# SOIL CARBON DYNAMICS IN DIFFERENT SUCCESSIONAL STAGES OF TROPICAL FORESTS

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*Abstract:* The rates of ecological processes change with successional patterns and disturbances. Soil respiration rates are influenced by many abiotic factors, but how forest age influences soil respiration rates is poorly understood. We examined the effects of soil temperature, soil moisture, and litter quantity on soil respiration rate between forests of different successional stages and their effects. Soil respiration rate tended to increase from early successional stages to secondary growth, but decreased from secondary growth to primary growth; this could be due to differences in the quality and/or quantity of litter input. Soil respiration rates and soil moisture did not differ between successional stages but soil temperatures averaged 1.6°C warmer in early successional plots. As the relative proportion of young forests increases from anthropogenic effects, understanding the resulting effects on pools and fluxes of soil carbon will become more important.

*Key words: carbon content, decomposition, litter quality, litter quantity, soil respiration rate, temperature, water content*

## INTRODUCTION

Tropical forests are a mosaic of different successional stages, ranging from new gaps to stands with old trees and no recent tree falls. Abiotic and biotic forest characteristics such as temperature, litter quantity, litter quality and moisture levels probably change with successional stage. Temperature may be lower in late successional stages because of increased canopy cover. Litter quantity may be higher in late successional stages because of a higher standing biomass available to input litter. Litter quality may be lower in late successional stages because of increased secondary metabolites. Moisture levels may increase with forest age because soil evaporation rates decrease with decreased soil temperature, or because moisture levels may decrease with forest age because higher canopy cover reduces the amount of rainfall reaching the soil.

Abiotic and biotic differences between successional stages may affect effluxes and influxes associated with the pool of carbon in the soil. The main influx to this carbon pool is leaf litter, and the main efflux is respiration from the soil. We expected that soil respiration rates may be affected by forest characteristics associated with different successional stages.

We predicted that soil temperatures would be higher in early successional forests, and that soil respiration rates would also be higher than in older forests. Older forests may produce more leaf litter that leads to higher total respiration, but the rate of soil respiration per gram litter will not increase. Higher litter quality, associated with early successional forests, may lead to higher soil respiration rates in those forests. Higher soil moisture content may lead to higher soil respiration rates, so if soil moisture content increases with successional stage due to decreased soil evaporation, soil respiration rates may increase.

The influxes and effluxes of carbon pools in the soil determine the amount of carbon held in this pool. As soil respiration rates increase, the size of the soil carbon pool will decrease. Therefore, if soil respiration rates decrease with temperature and temperature decreases with successional stage, the size of the carbon pool stored in the soil will increase with successional stage. Similarly, if soil respiration rates decrease with litter quality and litter quality decreases with successional stage, pool sizes will increase with successional stage. Alternatively, if total soil respiration increases with litter

quantity but soil respiration rates do not increase with litter quantity, pool sizes will not change with successional stage even though total soil respiration would increase.

To examine the affect of successional stage on carbon size and soil respiration rates, we measured soil respiration rates, litter input rates, soil temperature, and soil moisture content in addition to the size of the soil carbon pool in three forests in different successional stages.

## METHODS

We took all measurements on 15 - 17 February 2004 at La Selva Biological Reserve, Puerto Viejo, Costa Rica. We measured litter fall for two days with 1.0 m x 1.7 m plastic sheets suspended approximately 1 m from the ground. We set up triplicate traps in primary, secondary (19 - 25 year old), and early successional forests (2 - 5 year old) with similar alluvial soil. From dry mass of the litter that collected in these traps, we calculated the grams of carbon per square meter per hour (g C $m^{-2}$ $hr^{-1}$) that is added to the soil.

We measured moisture content, carbon content, and mineral content for the organic horizon of these same forests by weighing samples from each forest, drying them at 100°C for 4 hours, weighing them again, burning them at 750°C overnight, and weighing them again. The difference between wet and dry weight is water content and the difference between dry and burned weight represents the size of the carbon pool. Unfortunately, our burning procedure melted the aluminum foil containers so the data could not be collected and carbon contents were not calculated.

We took three measures of soil respiration rates in each of the three forest ages using volumetric soil respirometers. All measurements were conducted in the laboratory at a relatively constant temperature of 25.6°C. We used the soil respiration methods described by Eaton et al. (1998). From these data, organic layer depths and bulk densities garnered from Sollins et al. (1994), and the ideal gas law we expressed soil respiration rates as grams of carbon released per square meter of soil per hour (g C $m^{-2}$ $hr^{-1}$) so as to compare with litter fall rates.

## RESULTS

Litter fall rates varied widely (0.74 - 15.81 g of dried leaves collected) as did soil respiration rates (0.43 - 2.20 mL of $O_2$ dry soil $g^{-1}$ $hr^{-1}$). Temperature differed significantly between primary, secondary, and early successional forests, rising as age decreased ($F_{2,7}$ = 23.48, P = 0.003; Table 1, Fig. 1). Percent water content did not differ significantly with successional stage ($F_{2,7}$ = 3.15, P = 0.13), so we did not examine any further correlations with water content. Leaf litter input did not differ significantly between primary, secondary and early successional forest

Table 1. Temperature, soil respiration rate, and litter fall rates (means ± SD) differ between forest types.

| Forest type | Temperature (°C) | Soil respiration (g C $m^{-2}$ $hr^{-1}$) | Litter fall (g C $m^{-2}$ $hr^{-1}$) | Percent water content |
|---|---|---|---|---|
| Early successional | 25.6 ± 0.3 | 0.030 ± 0.023 | 0.060 ± 0.050 | 53.4 ± 1.3 |
| Secondary | 24.6 ± 0.4 | 0.063 ± 0.011 | 0.015 ± 0.012 | 61.8 ± 5.1 |
| Primary | 24.0 ± 0.2 | 0.029 ± 0.017 | 0.024 ± 0.016 | 62.1 ± 6.3 |

($F_{2,7}$ = 1.64, P = 0.28) but the lowest amount of leaf litter fell in the secondary forest (Table 1, Fig. 1). Soil respiration rate did not differ significantly between primary, secondary, and early successional forest ($F_{2,7}$ = 2.34, P = 0.19), but soil respiration rate was highest in secondary forest (Table 1, Fig. 1). We were unable to estimate pool sizes because of our difficulties with the Muffle furnace.

## DISCUSSION

Soil respiration rate does not have a linear relationship with forest age, but appears to have a more complex pattern. While we expected to see soil moisture content differ between successional stages, we found no such pattern. The range of soil moisture that we found was very small, and seemed unlikely to influence soil respiration rates. Assuming a typical temperature response ($Q_{10}$ = 2), mean temperature difference between early successional and primary forest (1.6°C) would roughly correspond to an 11% increase in soil respiration rate.

If there are real differences between successional stages in temperature controlled soil respiration rate, it could arise from the effects of litter quantity and/or litter quality. This could be tested by more thorough measurements of litter input rates and litter quality for microbes in stands of different ages. The relative importance could be examined by studying the size of the carbon pool. We would expect to see a decrease in the soil carbon pool with increasing forest age if the litter quality is the driving factor, while we would expect little or no change in the soil carbon pool with increasing forest age if the litter quantity is the driving factor. Future

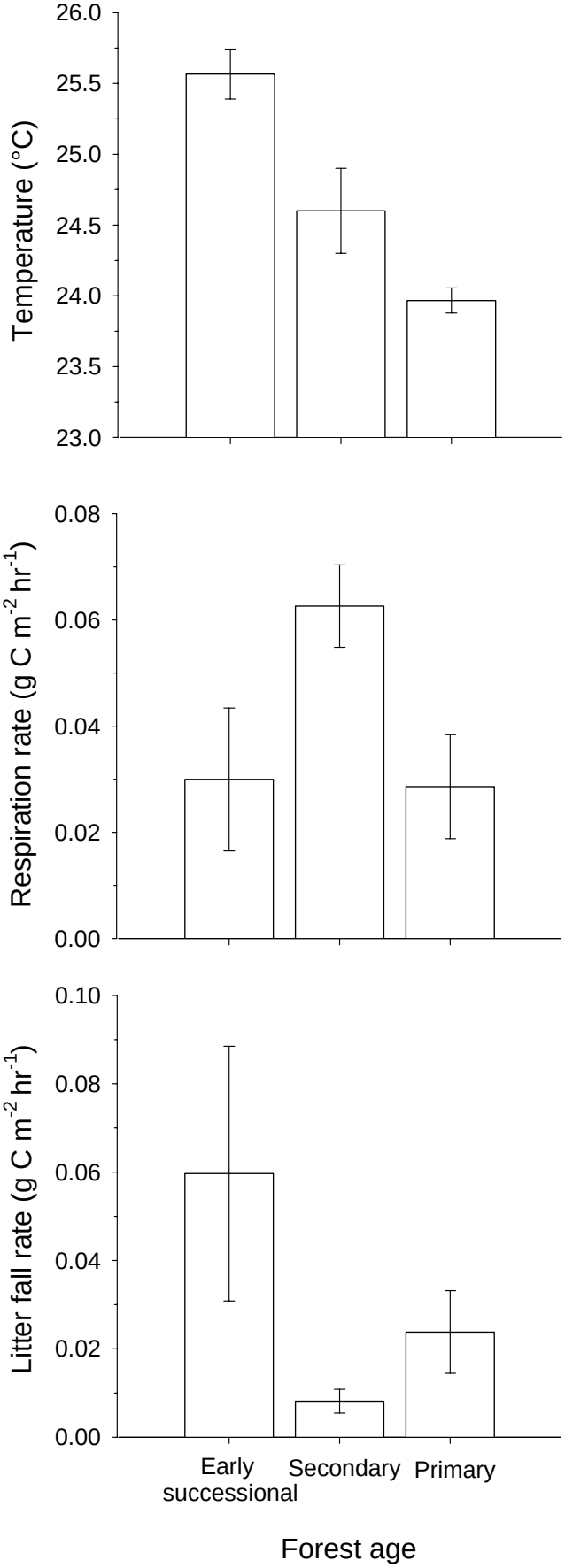


Figure 1. Comparison of mean temperature, respiration rate, and litter fall rate (± SE) between early successional, secondary, and primary tropical forests.

studies should examine the size of soil carbon pools in forests of different successional stages, as well as following the change in soil respiration rates and pool size for the same plot over time.

Our study suggests that the carbon stored in the forest soils and the rates of carbon efflux can change with forest age. Many more factors influence these rates, but according to the trend found here, increasing the proportion of forest in an early successional stage may not increase carbon efflux until the forests reach maturity. As deforestation increases, the proportion of forests in early successional stages has increased. Carbon dioxide concentrations are increasing globally, so the effect of the change in proportion of early successional to primary forest on carbon levels is important to understand.

## LITERATURE CITED

Eaton, G. K., R. F. Douzinas, A. M. Eaken, J. R. Mooney, D. L. Poulin and D. R. Rubenstein. 1998. A comparison of soil physical and biological characteristics in four Costa Rican forests. Dartmouth Studies in Tropical Ecology, p. 111-4.

Sollins, P., F. M. Sancho, R. Ch. Mata and R. L. Sanford. 1994. Soils and soil process research in La Selva: ecology and natural history of a neotropical rain forest. Eds. L. A. McDade, K. S. Bawa, H. A. Hespenheide and G. S. Hartshorn. University of Chicago Press: Chicago, IL, p. 34-53.