

Effects of throughfall reduction and fertilization on stem CO₂ efflux in a loblolly pine (*Pinus taeda*) plantation

Jinyan Yang¹ Yujie He² Doug P. Aubrey^{1,3} Mary Anne McGuire¹ Lisa Samuelson⁴ Robert O. Teskey¹

¹Warnell School of Forestry and Natural Resources, The University of Georgia, USA ²Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN 47906, USA

³Savannah River Ecology Laboratory, University of Georgia, Aiken, SC 29802, USA ⁴School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL 36849, USA



Introduction

- Stem CO₂ efflux (E_S), the diffusion of CO₂ from plant stems to the atmosphere, is an important component in regional and global carbon cycles.
- Historically, E_S was considered a direct measure of stem respiration as it was assumed that E_S represented the respiratory activity of local phloem, cambium, and ray cells; however, it is now accepted that it also incorporates some of the respiratory activity of cells located below the point of measurement, including those of roots and omits some of the locally produced CO₂ that remains within the stem.
- It has been suggested that E_S accounts for 11-23% and 40-57% of the carbon assimilated in temperate and tropical forests, respectively.
- Intensive management and predicted declines in precipitation are likely to affect the carbon budgets of loblolly pine (*Pinus taeda*) plantations in the southeastern United States. However, little is known about how E_S responds to decreasing soil moisture and changes in soil fertility.
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Objectives and hypotheses

- Objective (1) : to quantify impacts of throughfall reduction and fertilization on E_S ,
- Objective (2) : to determine physical and biological controlling factor of E_S .

Methods: Experimental design and treatments

- The study was performed at the Tier III site in Washington, GA (Fig. 1a).
- The experiment design was a 2 × 2 factorial combination of fertilizer treatment (two levels: no fertilization, C; or one-time fertilizer application, F; Fig. 1b) and precipitation throughfall reduction (two levels: no throughfall reduction, C; or 30% throughfall reduction, R; Fig. 1c) replicated in four blocks.
- There were 4 replicate plots for each treatment and 16 plots in total.



Fig 1. Map of Washington, GA Tier III site treatments (a). Different blocks are represented by differently colored borders around plots. Fertilization treatment (b) and throughfall reduction (c).

Methods: Stem CO₂ efflux (E_S) measurement

- Monthly we measured E_S , and stem temperature at 1cm depth (T) below the bark, from April 2014 to December, 2015 with a LI-6400-09 chamber (Fig. 2).

Methods: estimation of CO₂ efflux from roots (E_R)

- Soil CO₂ efflux (E_{Soil}) along with soil temperature and soil moisture from 2014 to 2015 were measured monthly with a LI-6400 portable gas exchange system (Fig. 3a).
- The CO₂ efflux from heterotrophs and ectomycorrhizal hyphae (E_{H+M}) were separated by comparing untrrenched plots with trenched plots that prevented root growth. Measurements were also taken monthly from 2014 to 2015 (Fig. 3b).
- The difference between E_{Soil} and E_{H+M} was used to estimate the CO₂ efflux from roots (E_R).

Results: Seasonal patterns of E_S and E_{S15}

- There were strong seasonal patterns in E_S in the four treatments in the two year period of measurement, the highest values were in spring while the lowest was in winter (Fig. 1).
- There were less obvious seasonal patterns of E_S normalized at 15°C (E_{S15}).
- E_S in the R treatment was significantly lower than in control in the growing season in 2014.

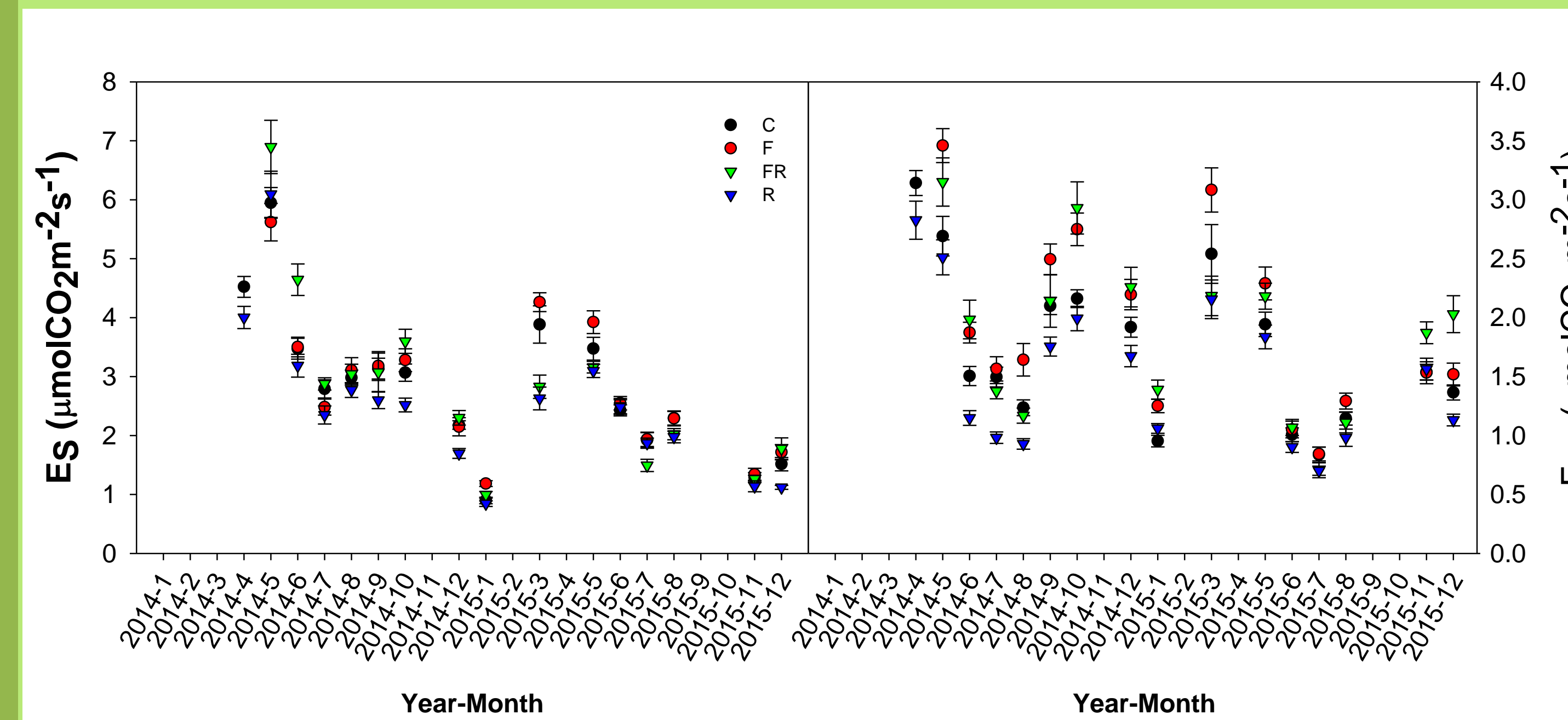


Fig 4. Seasonal patterns of E_S and E_{S15} .

Results: Response ratio (RR) of E_S in different treatments

- Throughfall reduction tended to have negative response ratio while fertilization and FR treatments had positive response ratio during the most of the measurement period (Fig. 5).
- The range of RR was from -0.11 to 0.27 in F, from -0.30 to 0.02 in R, and from -0.25 to 0.29 in FR.

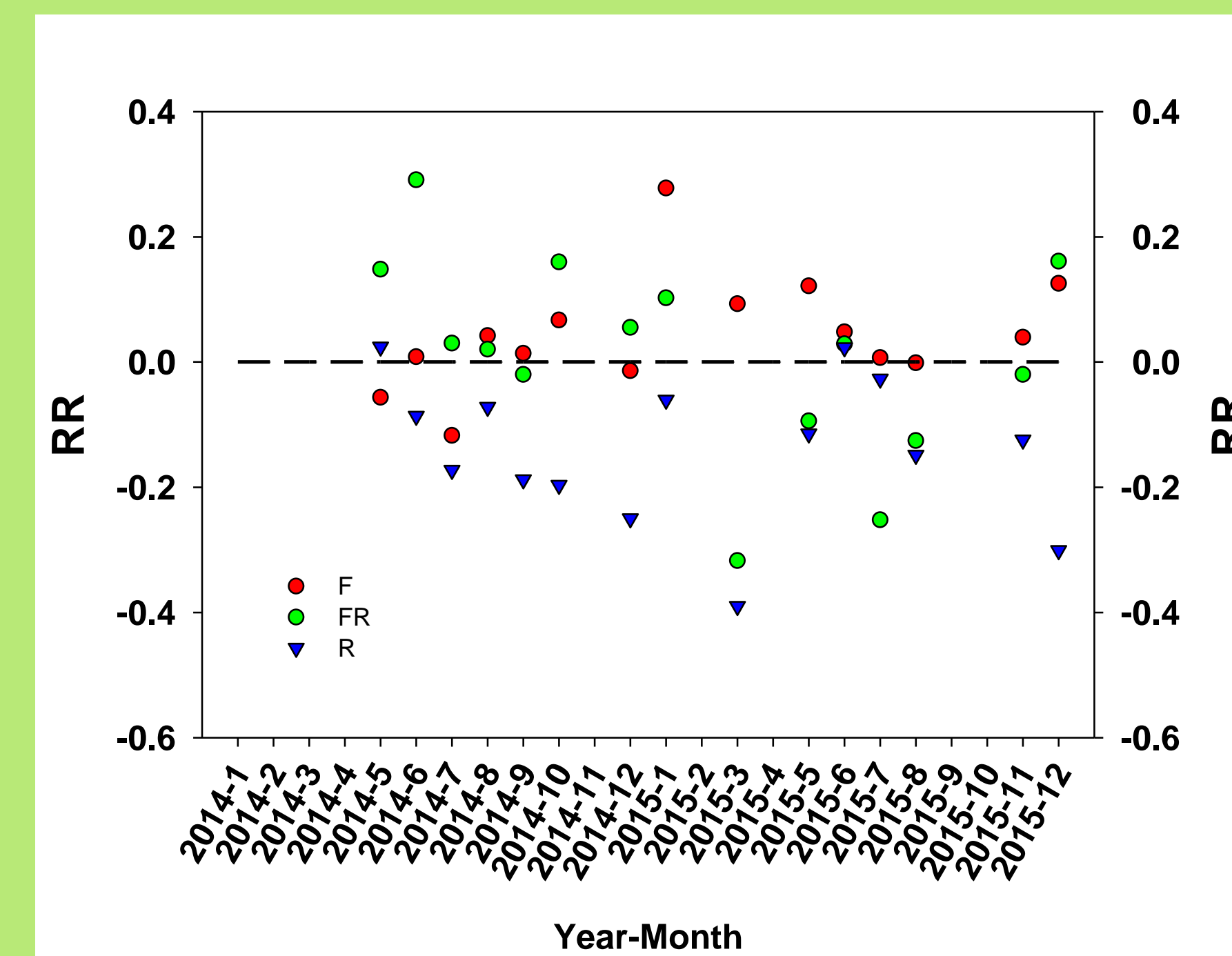
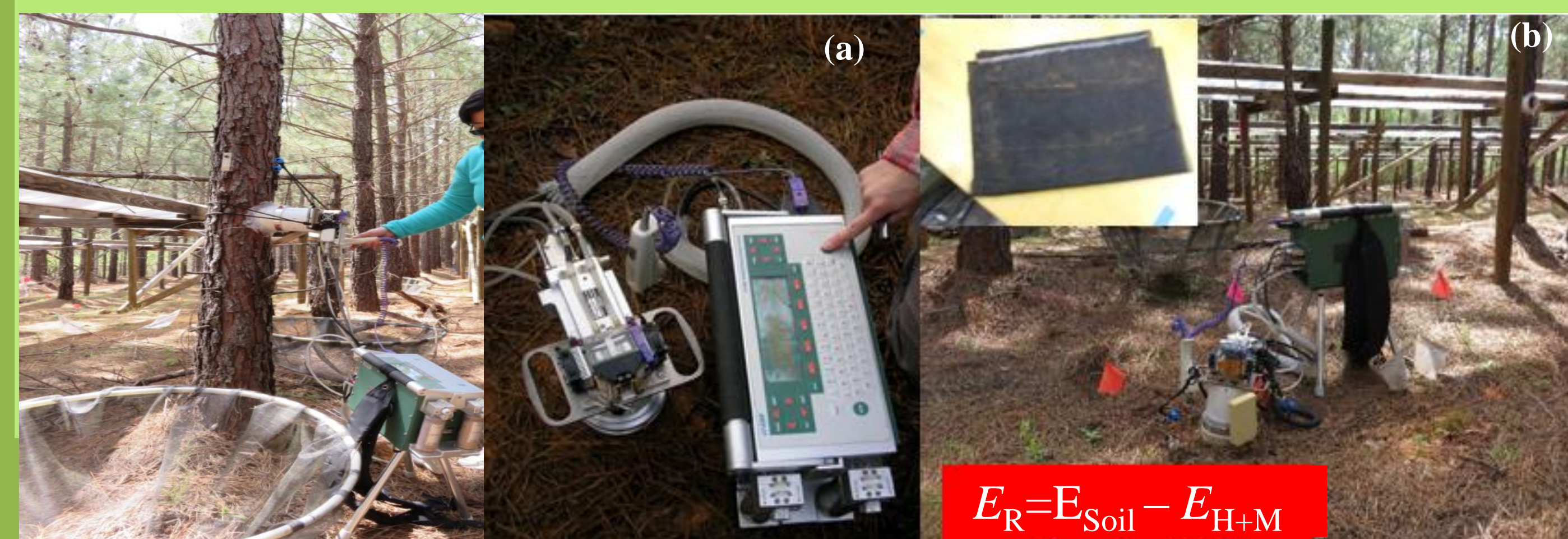


Fig 5. RR in different treatments. RR is the difference in natural logarithm between values of E_S in treatment and control plots.



- E_S
- 4 PVC collars/plot
- Monthly measurement

Fig 2. E_S measurement

- E_{Soil}
- 4 replicates/treatment
- 4 PVC collars/plot
- E_{H+M}
- Excluded roots & MycorHyphae
- Mesh Screen (41μm)

Fig 3. E_{Soil} and E_{MH} measurement

Results: Seasonal means for E_S , T , Q_{10} and E_{S15}

- Throughfall reduction (R) tended to decrease E_S by 18% while fertilization had no effect on E_S (Table 1).
- The E_S normalized at 15°C (E_{S15}) was significantly lower in the throughfall reduction than in the fertilization treatment for the total measurement period.
- The apparent Q_{10} of E_S was similar in all treatments, ranging from 1.92 to 2.17.

Table 1. Seasonal means for E_S , T and E_{S15} and Q_{10} . The significance level is $p < 0.05$.

Treatment	E_S	T	Q_{10}	E_{S15}
Control	2.75 ± 0.15	21.0 ± 0.37	2.16	1.72 ± 0.09 a
F	2.85 ± 0.16	20.98 ± 0.39	1.92	1.92 ± 0.11a
FR	2.83 ± 0.17	19.93 ± 0.32	2.17	1.84 ± 0.13 a
R	2.32 ± 0.14	20.74 ± 0.37	2.13	1.53 ± 0.09b

Results: P values for effects of treatments on E_S , E_{S15} and T

- There was a significant interaction between date and FR on E_S . There were no significant effects of F or R on E_S (Table 2). There was also a significant date effect on E_S .
- There was a significant interaction effect between date and R on E_{S15} .
- Measurement date had a significant effect on stem temperature.

Table 2. P values for effects of treatments on E_S , E_{S15} , and T . The significant level is at $p < 0.05$.

	F	R	F×R	Date	Date×F	Date×R	Date×F×R
E_S	0.413	0.177	0.058	0.041	0.456	0.449	0.036
E_{S15}	0.116	0.260	0.541	0.541	0.672	0.030	0.780
T	0.124	0.324	0.880	0.004	0.076	0.625	0.059

Results: E_S and stem temperature (T)

- Stem temperature explained 24% (F) to 41% (R) of the variation in E_S for the total measurement period among the treatments (Table 3).
- The R^2 values in the dormant season were lower than in the total measurement period in F, R and FR treatments.
- Stem temperature explained less than 20% of the variation in all treatments in the growing season, indicating that other factors affect E_S in the growing season.

Table 3. Regression models of E_S predicted using T in the four treatments in the two-year measurement period (Total) and in the dormant season (November to February). The regression models are of form: $\ln(E_S) = a + bT$.

Period	Treatments	a	b	df	F	Adj-R ²	RMSE	p
Total	C	-0.29	0.0537	235	104.9	0.31	0.45	<0.001
	F	0.0045	0.041	210	51.25	0.24	0.48	<0.001
	R	-0.31	0.0525	236	109.3	0.41	0.47	<0.001
	FR	-0.17	0.051	210	82.04	0.28	0.52	<0.001
Dormant season	C	-1.13	0.097	60	37.96	0.37	0.35	<0.001
	F	-0.68	0.074	61	15.8	0.20	0.37	<0.001
	R	-0.797	0.075	62	16.22	0.24	0.45	<0.001
	FR	-0.63	0.079	62	20.02	0.23	0.42	<0.001

Results: Correlation between E_S and E_R

- There were positive relationships between E_S normalized at 15°C (E_{S15}) and E_R normalized at 15°C (E_{R15}) in the four treatments during the total measurement period (Fig. 6).
- Using analysis of covariance, there were no significant differences detected between the slopes of the correlations between E_{S15} and E_{R15} in the four treatments.

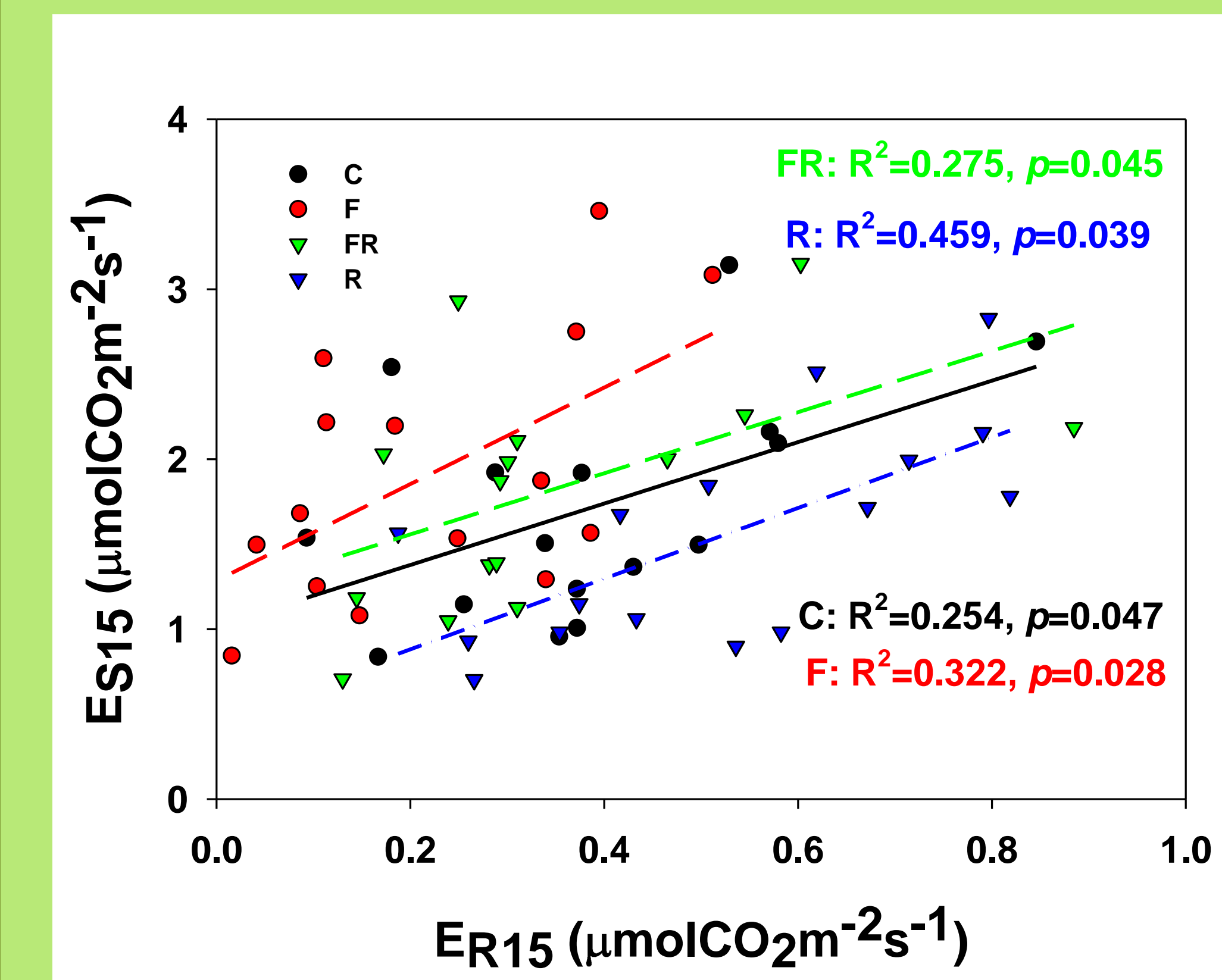


Fig 6. Relationships between residuals of E_S and E_R in different treatments.

Discussion and Conclusions

- Stem temperature explained 24% to 41% of the variation in E_S in all treatments in four treatments.
- There was a significant interactions between date and FR on E_S and between date and R on E_{S15} .
- Throughfall reduction significantly reduced E_S in the growing season in 2014.
- Root CO₂ efflux normalized at 15°C (E_{R15}) explained 25% to 46% of the variation in E_{S15} which may be related to the upward transport of CO₂ derived from roots via sapflow.
- The link between aboveground E_S and belowground E_R should be considered in assessing and modeling E_S .

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For further information

Please contact yangjy@uga.edu



United States Department of Agriculture
National Institute of Food and Agriculture



WARNELL
SCHOOL OF FORESTRY AND NATURAL RESOURCES
THE UNIVERSITY OF GEORGIA