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# Soil carbon and nitrogen content and stabilization in mid-rotation, intensively managed sweetgum and loblolly pine stands

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ABSTRACT

Intensive forestry has resulted in considerable increases in aboveground stand productivity including foliar and belowground biomass which are the primary sources of soil organic matter. Soil organic matter is important for the maintenance of soil physical, chemical and biological quality. Additionally, sequestering carbon (C) in soils may provide a means of mitigating increasing atmospheric carbon dioxide concentrations. In this study, we examined soil C and nitrogen (N) contents and stabilization in 12-year-old, intensively managed sweetgum (*Liquidambar styraciflua* L.) and loblolly pine (*Pinus taeda* L.) stands. The treatments examined include: (1) complete weed control; (2) weed control plus drip irrigation; (3) weed control plus drip irrigation and fertigation; and (4) (pine only) weed control plus irrigation, fertigation, and pest control. C and N stabilization was analyzed sequentially by fractionating the soil samples into six fractions using solutions of increasing density. These fractions represented increasingly stable organic matter pools. There was a trend towards increasing C and N contents with increasing management intensity that increase stand productivity; however, these differences were only significant for soil C content in sweetgum. Across all the sweetgum plots, soil C content generally increased with basal area (BA); no such relationship was found in loblolly pine although its BA was equal or higher than that of sweetgum. Generally, across all depths most C was found in the two lightest and in the heaviest fractions. These results suggest that changes to soil C due to increased forest management intensity which increases forest productivity, when they did occur, mostly did not change the percentages of C among soil density fractions over the 12 years of the experiment suggesting minimal inputs of recalcitrant C into the soil; however, even these transient changes may be still be important if intensive management is maintained over subsequent rotations.

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## 1. Introduction

Forests sequester carbon (C) occurs both *ex situ* and *in situ* (Johnsen et al., 2001). *Ex situ* C sequestration largely stems from the lifespan of products produced from harvested biomass (Skog and Nicholson, 1998; Skog, 2008). *In situ* C sequestration takes place above- and below-ground and is related to management activities that increase productivity and/or alter C allocation (Johnsen et al., 2001). Such intensive management strategies include activities such as cultivation, understory control, irrigation, fertilization and pest control. These strategies have resulted in considerable gains in forest productivity (Samuelson et al., 2008; Vance and Sanchez, 2006). However, the impact of these forest management strategies on belowground C dynamics is still unclear. In particular, the effect on C contained in soil organic matter is largely unstudied and can be difficult to detect (Johnsen et al., 2004). Besides its role in C sequestration, soil organic matter is critical for the maintenance of soil physical, chemical, and biological quality (Doran and Parkin, 1994; Stevenson, 1994; Jurgensen et al., 1997; Nambiar, 1997; Grigal, 2000). However, the mechanisms that control the internal cycling of soil organic matter are complex with multiple factors acting independently and in concert to impact C sequestration (Stevenson, 1994). Forest soil C levels are predicated by the balance between inputs and losses, which vary by climate, disturbance regime, plant and microbial community composition and activity, soil parent material, and time (Raich and Schlesinger, 1992; Jenny, 1994; Hanson et al., 2000; Ågren et al., 2001).

In forested ecosystems, soil organic matter primarily originates from two sources, forest floor leachates and belowground roots, and their subsequent turnover, both of which are directly affected by the net primary productivity (NPP) of the stand. Generally, with regards to mineral soil C, belowground C inputs outweigh the

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contributions from the forest floor. As the forest floor decomposes, C tends to be lost as $CO_2$ and consequently is a minor contributor to mineral soil C pools (Richter et al., 1999; Sanchez et al., 2006). What primarily determines forest soil organic C levels are contributions from roots via fine root turnover. Estimates of the net annual carbon budget of a tree relegated to root growth and maintenance are disputed but range from 20% to 65% (Persson, 1979). Any changes in the amount of C allocated to the root system will coincidently affect the amount of fine root material entering the soil organic matter pool. Fertilization has been shown to decrease loblolly pine fine root biomass (Maier and Kress, 2000) but increase turnover (King et al., 2002) on a nutrient deficient site. Coleman (2007) reported increases in fine root biomass with increasing resource availability for loblolly and sweetgum. Samuelson et al. (2004a, 2008) demonstrated that increasing management intensity on loblolly pine (*Pinus taeda* L.) stands in Georgia increased above- and belowground (coarse root) biomass and foliar biomass in loblolly pine. Similar results were detected by Coleman (2007) in a study examining the effects of irrigation and fertilization on four woody crop species (sweetgum (*Liquidambar styraciflua* L.), loblolly pine, American sycamore (*Platanus occidentalis* L.) and eastern cottonwood (*Populus deltoidies* Bartr.). Thus, any land management that increases NPP, also potentially increases the organic matter input into the soil.

In contrast to mineral soil C, the forest floor is a major contributor to mineral soil nitrogen (N) pools with fine root turnover being the other major contributor (Keeney, 1980; King et al., 2002). Nitrogen can be sequestered in the forest floor (Gholz and Fisher, 1982; Piatek and Allen, 2001; Powers et al., 2005) and is an important nutrient source for forest soils as the litter layer decomposes (Raison et al., 1987; Stump and Binkley, 1993). An exogenous nutrient supply, whether from the forest floor, throughfall, or applied through fertilization, can influence the rate of decomposition and the litter's nutrient release pattern. Fertilization has been found to increase litter decomposition rates (Prescott et al., 1992; White et al., 1988) and N accumulation in decomposing litter (Titus and Malcolm, 1987). Additionally, initial nutrient concentrations in litter, the endogenous nutrient supply, may also influence decomposition and nutrient dynamics. Berg et al. (1987) found that needles with higher initial nitrogen concentrations released N more rapidly but maintained higher N concentrations than needles with lower initial N concentrations. Thus, fertilization, besides increasing the growth of the current rotation, may increase productivity of subsequent rotations increasing C sequestration.

In addition to the simple quantity of soil C and N, its qualitative characteristics are important. By sequentially separating soil organic matter into fractions of increasing density, a profile of C and N stabilization emerges which can be used to better understand effects on soil organic matter in response to forest management activities. As Sollins et al. (2006) hypothesized and displayed, soil organic matter fractions with lower densities are more labile and transient than higher density fractions because higher density fractions "layer" organic matter onto an inner organic layer made up of peptidic and lignin-exchanged carboxylic compounds of which other organic compounds can sorb more readily onto. Using soil collected from a mixed Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*) stand, carbon mean residence time increased from ranged from 150 to >950 years from the lightest to the heaviest fractions measured (Sollins et al., 2006). As such, increases in fraction densities represent a gradation from active to passive C pools as described by Parton et al. (1987). Thus, shifts in C and N to higher density soil organic matter fractions indicate a relative stabilization effect, namely increased recalcitrance.

The first objective of this study was to quantify soil C and nitrogen (N) contents in sweetgum and loblolly pine stands under varying degrees of intensive management to determine the impact of management intensity and tree species on soil C and N contents 12 years after planting. A second objective was to explore whether any changes in the soil environment brought on by the treatments resulted in a change in the stabilization of the soil C and N. To determine the relative stability of the C and N stocks for the different treatments and tree species, we sequentially fractionated the soil samples into six fractions of affording differing stability. The study site is unique in that physiology of above and belowground (coarse root) growth of loblolly pine have been monitored for 11 years (Samuelson, 1998; Butnor et al., 2003; Samuelson et al., 2001, 2004b, 2008; Samuelson and Stokes, 2006), but management effects on soil C and N have not been investigated in either species until this point.

## 2. Materials and methods

### 2.1. Site description

In January 1995, International Paper Incorporated established a 15 ha research site in the Upper Coastal Plain (30°82′N, 84°76′W) on previously agricultural land. Mean annual precipitation and 24 hour temperature for the region are 1257 mm and 18.9 °C, respectively (Ruffner, 1980). The soils at the site were classified as sandy loam, well-drained Grossarenic Paleudults. For the native site, site index at base age 25 years was 18 m for loblolly pine.

In August 1994, soils were ripped to a 45 cm depth with a single-shank subsoiler and disc-harrowed the following November to eliminate soil compaction. Herbaceous vegetation was controlled using a broadcast spray of 1.5% (v/v) aqueous glyphosate solution applied in July and September 1994. The sweetgum plots and loblolly pine plots were adjacent to each other and are considered separate experiments. Treatment plots were arranged in randomized complete block designs with four treatments (three for sweetgum) and three replicates (blocks) and, on separate sub-plots, four loblolly pine improved second generation families and two sweetgum provenances. Growth and physiology of loblolly pine family 7–56 has been studied since planting to age 11 (Samuelson et al., 2008) and growth and physiology of one sweetgum provenance was monitored until age 4 (Samuelson et al., 2001). These same sources were examined in this study. Loblolly pine and sweetgum seedlings were assigned to separate 0.20 ha treatment plots within a block and hand-planted at a 2.4 m × 3.7 m spacing in January 1995. The measurement plot per species, family and treatment consisted of 28 trees in pine and 56 trees in sweetgum. Four treatments were applied and randomly assigned to treatment plots within the three blocks. The treatments were:

1. W: complete weed control maintained using a broadcast application of sulfometuron (0.1 kg $ha^{-1}$) and repeated applications of a 15% (v/v) aqueous glyphosate solution.
2. WI: weed control plus drip irrigation (Netafim Irrigation Inc., Altamonte Springs, FL) from March through December. Drip lines ran along tree rows on the south side of each tree.
3. WIF: weed control plus drip irrigation and fertigation (addition of a fertilizer solution to the irrigation water). Addition of fertilizer to the irrigation water began in May and continued through October. Annual applications of water and fertilizer over the first 10 years of the study are shown in Table 1.
4. WIFP: (pine only) weed control plus irrigation, fertigation, and pest control. Fusiform rust (*Cronartium quercuum* f. sp. *Fusiforme* ((Berk.) Miy. *ex* Shirai)) was controlled with applications