type 2 pine growth response and reported that out of the 14 installation trials tested over a 20 year period, nine installations exhibited a true Type 2 response, four were classified as a Pseudo Type 1 response, and one installation trial contained some installation blocks that represented a Type E response while others represented a Type F response. They concluded that although approximately two-thirds of the sites showed a Type 2 response, other response types should be expected. Because most growth and yield models assume a Type 2 response from hardwood control, they would likely overestimate pine response on Pseudo Type 1 response sites by as much as double the actual growth gains.

Generally, site preparation is used to clear the site prior to planting to allow access for planting and to give the planted trees an advantage over any competition. Shiver and Martin (2002) evaluated the effects of six site preparation and post planting competition control regimes (Burn Only; Chop and Burn; Chop, Herbicide, and Burn; Shear, Pile, and Disk; Herbicide and Burn; and Herbicide, Burn, and Complete Vegetation Control) on harvested sites in the Upper

Coastal Plain and Piedmont. Through age 12, they reported greater loblolly pine yield as site preparation intensity increased, and chemical treatments resulted in greater yields than mechanical treatments. Subsequent results for the planted loblolly pine growth through age 21 showed that the Herbicide, Burn, and Complete Vegetation Control treatment significantly increased loblolly pine mean diameter at breast height (dbh), height, basal area, and volume (Zhao et al. 2009). Pine productivity was consistently lowest on the Burn Only treatments followed by the Chop and Burn treatment. The Herbicide, Burn, and Complete Vegetation Control treatment showed the largest mean annual volume increment, followed in descending order by Shear, Pile, and Disk, Herbicide and Burn, Chop, Herbicide, and Burn, Chop and Burn, and lastly, Burn Only. Results through age 21 showed that a chop or herbicide treatment, when added to the Burn Only treatment, significantly increased loblolly pine yield. Complete control of all competition led to significant increases in loblolly pine production. Although the more intensive mechanical and chemical regimes tended to have higher yields, they also tend to be more expensive (Shiver and Martin 2002). Chemical site preparation treatments are typically less expensive than intensive mechanical site preparation treatments (Pehl 1983).

The influences of different cultural treatments on one and two year old loblolly pine in the Piedmont of North Carolina were reported by Haines and Davey (1979). They reported that pine growth in treatments that included the application of herbicide far exceeded the growth for treatments not including herbicides. In addition, treatments including mowing resulted in more total pine biomass than treatments including disking.

A Piedmont site preparation study also shows that diameter distribution and basal area of pine and hardwood varied among treatments (Harrington and Edwards 1997). The treatments tested were: (1) clearcut only (residual, nonmerchantable stems left), (2) manual cutting (residual stems greater than one dbh were manually felled), (3) shear-chop, (4) shear-chop-hexazinone, (5) shear-root rake-burn-disk, and (6) shear-root rake-burn-disk-fertilize-sulfometuron. In this study, site preparation reduced mean hardwood basal area by 36% when compared to plots that were simply clearcut and replanted. Planted pine basal area 12 years after site preparation was 2.7 times that without site preparation. Manual cutting resulted in greater volunteer pine abundance when compared to mechanical treatments. The mechanical treatments favored the growth of the planted pines and slowed the development of the volunteer pines and hardwoods. The presence of hexazinone in site preparation reduced the volunteer pine basal area by half but did not affect planted pine or hardwood basal area. It did however result in a 62% reduction of hardwood stem density when compared to treatments without hexazinone application.

In eastern Texas, Pehl (1983) evaluated the five-year loblolly pine growth response to treatments including clear-fell, burn, chop, and shear/pile. The shear/pile treatment tended to have larger loblolly pine trees at age five but differences among treatments in dbh, height, and biomass were not significant. Potential adverse effects, including soil compaction and surface organic matter removal, thought to be associated with mechanical site preparation treatments tested were not apparent, as soil bulk density and pine growth did not vary significantly among treatments.

Effects of the site preparation treatments chop versus shear, pile, and disk on planted loblolly pine and other vegetation were examined on a cutover site in the Piedmont of North Carolina under the direction of the Forest Nutrition Cooperative. The chop treatment led to plant communities dominated by hardwoods while the shear, pile, and disk site preparation led to a more even distribution of trees, shrubs, forbs and grasses (Fredericksen et al. 1991). Subsequent research on the same study found that there was an initial reduction in species diversity associated with the more intensive management regime and that the rate of secondary succession was altered depending on the intensity of the treatment regime (Jeffries 2002). Jeffries also reported that there were little differences present in species composition after canopy closure between treatments with varying site preparation intensity. Although the stands go through succession at different rates and by different processes, they arrive at their later-successional stages without altering cover species composition and diversity.

OBJECTIVES

The overall objective of this research was to quantify impacts of site preparation treatments and subsequent competition control regimes for loblolly pine plantations in the Piedmont and Upper Coast Plain on development of the hardwood component and on total stand biomass production through age 21.

Specific objectives of this study were to:

- Determine the most common hardwood genera present in loblolly pine plantations in the Upper Coastal Plain and Piedmont of the southeastern United States and the abundance of genera based on treatment
- Quantify effects of site preparation treatments and post-planting regimes on hardwood development in loblolly pine plantations in the Upper Coastal Plain and Piedmont of the southeastern United States.
- Determine the effect of site preparation intensity and post-planting competition control regimes on hardwood productivity index, pine productivity, and total stand productivity index.

Specific hypotheses tested:

- *Liquidambar*, *Quercus*, *Carya*, and *Liriodendron* will be the most common hardwood genera in loblolly pine plantations in the Upper Coastal Plain and Piedmont of the southeastern United States. The variety of genera will decrease as management intensity increases.

- Increasing intensity of site preparation will result in reduced hardwood trees per acre, basal area, weights, and productivity index.
- Total stand biomass (hardwood plus pine) will be greater in pine-dominated stands than in stands containing a greater hardwood component.

METHODS

Site Description and Study Design

I obtained data from regional field trials conducted as part of the Plantation Management Research Cooperative's (PMRC) Upper Coastal Plain/Piedmont Site Preparation Study. This study evaluated plantation loblolly pine growth differences among five treatments representing a range of site preparation intensities and a sixth treatment that included complete competition control following planting. The six treatments tested were (1) Burn, (2) Chop and Burn, (3) Shear, Pile, and Disk, (4) Chop, Herbicide, and Burn, (5) Herbicide and Burn, and (6) Herbicide, Burn, and Complete Vegetation Control. The Burn treatment consisted solely of a broadcast burn in August while the Chop and Burn treatment added a single pass with a drum roller chopper in June before the burn in August. The Shear, Pile, and Disk treatment began with a single pass of a KG blade followed by debris piling and flat-harrowing in June. The Chop, Herbicide, and Burn treatment consisted of a single pass with a drum roller chopper in June, broadcast application of 3% RoundUp (glyphosate) in August and a broadcast burn one month after herbicide application. The Herbicide and Burn treatment consisted of the application of 20 pounds each of Tordon (picloram) and Pronone (hexazinone) in April and a broadcast burn in August. Lastly, the Herbicide, Burn, and Complete Vegetation Control treatment added annual direct herbicide spot spraying to the Herbicide and Burn treatment to result in a competition free environment for the planted pine throughout the rotation.

The sites were established at 25 locations throughout the Upper Coastal Plain and the Piedmont of Alabama and Georgia on stands that were harvested during 1984. Site factors such as soil type, slope, and past land management within each location were relatively uniform. On each site, seven 0.5 acre plots were installed and treatments were randomly assigned. At each installation, one treatment was randomly assigned to two plots to provide replication. Treatments were applied during 1985 and the plots were planted during the 1985-1986 dormant season. Plots were double planted by hand using 1-0 bareroot, mixed bulk lot, first-generation improved stock seedlings at an 8 ft x 10 ft spacing (545 trees per acre). The planted seedlings were spaced at intervals of two feet and, if both seedlings survived the first growing season, one was randomly selected and removed. Measurements were conducted on a 0.2 acre interior measurement plot that contained nine stratified, 4-ft radius circular competition subplots.

All plots and subplots were assessed every three years until age 21 with pine plot assessments beginning at age six and competition subplot assessments beginning at age three. Planted pine tree number, diameter at breast height, crown class, and heights of a subsample were recorded for trees in the main plot. Height to live crown of the planted pine was also recorded beginning at age 15. All plants in the subplots were classified into as herbaceous plants, non-arborescent woody plants, and arborescent woody plants. Species, diameter at breast height, total height, height to the live crown, and the crown width were recorded for each arborescent woody plant.

All plots were fertilized with 200 pounds per acre of nitrogen and 25 pounds per acre of phosphorus (385 pounds urea per acre and 125 pounds diammonium phosphate per acre) prior to the 14th growing season. Because of insect damage or errant thinning, only 19 of the original 25 planted installations remained active after the 21st growing season. Only the 19 installations active at age 21 were used for the present analyses.

Stand Attribute Calculation

Hardwood attributes were evaluated at three year intervals from age 3 to age 21 and included species composition, basal area per acre, trees per acre, crown volume index per acre, total tree (stem plus branch) dry weight per acre and total stem merchantable (6 inch dbh to 3 inch top) dry weight per acre. The proportion of basal area of non-planted arborescent plants at age 21 was sorted by genera and reported by individual treatment and over all treatments. Crown volume index was calculated as the area of a cylinder, utilizing the crown length and crown width measurements. Hardwood weights were calculated according to Clark et al. (1986). Separate weight equations were used for "hard" hardwoods and "soft" hardwoods and in some cases, for specific genera (see Appendix 1). Once the basal area, crown volume index, and weights of each tree were calculated, totals for each subplot were calculated. These subplot totals were averaged for a given plot and age to determine an overall plot mean by age and were converted to per acre estimates. Because residual hardwoods were not initially measured at the time of pine planting, the age 3 weights were subtracted from each of the subsequent age assessments to estimate net hardwood productivity indices.

I classified hardwood abundance on the plots based on the age 21 hardwood basal area in the Burn Only plots. Only 16 of the 19 measured installations were used for these classifications because 3 of the installations had no recorded hardwoods at age 21. The hardwood abundance classes were Very Low (4 installations with mean hardwood basal area ranging from 0 to 5 square feet per acre), Low (5 installations with mean hardwood basal area ranging from 5 to 15 square feet per acre), Moderate (5 installations with mean hardwood basal area ranging from 15 to 30 square feet per acre), and High (2 installations with mean hardwood basal area greater than 30 square feet per acre).

Pine attributes were evaluated at ages 15, 18, and 21. Pine dry weight per acre and total stem merchantable (minimum 6 inch dbh to a 3 inch top diameter) dry weight per acre were calculated. Individual tree stem weights without bark were calculated according to Borders et al. (2004). Individual tree bark weights were determined by estimating bark volume from equations for tree volume with and without bark (Borders et al. 2004) and applying a bark specific gravity of 0.303 (Phillips and Schroeder 1972) to the estimated bark volume. Branch wood and bark dry weight was estimated according to Baldwin et al. (1997). As live crown length was only measured at ages 15, 18, and 21 years and estimates of branch wood and bark dry weight required live crown length measurements, pine weight attributes were only calculated for ages 15, 18 and 21 years.

Total hardwood dry weight (stem, branches, and bark) was summed with the total pine dry weight (stems, branches, and bark) to obtain total stand dry weight per acre for ages 15, 18, and 21 years. Similarly, hardwood merchantable dry weight and pine merchantable dry weight were added by plot and age combination to determine total stand merchantable dry weight for ages 15, 18, and 21 years.

Hypothesis Testing

The mixed model approach in Statistical Analysis Systems (SAS) was used to perform analyses of variance (ANOVA's) tests to detect treatment effects (Littell et al. 1996) on hardwood basal area, trees per acre, crown volume indices, hardwood total and merchantable weights, pine total and merchantable weights, and total stand (pine plus hardwood) total and merchantable standing weight and net productivity indices. The location and the location x treatment interaction were treated as random factors in the analyses. The fixed effects were treatments. The degrees of freedom method utilized was the containment method. P-value results for treatment effects from analyses of variance are provided in Appendix 2. The means separation test used was Fisher's Least Significant Difference (LSD). A significance level of alpha = 0.05 was used.

RESULTS

Non-Planted Arborescent Vegetation

Non-Planted Arborescent Species Composition

Across treatments at age 21, *Liquidambar* constituted nearly 50% of the volunteer basal area, followed by *Quercus* (27%), *Carya* (5%), *Prunus* (5%), *and Nyssa* (3%) (Figure 1). *Liquidambar* also made up nearly half of the total number of volunteer stems counted. Because of the very low frequency of naturally regenerated pine (<3%), the non-planted arborescent component will collectively be referred to as hardwood.

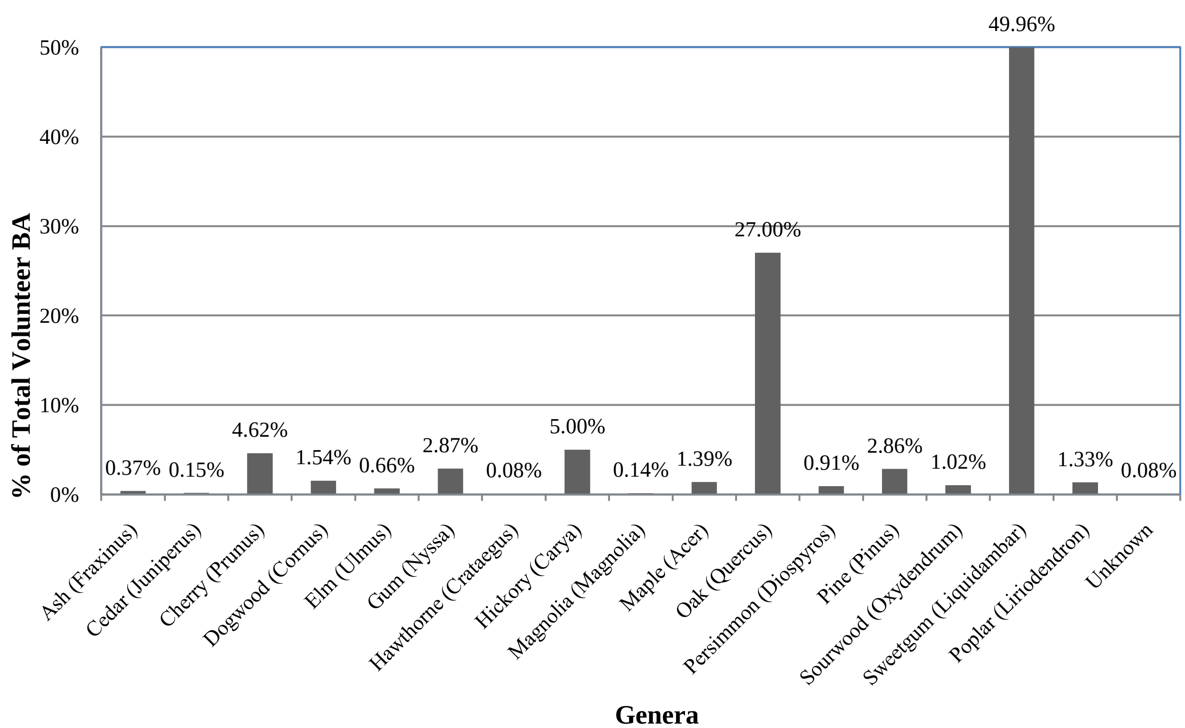

Figure 1. Percentage of total non-planted arborescent basal area by genera at plantation age 21 across all treatments on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

At age 21, *Liquidambar* and *Quercus* were the predominant genera with respect to basal area on all treatments with the exception of the Herbicide and Burn treatment where *Quercus* ranked sixth (Table 1). All non-planted vegetation was controlled on the treatment with complete vegetation control. The most commonly occurring genus for the Burn Only treatment was *Quercus* while the most common genus for all other treatments was *Liquidambar*. Of the genera recorded, only *Acer, Liquidambar, Nyssa, Prunus,* and *Quercus* were present in plots of each treatment at age 21. Naturally seeded *Pinus* spp. occurred on the Burn Only treatment and to a smaller extent on the Chop and Burn treatment. The Herbicide and Burn treatment had the greatest number of genera at age 21 (12 genera), followed by Burn Only (11 genera), Chop, Herbicide, and Burn (9 genera), Shear, Pile, and Disk (9 genera), and Chop and Burn (7 genera).

Table 1. Mean genera specific abundance by percent of non-planted arborescent basal area by treatment at plantation age 21 on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

	Treatment				
Genera	Burn Only	Chop & Burn	KG, Disk, & Rake	Chop, Burn, & Herb	Herb & Burn
Ash *(Fraxinus)*					2.2%
Cedar *(Juniperus)*				1.1%	
Cherry *(Prunus)*	1.9%	13.8%	4.7%	2.6%	5.0%
Dogwood *(Cornus)*	2.5%		0.9%		2.3%
Elm *(Ulmus)*			0.8%	3.2%	0.8%
Gum *(Nyssa)*	0.9%	7.4%	1.4%	1.9%	5.9%
Hawthorne *(Crataegus)*			0.6%		
Hickory *(Carya)*	11.5%	0.4%			0.9%
Magnolia *(Magnolia)*	0.3%				
Maple *(Acer)*	0.4%	3.5%	0.6%	1.1%	2.8%
Oak *(Quercus)*	47.6%	15.6%	16.0%	16.0%	3.4%
Persimmon *(Diospyros)*	0.3%		0.5%	1.1%	3.4%
Pine *(Pinus)*	6.7%	0.5%			
Sourwood *(Oxydendrum)*	0.9%			4.8%	
Sweetgum *(Liquidambar)*	27.0%	58.8%	74.4%	68.3%	65.0%
Poplar *(Liriodendron)*					7.9%
Unknown					0.5%

Standing Hardwood Attributes

Hardwood basal area was greater on the Burn Only treatments throughout the assessment period (Table 2, Figure 2). Hardwood basal area generally increased with time. The hardwood basal area on the Burn Only treatment was significantly greater than the basal area observed on the other treatments for each of the ages evaluated.

Throughout most of the assessment period, the Burn Only treatment had significantly more hardwood trees per acre than the other treatments (Figure 3). Through age 18, the number of hardwood trees per acre on the Burn Only treatment remained significantly greater than on the remaining treatments. Although only significantly different from the Burn Only treatment, the Chop and Burn treatment consistently had the second greatest number of hardwood trees per acre at each age assessed.

Crown volume index per acre was significantly greater in the Burn Only treatment when compared to the other treatments except at age 3 (Figure 4). Among the remaining treatments, the Chop and Burn treatment tended to have the highest mean crown volume index per acre.

Table 2. Mean hardwood basal area, trees per acre, and crown volume index by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.[1]

	Age 3			Age 6			Age 9			Age 12			Age 15			Age 18			Age 21		
Treatment[2]	**Hardwood Basal Area (square feet per acre)**																				
	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
B	20.23	a	5.62	29.69	a	6.00	38.71	a	6.90	40.38	a	7.80	48.01	a	7.70	52.74	a	9.29	56.16	a	9.15
CB	0.49	b	5.45	1.61	b	5.82	5.14	b	6.69	8.43	b	7.56	10.48	b	7.45	10.11	b	8.98	15.61	b	8.83
SPD	0.06	b	5.16	0.61	b	5.50	2.62	b	6.33	5.63	b	7.15	7.53	b	7.05	10.19	b	8.51	13.37	b	8.35
CHB	0.20	b	5.45	1.09	b	5.82	3.58	b	6.69	7.31	b	7.55	7.48	b	7.44	11.87	b	8.97	13.64	b	8.81
HB	0.43	b	5.16	1.68	b	5.50	5.55	b	6.33	10.06	b	7.15	10.86	b	7.04	13.58	b	8.50	15.80	b	8.34
	Hardwood Trees Per Acre																				
	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
B	355	a	67	319	a	48	433	a	69	493	a	82	512	a	76	475	a	78	487	a	78
CB	125	b	66	91	b	47	226	b	66	279	b	79	327	b	72	289	b	73	361	a	73
SPD	31	b	63	31	b	44	109	b	63	171	b	75	206	b	69	241	b	70	284	a	69
CHB	78	b	66	64	b	47	128	b	66	179	b	78	183	b	72	220	b	72	266	a	72
HB	109	b	63	71	b	44	193	b	63	260	b	75	260	b	68	280	b	69	306	a	69
	Hardwood Crown Volume (thousands of cubic feet per acre)																				
	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
B	15.5	a	5.2	82.6	a	11.8	111.1	a	14.9	121.8	a	21.1	141.6	a	19.3	161.2	a	27.6	159.3	a	23.5
CB	0.9	a	5.0	11.7	b	11.5	35.0	b	14.4	50.1	b	20.4	68.6	b	18.2	77.3	b	26.1	102.5	b	21.7
SPD	0.2	a	4.8	4.9	b	10.9	15.9	b	13.6	29.4	b	19.5	50.9	b	17.3	68.2	b	24.8	71.6	b	20.6
CHB	0.5	a	5.0	9.4	b	11.4	21.8	b	14.3	39.1	b	20.4	51.3	b	18.1	82.4	b	25.8	83.2	b	21.3
HB	0.7	a	4.8	12.6	b	10.9	30.4	b	13.6	48.4	b	19.5	56.0	b	17.2	66.3	b	24.6	71.2	b	20.3

[1]For each age class, means within age columns followed by different lowercase letters differ significantly at $P < 0.05$ and standard errors comprise each column following means separation results.

[2]B = Burn Only; CB = Chop & Burn; SPD = Shear, Pile, & Disk; CHB = Chop, Herbicide, & Burn; HB = Herbicide & Burn.

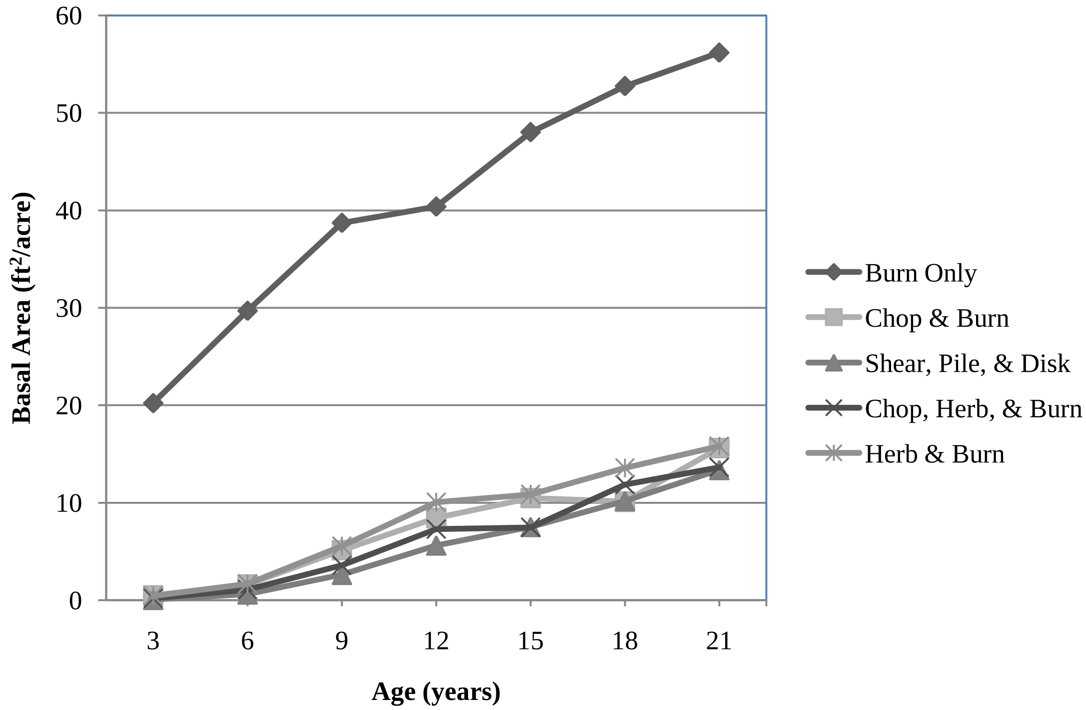

Figure 2. Mean hardwood basal area per acre by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

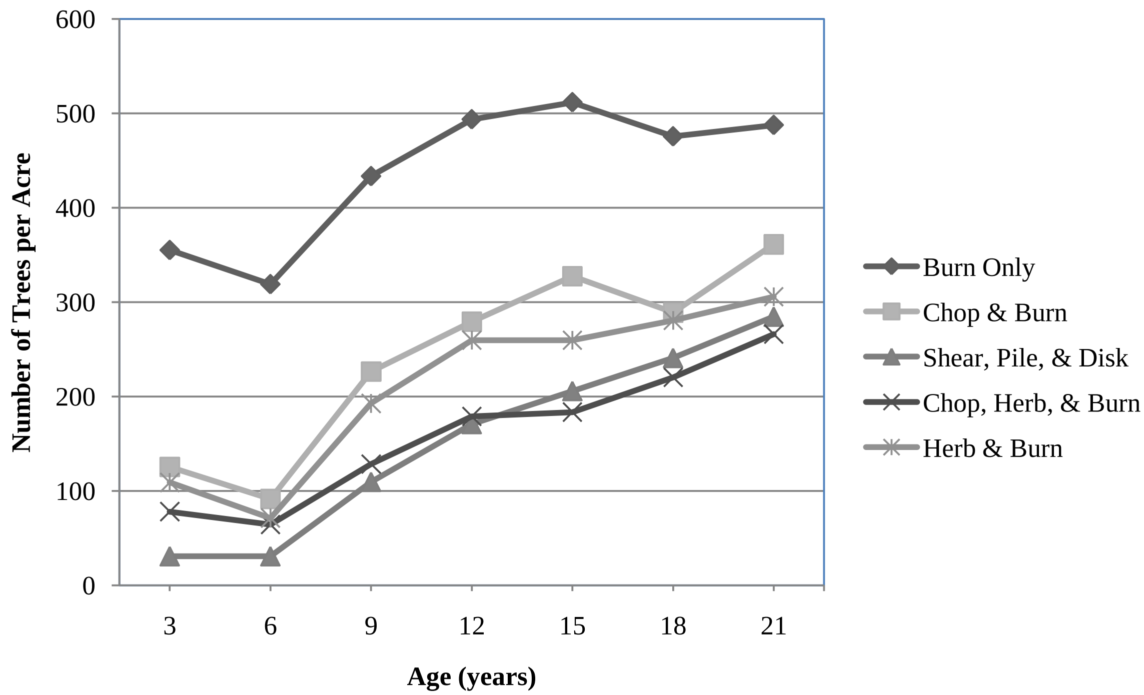

Figure 3. Mean hardwood trees per acre by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

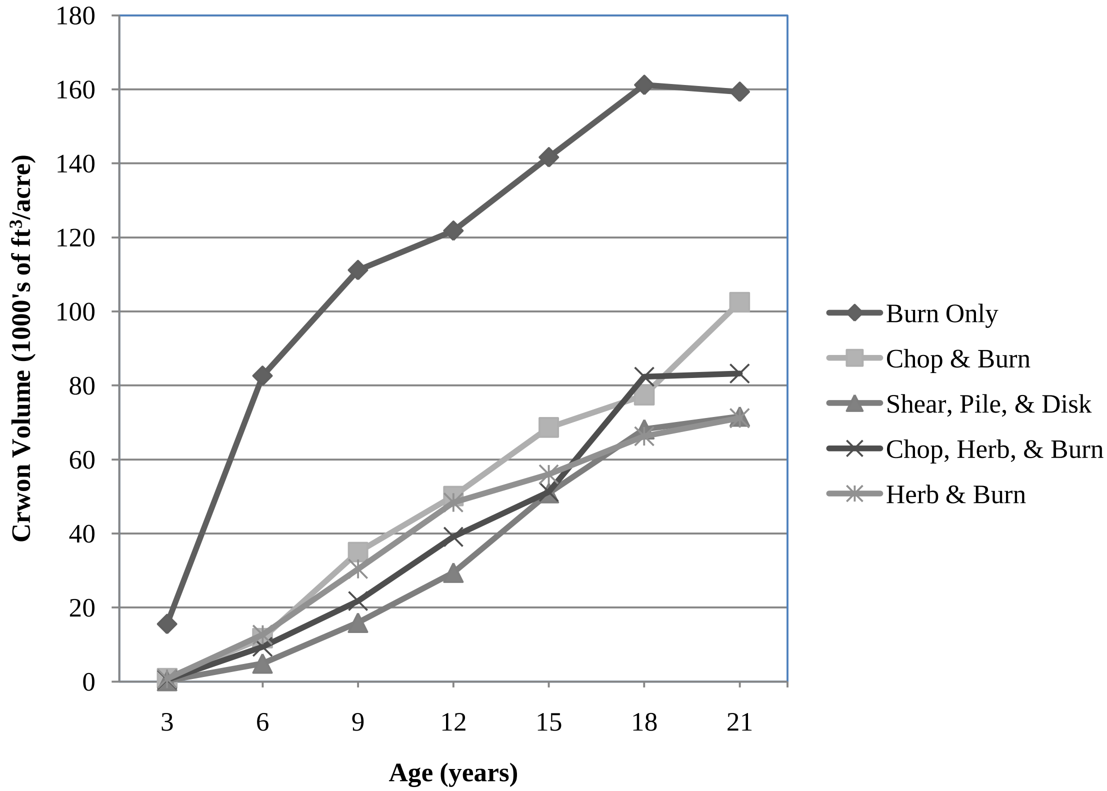

Figure 4. Mean hardwood crown volume index per acre by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

Standing Hardwood Weight and Net Productivity Index

Total hardwood weights were greatest on the Burn Only treatment; the Herbicide, Burn, and Complete Vegetation Control treatment eliminated hardwoods; and the other treatments had comparable hardwood weights during the study period (Table 2). With the exception of the Herbicide, Burn, and Complete Vegetation Control treatment, hardwood weights per acre increased with age. Hardwood weights on the Burn Only treatment were significantly greater than those observed for the other treatments throughout the study period except at age 3. Per acre hardwood weights among the remaining treatments did not differ. The Burn Only treatment was the only treatment with an appreciable hardwood component at the initiation of the study as indicated by the total weight (Figure 5) and merchantable weight (Figure 6) at plantation age 3.

Hardwood total weight per acre developed slowly on treatments other than Burn Only. Hardwood merchantable dry weight remained negligible on all but the Burn Only treatment throughout the study period, although some hardwoods on treatments other than the Burn Only treatment grew into the merchantable class by year 18.

Table 3. Mean hardwood weights (dry tons per acre) by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.[1]

Treatment[2]	Age 3			Age 6			Age 9			Age 12			Age 15			Age 18			Age 21		
	Total Tree Dry Weight																				
	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
B	7.04	a	2.20	8.53	a	2.06	11.99	a	2.67	14.22	a	3.16	17.69	a	3.53	23.91	a	5.11	24.06	a	4.51
CB	0.05	a	2.13	0.26	b	2.00	1.00	b	2.59	2.00	b	3.06	2.87	b	3.42	3.08	b	4.95	4.90	b	4.37
SPD	0.01	a	2.02	0.11	b	1.89	0.54	b	2.45	1.28	b	2.90	2.18	b	3.24	3.58	b	4.68	4.16	b	4.13
CHB	0.02	a	2.13	0.19	b	2.00	0.77	b	2.59	1.87	b	3.06	2.41	b	3.42	4.49	b	4.94	4.62	b	4.36
HB	0.05	a	2.02	0.29	b	1.89	1.11	b	2.45	2.55	b	2.90	3.09	b	3.23	4.52	b	4.68	5.53	b	4.13
	Stem Merchantable Dry Weight																				
	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
B	4.78	*		5.11	*		6.35	*		7.66	*		8.96	*		13.47	a	3.44	14.49	a	3.25
CB	0.00	*		0.00	*		0.00	*		0.00	*		0.00	*		0.00	b	3.34	0.33	b	3.15
SPD	0.00	*		0.00	*		0.00	*		0.00	*		0.00	*		0.82	b	3.16	0.91	b	2.98
CHB	0.00	*		0.00	*		0.00	*		0.00	*		0.00	*		1.28	b	3.34	0.86	b	3.14
HB	0.00	*		0.00	*		0.00	*		0.00	*		0.00	*		0.66	b	3.16	0.94	b	2.97

[1]For each age class, means within columns followed by different lowercase letters differ significantly at $P < 0.05$ and standard errors each column following means separation results.

[2]B = Burn Only; CB = Chop & Burn; SPD = Shear, Pile, & Disk; CHB = Chop, Herbicide, & Burn; HB = Herbicide & Burn.

*No test.

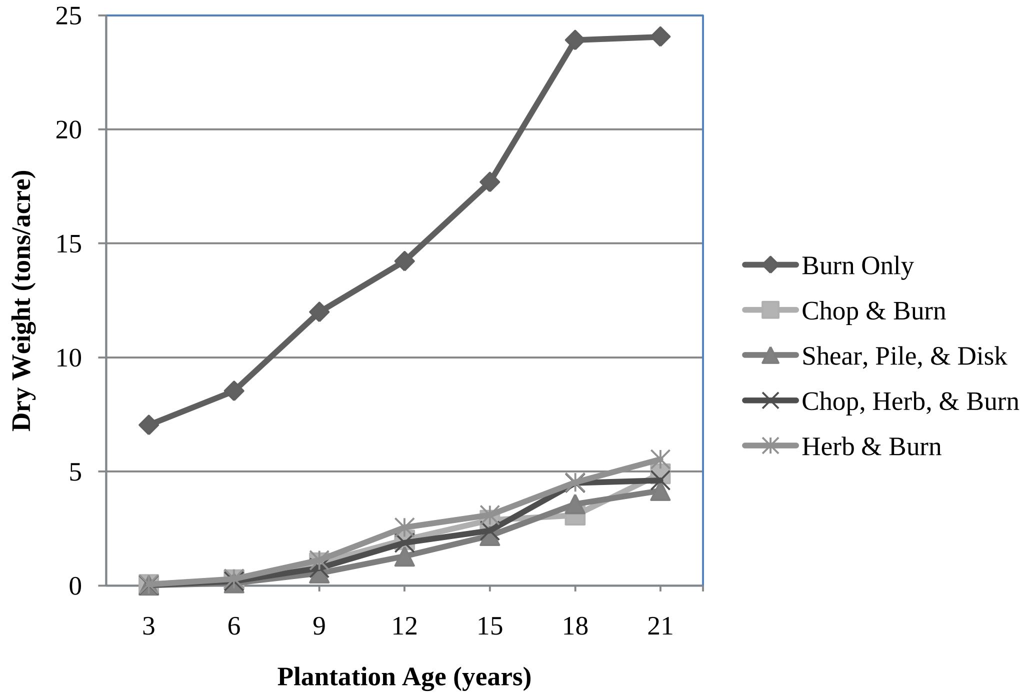

Figure 5. Mean hardwood total tree dry weight per acre by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

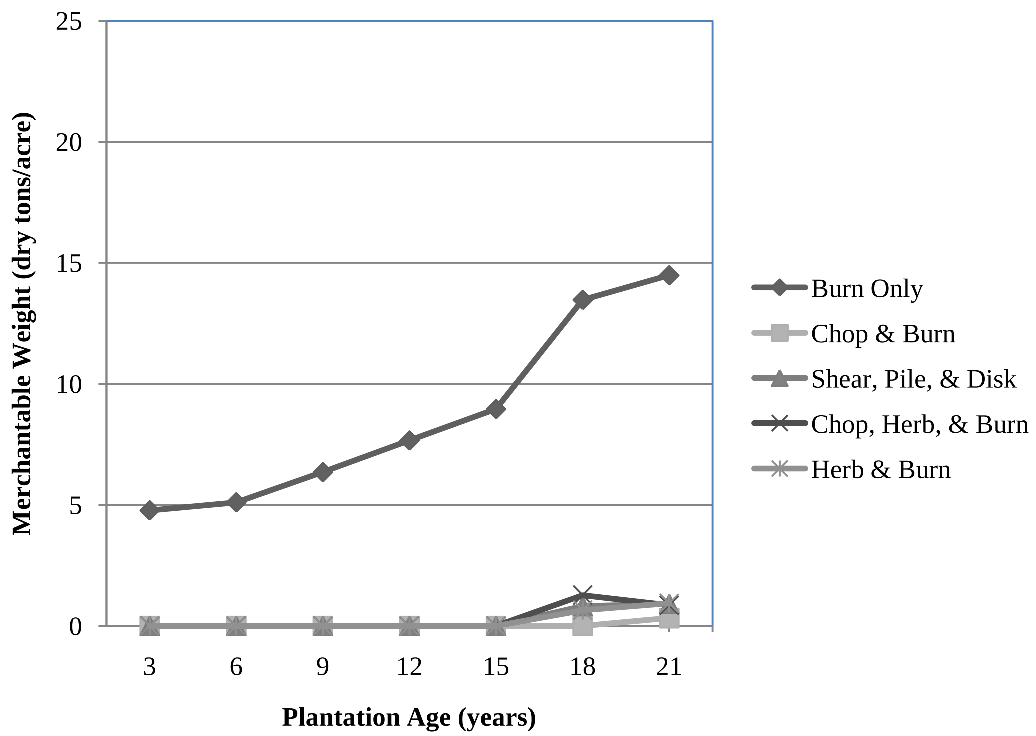

Figure 6. Mean hardwood merchantable dry weight per acre by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

Hardwood net productivity index was greater in the Burn Only treatment when compared to the remaining treatments at all ages (Table 4). At each age classification, the Burn Only treatment productivity index values are three times greater than that of the next highest treatment. Each of the remaining four treatments that did not include complete vegetation control had similar net productivity index values throughout the assessment period.

Table 4. Mean hardwood net productivity index (dry tons per acre) by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.[1]

Treatment[2]	Age 6			Age 9			Age 12			Age 15			Age 18			Age 21		
	Hardwood Net Productivity Index																	
	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
B	1.49	a	0.37	4.96	a	0.76	7.18	a	1.57	10.65	a	1.96	16.88	a	3.55	17.03	a	3.10
CB	0.21	b	0.36	0.95	b	0.74	1.95	b	1.52	2.82	b	1.89	3.03	b	3.43	4.85	b	2.98
SPD	0.10	b	0.34	0.53	b	0.70	1.27	b	1.44	2.18	b	1.79	3.57	b	3.25	4.16	b	2.82
CHB	0.17	b	0.36	0.75	b	0.74	1.85	b	1.52	2.39	b	1.89	4.47	b	3.43	4.59	b	2.97
HB	0.25	b	0.34	1.06	b	0.70	2.50	b	1.44	3.04	b	1.79	4.48	b	3.25	5.48	b	2.81
	Hardwood Net Merchantable Productivity Index																	
	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE	Mean		SE
B	0.331	*		1.58	*		2.88	*		4.18	*		8.69	a	2.13	9.71	a	2.19
CB	0	*		0.00	*		0.00	*		0.00	*		0.00	b	2.06	0.33	b	2.11
SPD	0	*		0.00	*		0.00	*		0.00	*		0.82	b	1.95	0.91	b	2.00
CHB	0	*		0.00	*		0.00	*		0.00	*		1.28	b	2.06	0.86	b	2.11
HB	0	*		0.00	*		0.00	*		0.00	*		0.66	b	1.95	0.94	b	2.00

[1]For each age class, means within columns followed by different lowercase letters differ significantly at P < 0.05 and standard errors comprise each column following means separation results.
[2]B = Burn Only; CB = Chop & Burn; SPD = Shear, Pile, & Disk; CHB = Chop, Herbicide, & Burn; HB = Herbicide & Burn.

<u>Planted Pine Dry Weight</u>

Total and merchantable pine weight at ages 15, 18, and 21 years were greatest on the Herbicide, Burn and Complete Vegetation Control treatment, least on the Burn Only treatment, and intermediate for the other treatments (Table 5). The Herbicide, Burn, and Complete

Vegetation Control treatment maintained greater total dry weight and merchantable dry weight at each assessment while the intermediate treatments became more similar by age 21.

Treatment trends with plantation age are similar for total pine tree dry weight (Figure 7) and pine merchantable stem dry weight (Figure 8) with the Herbicide, Burn, and Complete Vegetation Control treatment and the Burn Only treatment defining the upper and lower bounds, respectively. By age 21, the Herbicide and Burn, the Shear, Pile, and Disk, and the Chop, Herbicide, and Burn treatments are clustered below the maximum mean weights observed on the Herbicide, Burn, and Complete Vegetation Control treatment.

Table 5. Mean planted pine total and merchantable weights (tons per acre) by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.[1]

	Age 15			Age 18			Age 21		
Treatment	Total Tree Dry Weight								
	Mean		SE	Mean		SE	Mean		SE
Burn Only	21.39	a	2.45	32.46	a	3.14	42.29	a	3.57
Chop & Burn	30.78	b	2.39	44.91	b	3.05	57.40	b	3.36
Shear, Pile, & Disk	34.80	c	2.32	49.33	c	2.97	61.14	b	3.26
Chop, Herb, & Burn	34.32	bc	2.38	49.06	bc	3.04	61.34	b	3.32
Herb & Burn	36.96	c	2.32	51.35	c	2.96	60.79	b	3.23
Herb, Burn, & CVC	45.03	d	2.34	59.15	d	2.98	68.45	c	3.24
	Stem Merchantable Dry Weight								
	Mean		SE	Mean		SE	Mean		SE
Burn Only	17.22	a	2.16	27.25	a	2.81	36.53	a	3.23
Chop & Burn	25.50	b	2.10	38.43	b	2.74	50.26	b	3.05
Shear, Pile, & Disk	29.00	c	2.05	42.30	c	2.66	53.47	b	2.96
Chop, Herb, & Burn	28.62	bc	2.09	42.10	bc	2.72	53.70	b	3.01
Herb & Burn	30.93	c	2.04	44.18	c	2.66	53.30	b	2.93
Herb, Burn, & CVC	38.16	d	2.06	51.27	d	2.68	60.21	c	2.94

[1]For each age class, means within columns followed by different lowercase letters differ significantly at $P < 0.05$ and standard errors comprise each column following means separation results.

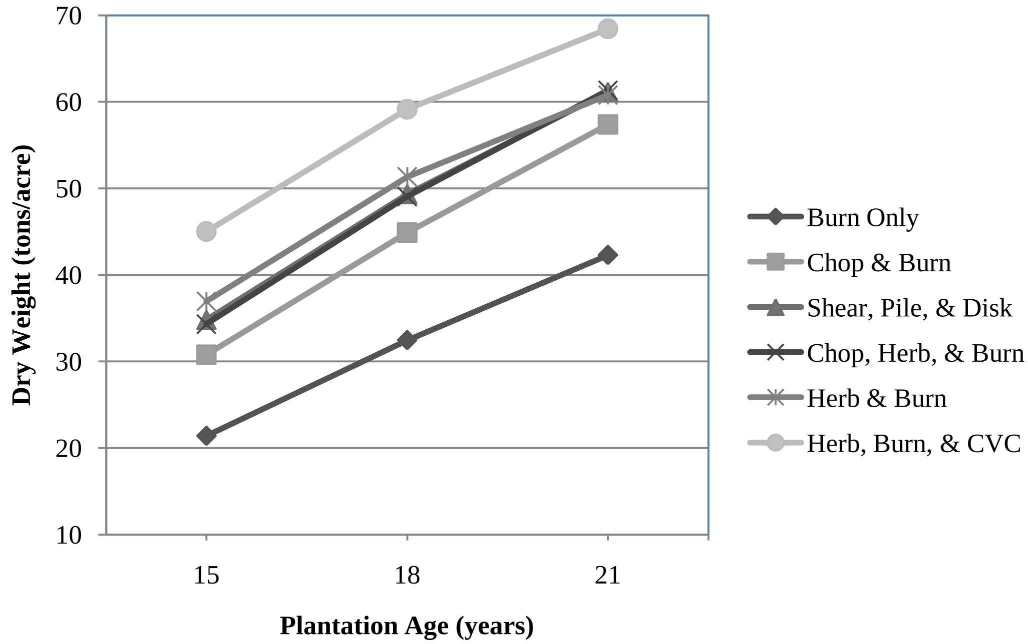

Figure 7. Mean planted pine total dry weight per acre by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

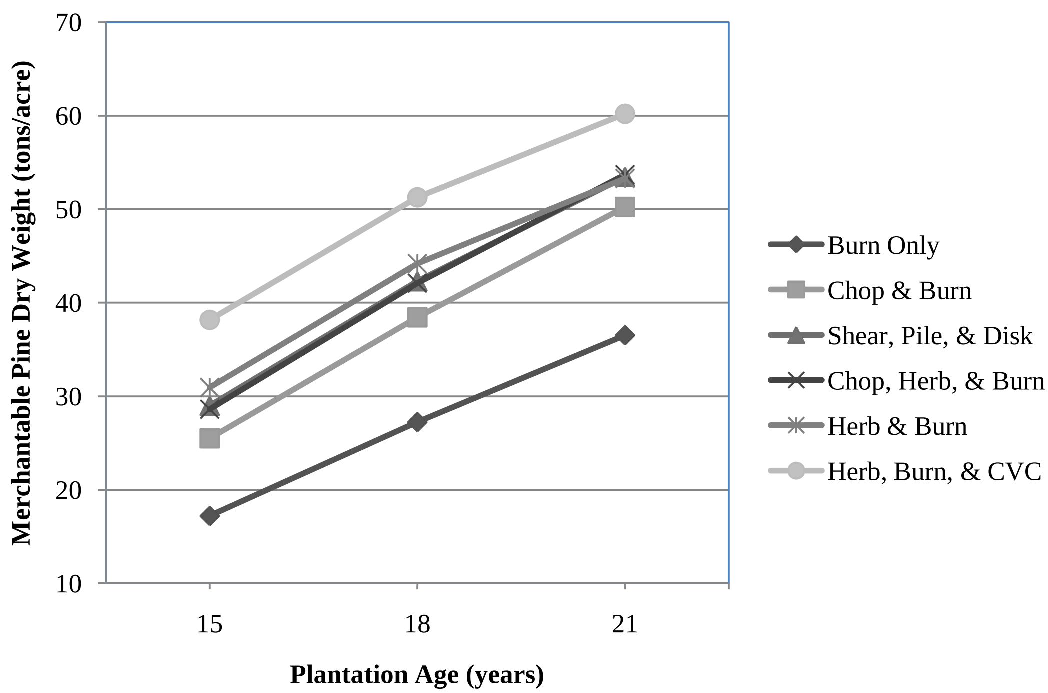

Figure 8. Mean planted pine merchantable dry weight per acre by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

Total Stand Attributes

Total Stand Dry Weight

Significant differences in total weight were observed among treatments at age 15, but by age 18, none of the treatments differed statistically (Table 6, Figure 9). At age 15, the Herbicide, Burn, and Complete Vegetation Control treatment had significantly greater merchantable dry weight than the other treatments (Table 6, Figure 10).

The Burn Only treatment had more than 35% of total weight in hardwoods at ages 15 through 21, the Herbicide, Burn, and Complete Vegetation Control treatment had no hardwood, and in the remaining treatments hardwoods comprised 5-10% of the total weight (Figure 11). The portion of the total biomass on the Burn Only treatment plots in hardwood decreased from about 45% to about 35% from plantation age 15 to 21, respectively.

Table 6. Mean total standing arborescent weights (tons per acre) by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.[1]

	Age 15			Age 18			Age 21		
Treatment	Total Tree Dry Weight								
	Mean		SE	Mean		SE	Mean		SE
Burn Only	39.82	ab	3.69	57.31	a	5.20	67.51	a	4.76
Chop & Burn	33.65	a	3.58	48.00	a	5.04	62.30	a	4.41
Shear, Pile, & Disk	37.00	a	3.44	52.92	a	4.83	65.31	a	4.24
Chop, Herb, & Burn	36.73	a	3.57	53.55	a	5.03	65.96	a	4.34
Herb & Burn	40.08	ab	3.43	55.87	a	4.82	66.32	a	4.18
Herb, Burn, & CVC	45.03	b	3.49	59.15	a	4.91	68.45	a	4.20
	Merchantable Dry Weight								
	Mean		SE	Mean		SE	Mean		SE
Burn Only	26.92	a	2.83	41.67	a	3.88	52.17	ab	3.90
Chop & Burn	25.51	a	2.75	38.44	a	3.76	50.59	a	3.62
Shear, Pile, & Disk	29.01	a	2.64	43.14	a	3.61	54.38	ab	3.48
Chop, Herb, & Burn	28.62	a	2.75	43.37	a	3.75	54.57	ab	3.56
Herb & Burn	30.96	a	2.64	44.83	a	3.60	54.24	ab	3.43
Herb, Burn, & CVC	38.16	b	2.68	51.27	b	3.66	60.21	b	3.45

[1]For each age class, means within columns followed by different lowercase letters differ significantly at $P < 0.05$ and standard errors comprise each column following means separation results.

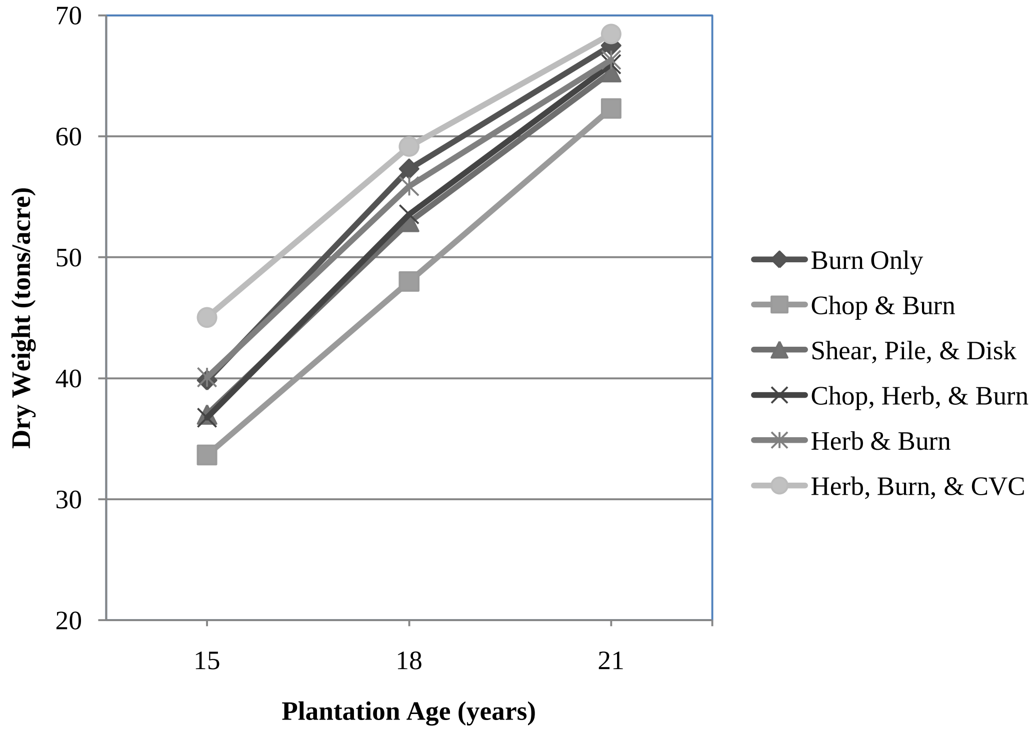

Figure 9. Mean total dry weight by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

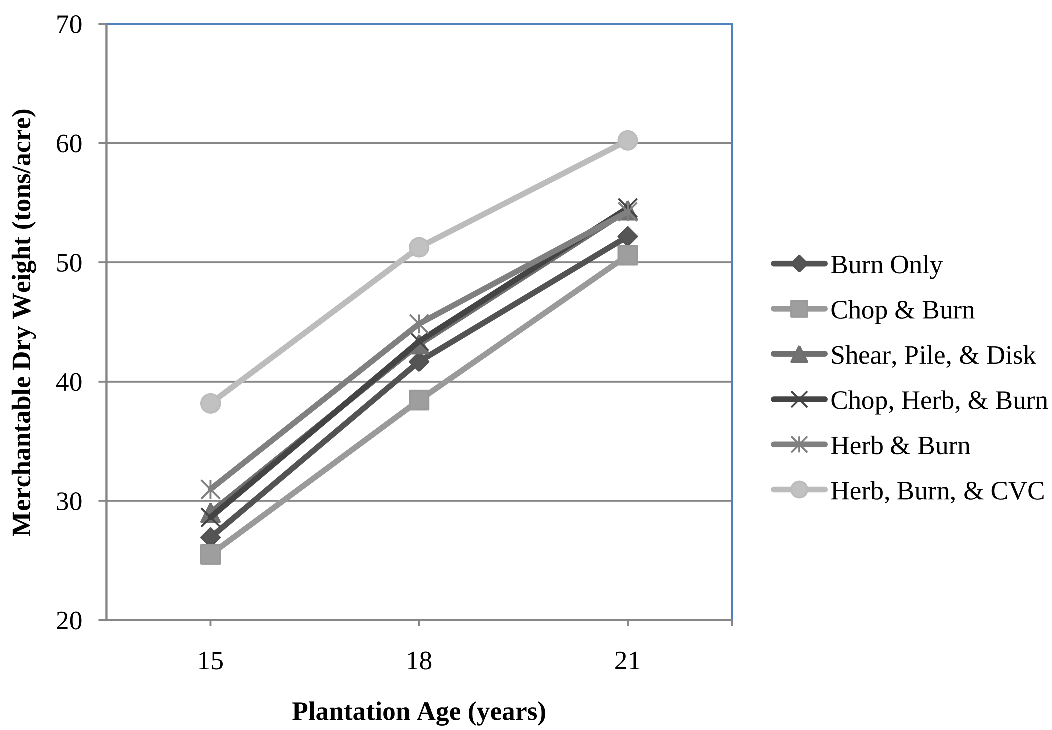

Figure 10. Mean total merchantable dry weight by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

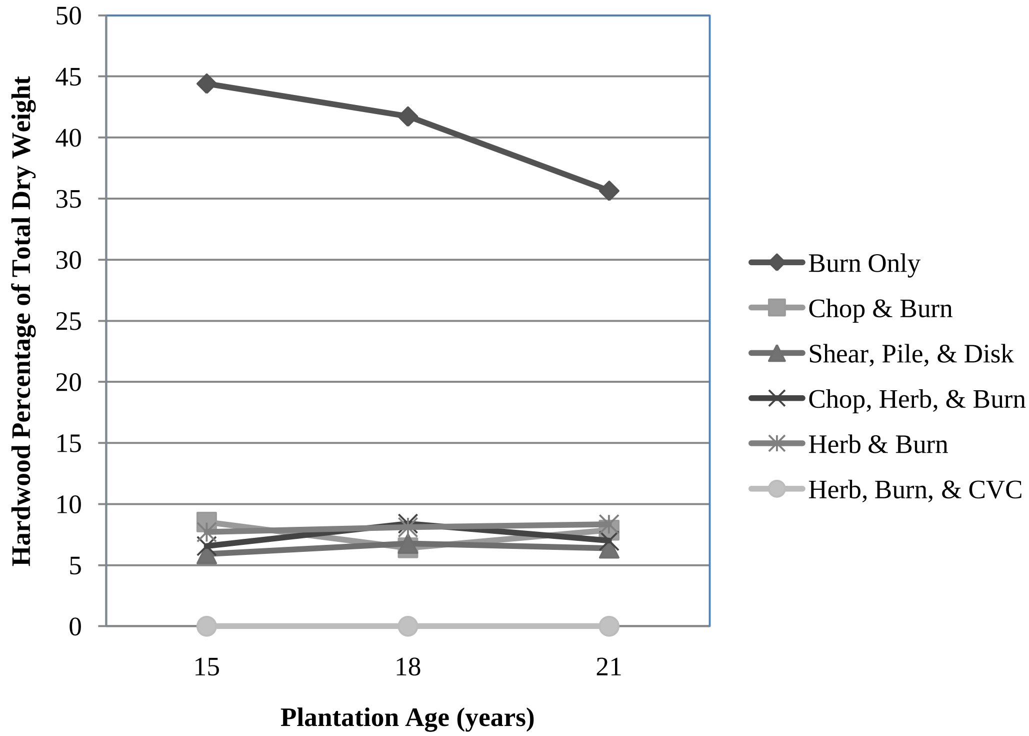

Figure 11. Mean hardwood percentage of total dry weight by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

Net Productivity Index

Total net productivity index (stem and branch) increased as the treatments become more intensive (Table 7, Figure 12). The Burn Only and the Chop and Burn treatments had the least net productivity index (total and merchantable) while the Herbicide, Burn, and Complete Vegetation Control treatment consistently had the greatest net productivity index. The remaining treatments had similar and intermediate levels of total and merchantable net productivity indices. Differences in total net productivity index and merchantable net productivity index were more pronounced at age 15 than age 21. At age 15, total net productivity index ranged from 33 to 45 dry tons for the various treatments, with significantly greater productivity indices on the Herbicide, Burn, and Complete Vegetation Control treatment than on the other treatments. By age 18, the various treatments show no significant differences in total net productivity indices and range from 50 to 59 dry tons per acre. At age 15, total merchantable productivity index ranges from 22 to 38 dry tons per acre, again with the Herbicide, Burn, and Complete Vegetation Control treatment producing significantly greater weights than the remaining treatments. Total merchantable productivity index on the Herbicide, Burn, and Complete Vegetation Control treatment stays significantly greater than the other treatments at age 18 and is only similar to the Shear, Pile, and Disk treatment by age 21.

Table 7. Total net productivity index (dry tons per acre) by treatment and plantation age on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.[1]

Treatment	Age 15			Age 18			Age 21		
	Total Net Productivity Index								
	Mean		SE	Mean		SE	Mean		SE
Burn Only	32.79	ab	2.91	50.28	a	4.31	60.47	a	4.26
Chop & Burn	33.61	a	2.82	47.95	a	4.18	62.25	a	3.97
Shear, Pile, & Disk	36.99	ab	2.75	52.92	a	4.05	65.30	a	3.83
Chop, Herb, & Burn	36.71	ab	2.81	53.53	a	4.16	65.94	a	3.92
Herb & Burn	40.03	b	2.74	55.82	a	4.03	66.27	a	3.79
Herb, Burn, & CVC	45.03	c	2.76	59.15	a	4.08	68.45	a	3.80
	Total Net Merchantable Productivity Index								
	Mean		SE	Mean		SE	Mean		SE
Burn Only	22.14	a	2.30	36.89	a	3.29	47.39	a	3.64
Chop & Burn	25.51	ab	2.24	38.44	a	3.19	50.59	a	3.39
Shear, Pile, & Disk	29.01	bc	2.18	43.14	a	3.09	54.38	ab	3.27
Chop, Herb, & Burn	28.62	c	2.23	43.37	a	3.18	54.57	a	3.34
Herb & Burn	30.96	c	2.17	44.83	a	3.08	54.24	a	3.23
Herb, Burn, & CVC	38.16	d	2.20	51.27	b	3.11	60.21	b	3.24

[1]For each age class, means within columns followed by different lowercase letters differ significantly at P < 0.05 and standard errors comprise each column following means separation results.

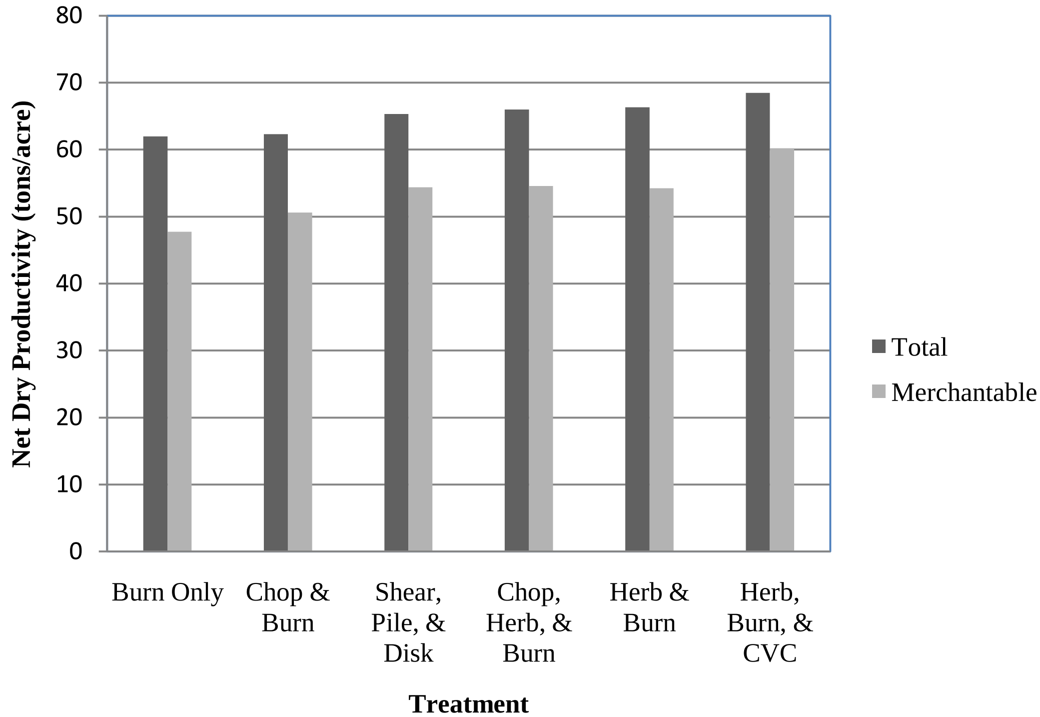

Figure 12. Mean total and merchantable net productivity index (dry tons per acre) by treatment at plantation age 21 on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

__Standing Dry Weight and Net Productivity Index by Hardwood Abundance Site Class__

At age 21, hardwoods represented a small component of total standing biomass (Figure 13) and net productivity index (Figure 14) across hardwood site classes for all treatments with the exception of the Burn Only treatment. Standing hardwood biomass and hardwood net productivity index were extremely high on High hardwood sites for the Burn Only treatment. Trends in net productivity index resemble those of total standing dry weight except that net productivity index of hardwood on High hardwood abundance sites is less than the total standing dry weight in the Burn Only treatments.

There was a trend on the Burn Only treatment of decreasing pine net productivity index from Low to Moderate to High hardwood abundance site classes (Figure 14). There was a small response in pine net productivity index to site preparation treatments and post-planting regimes on Very Low hardwood abundance site classes and a marked pine net productivity index response on Low, Moderate, and High hardwood abundance sites.

Through age 21, total net productivity index was greater or similar for relatively more pine dominated stands as compared to stands with relatively more hardwood (Figure 14). Total net productivity index on the Herbicide, Burn, and Complete Vegetation Control treatment was consistently greater than that for other treatments on Low and Moderate hardwood abundance sites and similar to that of most treatments on Very Low hardwood abundance sites. On High hardwood abundance sites, total net productivity index for the pine only Herbicide, Burn, and Complete Vegetation Control treatment was greater than that on the Chop and Burn and Herbicide and Burn treatments but less than that on the Burn Only, Shear, Pile, and Disk, and Chop, Herbicide, and Burn treatments. Total net productivity index in planted pine only stands (Herbicide, Burn, and Complete Vegetation Control) tended to be less on the Very Low and High hardwood abundance installations than on Low and Moderate hardwood abundance installations.

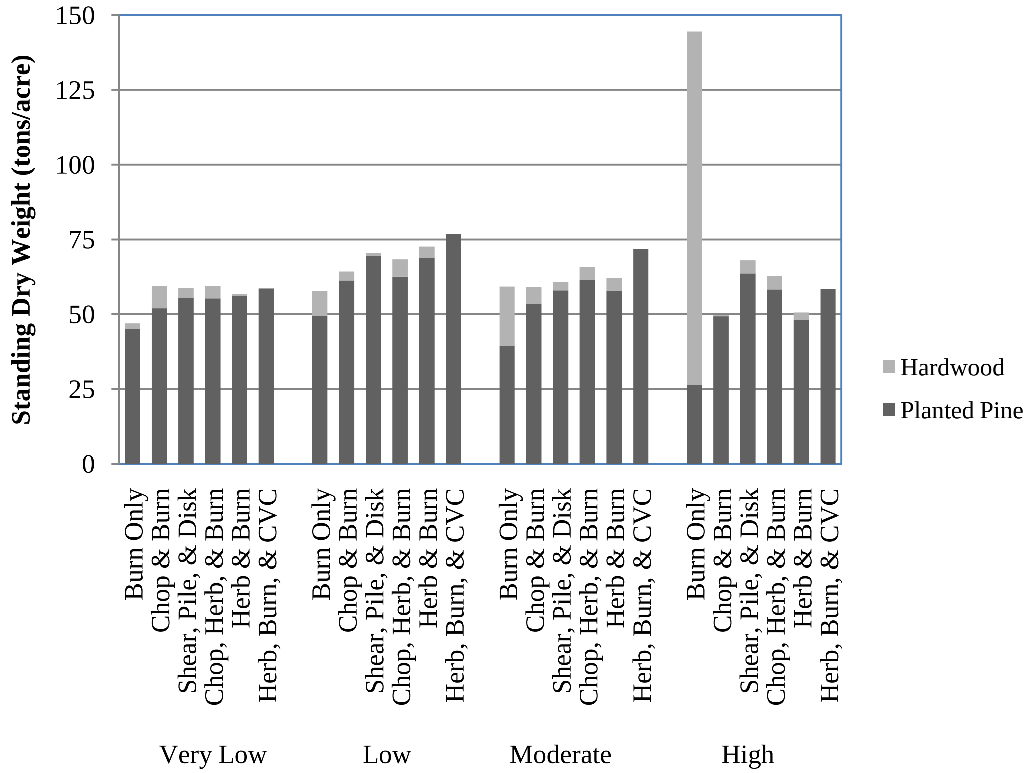

Figure 13. Mean total standing dry weight tons per acre of hardwood and planted pine by treatment for four hardwood abundance site classes at plantation age 21 on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

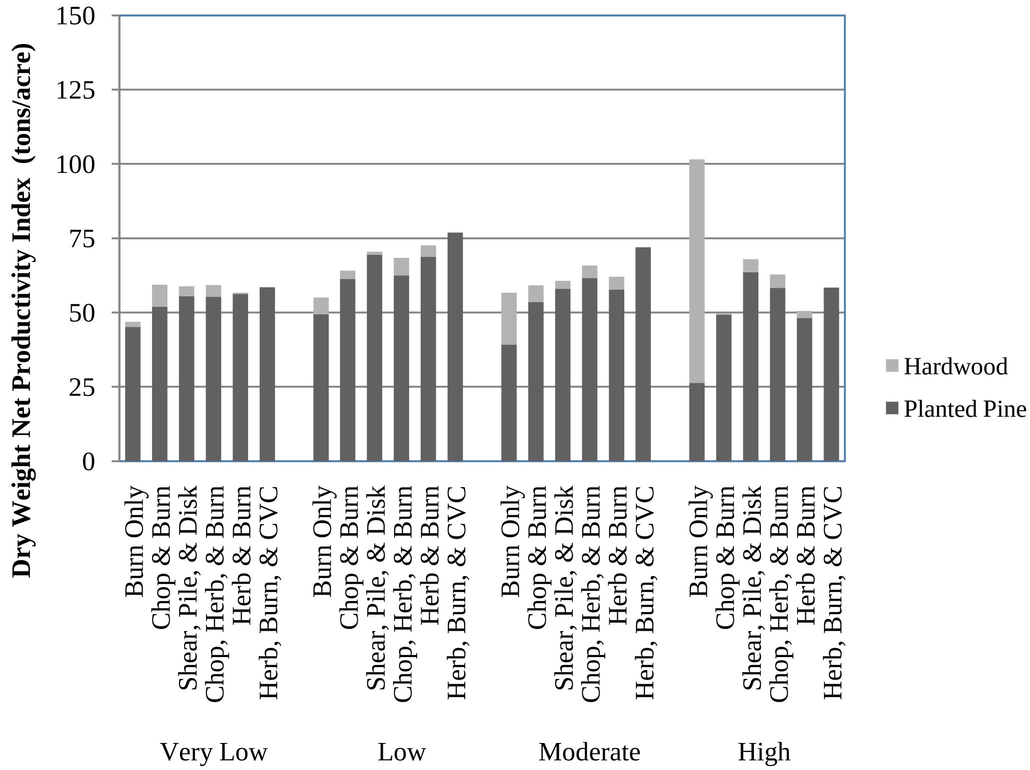

Figure 14. Mean total net dry weight productivity index tons per acre of hardwood and planted pine for four hardwood abundance site classes at plantation age 21 on 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

DISCUSSION

<u>Non-Planted Arborescent Vegetation</u>

<u>*Non-Planted Arborescent Species Composition*</u>

Similarly to Miller et al. (2003b), the most commonly occurring genera in the planted pine stands of this study included *Liquidambar, Quercus, Carya,* and *Nyssa*. Of these, *Liquidambar* constituted the highest percentages of basal area and trees per acre among the hardwood population at age 21. Many of the hardwoods present on the study sites were either standing residuals on the Burn Only treatment or likely sprout-origin. The standing residuals have a competitive advantage over either the sprout-origin or seedling-origin individuals because of their ability to capture both above ground and below ground resources. The sprout-origin individuals grow from cutover stumps or downed trees and may have a competitive advantage over seedlings because they are able to use established root systems of the parent tree.

The Herbicide and Burn treatment showed the greatest variety of genera and was the only treatment in which the oaks were not among the most dominant in terms of basal area percentage and where either *Fraxinus* or *Liriodendron* were present. The differences in competition between the Herbicide and Burn treatment and the Chop, Herbicide, and Burn treatment may be explained by the use of different herbicides. Roundup (glyphosate), a non-selective herbicide, was used in the Chop, Herbicide, and Burn treatment while a mixture of Tordon (picloram), a woody and herbaceous control herbicide, and Pronone (hexazinone), a non-selective herbicide was used in the Herbicide and Burn treatment. This later mixture may better control regrowth of oak competition when compared to the other treatments. The other genera present in only one treatment included *Magnolia* (Burn Only), *Crataegus* (Shear, Pile, and Disk), and *Juniperus* (Chop, Herbicide, and Burn).

Factors other than treatment may affect species composition. These can include but are not limited to the seed bank, past land use, neighboring stand type, soil type, climate, stand density, and water table level (Wear and Greis 2002). Because so many factors exist that can have control over the presence of volunteer species, it is difficult to determine specific reasons why certain species may be present. In the case of this study, all of the recorded species are common in the Piedmont and Upper Coastal Plain and occur with planted pines as well as in natural stands.

Standing Hardwood Attributes

Hardwood basal area per acre was greatest in the Burn Only plots because the residual hardwoods that were not killed by the broadcast burn were already established and had a competitive advantage over planted pines or new natural regeneration. In the other treatments, the majority of the live hardwoods were either killed or damaged by mechanical or chemical site preparation prior to the pines being planted.

The Burn Only plots tended to have the greatest number of hardwood trees per acre due to the significant amount of residual trees established prior to pine planting. The shading provided by these residual standing hardwoods would have led to higher pine mortality as well as more favorable conditions for species that are more competitive in shade. The decrease in hardwood trees per acre that is evident following age 15 is likely due to faster growing planted pines increasing their relative dominance in the stand. Once the pines begin to close the canopy, the amount of resources available to other competition decreases and vigor of impacted hardwoods declines.

Each treatment showed decreases in hardwood trees per acre between age 3 and age 6, likely due to some amount of shading as the faster growing pines began to overtop some of the less competitive hardwoods. Similar to Fredericksen et al. (1991), plots that had chemical site preparation generally showed delayed increases in hardwood growth and hardwood trees per acre relative to the Chop and Burn treatment. Chop treatments succeed at felling the small to moderate size residual standing timber but, even if followed by a burn, often result in some hardwood sprouting in the absence of an effective herbicide application. Broadcast burns, which would eliminate most of the smaller stems, can encourage regrowth if not combined with an effective application of herbicide. This leads to an expected greater number of hardwood stems per acre in the less effective mechanical treatments, when compared to the treatments that included herbicides. The Shear, Pile, and Disk treatment had low numbers of hardwood trees per acre, similar to those for the treatments including herbicides. This is not surprising because the Shear, Pile, and Disk treatment is the most intensive mechanical treatment tested. This treatment involves a pass with a bulldozer-mounted blade designed to shear and split stumps, the concentration of the coarse woody debris outside of the plot areas, and a pass with a disk harrow to further chop and control the remnants of the prior stand and to till the soil.

Hardwood crown volume index per acre correlates with the basal area per acre and weights per acre because larger hardwoods tend to have proportionately greater crown lengths and greater crown widths. The residual hardwoods in the Burn Only treatment result in the high crown volume index numbers throughout the assessment period on this treatment.

Standing Hardwood Weight and Net Productivity Index

The Burn Only treatment had significantly greater standing hardwood weights than the remaining treatments. Many of the residual hardwoods survived the broadcast burn and had a competitive advantage over the planted pines. Similar to the results of Harrington and Edwards (1997), the early advantage of the standing residual hardwoods carried throughout the assessment period in the study reported here.

The impact of residual hardwood stems on the Burn Only treatment was particularly pronounced on merchantable weight. This treatment had some merchantable weight at plantation age 3 while none of the hardwood stems present on the other treatment plots reached merchantable size (6 inch dbh to 3 inch top) until age 18. After these stems progressed to the merchantable category, the merchantable weight estimates for treatments other than the Burn Only treatment were similar, likely because a small amount of stems were present and because these stems all sprouted or became established at approximately the same time as the planted pines. Hardwood productivity index during the 21-year assessment period mirrored trends for standing dry weight.

Although the net productivity index values were calculated based on plantation age 3 assessments, they serve as a representation of the relative net productivity trends. This study would have benefited from having measurements of the residual standing trees before pine planting.

Planted Pine Dry Weight

Treatment trends reported here for planted pine productivity are similar to those reported for this study through age 12 by Shiver and Martin (2002) and through age 21 by Zhao et al.

(2009). The current analysis reports the least pine growth on the Burn Only treatment, greatest growth on the Herbicide, Burn, and Complete Vegetation Control treatment, and intermediate growth on the intermediate treatments. The hardwood residuals may explain the disparity in treatment means for planted pines in the Burn Only treatment when compared to the remaining treatments (Shiver and Martin 2002). The current analysis is unique in that it reports total tree and merchantable stem net dry weights of the planted pines rather than total and merchantable stem green weights.

Mean net pine productivity index increased with treatment regime intensity and with decreased levels of competition. Control of competition by more intensive site preparation leads to greater pine growth responses (Bacon and Zedaker 1987, Creighton et al. 1987, Fredericksen et al. 1991, Jokela et al. 2000, Lauer and Glover 1998, Miller et al. 2003a, Shiver and Martin 2002, Shiver and Shackleford 1996). However, competition elimination may not be the most optimal option to encourage pine growth. Bacon and Zedaker (1987) found that the greatest pine growth responses to competition control followed two-thirds hardwood removal, rather than total removal. Although planted pine growth rates may not approach their maximum under cost effective regimes, we can favor planted pine growth by reducing competition, providing additional nutrition, or a combination of both (Borders and Bailey 2001). At age 21 in the current study, the rotation length complete competition control regime resulted in about 8 and 7 additional total and merchantable dry tons per acre, respectively, as compared to the Herbicide and Burn treatment.

Total Stand Attributes

Total Stand Dry Weight

Early in the development of these plantations, the differences in total stand dry weight among the treatments was linked to the amount of residual hardwoods that survived plantation establishment. The residual hardwoods present in the Burn Only treatment plots had considerable weight at plantation establishment and subsequently grew at a high rate because of their competitive advantage relative to the recently planted pines. As time progressed, the planted pines constituted a higher percentage of the total production in these plots. Because there was a substantial amount of residual hardwoods in the Burn Only plots and differences in pine weights among treatments were decreasing at later ages due to relative stocking conditions, total stand weight did not differ markedly among treatments at age 21.

Stand merchantable weight estimates for the Burn Only treatment remained relatively high because of the residual hardwoods that were in the merchantable class (6 inch DBH to 3 inch top) at the time of stand establishment. The relative greater total merchantable weight on the Burn Only treatment at early ages quickly dissipated as the planted pines on the remaining treatments began to mature into merchantable trees by age 12.

Net Productivity Index

The total net productivity index for age 15 through age 21 generally increased with the intensity of the site preparation treatment. Total productivity index was similar among the more intensive treatments. Significant differences among treatments were apparent at age 15 but not at age 18.

At age 21, the extra pine total net volume (7.6 tons per acre) on the Herbicide, Burn, and Complete Vegetation Control treatment as compared to the Herbicide and Burn treatment is similar to the amount of average hardwood total net productivity index (5.5 tons per acre) in the Herbicide and Burn treatment. This appears to validate the findings by South and Miller (2007) that the growth response after competition control does not always result in a strict Type 2 response (increased maximum carrying capacity for pine plus hardwood as well as a shortened establishment phase). The decreasing range in total net productivity index among treatments from age 15 (33 to 45 respective tons per acre from Burn Only to Herbicide, Burn, and Complete Vegetation Control) to age 21 (61 to 68 respective tons per acre from Burn Only to Herbicide, Burn, and Complete Vegetation Control) and the change from statistically significance among treatments at age 15 but not at age 21 probably reflects different levels of intra-species competition among the planted pine. The planted pine on the Herbicide, Burn, and Complete Vegetation Control treatment had reached growth limited stocking levels at an earlier age than on the other treatments and pine growth had slowed relative to that on other treatments (Zhao et al. 2009).

Standing Dry Weight and Net Productivity by Hardwood Abundance Site Class

Division of the installations into hardwood abundance site classes allowed examination of how treatment responses varied among sites with differing hardwood pressure. These classes were based on hardwood basal area recorded at plantation age 21 in the Burn Only treatment plots. Plantation age 21 total standing dry weight and net dry weight productivity index were of particular interest on the Burn Only treatment on High hardwood abundance sites. There were two installations in this class, each with plantation age 21 hardwood basal area greater than 85 square feet per acre. As a whole, stand development on High hardwood sites on the Burn Only treatment had much lower pine productivity and much higher hardwood or total net productivity indices than any other treatment-hardwood abundance site class combination. The effect of the standing residuals was very dominant.

The greater response in pine productivity to the complete competition control regime on sites with greater hardwood pressure than on sites with less pressure is consistent with past research findings. Similarly, Miller et al. (2003a) documented greater responses to hardwood control on sites with greater hardwood pressure than sites with less hardwood pressure.

Net productivity index through age 21 was similar or often greater in pine-dominated stands as compared to stands with pine and a relatively minor hardwood component. This finding was similar to that reported by South and Miller (2007) that competition control often resulted in a Type 2 response (increase in carrying capacity and response not explained by a species shift) and less frequently resulted in a Pseudo-Type 1 response (pine growth was increased while the total above-ground biomass of the mixed stand was not altered by the species shift).

Given that pine dominated stands tend to be more productive, forest managers will likely continue to emphasize management for pine productivity. However, significant changes in future hardwood market economics may encourage managers to adjust management regimes. If biodiversity and improved hardwood markets are main factors, less intensive site preparation and post planting vegetation control may prove to be of higher value than in the past.

CONCLUSIONS

Increasing levels of site preparation and post-planting competition control had pronounced effects on the hardwood component in planted loblolly pine stands. At age, 21, *Liquidambar* was the predominant hardwood genera over all site preparation treatments with hardwoods, with the exception of the Burn Only treatment where *Quercus* was predominant. Treatment responses on hardwood development ranged from hardwood being effectively eliminated by the Herbicide, Burn, and Compete Vegetation Control treatment to hardwood comprising a significant portion of the stand in the Burn Only treatment. The remaining treatments were generally intermediate in terms of hardwood basal area, number of trees, crown volume index, standing total and merchantable weight, and net productivity index per acre.

Site preparation and competition control regimes had a marked effect on planted pine net total and merchantable productivity. Overall, pine net productivity was greatest following the sustained vegetation control afforded by the Herbicide, Burn, and Complete Vegetation Control treatment, least on the Burn Only treatment, and intermediate on the remaining site preparation treatments.

Mean standing total biomass including planted pine and naturally regenerated hardwood at plantation age 21 did not differ significantly among treatments, in part due to larger residual hardwood from the previous rotation on the Burn Only treatment. Mean total standing biomass by treatment ranged from 62 to 69 dry tons per acre at age 21.

Although differences in total net productivity index (pine plus hardwood) among treatments were not statistically significant, at age 21, there was a clear trend of increasing net productivity index moving from the Burn Only treatment to the Herbicide, Burn, and Complete

Vegetation Control treatment and this later treatment had significantly greater net total productivity index than the other treatments at age 15. More complete competition control not only increase mean pine productivity but increased mean total net productivity index, at least at age 15. After age 15, relatively high pine stocking levels on the complete competition control plots likely resulted in slowing age 15-21 year periodic growth relative to other treatments.

Pine net productivity was by far the dominant contributor to total net productivity index with the exception of very substantial hardwood net productivity index on Burn Only plots on several installations with large residual hardwood trees. Pine net productivity relative to productivity index on the Burn Only plots tended to be greater at locations with more abundant hardwood on the Burn Only plots than locations with less abundant hardwood.

The key finding that more pine dominated stands tend to be more productive in biomass production than stands with pine hardwood mixtures prior to the onset of growth limiting stocking levels implies that the current focus of managers to focus on pine productivity is warranted. Also, the trend of greater pine response on sites with more hardwood confirms current prescription approaches. However, in the event of a significant shift in relative pine/hardwood markets and stumpage, hardwood plantations may become financially feasible.

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APPENDIX 1

Appendix 1. Common and scientific names of species classified as "hard" and as "soft" hardwoods.

<u>"Hard" Hardwoods</u>

Bald Cypress	*Taxodium distichum*
American Beech	*Fagus grandifolia*
Bigleaf Magnolia	*Magnolia macrophylla*
Choke Cherry	*Prunus virginiana*
Eastern Red Cedar	*Juniperus virginaina*
Black Cherry	*Prunus serotina*
Chestnut Oak	*Quercus prinus*
Hawthorne	*Crataegus* spp.
Dogwood	*Cornus florida*
Elm	*Ulmus* spp.
Florida Maple	*Acer barbatum*
Hickory	*Carya* spp.
Holly	*Ilex* spp.
Locust	*Robinia pseudoacacia*
Live Oak	*Quercus virginiana*
Red Mulberry	*Morus rubra*
White Mulberry	*Morus alba*
Persimmon	*Diospyros virginiana*
Plum	*Prunus americana*
Pond Cypress	*Taxodium ascendens*
Runner Oak	*Quercus margarettae*
Red Oak	*Quercus rubra*
Service Berry	*Amelanchier arborea*
Scrub Oak	*Quercus berberidifolia*
Swamp Dogwood	*Cornus amomum*
Sourwood	*Oxydendrum arboreum*
Sparkleberry	*Vaccinium arboreum*
Winged Elm	*Ulmus alata*
White Oak	*Quercus alba*
Water Oak	*Quercus nigra*
Chinaberry	*Melia azedarach*

<u>"Soft" Hardwoods</u>

American Chestnut	*Castanea dentata*
Ailanthus	*Ailanthus altissima*
Alder	*Alnus glutinous*
Ash	*Fraxinus excelsior*
Azalea	*Rhododendron* spp.
Baccharis	*Baccharis halimifolia*
American Beautyberry	*Callicarpa americana*
Blackgum	*Nyssa sylvatica*
Birch	*Betula nigra*
Blueberry	*Vaccinium corymbosum*
Buckthorn	*Rhamnus cathartica*
Buckeye	*Aesculus sylvatica*
Crepe Myrtle	*Lagerstroemia indica*
Chinkapin	*Quercus muehlenbergii*
Elderberrry	*Sambucus nigra*
Sebastianbush	*Sebastiania ligustrina*
Fetterbush	*Lyonia lucida*
Fringetree	*Chionanthus virginicus*
Gallberry	*Ilex glabra*
Grape	*Vitis vinifera*
Hackberry	*Celtis occidentalis*
Devil's Walking Stick	*Aralia spinosa*
Sweetleaf	*Stevia rebaudiana*
Huckleberry	*Vaccinium parvifolium*
Hazel	*Hamamelis virginiana*
Laurel	*Quercus laurifolia*
Loblolly Bay	*Gordonia lasianthus*
Magnolia	*Magnolia grandiflora*
Mimosa	*Albizia julibrissin*
Oak Leaf Hydrangea	*Hydrangea quercifolia*
Palmetto	*Serenoa repens*
Pepper Bush	*Clethra acuminata*
Red Bay	*Persea borbonia*
Privet	*Ligustrum japonicum*
Paw-Paw	*Asimina triloba*
Redbud	*Cercis canadensis*
Red Maple	*Acer rubrum*
Sassafras	*Sassafras albidum*
Sweetgum	*Liquidambar styraciflua*
Strawberry Bush	*Euonymus americanus*
Sumac	*Rhus copallina*
Sweetbay	*Magnolia virginiana*
Sycamore	*Platanus occidentalis*
Titi	*Cyrilla racemiflora*

Tupelo	*Nyssa sylvatica*
Vaccinium	*Vaccinium* spp.
Willow	*Salix babylonica*
Yellow Poplar	*Liriodendron tulipifera*
Cucumbertree	*Magnolia acuminata*

APPENDIX 2

Appendix 2. P-values for treatment effects for hardwood, pine, and combined hardwood and pine stand attributes by plantation age for 19 study sites in the Piedmont and Upper Coastal Plain of Georgia and Alabama.

	Pr > F						
Attribute	Age 3	Age 6	Age 9	Age 12	Age 15	Age 18	Age 21
Hardwood BA	**0.0459**	**0.0025**	**0.0012**	**0.0073**	**0.0007**	**0.0030**	**0.0036**
Hardwood TPA	**0.0002**	**<.0001**	**0.0039**	**0.0057**	**0.0069**	**0.0450**	0.1469
Hardwood Crown Vol. Index	0.1634	**<.0001**	**<.0001**	**0.0017**	**0.0011**	**0.0345**	**0.0267**
Hardwood Dry Weight	0.0940	**0.0153**	**0.0113**	**0.0191**	**0.0077**	**0.0166**	**0.0080**
Hardwood Merch. Weight	ND	ND	ND	ND	ND	**0.0316**	**0.0096**
Hardwood Productivity Index	ND	**0.0387**	**0.0002**	**0.0243**	**0.0053**	**0.0183**	**0.0142**
Hardwood Merch. Productivity Index	ND	ND	ND	ND	ND	**0.0193**	**0.0054**
Pine Dry Weight	ND	ND	ND	ND	**<.0001**	**<.0001**	**<.0001**
Pine Merch. Weight	ND	ND	ND	ND	**<.0001**	**<.0001**	**<.0001**
Total Dry Weight	ND	ND	ND	ND	**0.0412**	0.3247	0.6867
Total Merch. Weight	ND	ND	ND	ND	**0.0005**	**0.0362**	0.1231
Total Productivity Index	ND	ND	ND	ND	**<.0001**	0.0927	0.4352
Total Merch Productivity Index	ND	ND	ND	ND	**<.0001**	**0.0001**	**0.0149**

ND=No Data.