Rapid transpiration accompanies soil carbon loss in the rhizosphere of *Populus fremontii*

Nick Bader and **Weixin Cheng** — Department of Environmental Studies, University of California, Santa Cruz, CA 95064

Introduction

The prediction of soil organic carbon (SOC) stocks under various management regimes will become increasingly important as more political effort is applied to the mitigation of climate change. However, our current tools for predicting SOC stocks are limited by our ignorance of critical belowground processes. In the presence of plant roots, the rate of SOC decomposition can be greatly accelerated or inhibited, depending on plant species and phenology. For example, Cheng et al. (2003) found that decomposition of SOC in pots planted with *Glycine max* L. and *Triticum aestivum* L. was accelerated respectively by as much as 383% and 287% relative to pots without plants. This rhizosphere priming effect (RPE), if sustained, could dramatically alter future SOC stocks. Unfortunately, rhizosphere priming is currently difficult to measure in the field because of the need to separate root and soil components of belowground respiration. There is consequently a need to determine the factors controlling the magnitude of the RPE, and the seasonal changes to SOC stocks due to the RPE. In this study, we measured the RPE of *Populus fremontii*, a riparian tree common at low altitudes in California.

Fig. 1. Preparation for trapping CO_2 respired from the soil and rhizosphere. The pale blue material coating some of the pots is flexible silicone rubber, designed to isolate the soil gases from the ambient atmosphere.

Materials and methods

We measured soil-derived respiration using Cheng's (1996) stable isotope method. Briefly, plants are raised in leak-tested PVC containers rather than standard greenhouse pots. Before sampling, the soil surface is sealed with a poured silicone rubber mold (Fig 1). This isolates the soil atmosphere from the ambient atmosphere. Residual CO_2 is then removed from the soil atmosphere before sampling by circulating the isolated air through a CO_2 scrubber.

The scrubber is then replaced with a NaOH trap and the soil atmosphere is periodically circulated through the system (Fig. 2). The NaOH trap captures greater than 99% of the CO_2 in circulation, thus reducing the potential pitfall of preferential isotope absorption (Cheng 1996). Next, the CO_2 in the NaOH traps is precipitated as $SrCO_3$, which is rinsed free of NaOH and analyzed for stable C isotopes in a mass spectrometer.

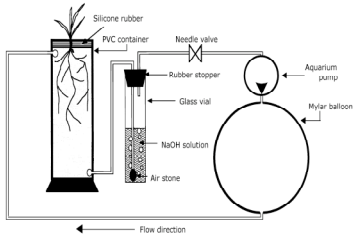

Fig. 2. Diagram of the apparatus used in the experiment. Modified from Cheng (1996).

In the pots planted with *P. fremontii*, the plant-derived C can be separated from the soil-derived C with the following relationship (from Cheng, 1996):

$$C3 = C_{total}\,[(\delta_t - \delta_4)/(\delta_3 - \delta_4)],$$

where C3 is the total carbon derived from the C3 plant, C_{total} is the total amount of carbon trapped, δ_t is the $\delta^{13}C$ value of the trapped carbon, δ_3 is the $\delta^{13}C$ value of the C3 plant, and δ_4 is the $\delta^{13}C$ value of the C4 soil.

The temperature and humidity of the planting site were measured with HOBO dataloggers. All pots were weighed before and after each watering. Evaporation and evapotranspiration were calculated by the mass loss between waterings of the control and planted pots, respectively. Transpiration was then calculated as evapotranspiration minus evaporation.

Average water content was estimated after the experiment assuming (1) water content decreased linearly between measurements, and (2) plant mass increased linearly between planting and harvest dates.

Results

All data analysis and graphs were prepared with the R language (RDCT, 2003). Plant-derived soil respiration was very high compared to soil-derived respiration (Fig. 3). Differences in soil-derived respiration are summarized in Table 1.

DAP[b]	Respiration (mg C pot^{-1} day^{-1})[a] Control	*P. fremontii*	Sig.[c]
36	9.15±1.24	7.67±1.39	
72	15.62±2.77	2.68±0.90	*
108	9.54±0.76	5.33±1.20	
142	4.44±1.02	12.36±1.05	**
148	16.04±1.72	27.91±4.03	(p=0.053)
168	6.75±1.15	15.10±6.71	
246	1.94±0.18	4.10±0.15	***

a: mean ± standard error; n = 4
b: days after planting
c: significance from t-test using Welch's df estimate

The net priming effect is the soil-derived respiration from the plant treatment minus the respiration of the no-plant controls. When the net rhizosphere priming effect is plotted, a clear pattern emerges (Fig. 5): initially, soil respiration is suppressed. By about 140 days, however, this effect reverses and soil-derived respiration in the plant treatment surpassed respiration in the no-plant controls.

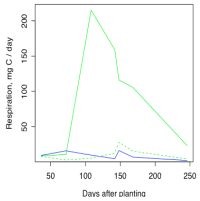

Fig. 3. Total belowground respiration can be subdivided into total plant-derived or rhizosphere respiration (green line), soil-derived respiration from the plant treatments (dashed green line), and respiration from the no-plant controls.

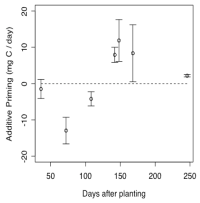

Fig. 4. Net rhizosphere priming effect. The dotted line represents the "background" respiration, i.e. the respiration of the no-plant controls.

Conclusions

The pattern of rhizosphere priming shown in Fig. 4 is in agreement with Bottner et al. (1988) and Salih and Bottner (1988), who reported that planted treatments showed reduced decomposition during the first 150 days and accelerated decomposition thereafter, compared to no-plant controls. Because both positive and negative priming effects were measured, the expected net effect of P. fremontii roots on SOM decomposition was not significantly different from zero. However, numerous researchers have noticed only positive priming effects that peak during the growing season, with no initial suppression, or small negative priming effects that persist throughout the growing season (e.g. Cheng et al., 2003). In such a case, the presence of roots might reduce SOC.

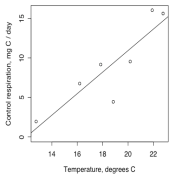

Fig. 5a. Soil respiration rate vs. temperature in the controls ($p < 0.01$, adjusted $R^2 = 0.74$),

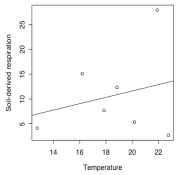

Fig. 5b. Soil respiration rate vs. temperature in the planted treatments ($p > 0.58$, adjusted $R^2 = 0.12$).

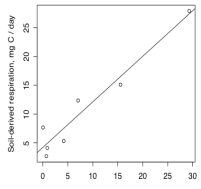

Fig. 6. Soil-derived respiration rate vs. transpiration/evap. index. Intercept = 4.21678; slope = 0.79131, $p > 0.001$, adjusted $R^2 = 0.92$.

The respiration rates of the no-plant controls were correlated with temperature (Fig. 5a). However, the respiration of soil-derived C from the *P. fremontii* treatment was not correlated with temperature (5b), but with the transpiration / evaporation quotient (Fig. 6). This quotient is a measure of how many times more water was lost because of the presence of the plant. This implicates plant architecture as an important factor regulating rhizosphere soil respiration, and suggests the importance of both leaf surface area (perhaps related to photosynthetic production of rhizodeposits) and root surface area. Other researchers have noted the importance of photosynthesis (Kuzyakov, 2002) and plant biomass (F. Dijkstra, pers. com.) as controls of rhizosphere priming. The influence of plant roots on temperature and moisture effects cannot be ruled out as important factors. We are currently measuring temperature and moisture distribution differences in the planted and unplanted treatments to assess the significance of these effects.

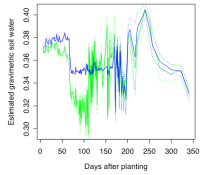

Fig. 7. What about water? SOC decomposition is known to vary with water content. Although we kept soil water as constant as possible, differences (left) may explain the early negative priming effect. Right: current measurements of temperature and moisture in a greenhouse pot.

Literature cited

Bottner, P., Z. Sallih, and G. Billes, 1988. Root activity and carbon metabolism in soils. *Biology and Fertility of Soils* 7: 71-81.
Cheng, W., 1996. Measurement of rhizosphere respiration and organic matter decomposition using natural ^{13}C. *Plant and Soil* 183: 263-268.
Cheng, W., D.W. Johnson, and S. Fu, 2003. Rhizosphere effects on decomposition: controls of plant species, phenology, and fertilization. *Soil Science Society of America Journal* 67: 1418-1427.
Kuzyakov, Y. 2002. Factors affecting rhizosphere priming effects (review). *Journal of Plant Nutrition and Soil Science* 165: 382.
R Development Core Team (2003). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-00-3, URL http://www.R-project.org.
Sallih, Z. and P. Bottner, 1988. Effects of wheat (*Triticum aestivum*) roots on mineralization rates of soil organic matter. *Biology and Fertility of Soils* 7: 67-70.

Acknowledgments

I greatly appreciate the contribution of the Kearney Foundation, whose support has made this research, and future research, possible.