SOIL CO_2 EFFLUX TRENDS FOLLOWING THE THINNING OF A 22-YEAR-OLD LOBLOLLY PINE PLANTATION ON THE PIEDMONT OF VIRGINIA

M.F. Selig and J.R. Seiler[1]

Abstract—Due to the growing concern over increasing atmospheric CO_2 concentrations, it has become increasingly important to understand the influence forest practices have on the global carbon cycle. The thinning of loblolly pine (*Pinus taeda*) plantations in the Southeastern United States is a common silvicultural practice and has great potential to influence carbon fluxes. In order to quantify the effects of thinning on CO_2 efflux (E_c), measurements were taken monthly for 1 year, following the thinning of a 22-year-old loblolly pine stand. Soil moisture and temperature were measured concurrently with respiration. E_c measurements were taken at positions adjacent to trees and new stumps, as well as 1.22 m away. E_c appeared to exhibit a slight increase in thinned stands; however, all significant differences were explained by the higher temperatures in thinned stands. This suggests that other than through increasing temperature, thinning does not significantly affect soil E_c, as gains and losses in respiration from many altered biological processes may cancel each other out.

INTRODUCTION

It is estimated that 40 percent of all belowground carbon is located in forest soils (Dixon and others 1994). Loblolly pine (*Pinus taeda*) plantations currently occupy over 13 million ha of forested soils in the Southeastern United States (Shultz 1997). Therefore, forest operations within these managed stands that impact the carbon cycle have the ability to greatly affect global carbon dynamics by altering growth and decomposition above and below ground.

The thinning of pine plantations is a commonly used silvicultural procedure. The process involves the systematic harvest of several trees from a young stand, with the intent of re-allocating growth from many small trees to fewer large trees. This practice will invoke both physiological and growth responses for the remaining trees and microclimatic changes within the modified stand (Smith and others 1997). Remaining trees will have increased growth rates (Ginn and others 1991, Peterson and others 1997) and eventually basal area and volume of thinned stands will converge on levels equal to unthinned stands (Della-Bianca and Dils 1960, Hasenauer and others 1997, Pienaar and others 1985) resulting in equal aboveground carbon sequestration and inputs into the system.

As stumps and root systems from harvested trees sit in the newly modified stand, increased forest floor temperatures and soil moisture will begin to decompose the belowground biomass (Della-Bianca and Dils, 1960, Nowak and others 1990). Thinning will affect root activity of remaining trees through its influence on environmental and physiological variables such as light, mineral nutrient and water availability, and photosynthate production and partioning (Santantonio and Santantonio 1987). Thinning may also help promote root growth by providing root channels from decomposing roots of harvested stumps. Van Lear and others (2000) showed that the concentration of resources and low soil strength in root channels from trees harvested 10 years prior provided a favorable rooting environment for remaining trees.

The effects of thinning will likely alter E_c within the modified stand. E_c is the combination of heterotrophic and autotrophic respiration. Heterotrophic respiration refers to the CO_2 emitted from microbial activity (decomposition of organic matter) within the soil. Autotrophic respiration is considered to be the sum of direct root and associated microbial rhizosphere respiration (Hanson and others 2000). Global E_c rates have been estimated to be between 60-80 Pg (1 x 10^{15} g) of carbon per year (Raich and Potter 1995, Raich and Schlesinger 1992, Schlesinger 1977) with an estimated 598 gC per m^2 per year coming from temperate pine forests (Schlesinger 1977). These carbon dioxide emissions from soils exceed all other terrestrial atmospheric carbon exchanges with the exception of gross photosynthesis (Raich and Schlesinger 1992).

The thinning of a loblolly pine stand will lead to a complex mix of CO_2 fluxes from the soil. Root systems of harvested trees will likely die, unless grafting occurs, reducing autotrophic respiration. Remaining trees will likely increase root growth and respiration, reoccupying the site. Temporary autotrophic respiration additions may also be seen from advantageous understory growth. Decomposition of old roots will also increase heterotrophic respiration rates. The objective of this study was to determine how all of these individual processes caused by the thinning of a 22-year-old plantation would affect soil CO_2 E_c trends over the course of one year following harvest.

METHODS AND MATERIAL

Study Site

The study site is located on the upper Piedmont at the Reynolds Homestead Forest Resources Research Center in Critz, VA. The area receives an average of 1,150 mm of precipitation, maintains an average annual temperature of 14.3 °C, a maximum mean temperature of 21.3 °C, a minimum annual average of 7.3 °C and 193 frosted days extending from mid-March through mid-October (NOAA 2001).

[1] Graduate student and Professor, Department of Forestry, College of Natural Resources, Virginia Polytechnic Institute and State University, Blacksburg, VA, respectively.

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Historically, this land was in agricultural fields until 1980 when three replicate 0.222-ha sites were planted with loblolly pine seedlings, using 3.05-m by 3.05-m spacing. Stand one is located on a Lloyd clay loam, and stands two and three are located on a Wickham loam. In March of 1988, half of each stand was thinned diagonally, leaving square spacing of 4.31 m by 4.31 m. Crown closure was reached again approximately 6 years after the thinning.

The thinned section of the stand was thinned again in April 2002 by the removal of every other row of trees. A majority of the slash was removed from the site. The resultant treatment then contained 22-year-old loblolly pines at 6.1-by 6.1-m spacing and a mix of new and old stumps. Following the second thinning, thinned stands had a basal area of 23.0, 20.8, and 18.9 m^2 per ha while unthinned stands maintained 55.1, 59.0, and 49.7 m^2 per ha in blocks one, two, and three respectively.

Experimental Layout

Past studies (Pangle and Seiler 2002, Wiseman 2001) have revealed a strong measurement position effect on E_c. Measurements taken near trees have significantly higher E_c rates. Therefore, measurements were taken both near and away (approximately 1.22 m away) from trees and stumps. To adequately characterize the effect of thinning on E_c, measurements were taken both near and away from thinned trees, new stumps, and old (1988 thinning) stumps. In the unthinned treatment, measurements were taken near and away from trees. Four locations in each treatment were identified and measured and used as subsamples. Near and away positions were analyzed in the analysis as a split.

Soil Respiration Measurements

E_c measurements were taken monthly beginning in February 2002, 2 months prior to thinning and continued for 1 year following thinning. E_c was measured using the LiCor 6200 infrared gas analyzer (LiCor Inc., Lincoln, NE). A dynamic closed cuvette chamber system was used in conjunction with the LiCor 6200. The cuvette chamber was constructed using PVC piping for walls, a plexi-glass top, and an aluminum edge on the bottom. The chamber has an internal diameter of 25.5 cm, stands 13.5 cm tall, and has an entire system volume of 6,744 cubic cm. The aluminum edge on the bottom of the chamber allowed it to cut through needles on the forest floor, reducing error imposed by sub-litter airflow caused by windy conditions.

The LiCor 6200 was recalibrated before every day of data collection. The system was zeroed before data collection at every block. Measurements were taken at the base of the tree, new stump, or old stump, and approximately 1.5 m away from the object. Effort was taken to place the chamber on bare forest floor, as photosynthesizing or respiring vegetation will alter E_c measurements.

Respiration rates were determined by measuring E_c for a continuous 30-second period. The LiCor 6200 then calculated the E_c rate using equation (1):

$$\text{Soil } E_c = [(\Delta C/\Delta t)(PVt/RT)] / \text{Area} \quad (1)$$

where C = $[CO_2]$, t = time (30 seconds), P = atmospheric pressure, Vt= system volume, R = universal gas constant, and T = temperature.

Soil Moisture and Temperature

Soil moisture and temperature were measured concurrently with E_c. Soil moisture was measured to a depth of 12 cm using a HydroSense moisture meter (Campbell Scientific, Australia). Measurements are expressed as a volume percent. Temperature was measured to a depth of approximately 7 cm using a Digi-sense temperature gauge (Cole-Parmer Instrument Co., Niles, IL), and expressed to the nearest 0.1 °C.

Statistical Analysis

Analysis of variance was performed using a split-block design using JMP IN® statistical discovery software Version 4 (SAS Institute, Cary, NC). Two analyses were performed. In one analysis, E_c of thinned trees, unthinned trees, new stumps, and old (1988 thinning) stumps were compared separately for each sampling date. In a second analysis, thinned and unthinned average E_c was compared. Soil temperature was later added to each model as a covariate to determine if differences found were due primarily to changes in soil temperature.

A time series analysis was also performed to detect differences between treatment types and location of treatment types over the 1 year sampling regime, by using sampling date as a split in the ANOVA.

RESULTS

E_c ranged from 0.0934 to 17.98 µmolCO_2 per m^2 per second in thinned stands and 0.1032 to 14.400 µmolCO_2 per m^2 per second in unthinned stands. E_c was higher in thinned stands on 8 out of 12 sampling dates (fig. 1). The difference in E_c between thinned and unthinned stands was only statistically significant on 3 of the 12 sampling dates ($p < 0.10$) (fig. 1). E_c was higher in the thinned stands on

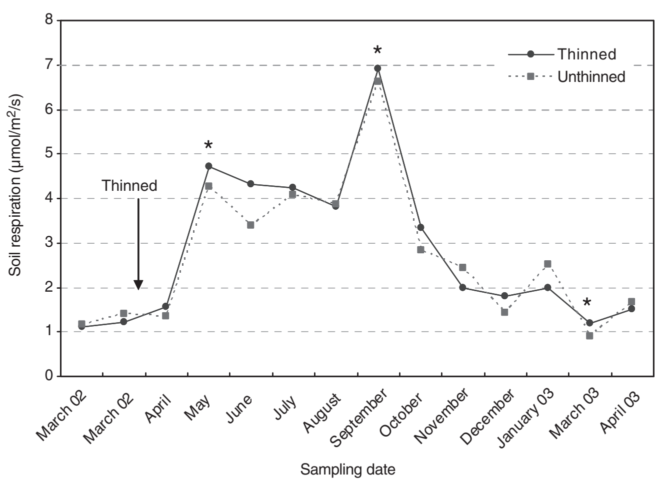

Figure 1—Soil respiration rates of thinned and unthinned 22-year-old loblolly pine plantations on the piedmont of Virginia, thinned April, 2002. An asterisk indicates a significant difference between thinned and unthinned stands (p <.10).

all three of the significant dates. However, when soil temperature was used as a covariate in the ANOVA for the May, December, and March dates, the difference between the thinned and unthinned stands became insignificant.

Soil temperature ranged from 3.1 to 25.8 °C in thinned stands and 3.8 to 22.5 °C in unthinned stands. Temperature was significantly different between the thinned and unthinned stands for 10 of the 12 sampling dates (fig. 2). Temperature was significantly higher in the thinned stands for the March and May sampling dates. On the December sampling date temperature was significantly lower in the thinned stands.

Figure 3 illustrates that there is no discernable pattern or significant difference in E_c between the new stumps, 14-year-old stumps, trees in the thinned stands, and trees in the unthinned stands on any date. This figure also illustrates the high variability between the different measurement plots within the thinned stands.

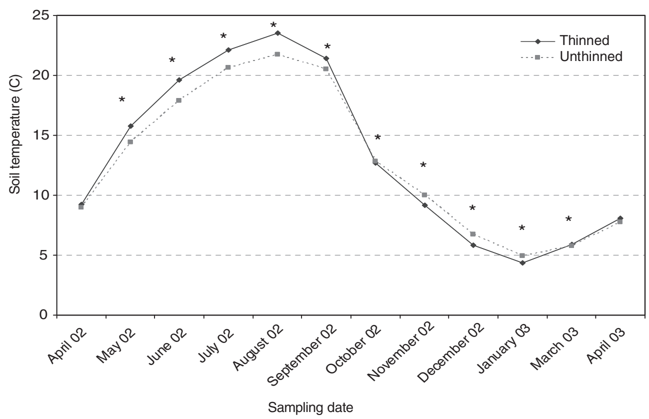

Figure 2—Soil temperature of thinned and unthinned stands of a 22-year-old loblolly pine plantation on the Piedmont of Virginia. An asterisk indicates a significant difference between thinned and unthinned stands (p <.10).

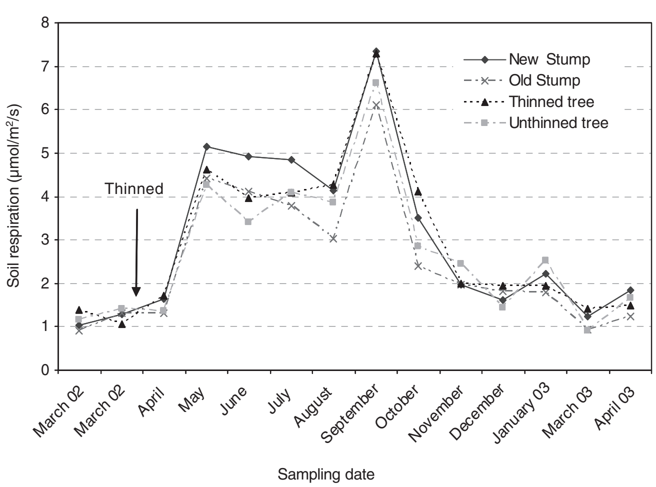

Figure 3—Soil respiration rates of new stumps, old stumps, trees located within a thinned stand and trees located within an unthinned 22-year-old loblolly pine plantation on the Piedmont of Virginia, thinned April, 2002.

DISCUSSION

While there does appear to be a slight increase in E_c following thinning, this is likely explained by altered soil temperatures. Thinning does have a significant effect on soil temperature on 10 of the 12 sampling dates, and any significant increase in E_c disappears once temperature is used as a covariate. Nowak and others (1990) and Della-Bianca and Dils (1960) also observed increases in soil temperature following thinning. Temperature is already known to be a significant driver of E_c (Trumbore and others 1996).

The lack of a strong difference between thinned and unthinned stands is also likely due to a variety of altered biological processes canceling each other out. Popescu (2001) observed a decrease in E_c following a clearcut of a loblolly pine stand on the Piedmont of Virginia. This was attributed to the loss of root respiration following the harvest of the trees. Therefore, the expected loss of root respiration caused by the harvesting of half of the trees in the thinned stand is likely being compensated for by the increased heterotrophic respiration supplied by the decomposition of dying roots. Van Lear (2000) and Santantonio and Santantonio (1987) both observed that thinning will likely increase growth of remaining trees. Increased growth rates of remaining roots are possibly increasing root respiration, again helping to buffer the loss in respiration suffered from the harvest of trees. The erratic patterns of E_c from the different types within the thinned stand may be a result of the variety of biological processes taking place after the disturbance.

Further work is needed to determine the individual underground processes that cause this phenomenon. The separation of autotrophic and heterotrophic respiration, as well as monitoring of root decomposition, would aid in explaining the true drivers.

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