EFFECTS OF FERTILIZATION AND IRRIGATION ON COMPONENTS OF SOIL CARBON EFFLUX AND SOIL RESPIRATION IN LOBLOLLY PINE PLANTATIONS

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Extended abstract—Soil carbon dioxide (CO_2) evolution is a combined product of the metabolic activity of plant roots and both free-living and symbiotic heterotrophs. Soil CO_2 efflux (S_f) rates are the second largest carbon flux in the global carbon cycle and the largest terrestrial contributor of CO_2 (Raich and Schlesinger 1992). The components of S_f can be broken down into heterotrophic respiration (R_H) and autotropic root respiration (R_R). Quantifying S_f and understanding the contribution of R_H and R_R on intensively managed sites is fundamental to understanding the carbon cycle and implications for carbon sequestration (McElligott and others 2016).

Loblolly pine (*Pinus taeda*) is used extensively for commercial timber and fiber production in the Southern United States. Fertilization and, to a lesser degree, irrigation, are increasingly being used to raise productivity in managed pine stands. For example, 238,000 ha of southeastern pine forests were fertilized in 2016 (Albaugh and others 2018). While fertilization can dramatically increase stand productivity and leaf area (Albaugh and others 2004, Samuelson and others 2004a), the effects on belowground carbon allocation and S_f are equivocal. Changes in nutrient availability can have a differential effect on fine root production and microbial respiration, altering the relative contributions of R_R and R_H to S_f (Butnor and others 2003, Maier and Kress 2000, Samuelson and others 2004b).

We examined the effects of fertilization and irrigation on S_f in a 16-year-old loblolly pine plantation and quantified how root biomass, forest floor litter, and soil coarse organic fragments influenced S_f. The objectives of the study were to (1) examine the effect of fertilization and irrigation on S_f and (2) quantify component contributions of R_H and autotrophic root respiration R_R.

The main study had a randomized complete block design with a 2 × 2 factorial combination of nutrition (no addition, -F, and complete nutrition, +F) and irrigation (no addition, -I, and well watered, +I) replicated four times (Albaugh and others 1998). After 10 years of treatment, five 1-m^2 by 50-cm-deep organic matter treatment pits (O, subplots) were randomly installed in each treatment plot: control (C, no treatment); litter removed (L); roots removed (R); roots and mineral soil coarse organic fragments (>2 mm) removed (RX); and roots, coarse organic fragments, and litter removed (RXL). On 13 days between July 2001 and December 2002, measurements of S_f were taken using a LI-6400 (LI-COR, Lincoln, NE) portable photosynthesis system at two points per subplot. Soil CO_2 efflux was modeled as a function of

$$S_f = S_{f,20} {}^* e^{(q^*(T\text{-}20))} \qquad (1)$$

where

$S_{f,20} = S_f$ at 20 °C, q = temperature coefficient, and T = soil temperature at 10 cm.

The whole-plot (F and I), subplot (pits) and interactive effects of treatment and day of measurement on S_f were tested using repeated measures analysis of variance (Proc Mixed, SAS Institute Inc., Cary, NC, USA) with block as a random factor and treatments as fixed factors. A first-order autoregressive covariance structure (AR(1)) was selected based on AIC fit statistics. Treatments differences in LSMEANs were evaluated with Tukey's test.

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Fertilization and irrigation treatment increased S_f by 25 percent (p = 0.005) and 17 percent (p = 0.046), respectively, and there was no significant F x I interaction (p = 0.46). Irrigation increased S_f mainly during the growing season (I x Day p = 0.001). Average S_f was 2.14, 2.46, 2.74, and 3.40 μmol m^{-2} s^{-1} (SE = 0.23) in the -F-I, -F+I, +F-I, and +F+I treatments, respectively. Fertilization increased S_f, likely due to increased R_R from a nearly doubling of root biomass. In 2002, the fertilization treatments had an almost 2.4-fold greater coarse root biomass than non-fertilized treatments (Albaugh and others 2004), resulting in higher R_R.

Soil temperature explained 60 to 80 percent of the variation in S_f. $S_{f,20}$ increased with fertilization and irrigation, while q was increased by irrigation, but decreased with fertilization. There was no significant F x I on either parameter. There were significant whole-plot x pit interactions ($p < 0.05$) on $S_{f,20}$ (table 1). The responses of $S_{f,20}$ and q to the removal of organic matter varied with treatment.

The temperature sensitivity was similar among C, L, RX, and RXL pits, but were significantly higher in the R pits (fig. 1). On the other hand, $S_{f,20}$ was significantly greater in the C (no organic matter removal) pits than in pits where litter (L), roots (R), or coarse organic fragments (RX, RXL) were removed. $S_{f,20}$ in the L, R, and RX pits was 18, 23, and 24 percent lower, respectively, than in the C pits. This reduction in S_f due to R_R was similar to other studies in managed loblolly pine plantations (McElligott and others 2016). There was no significant difference in $S_{f,20}$ between R and RX treatments (p = 0.798), which suggest that the decomposition of coarse organic fragments contributed only a small amount of CO_2 to S_f.

There was a significant fertilization and irrigation interaction with organic matter treatment (F x O and I x O), likely caused by a larger +F and +I effect on S_f in the C and L pits that contained roots. This was likely due to increased R_R rather than R_H. Surprisingly, removal of roots, coarse organic matter, and litter (RXL) reduced $S_{f,20}$ by only 50 percent. This indicates that a considerable amount of S_f came from R_R and R_H from outside of the pit. Because of this, the root/coarse organic matter exclusion pit approach used here, by itself, is unlikely to produce robust estimates of the ratio R_R/S_f or R_H/S_f.

Table 1—ANOVA for treatment effects on parameters in equation 1

Treatment effect	$S_{f,20}$	q
	p-values	
Fertilization (F)	<0.001	0.023
Irrigation (I)	0.025	0.001
F x I	0.775	0.255
Organic matter (O)	<0.001	<0.001
F x O	0.002	0.915
I x O	0.007	0.243
F x I x O	0.124	0.562

$S_{f,20}$ is soil CO_2 efflux at 20 °C and q is the temperature sensitivity.

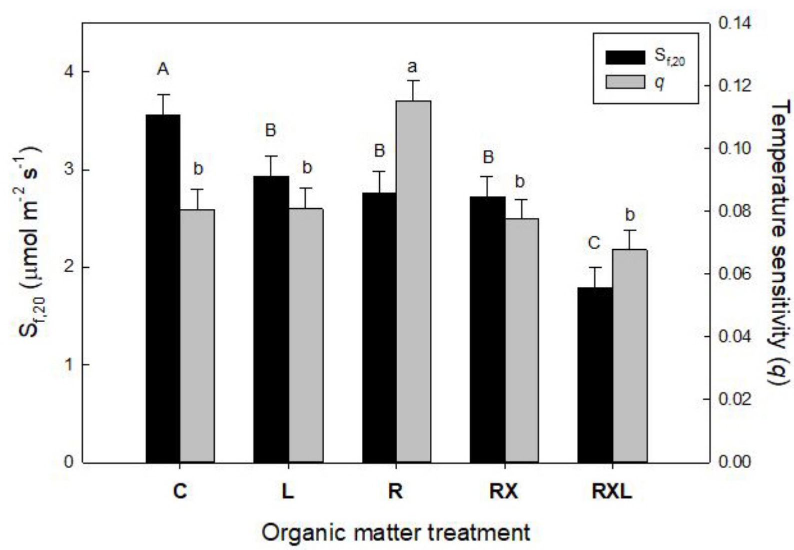

Figure 1—LSMEANs for soil CO_2 efflux at 20 °C ($S_{f,20}$) and temperature sensitivity (q) (equation 1). Organic matter treatments were C - no treatment; L - litter removed; R - roots removed; RX - roots and coarse organic fragments (>2 mm) removed; RXL - roots, coarse organic fragments, and litter removed. Means with the same letter (upper case for $S_{f,20}$, lower case for q) are not significantly different at α= 0.05.

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