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The effect of fertilization levels and genetic deployment on the isotopic signature, constituents, and chemistry of soil organic carbon in managed loblolly pine (*Pinus taeda* L.) forests ☆

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ABSTRACT

Soil organic carbon (SOC) mass and its constituents, chemistry, and isotopic signatures ($\Delta^{14}C$, $\delta^{13}C$) were examined for two different loblolly pine (*Pinus taeda* L.) research installations located in north-central Florida. Both studies were designed as split-plots with the whole plots as different levels of fertilization and herbicide application (cultural intensity), and full-sib families of loblolly pine were the splits. The cultural intensities and the families of loblolly pine were different at each site and so each site was analyzed separately. The plantations were aged 9 or 10 years at the time of soil sampling. At both sites, the overall mass of SOC to a depth of 0–30 cm was unresponsive to the level of family growth or cultural intensity and did not show a trend with aboveground biomass. The SOC pool was further separated into live roots and wood; and density fractionation was used to separate the SOC sample into a light fraction (LF) (<1.7 g cm^{-3}) and heavy fraction (HF) with the LF dissected further for charcoal and dead roots. Higher fertilization levels generally depressed fine root (<1 mm) biomass, but whether the effect was significant varied with family and soil horizon. The HF was a relatively small component (<5%) of SOC in these sandy textured soils, but at one of the two sites, the HF was significantly increased with more intensive silviculture and for the faster growing family. The $\Delta^{14}C$ value of the LF-SOC for one slow growing family under low culture (136 ± 11‰) differed from the faster growing low culture plot, and its relationship to the atmospheric $\Delta^{14}C$ record suggested that the LF-SOC likely originated prior to stand establishment. The LF chemistry was determined with solid-state ^{13}C nuclear magnetic resonance (NMR) and cultural intensity did not significantly affect SOC chemistry. However, the family effect was significant for carbohydrates at one site, and for lignin and lipids at the other site. Overall, these results suggest that tree genetics in managed forests can influence SOC chemistry and that the relatively small fractions of SOC can change with management intensity; however, the effect of cultural intensity is minimal for the largest components of SOC and there is no clear relationship between SOC dynamics and aboveground production under the management regimes, and stand ages, examined with these two research installations.

1. Introduction

The forests of the southeastern United States are important to the region's C cycling, offsetting nearly 13% of annual anthropogenic CO_2 emissions through C sequestration (Han et al., 2007). The region's forests are changing; however, with a growing proportion of the land base that was once unmanaged woodland now being intensively managed pine forests (Wear and Greis, 2002). Intensive pine forest management involves silvicultural practices such as fertilization, the control of competing vegetation,

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and the planting of genetically-improved seedlings. These practices are used because they increase net primary production, which could affect regional C budgets through sequestration in long-lived wood products and by shortening the time before peak biomass is reached (Gan et al., 2012). In addition, soil organic carbon (SOC) response to these treatments could be beneficial to C sequestration as some studies have observed increased SOC with fertilization (Shan et al., 2001; Vogel et al., 2011). Alternatively, a negative trend in SOC has been observed with intensive weed control (Shan et al., 2001; Echeverría et al., 2004). Tree genetic makeup has also been shown to shift soil structure and C distribution in SOC fractions in as few as 6 years after planting (Sarkhot et al., 2008). Together these studies suggest that management approaches may change the SOC dynamics of managed forests, potentially altering the degree that these forests offset anthropogenic emissions of CO_2.

Forest management approaches are designed to increase forest productivity, as a result, the practices will also mostly increase the rate of C input to SOC. Silvicultural treatments increase aboveground productivity, and with this change the rate of canopy development and self-thinning rates, resulting in increased needle and wood litter inputs to the surface SOC (Jokela and Martin, 2000). Leaching of dissolved organic carbon to surface mineral soils may also increase with organic layer thickness, and belowground inputs to SOC as coarse root fractions would increase with tree size (Jenkins et al., 2003). In contrast to aboveground components of the C cycle, fine root production with fertilization in managed loblolly pine forests can decrease (Maier and Kress, 2000) or increase (King et al., 2002). The elimination of competing understory plants has been shown to decrease root biomass in managed pine stands (Shan et al., 2001). In comparison to silvicultural practices, the effects on belowground processes by the deployment of specific genotypes is less studied for southern pine forests, but Tyree et al. (2014) found that variation in aboveground characteristics for different genotypes of loblolly pine corresponded to variation in both soil CO_2 efflux and heterotrophic respiration.

Losses of C from SOC will be directly affected by how silvicultural practices influence microbial activity as it responds to changes in nutrient availability, the chemistry and abundance of different substrates, and soil structure. For nutrient availability, microbial response to N additions has been extensively studied, but the results have been mixed. Many studies have observed a suppression of the microbial enzymes that are focused on recalcitrant materials (e.g. lignin) (Neff et al., 2002; Keeler et al., 2009), while the decomposition of more easily decomposed materials (e.g. cellulose) has either increased or not changed (Sinsabaugh et al., 2005; Grandy et al., 2008). In grain agricultural systems, SOC has sometimes increased with fertilization (Luo et al., 2010), but the effect is often dependent on the soil depth examined (Khan et al., 2007). Similar to cereal cropping systems, intensively managed southern pine forests are often fertilized with both N and P together (Fox et al., 2007), with K and other macronutrients (Carlson et al., 2014), or in a mixture that includes micronutrients (Vogel and Jokela, 2011); these varied nutrient additions could cause significant deviation from what has been commonly observed for N alone. Nutrient additions may also indirectly affect the chemistry of what substrate is deposited because of changes in relative allocation between roots and aboveground litter (King et al., 2002), which might shift among different genotypes of loblolly pine (Tyree et al., 2014). The chemistry of litter tissues is also directly affected by competition control, which generally removes deciduous species that often have a tissue chemical makeup that results in faster decomposition. In contrast, native SOC from deciduous forests can have lower rates of microbial respiration rates than SOC from coniferous forests (Fissore et al., 2008). Genotypes of loblolly pine will naturally have differences in tissue chemistry, with a commonly planted genotype in managed forests having a variant in the lignin concentration of wood (Ralph et al., 1997). Moreover, resin production is under significant genetic control and increases with the rate of tree growth (Westbrook et al., 2013).

Forest management in the southeastern United States generally involves the varied use of multiple practices (fertilization, competition control, genetic deployment) to increase tree productivity. Because these silvicultural practices are applied in range of ways that make it difficult to relate binary treatment designs (e.g. fertilization vs. no-fertilization) to actual forestry practices, the overall objective of this research was to determine if the level of tree productivity brought about by silvicultural intensity (fertilization levels, competition control) and the genetic deployment of specific families of loblolly pine affected the accumulation of SOC, and the chemical makeup of SOC. Two sites that had contrasts in silvicultural experiments and that incorporated two replicate family blocks × silvicultural intensity treatments were studied in north-central Florida. Previous research in one of the proposed research sites indicated that both Fertilization and Family influenced soil aggregate formation and stabilization in as few as 4 years (Sarkhot et al., 2007a,b, 2008). We hypothesized that increased aboveground productivity would correspond to an increase in soil C amounts and that this change would be reflected in changes in chemistry and a shift in the radiocarbon signatures of SOC towards modern atmospheric values.

2. Methods

The two research sites are part of a series of experiments established by the University of Florida's Forest Biology Research Cooperative. These experiments were designed to test the effects of relative levels of management intensity and genetic deployment on forest growth. One study site was located northeast of Gainesville, FL, in the Austin Carey Experimental Forest (ACF) (29°44′58″N, 82°13′03″W). The other study site was located near Sanderson, FL (30°14′25″N, 82°19′54″W). The areas have a similar average temperature of 20 °C, with Lake City, FL approximately 14 km west of Sanderson having an average precipitation of 1360 mm and Gainesville, FL approximately 8 km from ACF having an average precipitation of 1228 mm (National Climate Data Center, 1971–2000). Both studies were established on poorly drained Spodosols (Pomona and Leon series for the ACF and Sanderson sites, respectively) (USDA Soil Survey Staff). The Pomona series is classified as a sandy, siliceous, hyperthermic Ultic Alaquod, while the Leon series is classified as a sandy, siliceous, thermic Aeric Alaquod. The Pomona series has a Bh (spodic) horizon within 74 cm of the surface and a Btg (argillic) horizon at a depth of 130 cm. The Leon series has a Bh horizon within 38 cm of the surface, but does not contain an argillic horizon.

Both of the studied forests were previously slash pine (*Pinus elliottii* Engelm *var. elliottii*) forests, and after the initial harvest a raised bed was created with a harrow plow. The beds at the high and low intensity Sanderson plots, and the high intensity ACF plots received two passes of the plow, and the low intensity ACF plot received one pass of the plow. The loblolly pine was hand planted, with the Sanderson site planted in January 2000 and the ACF site planted in December 2000, resulting in a 1-year difference in stand age. The high and low intensity treatments were both treated before planting with the herbicides Chopper® (imazapyr) and Garlon® (triclopyr) at manufacturer-prescribed rate listed on the packaging. After the initial planting, divergent levels of fertilization and herbicide control were implemented in order to create variation in management intensity that could be used to assess tree growth response. At both sites, the high intensity management