

ESTIMATING SOIL CO₂ EFFLUX IN MANAGED LOBLOLLY PINE ECOSYSTEMS: WHAT WE KNOW AND HOW WE CAN APPLY IT TO ENHANCING CARBON SEQUESTRATION



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Abstract

Intensively managed loblolly pine (*Pinus taeda* L.) stands account for over 13 million hectares of forested land in the southeastern United States and represent a potentially manageable carbon sink and store that could be effective in partially offsetting anthropogenic CO₂ emissions. Effective carbon sequestration management of these stands requires an understanding of factors influencing soil CO₂ efflux in this immense ecosystem. Certain management regimes appear to reduce carbon turnover, amplifying the carbon storage capacity of loblolly pine stands. For example, common forest operations such as thinning and fertilization may increase belowground carbon storage over a rotation since both practices potentially enhance biomass productivity and at the same time may have direct impacts on the rate of below ground carbon turnover. In order to determine the impact of management practices on carbon storage and turnover, we are currently quantifying CO₂ flux rates and soil carbon across a wide range of sites and management practices in the loblolly pine ecosystem.

In all of our studies soil temperature and stand age are the major drivers in estimating CO₂ efflux.

Using this knowledge we have developed simple equations that can be used to predict soil CO₂ efflux over a managed rotation length for loblolly pine on the piedmont or coastal plain.

Thinning of loblolly pine plantations may be a very effective practice for increasing carbon sequestration in loblolly pine stands. Thinning did not significantly increase soil CO₂ efflux and soil carbon was increased 14 years after an earlier thinning.

Fertilization may potentially increase belowground carbon storage through both enhanced biomass productivity and by reducing soil CO₂ efflux. We found fertilization reduces soil CO₂ efflux which in the long term could lead to increases in soil carbon. We have data to suggest that although specific root respiration may increase, a concurrent reduction in microbial respiration may result in reduced soil carbon losses in fertilized treatments over the short-term.

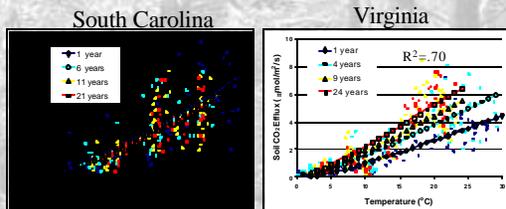
Methods

- Soil CO₂ efflux was measured using a closed dynamic system (LiCor 6200) over a range of stand ages, site qualities, cultural practices, and climates representative of the southeastern U.S. loblolly pine ecosystem. Soil temperature and moisture were measured concurrently.
- Spatial variation in soil CO₂ efflux within a stand was investigated
- Common cultural practices investigated include fertilization, thinning, and site preparation methods typical of intensive loblolly pine management
- Soil carbon content along spatial and temporal gradients was measured



Results

1 Temperature and age effects on soil CO₂ Efflux

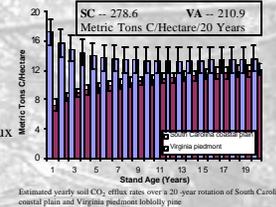


Soil CO₂ efflux and corresponding trend lines, across soil temperatures and age classes on the South Carolina coastal plain and Virginia piedmont loblolly pine stands.

- Soil temperature exerts a strong influence on soil CO₂ efflux on both the South Carolina coastal plain and the Virginia piedmont
- Stand age is weakly negatively related to soil CO₂ efflux in South Carolina and strongly positively correlated with soil CO₂ efflux in Virginia

2 Temporal patterns of soil CO₂ efflux over a 20-year rotation on Virginia piedmont and South Carolina coastal plain

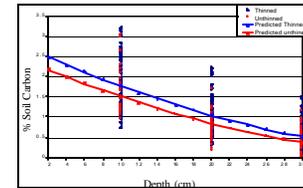
- Variable management, climate, and site productivity impact soil CO₂ efflux
- High intensity site preparation in South Carolina increases microbial driven soil carbon turnover early in the rotation
- Growth of respiring root biomass over a rotation contributes to increasing CO₂ efflux rates on both locations



Estimated yearly soil CO₂ efflux rates over a 20 year rotation of South Carolina coastal plain and Virginia piedmont loblolly pine.

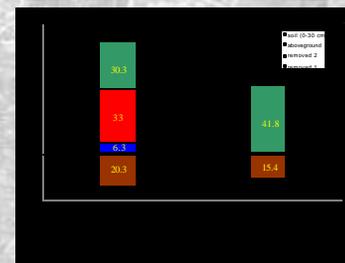
3 Thinning effects on percent soil carbon and total carbon storage

- A 24.2% gain in soil carbon was seen 14 years after the thinning of an 8-year-old loblolly pine plantation on the piedmont of Virginia



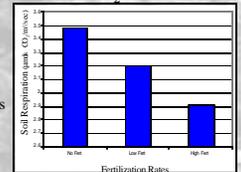
Volumetric soil carbon as affected by thinning and depth on a 22-y old loblolly pine plantation on the piedmont of Virginia (pc-01).

- Thinning results in large increases in aboveground commercial wood production and higher soil carbon storage, resulting in 36.4% increase in stored carbon over a 22-year rotation

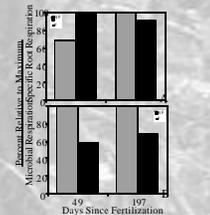


4 Fertilization effects on soil CO₂ efflux

- While fertilization increased above and below ground growth rates, soil CO₂ efflux decreased with increasing fertilization rates
- Fertilization temporarily increased specific root respiration and reduced microbial respiration over the longer-term, which may lead to lower soil CO₂ efflux rates and less microbial driven soil carbon turnover



Soil CO₂ efflux as influenced by fertilization in a 5-year-old loblolly pine plantation on the piedmont of Virginia



Relative mean specific root respiration (A) and relative mean microbial respiration (B) in non-fertilized and fertilized loblolly pine.

Conclusions

- Soil temperature and stand age can be used to explain 50% or more of the variation in soil CO₂ efflux in managed loblolly pine stands (panel 1).
- There are clear spatial patterns and temporal patterns to soil CO₂ efflux (panel 1).
- Empirical models are now available that can predict soil CO₂ efflux at any age or for an entire rotation of managed loblolly pine (panel 2).
- Thinning of loblolly pine will result in increased carbon sequestration both by increasing above ground yield over a rotation and by increasing soil carbon content (panel 3).
- Fertilization of loblolly pine will increase carbon sequestration enhancing above yields and increasing below carbon storage (panel 4).

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Comparing Short-term C Metabolism in Soils from Four Different Ecosystems

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Abstract

The rate at which a soil metabolizes new carbon may suggest its potential to sequester C. Soils from different ecosystems have different microorganisms and thus, may mineralize C differently. The soils were from four ecosystems: tallgrass prairie, cropland, shrub-steppe, and Douglas fir forest. We monitored transformation of a simple ¹⁴C-labeled substrate (glucose) over 12 weeks. Specific activities of evolved CO₂ were used to compare soils. The prairie soil showed no evidence of preferential metabolism of glucose-C, nor did it appear that endogenous C was particularly metabolized. Respiration patterns in the other three soils indicate that preferential metabolism did occur.

Introduction

The short-term cycling of C may offer insights to the C sequestration potential of a soil. Furthermore, the short-term cycling of carbon is intimately linked with the availability of nitrogen (Henriksen and Breland, 1999). Insufficient N may cause SOM degradation as SOM-N is “mined” by soil organisms, whereas an excess of N may cause SOM degradation as SOM-C is consumed in response. Sequestration of C in soils that are N-limited may be enhanced by the addition of an appropriate quantity of N, thereby preventing this microbial decomposition of native soil organic matter for N (Ladd et al., 1992).

The “priming” of endogenous soil C, *i.e.*, its mineralization in response to the addition of fresh C, can affect the long-term sequestration of C in soils (Bell et al., 2003). However, in some soils to which glucose was added, this priming effect has been observed to be offset by enhanced storage of the freshly added C in soil, resulting in a net increase in C storage in soil (Dalenberg and Jager, 1989). We propose that studying the short-term dynamics of freshly added carbon to soils will enhance our ability to speculate about the long-term fate of the freshly added C and its effect on the endogenous soil organic C. We compare the short-term mineralization of C from soils that were amended with a ¹⁴C-labeled readily available substrate (glucose) with those that were amended with glucose and nitrogen.

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Methods and Materials

The soils studied came from four ecosystems: the semiarid shrub-steppe (Richland, WA), a no-till wheat-pea farm (Palouse, WA), tallgrass prairie restored in 1979 (Batavia, IL), and a Douglas fir forest (Buckley, WA). Selected characteristics of these soils are presented in Table 1.

Subsamples (5 g) of surface soils (0-5 cm) collected from each ecosystem were treated with a quantity of ^{14}C -UL-glucose to generate maximum respiratory response (Table 2); no N was added (0). A second treatment was included in which N was added such that the ratio of added C:N was 20:1. Potassium hydroxide (0.5 M) traps were placed inside each incubation unit to capture respired CO_2 . Traps were changed weekly and titrated with HCl to determine CO_2 respiration for the 12 weeks of the experiment. The activity of these traps was also measured using liquid scintillation counting to determine the specific activity of the $^{14}\text{CO}_2$ evolved. Triplicate samples of each soil were destructively sampled at 1, 2, 4, 8, and 12 weeks. These soil samples were sequentially extracted for water soluble C (WSC), soil microbial biomass C (SMBC), and humic C (HC). Water extracts were done in a 1:10 soil:water slurry, SMBC determined by chloroform fumigation-extraction, and HC determined by overnight extraction of the non-fumigated half of the sample (0.5 M NaOH). Aliquots of each extract were counted to determine the activity of ^{14}C incorporated into each fraction.

Table 1. Selected characteristics of study soils, and the amount of C added as glucose to each soil in this experiment.

Location	Soil Texture	C (mg g^{-1} soil)	N (mg g^{-1} soil)	C addition ($\mu\text{g g}^{-1}$ soil)
Shrub-steppe, Richland, WA	Loam	8.5	0.85	600
No-till farmland, Palouse, WA	Silt loam	46.6	36.7	1600
Restored tallgrass prairie, Batavia, IL (Fermi National Lab)	Silt loam	49.9	4.59	800
Douglas fir forest, Buckley, WA	Sandy loam	88.8	5.27	1600

Results and Discussion

The maximum utilization rate of glucose, indicated by $^{14}\text{CO}_2$ evolution, was not affected by N addition suggesting that none of the study soils were N-limited (Fig. 1). The pattern and metabolic use of the energy source differed among ecosystems.

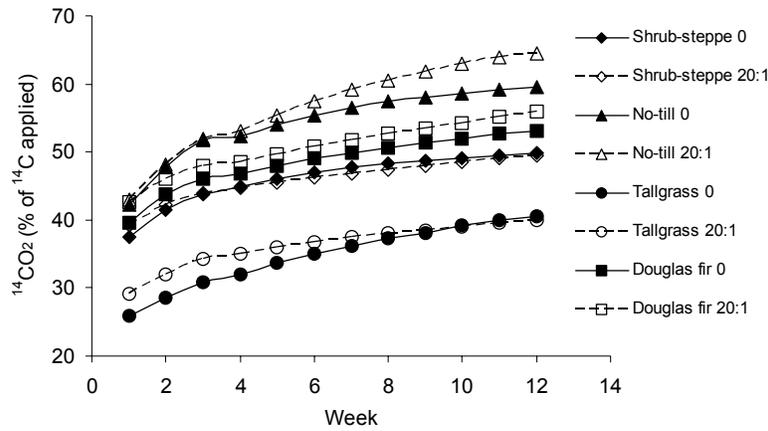


Figure 1. $^{14}\text{CO}_2$ evolution from soils treated with ^{14}C -UL-glucose alone, and from soils treated with ^{14}C -UL-glucose and nitrogen ($\text{C}_{\text{glucose}}:\text{N} = 20:1$).

Without the addition of N the no-till and Douglas fir soils showed a high metabolic throughput of added C possibly indicating a soil C limitation (Fig. 2). Whereas, the shrub-steppe and tallgrass soils showed a lower and steadier metabolism of glucose, indicating potentially more C storage from added substrates in these soils. With the addition of N the specific activity of CO_2 remained higher than the no N treatment such that the time to steady-state specific activity was increased by 1 to 2 weeks. This indicates induction of rapid recycling of C within microorganisms due to N addition.

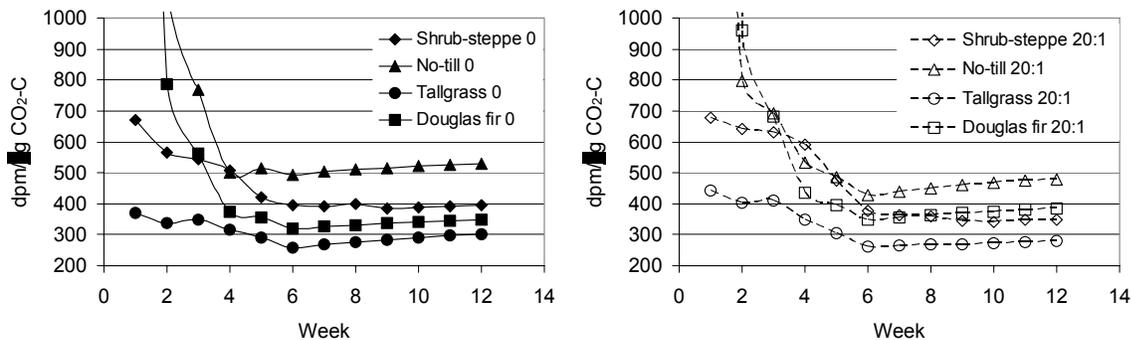


Figure 2. Specific activity of CO_2 evolved from (a) the four soils without additional N, and (b) the four soils with additional N.

Comparing the CO_2 specific activity of the 2 soils that showed potential for greater C storage (Fig. 3a) shows why we see little difference in total C utilization with N additions. The pattern of glucose consumption in the added N treatments is greater than without added N until week 6 where the specific activity decreases to below that of the no N addition soil. This decrease in the cycling of ^{14}C offsets the

initial rapid cycling and at 12 weeks the treatments are similar in substrate utilization. If these trends continued, more of the C added would be sequestered in the N treatment than the no N treatment suggesting that soils in which freshly added C is rapidly cycled will have the greatest C sequestering potential. However, in the soils with the high throughput of added C (Fig. 3b) the patterns were not so evident.

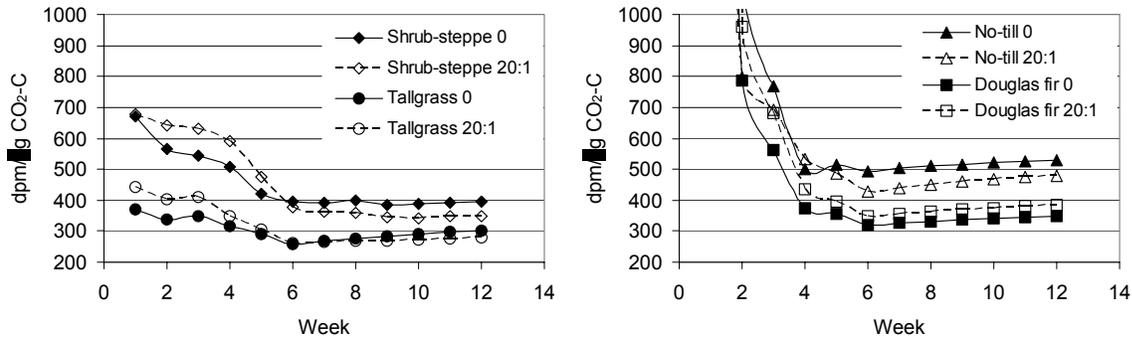


Figure 3. Specific activity of CO₂ evolved from (a) both treatments of the shrub-steppe and tallgrass prairie soils, and (b) both treatments of the no-till farmland and Douglas fir forest soils.

At the end of the incubation, the shrub-steppe soils had mineralized 50% of the ¹⁴C applied as glucose to ¹⁴CO₂ (Fig. 4). The no-till soil similarly mineralized 60-64% of the added ¹⁴C, the tallgrass prairie soil 40%, and the Douglas fir forest soil 53-56% (Fig. 4). The initial incorporation of the glucose-derived ¹⁴C into the humic fraction was rapid and tended to be greatest in the added N treatment. However over time this fraction was mineralized to CO₂. The remaining 40 to 60% of the added glucose cycled into a resistant soil C fraction after 12 weeks, however as seen in Figures 2 and 3 is still being mineralized at a slow rate. The rapid turnover of cellular material is evident by the small and consistent amount of ¹⁴C in the microbial biomass. It is noteworthy that 40-60% of the applied ¹⁴C was not recovered in any of the extracts. This suggests that it may be stored in the soils in a persistent form that is not readily available for microbial metabolism.

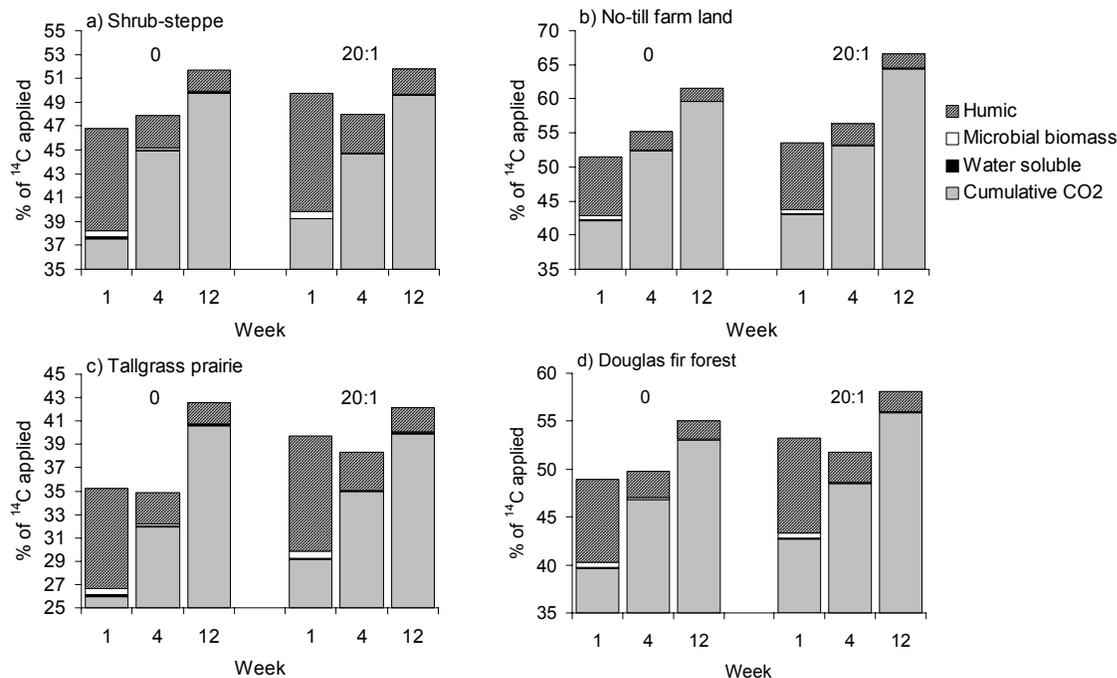


Figure 4. Redistribution of glucose-derived ^{14}C into humic-C, microbial biomass-C, water soluble-C, and CO_2 at 1, 4, and 12 weeks of incubation for both glucose (0) and glucose + N (20:1) treatments for all four soils: a) Shrub-steppe soil, b) No-till farmed soil, c) Tallgrass prairie soil, and d) Douglas fir forest soil.

Concluding Comments

Our study points out that using cumulative loss functions or cumulative production graphs do not show the internal dynamics of C cycling. In the utilization of glucose it appears that N had little effect, however on more detailed analysis we observed that over time N additions could force added C into more resistant soil C pools. This would result in greater C sequestration. In addition, it appears that the initial metabolic capacity of soils may indicate their potential for sequestering C. These types of substrate addition experiments may be useful in developing an index of soil C storage. Our follow up work will address the question of metabolic capacity versus potential C storage.

Acknowledgements

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