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# Whole-tree and forest floor removal from a loblolly pine plantation have no effect on forest floor $CO_2$ efflux 10 years after harvest

John R. Butnor *, Kurt H. Johnsen, Felipe G. Sanchez

*USDA Forest Service, Southern Research Station, 3041 Cornwallis Road, Research Triangle Park, NC, USA*

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**Abstract**

Intensive management of southern pine plantations has yielded multifold increases in productivity over the last half century. The process of harvesting merchantable material and preparing a site for planting can lead to a considerable loss of organic matter. Intensively managed stands may experience more frequent disturbance as rotations decrease in length, exposing the stands to conditions that favor decomposition. To better understand the effects of organic matter removal on forest floor $CO_2$ efflux ($S_{ff}$), we measured $S_{ff}$ quarterly in 2001 in a 10-year-old loblolly pine (*Pinus taeda* L.) plantation in eastern North Carolina that received different harvest and site preparation treatments. The treatments examined were removal of merchantable bole ($OM_0$) and whole-tree and forest floor removal ($OM_2$). The organic matter removal treatments did not affect soil moisture or soil temperature, the major variables that control seasonal fluctuations in $S_{ff}$. Mean $S_{ff}$ ranged from 2.23 to 6.63 $\mu$mol $m^{-2}$ $s^{-1}$ and there were no significant differences between the treatments, despite higher lateral root mass in $OM_0$ ($1552 \pm 427$ g $m^{-2}$) versus $OM_2$ ($701 \pm 86$ g $m^{-2}$). In both treatments, $S_{ff}$ did not correlate to root mass directly beneath each measurement chamber. In $OM_0$, $S_{ff}$ had a negative relationship with distance from the nearest tree, while $OM_2$ showed no effect of tree proximity. Whole-tree and forest floor removal during harvest and site preparation did not result in differences in $S_{ff}$ or soil C, 10 years after establishment. Both treatments resulted in a greater quantity of soil C, indicating that the disturbance associated with harvesting enhanced soil C, at least over the short term. We attribute this increase in soil C to rapid decomposition of previous stands root system.
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*Keywords:* Soil respiration; Soil C; Organic matter; Root mass; LTSP

## 1. Introduction

Soil $CO_2$ efflux is the main pathway for carbon (C) to move from terrestrial pools to the atmosphere, making it an integral part of the global C cycle (Schlesinger and Andrews, 2000). On a smaller scale, soil $CO_2$ efflux dynamics are monitored to determine whether a specific land use or management practice cause a system to be a source or a sink for atmospheric C (Maier and Kress, 2000; Maier et al., 2004). In managed pine systems that are subjected to frequent cycles of planting and harvesting, it is critical that management be conducted so that productivity is sustainable over time. One method to gain timely insight into long-term sustainability is to measure aboveground production over time, indexed to key soil attributes such as nutrient concentrations and cycling, and physical properties (i.e. bulk density). Detrimental impacts on these soil components might predict a reduction in future productivity. Assessing forest floor $CO_2$ efflux ($S_{ff}$) in conjunction with soil nutrient pools can provide further insight into management impacts on critical soil processes.

At harvest, substantial quantities of organic matter are removed and destined to become merchantable wood products. The quantity removed from managed pine plantations depends on the degree of tree utilization and the intensity of site preparation to regenerate the stand. Utilization may be limited to merchantable boles or, in the case of biomass harvesting, can include all tree components. Mechanical site preparation is used to improve the conditions for planting, seedling survival and reduce competition from woody vegetation. Site preparation can take many forms; drum chopping, disking, bedding, windrowing of debris, raking etc. and are selected to ameliorate specific site factors that limit tree growth. Site preparation is responsible for the largest gain in productivity over unmanaged, naturally regenerated southern pine forests (Stanturf et al., 2003). Practices that remove large quantities of organic matter (slash, forest floor, topsoil) are removing nutrients sequestered

* Corresponding author. Tel.: +1 802 951 6771; fax: +1 802 951 6368.
*E-mail address:* jbutnor@fs.fed.us (J.R. Butnor).

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in those materials and may limit long-term productivity (Johnson et al., 1982; Fox et al., 1989; Johnson, 1992; Stanturf et al., 2003).

There is no general trend for harvesting to reduce soil C in forests, the greatest impact comes from land use change from forest to pasture or agricultural production (Detwiler, 1986; Johnson, 1992). The effects of site preparation on soil C depend on the severity of disturbance, the type of preparation and the preexisting soil nutrient content (Sun et al., 2004). Except for practices, which incorporate harvest debris back into the soil, some loss of soil C is expected with site preparation and the early stages of reforestation (Johnson, 1992). Intensively managed sites will experience more frequent disturbances for site preparation as rotation ages decrease, exposing the sites to conditions that favor decomposition (increased forest floor temperature and moisture) until canopy closure occurs (Gough et al., 2005). As intensely managed plantations become more productive, larger quantities of C and nutrients will be sequestered in trees and removed at harvest (Powers et al., 1990).

Maintaining soil productivity is essential to managing for sustainable forestry and is the preferred outcome on both public and private lands. To better understand the effects of different levels of organic matter removal during harvesting and reestablishment of a pine plantation on soil $CO_2$ efflux, we measured $S_{ff}$ quarterly in a loblolly pine (*Pinus taeda* L.) plantation subjected to two organic matter removal levels. The objectives of this study are to determine if lasting effects of organic matter removal from a loblolly pine plantation can be detected in $S_{ff}$, root biomass, soil C and nitrogen (N) 10 years after the disturbance and subsequent re-establishment of the new stand.

## 2. Materials and methods

### 2.1. Study site and treatments

This study was conducted at the Croatian National Forest in Craven County, North Carolina. The site is located in the North Carolina Coastal Plain, has a mean annual temperature of 16 °C and receives 1360 mm of precipitation. The site was established in 1991 to support the Long Term Soil Productivity study (LTSP), which quantifies the impact of soil compaction and organic matter removal on forest productivity in the United States and Canada (Powers et al., 1990). Prior to harvesting the existing 60-year-old pine-hardwood forest, three replicated blocks were established. Block 1 was located in the Goldsboro soil series (fine-loamy, siliceous, thermic Aquic Paleudults), while blocks 2 and 3 were in the Lynchburg series (fine-loamy, siliceous, thermic aeric Paleudults). Within each block, nine experimental plots (0.4 ha) were established representing a $3 \times 3$ factorial of organic matter removal and compaction treatments. Three graduated levels of organic matter removal were applied during the harvest of the existing forest: removal of merchantable bole ($OM_0$), whole-tree removal ($OM_1$), and whole-tree and forest floor removal ($OM_2$), resulting in biomass losses of 146, 168 and 223 mg/ha (Powers et al., 2005). Compaction treatments were: no compaction ($C_0$), moderate compaction ($C_1$), and severe compaction ($C_2$). To achieve the desired compaction level, plots were compacted with one pass of a smooth drum vibrator roller without vibration for the $C_1$ treatment. The $C_2$ treatment received two passes with full vibration. Surface organic matter was removed before compaction so mineral and organic components would not be mixed. After compaction, the organic matter was redistributed on the plot. Heavy equipment was restricted from the $C_0$ treatment plots during harvesting and site preparation.

Once the primary treatments were created, half of each plot was maintained with complete weed control (mechanical and chemical (Accord, Arsenal and Oust[1])) the other half received no weed control. The plots were then planted with loblolly pine bare-root seedlings on a 3 m × 3 m spacing. We chose to study $S_{ff}$ in the $OM_0$ and $OM_2$ to cover the range from typical to severe organic matter removal. Findings on several LTSP installations indicated that soil compaction was short-lived and did not impact tree growth (Scott et al., 2004; Sanchez et al., 2006; Powers et al., 2005). Competing vegetation had minimal impact on total soil organic matter contents (Sanchez et al., 2006) but may increase labile carbon (Sanchez and Bursey, 2002). This in combination to the effect on microbial populations and activity (Busse et al., 2006) and understory diversity can affect $CO_2$ efflux. Since our goal was to isolate the effect of organic matter removal, it was necessary to examine only the plots without competing vegetation. Otherwise, it would not be possible to determine if any differences were due to the OM removal level or some other factor (i.e., labile C contents, microbial activity, soil fauna). In light of these results, all analyses in this study were confined to $C_0$ plots receiving complete weed control. The present study was conducted in 2001, 10 years after the installation of treatments and establishment of pine seedlings. By year 10, trees in both $OM_0$ and $OM_2$ had achieved crown closure and there were no differences in pine volume ($OM_0$, $103.78 \pm 6.84$ $m^3$ $ha^{-1}$ and $OM_2$, $105.69 \pm 9.29$ $m^3$ $ha^{-1}$; Sanchez et al., 2006).

### 2.2. Measurement of $S_{ff}$

The Automated Carbon Efflux System (ACES) (US Patent 6,692,970) was used to measure $S_{ff}$ in this study. The ACES is a multi-port respiration system, which sequentially measures $CO_2$ fluxes from 15 chambers using an open technique. The configuration used for this study employed 25 cm diameter circular chambers, connected to the multi-port controller by 15 m of tubing. One unit can effectively sample 15 locations within a 225 $m^2$ footprint. A detailed description of the ACES and comparison to other commercially available systems is presented by Butnor et al. (2005).

A complete randomized block design with split-plots was used to study the impact of organic removal level on $S_{ff}$ (3 blocks, 2 organic removal levels, 3 distance from tree split-

[1] Product or manufacturer name is included for the benefit of the reader and does not imply endorsement by the United States Forest Service.

plots). Within each organic removal treatment, 15 $S_{ff}$ measurement locations were selected by randomly choosing five trees and locating three permanent measurement locations at distances of 0.5, 1 and 2 m from the base of each tree to create the split-plot. Considering the 3 m × 3 m tree spacing, the 2 m distance was located diagonally between trees. $S_{ff}$ was measured at four periods in 2001: March (day 78–81), June (day 155–158), August (day 218–219 and 225–227) and October (day 281–288). Both treatments ($OM_0$ and $OM_2$) within a given block were measured simultaneously with two different ACES units for a 24 h period, yielding 9 measurements of $S_{ff}$ per chamber per day. In addition to $S_{ff}$, the ACES also measured air and soil temperature within each chamber. The automated measurement system did not have the ability to measure moisture in each chamber, so one central moisture probe was placed in each block/organic removal treatment combination.

### 2.3. Root and soil analysis

At the conclusion of the $S_{ff}$ monitoring in 2001, the litter and roots below each ACES soil chamber were collected (3 blocks, 2 organic removal levels, 3 distance from tree split-plots). First, the litter depth within the chamber footprint was measured, and then a large 25 cm diameter corer was placed over the area covered by the chamber to facilitate the collection of all unincorporated litter. The corer was driven 30 cm into the soil and the contents were placed in a bucket. The soil was immediately dry-sieved in the field and returned to the laboratory for processing. In the laboratory, live roots were rinsed free of debris, sorted into two size classes, fine roots (<2 mm) and coarse roots (>2 mm) and dried at 65 °C for several weeks. All litter was oven-dried at 65 °C for 1 week. Once dry, the roots and litter were weighed.

At the end of the experiment in February 2002, soil samples were collected for bulk density, C, and N analysis using an AMS compact slide hammer with 5 cm × 10 cm corer at depths of 0–10 cm, 10–20 cm, and 20–30 cm. Within each block/organic removal treatment combination, 10 random samples, which did not consider the distance from tree split-plot were collected. The samples were oven dried at 105 °C, weighed, and passed through a 2 mm sieve to remove any roots or coarse fragments. The mass and volume of roots were subtracted from the calculation of soil bulk density (g $cm^{-3}$); there were no coarse fragments to be considered. Sub-samples were then powdered and analyzed for total C and N by dry combustion (Flash EA 1112 CNS analyzer, ThermoFinnigan, Milan, Italy).

### 2.4. Data analysis

We utilized a randomized complete block design with split-plots to analyze the effects of organic matter removal and distance from the nearest tree on $S_{ff}$, root mass, litter mass, litter depth (3 blocks, 2 levels of organic matter removal and 3 distance from tree split-plots). The statistical significance of treatment effects were analyzed using the SAS System for Mixed Models (Littell et al., 1996; SAS Institute, Cary, NC, SAS software version 8.01). Since $S_{ff}$ was measured quarterly in 2001 at the same sample locations, it was necessary to use time as a repeated measure to analyze the effects of the split plot (Littell et al., 1996). Root mass, litter mass, and litter depth were assessed at the end of the experiment and did not require repeated measures. Bulk density, C, and N were measured at the end of the experiment, but the samples were not collected within the $S_{ff}$ chambers and did not consider the distance from tree split-plot. Soil samples were collected randomly within the organic removal treatments; hence analysis of soil characteristics (bulk density, organic C and total N) excluded the ‘‘distance from tree’’ split (3 blocks, 2 levels of organic removal). The response of $S_{ff}$ to changes in soil temperature was modeled using non-linear regression (SAS Institute, Cary, NC, SAS software version 8.01). The relationship between total root mass and $S_{ff}$ was analyzed using linear regression methods.

## 3. Results

### 3.1. Effect of organic matter removal on site conditions, soil properties and $S_{ff}$

During the four measurement periods in 2001, there was no significant difference in soil water content, air temperature or soil temperature between organic removal treatments established 10 years earlier (Table 1). Mean soil temperature varied from 11.5 to 25.6 °C allowing $S_{ff}$ measurements to be collected over a wide range of soil conditions (Fig. 1). $S_{ff}$ responded exponentially to changes in soil temperature (Fig. 2). Soil temperature explained 66% of the variation in $S_{ff}$ in $OM_0$ and 40% of the variation in $OM_2$. The influence of soil moisture on $S_{ff}$ was not determined, since it was measured at one location per plot, whereas $S_{ff}$ was measured sequentially for 24 h at 15 locations per plot. $S_{ff}$ was not affected by organic removal treatment at any measurement period (Fig. 1), nor if they were combined in a repeated measures analysis (NS, $F = 0.07$, $P = 0.82$). No differences in soil bulk density, organic C content or total N content were found between organic removal levels (Table 2). Forest floor litter depth was 3.63 ± 0.25 cm in $OM_0$ and 2.92 ± 0.34 cm in $OM_2$ (NS, $F = 2.08$, $P = 0.29$). Litter mass (dry) was 981 ± 105 g $m^{-2}$ in $OM_0$ and 979 ± 143 g $m^{-2}$ in $OM_2$ (NS, $F < 0.001$, $P = 0.99$).

### 3.2. Effect of organic matter removal on root mass and $S_{ff}$

Total root mass (fine + coarse roots) averaged across all distances from the nearest tree in $OM_0$ (1552 ± 427 g $m^{-2}$) was more than double $OM_2$ (701 ± 86 g $m^{-2}$). Fine roots accounted for 8% of the total mass in $OM_0$ (128 ± 4 g $m^{-2}$) and 18% of the total mass in $OM_2$ (124 ± 5 g $m^{-2}$). Absolute quantity of fine roots was similar between the treatments with coarse roots accounting for most of the difference; $OM_0$ (1424 ± 202 g $m^{-2}$) and $OM_2$ (577 ± 29 g $m^{-2}$). Cores collected at a distance of 0.5 m from a tree contained more than twice the root mass of the other positions in $OM_0$, while $OM_2$ did not show the same relationship (Fig. 3A). When total root mass was analyzed with SAS (mixed procedure) using the split-

Table 1
Average volumetric water content, air temperature and soil temperature (5 cm) measured within ACES chambers during soil $CO_2$ efflux measurements over a 24 h period

| | Water content (vol.%) | | Air temperature (°C) | | Soil temperature (°C) | |
|---|---|---|---|---|---|---|
| | $OM_0$ | $OM_2$ | $OM_0$ | $OM_2$ | $OM_0$ | $OM_2$ |
| March 2001 | 30 | 22 | 11.2 | 11.7 | 11.5 | 12.3 |
| June 2001 | 22 | 20 | 25.5 | 26.3 | 25.6 | 23.6 |
| August 2001 | 17 | 19 | 25.4 | 25.0 | 25.0 | 24.8 |
| October 2001 | 15 | 11 | 15.7 | 16.3 | 18.0 | 18.7 |

No significant differences were observed between organic matter treatments ($\alpha = 0.05$).

plot design; the effect of organic matter removal was significant ($F = 6.73$, $P = 0.03$), while distance from nearest tree was not ($F = 3.34$, $P = 0.08$). The interaction of organic removal and distance effects were not significant at the 0.05 level by a small margin ($F = 3.65$, $P = 0.07$). Using the same analysis on coarse and fine root mass yielded the following results: coarse root mass, organic removal ($F = 6.73$, $P = 0.03$), distance from tree ($F = 3.33$, $P = 0.08$), interaction ($F = 3.63$, $P = 0.07$); fine root mass, organic removal ($F = 0.14$, $P = 0.72$), distance from tree ($F = 1.35$, $P = 0.31$), interaction ($F = 0.64$, $P = 0.55$). Fig. 3 illustrates that strong differences in root mass (A) did not have a commensurate effect on $S_{ff}$ (B). For both $S_{ff}$ and total root mass, distance from the tree had a significant effect in $OM_0$, but not in $OM_2$. Using linear regression, no relationship was observed between $S_{ff}$ and total root mass in the $OM_0$ ($R^2 = 0.06$, $P = 0.10$) or $OM_2$ ($R^2 = 0.04$, $P = 0.18$) treatments.

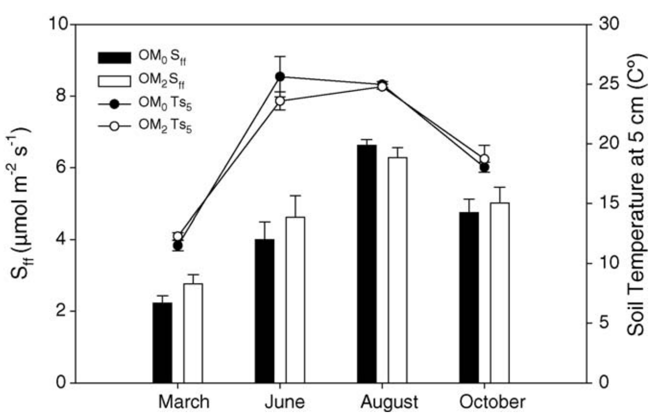


Fig. 1. Soil temperature and $S_{ff}$ (±S.E.) for both organic matter removal treatments at each measurement period in 2001. No significant differences were observed at any period ($\alpha = 0.05$).

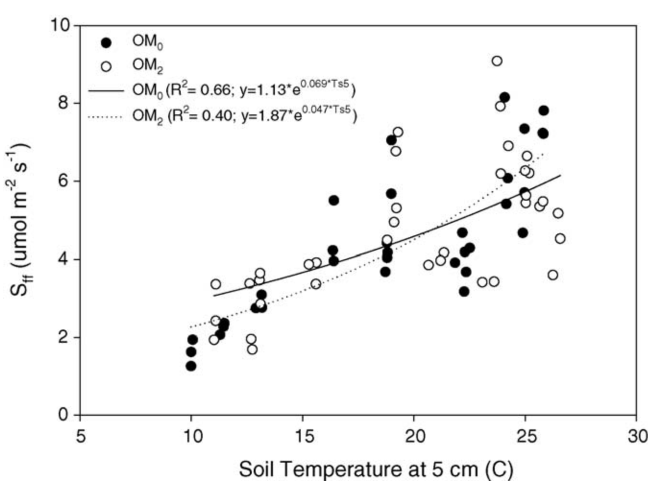


Fig. 2. Response of $S_{ff}$ to soil temperature measured at 5 cm. Each symbol represents the daily average of each unique month × block × organic matter removal × distance from tree combination ($n = 5$ chambers). The non-linear regression equations are not significantly different ($\alpha = 0.05$).

## 4. Discussion

Harvesting a stand at the end of a rotation, will cause an immediate change in structure, soil moisture and temperature regimes. Harvesting also results in a loss in C and nutrients stored in the merchantable products removed from the site. Residual slash, stumps and roots decay, releasing nutrients to the soil over a period of time. The LTSP network was developed to track the effects of management activities on forest productivity and soil quality. Five years after the treatments were installed and the plantings were established, pine volume in $OM_0$ was significantly higher (18%) than $OM_2$ (Scott et al., 2004). However, 10 years after establishment, the effect of organic removal on pine volume was no longer significant (Sanchez et al., 2006) in the plots used for this study (no compaction, herbicide applied). This agrees with findings reported at other LTSP sites in California, Idaho and Louisiana

Table 2
Average bulk density and C and N content (±S.E.) collected at three depths

| Soil depth (cm) | Treatment | | Pr > F |
|---|---|---|---|
| | $OM_0$ | $OM_2$ | |
| Bulk density (g cm$^{-3}$) | | | |
| 0–10 | 1.10 (0.02) | 1.11 (0.02) | 0.92 |
| 10–20 | 1.46 (0.02) | 1.31 (0.02) | 0.33 |
| 20–30 | 1.47 (0.03) | 1.40 (0.02) | 0.70 |
| Organic C (mg ha$^{-1}$) | | | |
| 0–10 | 26.0 (2.3) | 34.3 (3.3) | 0.50 |
| 10–20 | 19.7 (1.9) | 22.4 (1.9) | 0.66 |
| 20–30 | 15.0 (1.1) | 13.2 (1.6) | 0.44 |
| Total N (kg ha$^{-1}$) | | | |
| 0–10 | 812 (89) | 698 (84) | 0.65 |
| 10–20 | 525 (108) | 538 (68) | 0.95 |
| 20–30 | 413 (80) | 254 (71) | 0.38 |

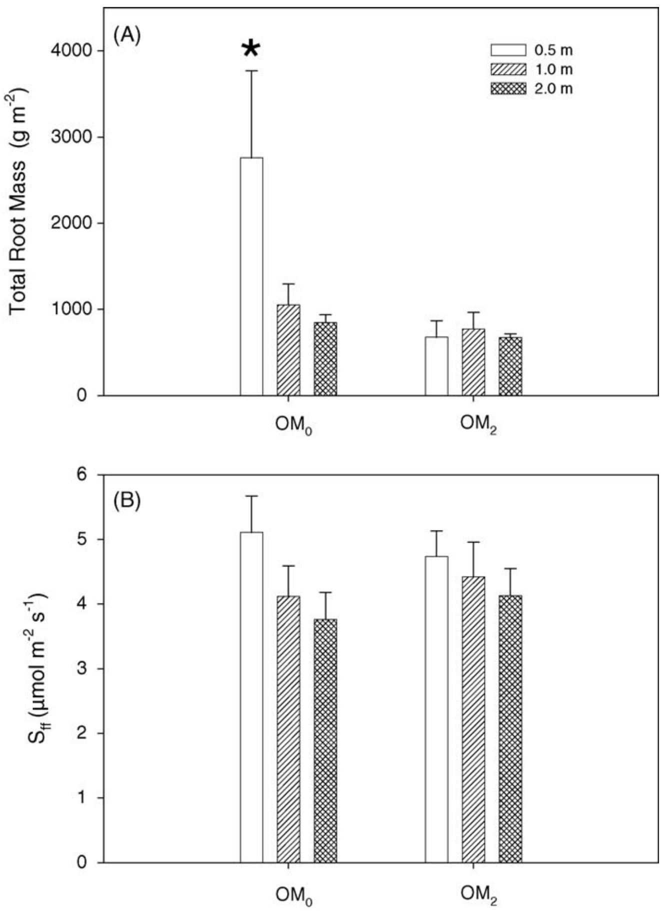


Fig. 3. Total root mass (±S.E.) collected at the end of the study (inset A) and mean $S_{ff}$ (±S.E.) averaged over all four measurement periods (inset B).

(Powers et al., 2004, 2005). Although pine volume was unaffected by organic removal after 10 years, root mass was significantly lower in $OM_2$ using our coring scheme (Fig. 3). We were unable to corroborate this finding with other reports of belowground sampling at this site. A whole-tree biomass harvest of one tree per plot and a 1 m × 1 m pit beneath each tree was conducted in the winter of 2001, did not reveal any differences between $OM_0$ and $OM_2$ (Ludovici, unpublished data). Only six trees from the whole-tree harvest correspond with the plots used in this study ($OM_0$ and $OM_2$, no compaction, herbicide applied), whereas our comprehensive coring scheme measured three distances from 30 trees and found significant differences between levels of organic matter removal. Additional research will be needed to determine if there has been a shift in C allocation to roots, or as observed for aboveground growth (pine volume), there is time lag in root accretion and $OM_2$ will eventually reach the same ratio. If trees in $OM_0$ actually have greater allocation to roots without incurring additional C losses via $S_{ff}$ there is the potential for enhanced belowground C sequestration.

Distance from tree was negatively correlated with $S_{ff}$ in $OM_0$. Other researchers have reported similar findings in loblolly pine plantations across a range of age classes (Pangle and Seiler, 2002; Gough and Seiler, 2004; Samuelson et al., 2004a; Wiseman and Seiler, 2004). Wiseman and Seiler (2004) observed that $S_{ff}$, root surface area and live root volume were higher at the base of trees, but root volume only explained a small amount of variation in $S_{ff}$. Samuelson et al. (2004a) reasoned that higher $S_{ff}$ near the base of trees is not only influenced by roots directly beneath the measurement chamber, but from large taproots and coarse roots deeper in the profile. Taproots account for a large percentage of total root mass in loblolly pine plantations. Allocation to taproots ranges from 39 to 87% (Albaugh et al., 2004; Samuelson et al., 2004b) and can account for more than half of all root-respired $CO_2$ (Maier and Kress, 2000). In $OM_2$, $S_{ff}$ was not correlated to tree proximity. This could indicate that the organic matter removal treatment is affecting allocation to the taproot and coarse root distribution. We do not have evidence of shifts in root allocation; further study would be needed to resolve this issue.

Assuming vertical movement of respired C directly from roots to the measurement chamber is unrealistic. Consequently, lateral movement of $CO_2$ in soil air may limit the usefulness of correlating roots to chamber measures of $S_{ff}$ (Gough and Seiler, 2004). However, given that $OM_0$ possessed twice the lateral root mass of $OM_2$, it is still remarkable that no difference in $S_{ff}$ was detected. In loblolly pine, fine roots have higher root-specific respiration rates than coarse roots, but they make up a small percentage of the total belowground mass (Maier and Kress, 2000). In the current study, fine root mass was very similar between the organic matter removal treatments.

In this study, root respiration was not measured separately from $S_{ff}$ and cannot be readily estimated. While it may be possible that root respiration is higher in $OM_2$, some of the implications are contradictory. Productivity of southern pine forests is limited by N and phosphorus (P) deficiencies throughout much its range (Allen, 1987) and this study site is classified as deficient for pine growth (Jokela and Long, 2004). The organic removal treatment did not significantly alter soil N levels, though $OM_2$ had significantly lower extractable soil P than $OM_0$ (Sanchez et al., 2006). Since no deleterious effects on aboveground productivity are apparent at year 10, the deficiency has probably not reached critical stage. In a 12 year-old loblolly pine plantation established on a nutrient limited site, Maier et al. (2004) reported that root respiration accounted for one third of $S_{ff}$ on unfertilized plots and half of $S_{ff}$ on fertilized plots. If organic removal had caused a nutritional limitation on productivity, lower root respiration would be anticipated. Loblolly pines are very responsive to available soil nutrition; increased root allocation (particularly to fine roots) has been reported on nutrient limited sites (Maier and Kress, 2000). The root allocation response expected under nutrient limiting conditions runs counter to the observation that root mass is lower in $OM_2$.

Both $OM_0$ and $OM_2$ had more soil C 10 years after establishment than the previous 60-year-old mixed stand (Fig. 4). We hypothesize this to be due a pulse of organic matter entering the soil from the rapid decomposition of the previous stand's root system. This C pulse followed clear-cutting and is indicated by the distinct increase organic C concentration through year 5 in the upper 10 cm of soil (Fig. 4). The lower

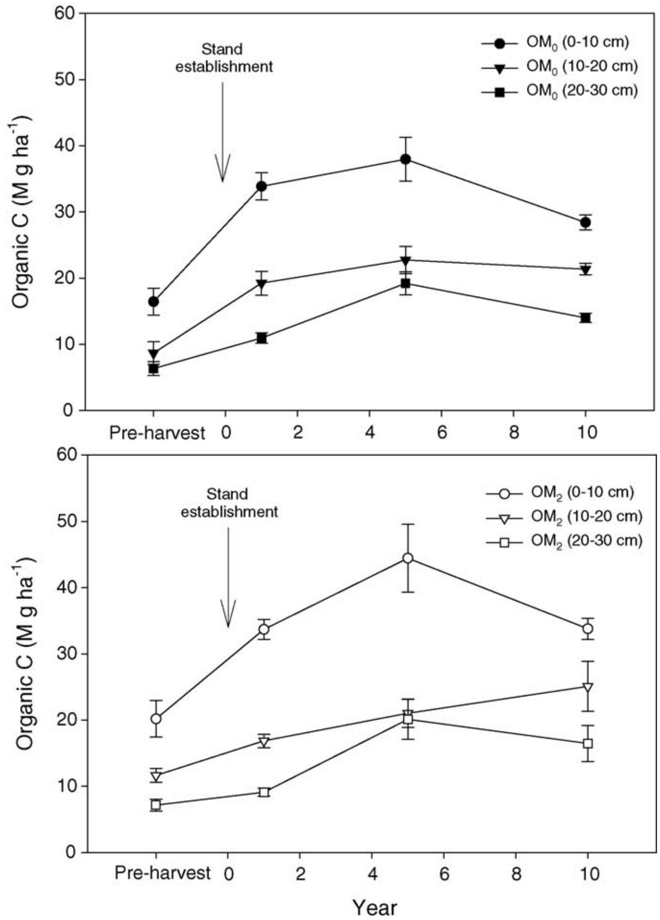


Fig. 4. Organic C content measured prior to study installation (year = 0) and subsequently at years 1, 5 and 10 (Powers et al., 2004, 2005). The year 10 measures were collected independently in a separate study and are not directly linked to data presented in Table 2.

depths in the profile exhibited the same response after a time lag. The amount of organic C lost from the upper 10 cm of soil between year 5 and 10 was 11% greater for $OM_2$ than $OM_0$ ($OM_0$, 9.55 mg $ha^{-1}$; $OM_2$, 10.67 mg $ha^{-1}$) (Fig. 4). Only a portion of this amount is lost to oxidative processes, some is sequestered by autotrophs. Organic C content in the upper 10 cm of soil was 26% higher in $OM_2$ at year 10, though this difference was not significant (Table 2). Powers et al. (2004, 2005) independently assessed organic C at year 10 and reported $OM_2$ to be 15% higher than $OM_0$ (NS; Fig. 4). Li et al. (2003) found that there was no difference in microbial C between organic matter removal treatments, indicating that they contain similar soil C pools in both recalcitrant and ephemeral forms.

While it appears that soil C has been enhanced by harvesting, it is important to consider that soil C in the upper 10 cm of soil peaked at year 5 and declined at year 10. We do not know what concentration of soil C would be found if this stand was allowed to mature for 60 years, to compare to the prior stand. Intensive management of loblolly pine in eastern North Carolina has reduced rotation lengths to less than 20 years. This site has undergone a land use change to intensive forest management and the mid-rotation results show that soil C is not adversely affected by organic matter removal. It is likely that remnants of the prior stand are still dominating soil C dynamics, as these materials cycle out of the system, the long-term effects of intensive management on productivity and sustainability be better understood.

## 5. Conclusions

Whole-tree and forest floor removal ($OM_2$) during harvest and site preparation did not result in differences in $S_{ff}$ or soil C relative to conventional harvesting ($OM_0$), 10 years after establishment. At year 10, both treatments resulted in a greater quantity of soil C, indicating that the disturbance associated with harvesting enhanced soil C; at least over the short term. We attribute this increase in soil C to rapid decomposition of previous stands root system. As remnants of the prior stand continue to decompose and play a lesser role in soil C dynamics, it is not known whether the shorter rotation lengths anticipated under intensive forest management will continue to enhance soil C. This highlights the need to research C dynamics through successive rotations. No significant treatment effects were noted for soil C, soil N, litter mass or litter depth. Trees in the $OM_0$ treatment had significantly more lateral roots.

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