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Loblolly pine growth and soil nutrient stocks eight years after forest slash incorporation

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ABSTRACT

Incorporation of forest slash during stand establishment is proposed as a means of increasing soil carbon and nutrient stocks. If effective, the increased soil carbon and nutrient status may result in increased aboveground tree growth. Eight years after study installation, the impact of forest slash incorporation into the soil on soil carbon and nutrient stocks, foliar nutrients and loblolly pine growth are examined on mineral and organic sites on the North Carolina Lower Coastal Plain. Treatments include leaving forest slash on the surface and flat planting (control); V-shear and bedding (conventional), mulch forest slash followed by bedding (strip mulch) and mulch forest slash and till into the soil followed by bedding (strip mulch till). After eight years, mulching and/or tillage did not have a significant impact ($p > 0.05$) on soil bulk density or soil chemical properties (pH, cation exchange capacity, soil nutrients). Additionally, neither tree foliar nutrients nor stand volume were significantly impacted. However, significant effects were observed for soil phosphorus contents and stand volume between the control plots and the other treatment plots. For example, the mean stand volumes on the mineral site were 24.49 ± 1.28, 38.16 ± 2.90, 44.59 ± 3.07 and 46.96 ± 2.74 m^3 ha^{-1} for the control, conventional, strip mulch and strip mulch till plots. These observations are more likely due to the effect of bedding rather than mulching or tillage of the forest slash. These results are consistent for the mineral and the organic sites. Considering the greater expense to install the mulch and tillage treatments, the lack of a treatment effect on soil carbon and nutrient stocks and tree growth does not justify these treatments on these sites.

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1. Introduction

With the development of carbon (C) based market systems addressing climate change concerns and the increasing demands on our natural resources, land managers have an incentive to increase the productive potential and C storage capacity of their lands beyond historic measures (Ramakrishna and Davidson, 1998; Lal, 2001; Kimble et al., 2003). This is a major issue in the Southern United States where forest soils are typically C and nutrient deficient, a condition that has been exacerbated by past agriculture use (Giddens and Garman, 1941). Restoring degraded soils can lead to increased productivity and C sequestration in forest systems. Maintaining or enhancing, soil organic matter levels is critical for the maintenance of a soil's physical, chemical, and biological integrity (Nambiar, 1997; Grigal, 2000). Although we know that a large proportion of the C cycle in forests occurs belowground, much is yet to be learned about the response of belowground C dynamics to forest management practices. Consequently, increasing C storage in forest ecosystems may not be straight forward since the mechanisms that control the internal cycling of soil organic matter in response to land management are complex (Stevenson, 1994). This is best recognized by the resistance to long-term changes in soil C storage under varying forest management practices (Johnson, 1992; Richter et al., 1999; Johnson and Curtis, 2001; Sanchez et al., 2006a,b).

Nevertheless, forest land managers are investing in genetic and silviculture improvement strategies to enhance forest production and C storage in the soil. A silviculture avenue being explored is increasing the soil C and nutrient stocks of degraded soils by incorporating organic amendments with logging residues being a readily available source (Buford et al., 1999). In the Southeastern United States, logging residue left on the surface decompose rapidly and are unlikely to be a major contributor to the mineral soil (Van Lear et al., 1995; Tiarks et al., 1999; Richter et al., 1995, 1999). However, incorporating harvest residues in mineral soil offers the promise for improving long-term C storage (Buford and

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Stokes, 2000). The incorporation of masticated forest slash may provide protection from erosion, conserve moisture, and moderate soil temperature. Incorporating the masticated material by tilling the soil may also enhance soil structure and loosen the soil permitting improved air and water infiltration. Additionally, large amounts of C, phosphorus (P), and nitrogen (N) are contained in the forest floor (Van Lear et al., 1995; Richter et al., 1995) which, once incorporated, would increase their stocks in the mineral soil.

Incorporation of forest slash as a site preparation technique has been investigated for different tree species across the world (Smethurst and Nambiar, 1990; Gonclaves et al., 1999; Pérez-Batallion et al., 2001; Sanchez et al., 2000, 2007). Early results from these field studies have shown increases in soil C and nutrient stocks in addition to improved tree growth. However, these results were from early stand establishment and have not, to our knowledge, been extended later into the rotation. In this manuscript we examine the impacts on soil properties (C and macronutrient content, cation exchange capacity (CEC), pH, bulk density), tree nutrition (foliar nutrients) and stand development (stand volume) as a result of forest slash incorporation on two loblolly (*Pinus taeda*) pine plantations in the Southern United States, eight years after study installation.

2. Materials and methods

2.1. Study sites

The study was installed in October 1997 to compare mulching and tilling with conventional site preparation techniques on two sites: a wet pine flat with a sandy loam horizon over a clay horizon (mineral site) and a pocosin site with deep organic soil (organic site). The wet flat site soil is a Lenoir Loam (Aeric Paleaquult) that has a sandy loam horizon (ochric epipedon) over a clay (argillic) subsurface horizon. The pocosin is a Pantego Loam (Umbric Paleaquult) characterized by a moderately deep organic surface horizon (histic epipedon). The sites are located in the Lower Coastal Plain region of eastern North Carolina in Beaufort County. The area receives approximately 1350 mm of annual precipitation with 55 percent of the total generally received between April and September. Mean daily temperatures range between 2 and 30 °C with a mean winter temperature of 8 °C and a mean summer temperature of 25 °C. Existing loblolly pine plantations on the mineral and organic sites were harvested in January and August 1997, respectively. The trees were harvested with a conventional sawhead feller-buncher and rubber tired skidder operation. A whole tree chipper was used on site to chip hardwoods for fuel chips prior to transportation.

2.2. Treatments

The area was blocked based on logging traffic (e.g. visible soil compaction) and micro-elevation and had 4 blocks per treatment in close proximity to ensure uniformity of residual slash, stump size and distribution, and soil. Treatment plots were 40 × 40 m (0.16 ha) with a measurement area of 20 × 20 m (0.04 ha). A 10.1 m buffer (post-harvest condition) was left between all blocks and treatment plots. The study design was a randomized complete block having 4 blocks and 4 site preparation treatments. The treatments were:

- Control (CON): plot was left in post-harvest condition and flat planted.
- Conventional (CVN): one pass of a dozer with a KG V-blade to shear stumps and roll logging debris to the sides to clear the strip for bedding. Another dozer was used on the second pass to apply fertilizer and to bed with a disk bedding plow.
- Strip Mulch (SM): a Rayco[1] Model T275 Hydra-Stumper was used to install the treatment. The machine has a 2.4 m horizontal rotating drum with 36 attached swing hammers that mulched logging slash, stumps, and humus layer and mixed the woody biomass into the soil. The machine was track mounted and powered by a 205 kw engine. The Rayco™ hydra stumper mulching head was used to mulch all slash and stumps in a 2 m wide strip along the left and right side of the bed line. The resulting 4.0 m wide mulched strip was centered on the bed lines and was then incorporated into the beds by the disk bedding plow.
- Strip Mulch and Till (SMT): same as the SM treatment except that the Rayco ™ mulching head was set to till the soil to a soil depth of 20 cm prior to bedding.

The treatments resulted in a gradient of site and soil disturbance with the disturbance increasing in the order of CON < CVN < SM < SMT. The SM plots differed from the CVN plots in that the surface material was masticated prior to bedding. The SMT plots had the highest level of disturbance in that the masticated material was actively incorporated into the soil prior to additional mixing by bedding.

Two additional treatments were installed at the mineral site to examine the operational costs of different mulching techniques. The results of this comparison were presented by Sanchez et al. (2000). These treatments were replicated on two of the four blocks at the mineral site. The additional treatments were:

- Broadcast mulch with bedding treatment (BB): broadcast surface mulching all slash and stumps within the treatment plot followed by bedding.
- Broadcast mulch without bedding (BNB): identical to the BB treatment except that there was no bedding.

In addition to providing a cost comparison, these extra treatments allow a comparison of the effect of slash mastication (either left on the surface (SM treatment) or incorporated into the soil (SMT treatment)), as compared to unaltered slash (i.e., CON and CVN treatments), on stand development.

All plots were planted, in February 1998, with genetically improved loblolly pine. Seedlings were pre-treated with Pounce® (38.4%, v/v, Permethrine) insecticide at the nursery and monthly backpack foliar applications began in May 1998 to control Nantucket pine tip moth (*Rhyacionia frustrana*). Backpack applied chemical weed control was utilized across the entire experiment area to minimize competition effects. Arsenal® (Imazapyr) and Oust® (sulfometuron-methyl), at 292 and 146 ml ha^{-1}, respectively, were banded along the beds for herbaceous release in April 1998. Before the planting operation, diammonium phosphate was applied (banded) at a rate of 235 kg ha^{-1} which provided 44.8 kg ha^{-1} of elemental P and 39.2 kg ha^{-1} of ammonium.

2.3. Sampling

In February 2006, three soil samples were collected along a diagonal transect within each measurement plot at each site. The samples were collected with a hammer driven 6.3 × 30 cm soil sampler and soil cores were collected at the 0–15, 15–30, and 30–45 cm depths. At each point a sample was taken from both a bed and interbed (where applicable) location. The proportion of area

[1] The use of brands and trade names is for the convenience of the readers and does not imply an endorsement by the USDA Forest Service or Weyerhaeuser Company.

covered by beds was roughly measured to be approximately two thirds, and the average soil C and nutrient contents across the plots were calculated accordingly. For each soil core, bulk density determinations were made. For each plot, soil samples were composited by depth for C and nutrient analysis. All soil samples were air-dried, passed through a 2-mm sieve, and weighed. Subsamples of the composites were analyzed for total C and N by dry combustion with detection by thermal conductivity (NA 1500 Carlo-Erba CNS). Soil nutrients (P, calcium (Ca), magnesium (Mg) and potassium (K) were determined by extraction with Mehlich III solution and analysis on a Thermo Jarrell Ash 61E Inductively Coupled Plasma (ICP) spectrometer (Council on Soil Testing and Plant Analysis, 1992).

In January 2006, height (HT) and diameter at breast height (DBH) measurements were taken from each tree in the measurement plots for each of the study sites. Individual tree stem volume was estimated with the equation: Stem Volume = 0.000029 $\times$ DBH^2 $\times$ HT. This equation is a modification of the equation of Smalley and Bower (1968). Height measurements were done in meters and DBH measurements were done in centimeters resulting in stem volume calculations in cubic meters. The sum of the stem volumes within the measurement area gave an estimate of stand volume ($m^3\ ha^{-1}$) for each treatment at each study site.

In January 2006, foliar samples were collected from 3 trees per plot along a diagonal transect on each treatment plot for both sites. For each tree, second year foliage was collected from the upper third of the crown. For each plot, the collected foliage was combined in one sample bag. The foliage samples were oven-dried, ground and analyzed for C and N concentrations by dry combustion. Foliar nutrient concentrations were determined by placing 0.5 g of foliage samples at 450 °C for 4 h. The ashed samples were cooled in a closed furnace and then removed. Twenty milliliters of 20% HCl solution was added to the ash. After an hour, the samples were filtered through Whatman #2 filter paper and the filtrates were analyzed for total nutrients by ICP spectrometry.

2.4. Statistical analysis

The effects of residue treatment on soil and foliar properties and tree growth were tested by two-way analysis of variance (ANOVA) using PROC MIXED (SAS 2000). The mineral and organic sites were analyzed as separate experiments. Tukey's Paired Comparison Procedure was used to compare treatment means within a site. Statistical significance was considered at α = 0.05. The responses to the BB and BNB treatments at the mineral site were not statistically analyzed but the results were compared descriptively.

2.5. Results and discussion

2.5.1. Soil bulk density

Soil porosity will be altered by harvest operations and site preparation practices. Harvest operations can decrease soil porosity due to compaction from heavy machinery. Conversely, site preparation practices such as soil tillage and bedding will increase soil porosity. The net impact and duration of these contrasting processes is dependent on various factors including initial bulk density, soil texture, and soil hydrology (Page-Dumrose et al., 2006). Eight years after study installation, soil bulk density at the mineral site was generally lower on the bedded plots (CVN, SM, and SMT plots) as compared with the CON plots where no bedding was done (Fig. 1A) while the opposite trend was observed at the organic site (Fig. 1B). This was observed at each depth but was not a significant effect ($p > 0.05$) in any instance. These results are consistent with the early (1.5 years after study installation) observations at these sites (Sanchez et al., 2000).

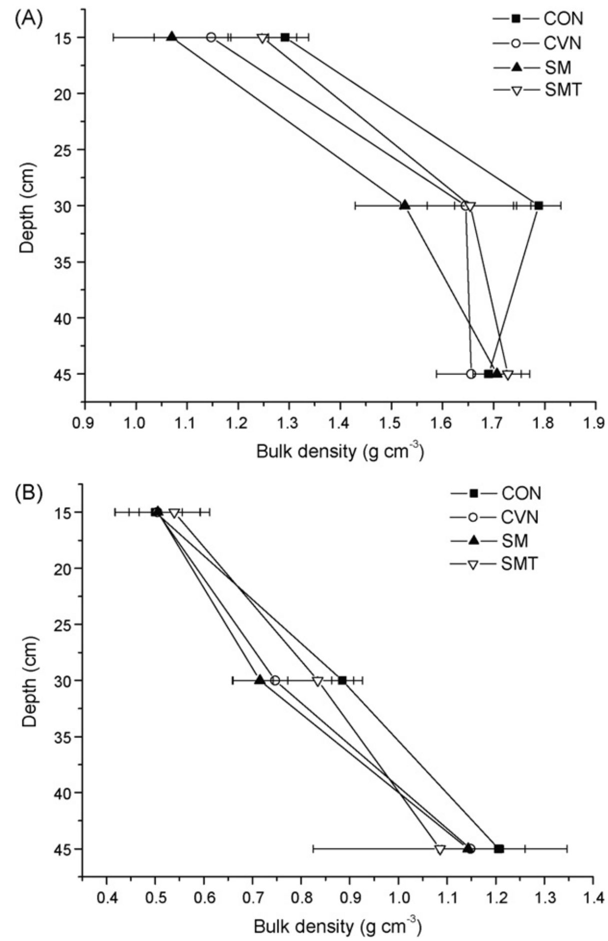

Fig. 1. Soil bulk density at the 0–15, 15–30 and 30–45 cm depths for each treatment plot at the (A) mineral and (B) organic sites on the North Carolina Lower Coastal Plain, eight years after study installation. Error bars represent standard error.

It is interesting to note that, although not significant, the bulk density of the SMT treatment plots was higher than that of the SM treatment plots on the mineral site. This is counterintuitive in which it could be expected that the greater mixing and incorporation of masticated slash on the SMT plots would result in lower bulk densities as compared with the SM plots. A potential explanation for this observation may be that there was accelerated heterotrophic respiration resulting in settling of soil particles and a natural densification of the soil (Gordon et al., 1987; Chen et al., 2000). This effect would be most likely on the drier mineral site as opposed to the wetter organic site where decomposition may be limited and the high water table may hamper settling of soil particles.

After eight years, the relative change in bulk density from the CON plots was greatest in the mineral site. Utilizing soils data from several sites that differed in soil texture, climate, hydrology, and soil series, Page-Dumrose et al. (2006) reported that soils that had higher initial bulk densities exhibited a smaller increase in bulk density despite concerted efforts to severely compact the sites. It stands to reason that the opposite would be true where sites with lower initial bulk densities (i.e., the organic site as compared to the mineral site) would exhibit a smaller decrease in bulk density due to bedding and/ or tillage as was observed in our plots (Fig. 1A and B).

2.5.2. Soil chemical properties

Despite the soil disturbance and manipulation from the treatments, there were generally no significant impacts on soil pH, CEC, and Ca, K and Mg contents for either site (Table 1), with

Table 1
Soil chemical properties at all depths for the mineral and organic mulching sites in the lower coastal plain of North Carolina collected in 8 years after establishment.

Treatment	Depth (cm)	pH	CEC (meq 100 g^{-1})	Ca (kg ha^{-1})	K (kg ha^{-1})	Mg (kg ha^{-1})
Mineral site						
CON[a]	0–15	4.65 (0.09)a[b]	20.02 (1.79)a	1018 (436)a	155 (25)a	150 (54)a
CVN	0–15	4.33 (0.08)a	23.95 (0.76)a	757 (156)a	133 (7)a	125 (12)a
SM	0–15	4.36 (0.08)a	23.33 (0.98)a	597 (82)a	131 (14)a	110 (13)a
SMT	0–15	4.44 (0.10)a	21.42 (0.60)a	806 (174)a	136 (5)a	131 (13)a
CON	15–30	4.65 (0.09)a	17.40 (0.49)a	549 (141)a	231 (8)a	174 (4)a
CVN	15–30	4.42 (0.06)a	22.31 (0.64)b	437 (75)a	196 (20)a	125 (12)b
SM	15–30	4.47 (0.07)a	20.57 (1.14)ab	396 (40)a	193 (20)a	133 (7)b
SMT	15–30	4.60 (0.13)a	18.32 (1.02)a	497 (51)a	191 (7)a	135 (7)b
CON	30–45	4.57 (0.13)a	21.18 (1.58)a	391 (62)a	317 (25)a	328 (41)a
CVN	30–45	4.45 (0.04)a	21.27 (0.41)a	370 (94)a	293 (29)a	232 (28)a
SM	30–45	4.39 (0.02)a	22.34 (1.04)a	502 (136)a	344 (55)a	316 (54)a
SMT	30–45	4.55 (0.10)a	22.14 (0.55)a	325 (15)a	324 (19)a	248 (11)a
Organic site						
CON	0–15	3.65 (0.09)a	34.83 (0.48)a	226 (39)a	83 (6)a	57 (7)a
CVN	0–15	3.57 (0.07)a	33.88 (0.71)a	208 (22)a	79 (14)a	56 (8)a
SM	0–15	3.76 (0.05)a	34.52 (0.67)a	212 (21)a	78 (8)a	59 (5)a
SMT	0–15	3.70 (0.07)a	34.24 (0.77)a	231	(36)a	90 (7)a
CON	15–30	3.75 (0.05)a	34.20 (0.49)a	168	(22)a	96 (11)a
CVN	15–30	3.64 (0.11)a	33.59 (0.50)a	191	(30)a	80 (12)a
SM	15–30	3.82 (0.03)a	34.28 (0.58)a	152	(22)a	59 (4)a
SMT	15–30	3.78 (0.08)a	33.62 (0.76)a	183	(24)a	80 (17)a
CON	30–45	3.90 (0.07)a	30.67 (0.89)a	132	(24)a	91 (17)a
CVN	30–45	3.89 (0.09)a	30.69 (0.76)a	150	(17)a	102 (22)a
SM	30–45	4.00 (0.05)a	31.04 (0.63)a	125	(21)a	92 (17)a
SMT	30–45	3.96 (0.08)a	31.63 (0.75)a	157	(43)a	95 (26)a

Standard errors are in parenthesis.
[a] Treatment codes are: CON = control, CVN = conventional, SM = strip mulch, and SMT = strip mulch and till.
[b] For each depth increment at each site, values within a column followed by the same letter are not significantly different at $\alpha \leq 0.05$ level.

the exception of small variations in the Mg content and CEC in the mineral site. At both sites, bedding generally increased extractable soil P contents (Fig. 2A and B); however, this effect was only significant at the 15–30 cm depth at the mineral site ($p = 0.012$). Bedding was not included as a separate factor in the statistical analysis; however, inferences can be made by comparing the bedded plots (CVN, SM and SMT) to the non-bedded plot (CON). Although not statistically significant, clear increases in extractable soil P contents relative to the CON treatment plot were seen for the bedded plots at both sites and at all depths. What is equally clear is that slash mastication with or without soil tillage (SM and SMT plots) offered no evident advantage in increasing nutrient stocks as compared to conventional (CVN plots) practices. The practice of bedding imparts a high level of soil physical disturbance, in addition to organic matter incorporation. Although the degree of soil disturbance follows the pattern of CON < CVN < SM < SMT, the bedding effect, as opposed to slash mastication and soil tillage, was the major contributor to the observed increases in extractable P contents for both sites.

Although not statistically significant, soil C content increased at each depth with bedding at the mineral site (Fig. 3A). There was no clear impact of bedding on soil C contents at the organic site (Fig. 3B). For the bedded plots at each site, slash mastication (SM and SMT plots) and soil tillage (SMT) did not demonstrate any consistent difference in soil C contents from the plots with non-altered slash (CVN) or non-tilled plots (SM and CVN). Soil N contents generally increased with bedding on the mineral plots and decreased on the organic plots (Fig. 4A and B); however, these differences were not statistically significant ($p > 0.05$) at any depth. Sanchez et al. (2000) reported similar trends for C and N early in the study; however, they hypothesized that the SMT treatment on the mineral site would eventually result in increased C and N sequestration in the soil. They reasoned that the observed increases in the proportion of C (and N) in the heavier (i.e., recalcitrant) density fractions were a harbinger of long-term soil C and N stabilization on these plots. Eight years into the study, the prediction of Sanchez et al. (2000) has not materialized with the SMT treatment demonstrating no significant difference from the other treatments. Soil organic matter pools are dynamic with C (and N) moving between labile and recalcitrant pools in response to soil disturbance until a new equilibrium is reached (Hassink and Whitmore, 1997; Jenkinson, 1990). It is probable that density fractions described by Sanchez et al. (2000) were in flux and had not yet reached an equilibrium state. Additionally, the density fractionation method used by Sanchez et al. (2000) and developed by Meijboom et al. (1995) called for solution densities of 1.37 and 1.13 g cm^{-3} to separate the light, medium and heavy fractions. Recently Sollins et al. (2006) was able to sequentially fractionate soil into eight fractions. The solution density range that they used was 1.65–2.50 g cm^{-3}, which they based on known mineral densities. If Sollins et al. (2006) are correct, it is possible that the heavy fraction that Sanchez et al. (2000) measured still contained light and medium fractions and thus was not an accurate indicator of C and nutrient stabilization at these sites.

Soil texture (especially clay and silt content) can affect the amount of C (and nutrients) that can be stabilized (Hassink and Whitmore, 1997; Six et al., 2002). The sandy nature of the soils in this study may hinder any long-term stabilization of soil C and nutrients. Also, the influence of climate on decomposition and C stabilization cannot be ignored. Sites with rapid decomposition rates, such as the sites in this study, are further limited in their potential to stabilize C (Six et al., 2002). Other mechanisms by which soil C can be stabilized include physical (aggregation, inclusion into small pore volumes) and biochemical (proportion of recalcitrant compounds such as lignin) protection (Balesdent et al., 2000; Six et al., 2002). These mechanisms were not explored in this experiment but may viable avenues to pursue in future studies.

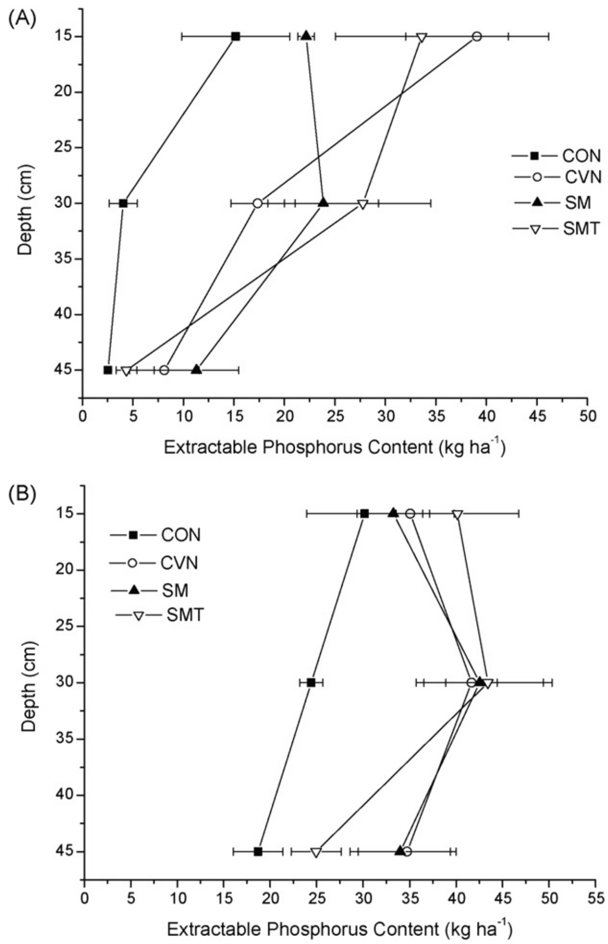

Fig. 2. Extractable soil phosphorus contents at the 0–15, 15–30 and 30–45 cm depths for each treatment plot at the (A) mineral and (B) organic sites on the North Carolina Lower Coastal Plain, eight years after study installation. Error bars represent standard error.

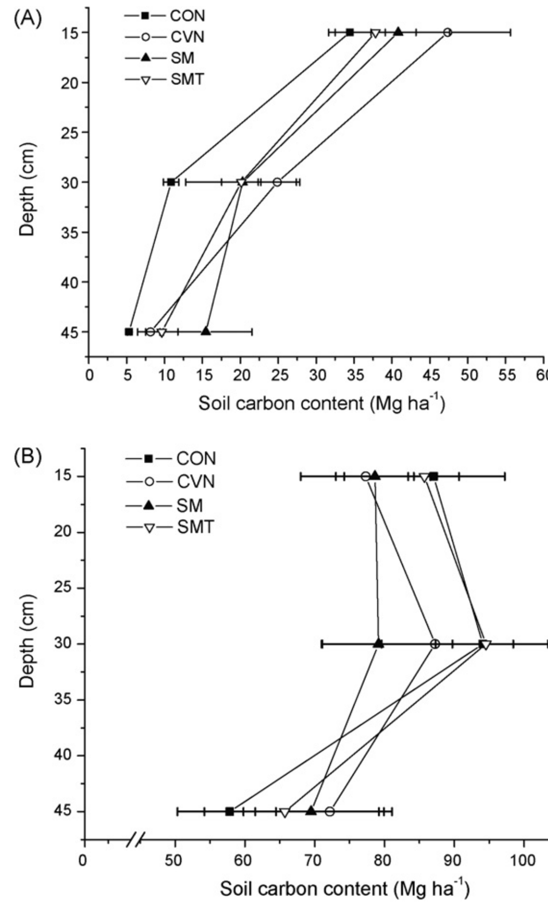

Fig. 3. Soil carbon contents at the 0–15, 15–30 and 30–45 cm depths for each treatment plot at the (A) mineral and (B) organic sites on the North Carolina Lower Coastal Plain, eight years after study installation. Error bars represent standard error.

2.5.3. Stand volume

At both sites, site preparation treatments that included bedding (CVN, SM and SMT) resulted in significantly higher stand volumes than the CON treatment (Fig. 5). However, there was no significant difference in stand volume between the unaltered (CVN), masticated (SM), and masticated and tilled (SMT) slash treatments. To more directly compare the effects of bedding on stand development at the mineral site, we compared stand volumes for plots with unaltered slash loads (CON versus CVN) and plots with masticated slash loads (BNB versus BB) (Fig. 6). In both comparisons, bedding increased stand volume; however, the effect was more pronounced in the unaltered slash plots (91% increase) than in the masticated slash plots (55% increase). An explanation for this discrepancy can be gleaned from comparisons between the flat planted plots (CON and BNB) and the bedded plots (CVN and BB) (Fig. 6). Mastication of the forest slash had a small effect on stand volume when the plots were bedded (6% increase) but a much larger effect when the plots were flat planted (30% increase). These results suggest that incorporation of organic matter, regardless of condition (i.e., unaltered or masticated), into the soil will improve stand growth. The observation that the flat planted plots benefited from mastication of the slash may be due to (1) alteration of soil moisture and temperate, (2) partial incorporation of masticated material, (2) increased soil disturbance resulting in C mineralization and nutrient release and (3) increased dissolved organic inputs from the masticated surface slash.

2.5.4. Foliar nutrients

Potential limitations in future stand development resulting from the treatments may be ascertained from inadequacies in foliar nutrition even when these limitations are not evident in tree growth measurements (Powers et al., 2005; Sanchez et al., 2006a,b). However, considering that there were few significant differences in soil nutrients in this study, it is not surprising that there were very little differences in foliar nutrients at each site (Table 2). At the mineral site, there were small increases in foliar P and Mg and small decreases in foliar K with bedding. At the organic site, only small increases in foliar N with bedding were observed. Foliar nutrient concentrations at both sites were near or above critical values for loblolly pine (Allen, 1987) and thus the small differences observed were probably not biologically relevant. No significant ($p > 0.05$) differences for any given element were observed at either site between the masticated (SM and SMT) and/or tilled (SMT) treatment plots as compared to the CVN treatment plots.

2.6. Conclusions

Preparing a site for forest plantings can be an expensive proposition (DuBois et al., 1997; McNabb, 1998) and landowners must have sufficient incentive to undertake these costs. The promise of increased productivity and increased soil C and nutrient stocks through the incorporation of harvest slash residues may be such an incentive. However, this study has demonstrated that these promises are not necessarily realized in loblolly pine stands on the North Carolina Lower Coastal Plain and thus does not justify

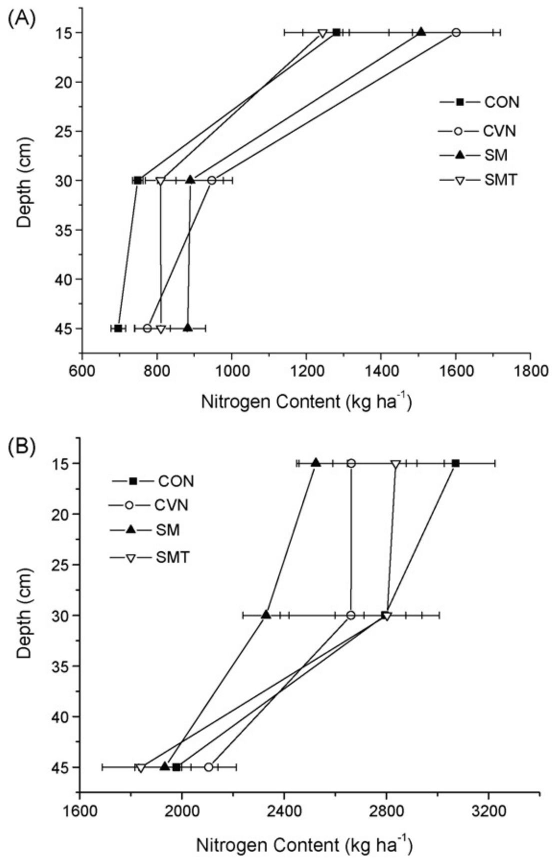

Fig. 4. Soil nitrogen contents at the 0–15, 15–30 and 30–45 cm depths for each treatment plot at the (A) mineral and (B) organic sites on the North Carolina Lower Coastal Plain, eight years after study installation. Error bars represent standard error.

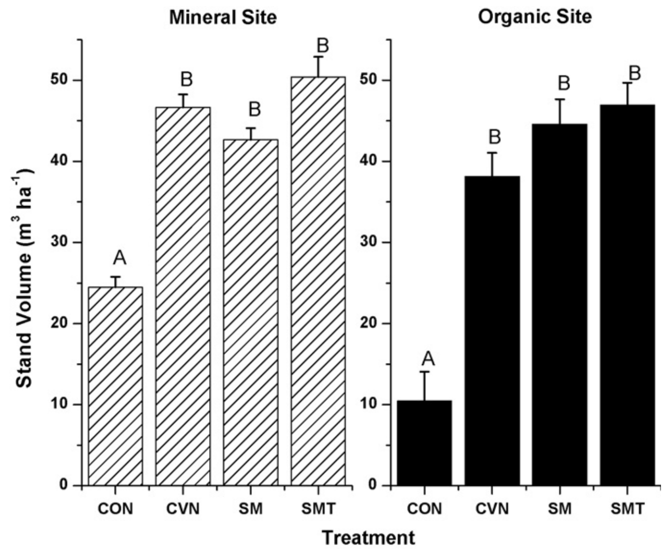

Fig. 5. Mean stand volumes for each treatment plot at the mineral and organic sites on the North Carolina Lower Coastal Plain, eight years after study installation. Error bars represent standard error. For each site, bars topped with the same letter are not statistically different at the $\alpha < 0.05$ level.

the increased costs. Sanchez et al. (2000) determined that the operational costs per hectare for the CVN, SM and SMT treatments were $196, $217 and $356 on the mineral site and $301, $337 and $471 on the organic site. These cost estimates were done in 2000; however, in today's market, these costs would probably be considerably higher, and more of a consideration, as a result of the increases in fuel costs. At these sites, the conventional practice of V-shearing followed by bedding and fertilization (CVN treatment) significantly improved stand growth over doing nothing (CON treatment); however, further increasing the intensity of the treatments by slash mastication (SM treatment) and soil tillage (SMT treatment) did not result in sufficient improvements that would justify the additional costs of treatment installation. These trends were also consistent for most of the soil and foliar measurements taken.

Despite the soil disturbance and slash incorporation, it is surprising that such a minimal impact was observed in soil properties and stand development. The primary treatment impact came from bedding and not from whether the slash was masticated or tilled into the soil. This effect is probably due to changes in soil moisture, temperature and aeration which were not addressed in this study. The lack of any significant soil C changes at year eight suggest that the early observations of Sanchez et al. (2000) were a result of increases in the labile soil C pool which was later respired as carbon dioxide. If slash mastication and incorporation into the soil is to be further investigated as a potential means of increasing soil C and nutrient stocks, a careful evaluation of additional factors (i.e., soil texture, soil aggregation, substrate quality) that impact soil C sequestration must be considered in developing an effective silvicultural strategy. As such, for the soils and sites investigated in this study, slash mastication and incorporation are not effective means of increasing long-term soil C and nutrient stocks and aboveground growth and do not justify the additional expense for treatment application.

Table 2
Foliar nutrients ($n = 4$) for the mineral and organic mulching sites in the lower coastal plain of North Carolina collected in 8 years after establishment.

Treatment	C (%)	N (%)	P (ppm)	Ca (ppm)	K (ppm)	Mg (ppm)
Mineral site						
CON[a]	53.4 (0.1)a[b]	1.23 (0.04)a	939 (13)a	3224 (296)a	4725 (177)ab	1115 (64)a
CVN	52.9 (0.1)a	1.28 (0.02)a	1151 (46)b	3609 (247)a	5062 (201)a	1297 (51)ab
SM	52.9 (0.1)a	1.16 (0.03)a	996 (52)a	3678 (247)a	4356 (90)b	1249 (24)ab
SMT	52.8 (0.2)a	1.20 (0.03)a	1097 (21)b	3859 (188)a	4397 (103)b	1317 (39)b
Organic site						
CON	53.6 (0.1)a	1.12 (0.03)a	1178 (12)a	3047 (125)a	4505 (493)a	910 (39)a
CVN	53.0 (0.1)a	1.19 (0.03)ab	1229 (56)a	2906 (125)a	4178 (249)a	1004 (90)a
SM	53.0 (0.2)a	1.30 (0.02)c	1291 (28)a	3284 (248)a	4557 (180)a	1075 (89)a
SMT	53.0 (0.1)a	1.26 (0.02)bc	1211 (36)a	2640 (263)a	4356 (219)a	933 (48)a

Standard errors are in parenthesis.
[a] Treatment codes are: CON = control, CVN = conventional, SM = strip mulch, and SMT = strip mulch and till.
[b] For each site, values within a column followed by the same letter at not significantly different at $\alpha \leq 0.05$ level.

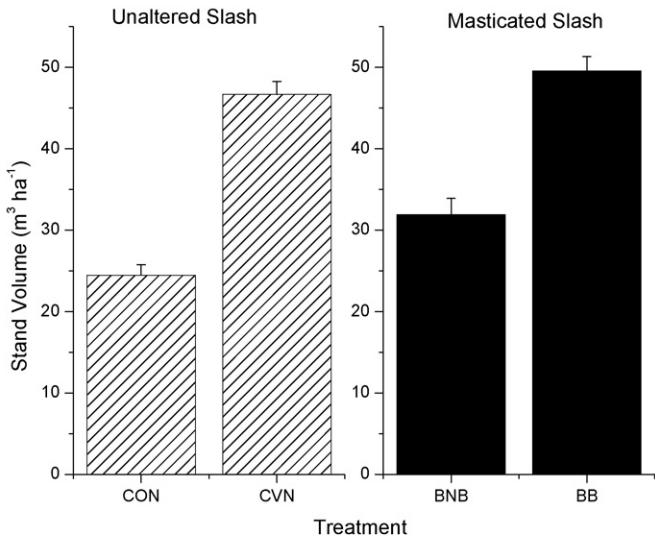

Fig. 6. Mean stand volumes, at year eight, on the mineral site on the North Carolina Lower Coastal Plain for treatment plots with unaltered and masticated slash. Error bars represent standard error.

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