PREDICTING SOIL CO_2 EFFLUX RATES IN THE LOBLOLLY PINE ECOSYSTEM ACROSS THE REGION

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Abstract—Patterns in soil CO_2 efflux (E_c) over a short rotation were examined using a chronosequence approach on South Carolina Coastal Plain and Virginia Piedmont loblolly pine (*Pinus taeda* L.) stands. E_c was measured over an entire year in four separate age classes at both measurement locations in order to capture spatial and temporal variation in E_c over a 20+ year rotation. Within each stand, spatial variability was also accounted for by taking measurements both near the base of the tree and between rows. We found that soil temperature (at 10 cm) was the major driver of E_c on both locations. We also observed a strong positive stand age effect on E_c in Virginia Piedmont stands and a weak negative relationship between age and E_c in the South Carolina Coastal Plain stands. Variation in site preparation intensity between the two locations may influence the rate of carbon turnover.

INTRODUCTION

Researchers have cited a continued need for better understanding and quantifying the role forest management may play in soil carbon turnover over a range of stand types and ages (Banfield and others 2002, Field and Fung 1999, Liski and others 2002, Turner and others 1995, Woodwell and others 1983). Inherent site characteristics along with forest management practices that commonly alter microclimate and productivity may directly impact E_c. However, the literature provides no clear consensus concerning the effect of forest management and E_c. Previous investigators observed an increase (Gordon and others 1987, Londo and others 1999, Lytle and Cronan 1998), decrease (Striegl and Wickland 1998), or no change (Edwards and Ross-Todd 1983, Fernandez and others 1993, Toland and Zak 1994) in E_c following clearcut harvesting. Differences among ecosystems and experimental designs may account for inconsistencies in the literature; however, the distinct differences found among investigators suggest that generalizations across all forest types are not appropriate when developing carbon budgets. Frequently, E_c and soil carbon turnover have been shown to increase with harvest intensity (Edwards and Ross-Todd 1983, Lee and others 2002, Londo and others 1999). Also, Mallik and Hu (1997) showed that soil respiration rates corresponded to the amount of organic matter incorporated into the soil during site preparation in boreal mixedwood forest.

In this report, we present information regarding the relationship between E_c and soil temperature, soil moisture, stand age, and measurement location within a stand for two locations differing in site quality, climate, and cultural practices. Our overall objective was to develop predictive models that would be used to estimate E_c from managed loblolly pine (*Pinus taeda* L.) stands across the region. We hypothesized that E_c would be primarily related to soil temperature.

MATERIALS AND METHODS

Loblolly pine stands located on the South Carolina Coastal Plain and the Virginia Piedmont were chosen since these locations represent two extremes in terms of site productivity, cultural practices, and climate within the managed range of loblolly pine. Because we wished to examine the variability of E_c over space and time, taking into account possible effects due to stand age, we chose stands that covered ages typical of a short rotation. Four replications consisting of 4 age classes were selected at each study location (South Carolina and Virginia) for a total of 16 study plots per location. Stands were grouped according to the following age classes: 1, 4 to 6, 8 to 12, and 18-to 25-years-old since planting (at beginning of the data collection). Replications had similar soil and drainage characteristics and were in close proximity (< 1 km) to each other.

Within each study plot, E_c measurements, soil temperature from 0 to 10 cm, and soil moisture from 0 to 10 cm were taken concurrently near the base of the tree and between rows (two measurement positions) in order to account for intrasite variability described by Pangle and Seiler (2002). Three sets of measurements, considered subsamples, were taken at each replication x ageclass x measurement position. Subsamples were averaged for analysis. Measurements began in April 2000 on the Virginia location and continued monthly through March 2001. Measurements in South Carolina began in August 2001 and continued bimonthly through the following August. An additional January 2003 measurement date in South Carolina was added in order to cover the range in temperature variability that is representative of the study location. A total of 96 measurements (on each parameter described below) were collected on a sampling date (4 replications x 4 ageclasses x 2 measurement positions x 3 subsamples). The resulting datasets for the South Carolina and Virginia locations include 768 and 1,152 sets of measurements, respectively. Our sampling allowed us to capture variability due to location,

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season, temperature, moisture, stand age, and measurement position within a stand.

Multiple linear regression analysis was used to assess the statistical relationship between E_c and potential explanatory variables including soil temperature, soil moisture, stand age, site index, and measurement position for each location.

RESULTS AND DISCUSSION

Our statistical modeling results show that a majority of the variance in E_c from both locations is explained by soil temperature, stand age, measurement position, and soil moisture. Soil temperature consistently explains the most variance in E_c from both locations. The common model developed separately for the Virginia Piedmont and the South Carolina Coastal Plain has the following form:

$$\begin{aligned} E_c = {} & B_0 + B_1(\text{Soil Temperature}) + \\ & B_2[\text{LN(Soil Temperature)}] + \\ & B_2[\text{LN(Stand Age)*(Soil Temperature)}] + \\ & B_3(\text{Measurement Position}) + B_4(\text{Soil Moisture}) \end{aligned} \quad (1)$$

The above model explains 54 percent and 77 percent of the variance in E_c on the South Carolina Coastal Plain and the Virginia Piedmont, respectively. The following simplified model, including only soil temperature and stand age drivers, explains 50 percent and 70 percent of the variance in E_c on the South Carolina Coastal Plain and the Virginia Piedmont, respectively:

$$\begin{aligned} E_c = {} & B_0 + B_1(\text{Soil Temperature}) + \\ & B_2[\text{LN(Soil Temperature)}] + \\ & B_3[\text{LN(Stand Age)*(Soil Temperature)}] \end{aligned} \quad (2)$$

Statistical comparisons of like coefficients associated with common models for each study location indicate that the relationship of E_c to model drivers differs between the South Carolina Coastal Plain and Virginia Piedmont. Therefore, a single model with identical coefficients is not appropriate for the two locations.

We observed a strong positive relationship between E_c and soil temperature on both study locations (fig. 1). However, we observed a different relationship between stand age and E_c on the South Carolina Coastal Plain in comparison to the Virginia Piedmont. Specifically, the Virginia Piedmont displayed a strong positive effect of age on E_c, while E_c from the South Carolina location exhibited a weak negative response to stand age. Stand age generally has a weak or inconsistent effect on E_c in forest stands according to previous reports (Ewel and others 1987, Klopatek 2002, Pyker and Fredeen 2003). However, variable management intensities may provide a better explanation of the differences we observed on the two locations. Generally, E_c increases as management intensity increases (Edwards and Ross-Todd 1983, Lee and others 2002, Londo and others 1999). Specifically, the intensity of site preparation and the amount of woody debris incorporated into the soil have been shown to have an effect on E_c and may explain why we observed higher rates in one-year-old South Carolina stands, in which slash was incorporated into beds during site preparation. The strong positive relationship

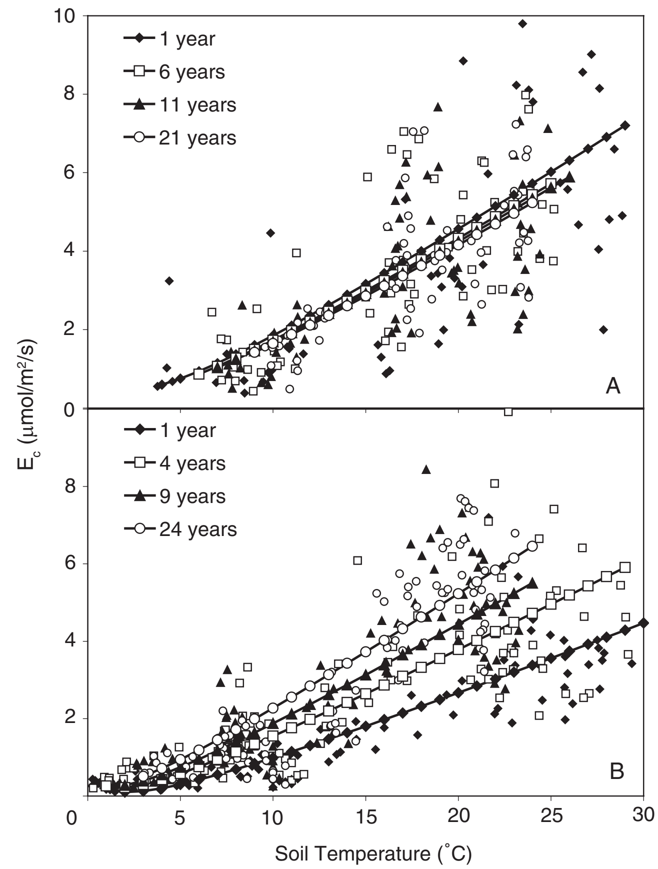

Figure 1— Relationship between soil temperatures (10 cm depth) and E_c in four age classes of loblolly pine stands located on the South Carolina Coastal Plain (A) and the Virginia Piedmont (B). Lines with symbols represent the linear regression line relating E_c to soil temperature for a given stand age class. Ages given represent the average age of the four replicated ageclasses.

between stand age and E_c in Virginia stands may be explained by increases in respiring root volume associated with stand age and a possible depression in microbial respiration rates following prescribed burning since several of the Piedmonts stands were burned for site preparation. Investigators have shown that burning reduces microbial respiration in European coniferous forests (Fritze and others 1993, Hernandez and others 1997, Pietikainen and Fritze 1993, Pietikainen and Fritze 1995); however, there have been no studies conducted in loblolly pine.

Dissimilarities in site quality, management, and climate between study locations likely impact the contribution of root and microbial respiration to E_c differently over a rotation. In the South Carolina Coastal Plain, the total contribution of microbial respiration to E_c likely increased with bedding, a relatively intensive site preparation. In one-year-old stands, E_c is greater on the South Carolina Coastal Plain relative to Virginia Piedmont across temperatures (fig. 1). The difference in E_c between the two locations is likely due to differences in the contribution of microbial respiration since one-year-old stands from both locations have minor contributions from respiring roots early in the rotation. With increasing stand age, coarse woody debris incorporated into beds was consumed, probably by microbes (data not shown). After coarse woody debris was exhausted as a source of carbon substrate, microbial respiration rates probably dropped, which may account for the slight reduction in E_c we observe with increasing stand age. The amount of E_c attributed to root respiration probably increases over time, which is consistent with the increase in root biomass we observe as stands age (data not shown). The preceding statement implies that inverse shifts in root respiration and microbial respiration offset changes in E_c over time in the coastal plain stands. In the Virginia Piedmont, a different trend likely occurred over time. The less intensive site preparation, which included prescribed burning in some stands, probably had no effect or decreased microbial respiration. Since the forest floor was not greatly disturbed in the Virginia Piedmont stands during site preparation, the contribution of microbial respiration to E_c may be impacted less in young stands. Respiring root biomass growth and possibly recovering microbial populations impacted by burning may account for the positive trend in E_c we observed in Virginia stands with age. A direct comparison of E_c between the two locations in greater than 20-year-old stands shows that E_c across temperatures is similar, indicating that any initial effects due to site preparation are nearly undetectable towards the end of the rotation.

Using equation 2, we generated predicted E_c values which were subsequently superimposed on E_c datasets from unrelated studies conducted on the South Carolina Coastal Plain and the Virginia Piedmont (data not shown). We generally found good agreement between our predicted values and actual E_c values, suggesting that our relatively simple model containing soil temperature and stand age drivers may explain a substantial amount of variance in E_c within the given areas of the region for which each model was developed.

CONCLUSIONS

A single predictive model for E_c must account for regional differences in cultural practices since site preparation and management intensity appear to affect carbon turnover rates. Specifically, bedding may enhance microbial driven carbon turnover early in a rotation on the South Carolina Coastal Plain while less intense soil disturbances and burning during site preparation on the Virginia Piedmont may minimally affect or depress microbial respiration. Since total root respiration likely increases with stand age on both locations, shifts in the contribution of microbial and root respiration partially explains the different relationship we observed between E_c and age on the two study locations.

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