Controls of Canopy Photosynthetic Activity on Roots and Soil Carbon Dynamics in Ponderosa Pine and Oak/Savanna Ecosystems

Allen Goldstein¹, Weixin Cheng², Dennis Baldocchi¹, Laurent Misson¹, Alex Gershenson², Jorge Curiel Yuste¹

Summary

The first objective of this research is to make the link between the seasonality of fine root dynamics and the carbon balance of the ecosystem. The second objective of this research is to improve our understanding of how canopy photosynthesis influences fine root initiation, growth and mortality. In order to reach these objectives, we combined CO₂ flux measurements (at ecosystem, soil, and leaf level) with aboveground (shoot, needle, stem) and belowground (fine root) growth dynamics. The first part of this research was conducted in a young Ponderosa pine plantation at the Blodgett Forest Ameriflux site, located at 1,315 m above sea level in the Sierra Nevada Mountains of California. One of our hypotheses was that fine root development at our site is a high priority and is tightly coupled to canopy photosynthesis and available soil water. This hypothesis is partially confirmed and mainly holds for the first part of the vegetation period when a tight coupling between photosynthesis and root growth was observed. This relationship appears to change during dry years, when belowground growth is extremely limited, while aboveground growth does not appear to be similarly affected. We found that the seasonal window for optimal root growth is extremely reduced at our site, partially due to low soil temperature during the winter and partially due to soil water stress during summer. However, when large rates of photosynthesis were observed following summer rains during the second part of the vegetation period in 2003, while temperature was optimal, root growth did not resume and mortality rates did not decrease.

The second hypothesis was that fine roots exert a major control over the seasonal patterns of soil respiration; and that such control is most apparent when roots are actively growing. This hypothesis is also partially confirmed because increases in soil and ecosystem respiration corrected for temperature variations were observed during the active growing period. However, the increase in respiration during root growth was limited in magnitude. The largest variation in soil respiration at our site occurred due to an increase in heterotrophic respiration during unusual rain pulse events in the second part of the vegetation period (summer). However, the activity of these heterotrophs was highly dependent on the earlier input of fresh soil labile carbon by the roots.

Objectives

1. Our first objective was to examine the effects of the overstory canopy density on the understory micrometeorology, and on the coupling between overstory and understory conditions, as well as the effects of the overstory canopy density on CO₂ flux partitioning between understory and overstory, and the environmental and biological factors that control

¹University of California, Berkeley
²University of California, Santa Cruz
understory CO\textsubscript{2} fluxes across different climates and forest types, both at night and during the day.

2. Our second objective was to examine the factors that control soil respiration in seasonally arid ecosystems as a way to better understand the response of the rates of soil organic matter decomposition to climate change.

3. Our third objective was to study the relationship between root dynamics (initiation, growth, and death) and climatic variables, such as soil moisture and temperature, and aboveground growth dynamics.

**Approaches and Procedures**

**Ponderosa Pine Site**

The field site was established in May 1997 in a Ponderosa pine plantation, owned and operated by Sierra Pacific Industries, and is part of the Ameriflux and Fluxnet projects. The plantation is located adjacent to Blodgett Forest Research Station, a research forest of the University of California, Berkeley. The forest constituting the sampled daytime ‘footprint’ of the tower was planted in 1990 and is dominated by Ponderosa pine (*Pinus ponderosa*). The major understory shrubs were manzanita (*Arctostaphylos* spp.) and *Ceonothus* spp. Since 1961, annual precipitation has averaged 163 cm (254 cm snow), with the majority of precipitation falling between September and May, and almost no rain in the summer. Summer temperature averages range from 14–27 ºC and winter temperatures from 0–9 ºC.

**Oak/Savanna Site**

The field study is an oak-grass savanna, part of the Ameriflux and Fluxnet projects, located at the lower foothills of the Sierra Nevada Mountains near Ione, California. The climate is Mediterranean, hot and dry with almost no rain in the summer and relatively cold and wet in the winter. Mean annual temperature and precipitation over the recent 30 years at a nearby weather station are 16.3 ºC and 559 mm, respectively. The overstory of the oak savanna consists of scattered blue oak trees (*Quercus douglasii*), with occasional gray pine trees (*Pinus sabinianna*). The understory landscape has been managed, as the local rancher has removed brush and the cattle graze the herbs.

**Measurements and Data Analysis**

1) Canopy scale measurements of CO\textsubscript{2} and energy fluxes at two levels by the eddy covariance method; 2) Meteorological variables (above-, sub-canopy, and vertical gradient); 3) Root dynamics, demography and biomass; 4) Stem, leaf, and shoot growth; 5) Ecosystem respiration chamber measurements; 6) Soil CO\textsubscript{2} gradient profile and continuous soil CO\textsubscript{2} efflux; 7) Leaf gas exchange; and 8) Soil incubation.

**Overstory Density Effect Analysis**

We performed a comprehensive review of the literature to gather information on sites at which eddy-covariance has been used to measure CO\textsubscript{2} and energy fluxes, both above and below the main forest canopy. Based on this review, we selected sites in evergreen and deciduous forests across a large range of climates and forest types. The sites are located in boreal, temperate and
Controls of Canopy Photosynthetic Activity on Roots and Soil Carbon Dynamics in Ponderosa Pine and Oak/Savanna Ecosystems—Goldstein

arid/semi-arid climates. The variables included in the analysis were (1) half-hourly meteorological data both above and below the main canopy, (2) half-hourly CO₂, water and energy eddy-covariance fluxes at these two levels, and (3) ancillary data such as species composition, overstory and understory heights and leaf area indexes (LAI). Some of the data were not available for all sites.

**Soil Organic Matter Decomposition**

An experiment was designed to study the three factors recognized as more determinant in decomposition patterns of soil organic matter (SOM): temperature, water and carbon (C) inputs. An analytical measurement system was developed to measure soil CO₂ efflux in a close loop with a sensitivity of 0.06 ± µmol m⁻² s⁻¹. A two-pool, first-order kinetic model was used to obtain estimates of the fast and the slow organic matter pool as well as its respective turnover times. Soils were collected from two contrasting ecosystems (Tonzi oak savanna and Blodgett ponderosa pine plantation), with different vegetation and climate, representative of the Californian landscape. Short-term temperature changes were applied periodically to the four different soils. Two treatments, dry-field condition (dry) and field capacity (wet) were applied to the collected soils over a period of 111 days.

**Root Dynamics**

Over the course of 2006, data for all the years of observation were analyzed for Blodgett Forest and partially analyzed for Tonzi oak savannah site. We also performed a comparison between two different software packages—Rootracker (Duke National Phytotron) and RootFly (Clemson University)—used for the analysis of fine root minirhizotron data in order to determine the error associated with mortality over-reporting that is inherent to some root tracing software packages. All data were collected using the minirhizotron method described in earlier reports.

**Results**

**Overstory Density Effect Analysis**

**Micrometeorology**

Figure 1a shows that attenuation of PAR increased with LAI_A of the main canopy. The shape of the relationship is concave with an asymptote at ~100 % and has been fitted with the exponential equation presented in figure 1a, without taking into account the effect of leaf angle or clumping ($r^2 = 0.99$, $p<0.01$). Denser canopies had higher PAR attenuation and lower PAR understory, and we expected that this would influence negatively the development of the understory vegetation. However, denser canopies did not necessarily have lower understory vegetation (LAI_B), and vice versa. It is likely that differences in climate influenced variation in leaf area index between sites, affecting both the overstory and understory.

The difference in wind direction between the overstory ($W_{DA}$) and the understory ($W_{DB}$) eddy-covariance systems has been calculated for the summer, when all sites were fully foliated. Wind direction differences presented in figure 1b reflect how much the wind direction in the understory deviate from overstory in absolute value, either to the left or to the right. Difference in wind direction between the two levels increased linearly with leaf area index above the sub-
canopy system ($LAI_A$) (fig. 1b, with $r^2 = 0.91$ and $p<0.01$). Daytime and nighttime differences in above versus below canopy wind direction were both related to leaf area index in a similar fashion, however the difference was generally higher at night (+12° on average).

![Figure 1](image1.png)

**Figure 1.** Mean summer meteorological variables above and below main canopies with different leaf area indexes

Daytime temperature was generally higher below the main canopy than above, and this difference was inversely correlated to $LAI_A$ ($r^2 = 0.9$, $p<0.01$) (fig. 1c). Nighttime temperature was higher above the canopy, with stronger inversions in open canopies ($r^2 = 0.61$, $p<0.05$) (fig. 1d). Consequently, the mean diurnal air temperature difference at the forest floor was higher for open canopies than for more closed canopies ($r^2 = 0.57$, $p<0.05$, not shown). We found no significant relationships between these differences and either wind speed, friction velocity ($u^*$), net radiation, latent heat flux, and sensible heat flux.

Figure 2a shows that during the day, attenuation of $u^*$ in the canopy was significantly higher in closed canopies than in more open canopies ($r^2=0.64$, $p<0.01$). During the night, this relationship did not hold ($r^2=0.00$, $p>0.05$), and average $u^*$ attenuation across the sites was 77% ($± 3.8$ standard deviation) (fig. 2a). The coupling coefficient $b$ (see equation 3) was significantly related to $LAI_A$, both during the day and night, meaning that closed canopy promoted different
turbulence regimes at the top and the bottom of the canopy (fig. 2b). However, this relationship was stronger during the night, with almost a total decoupling between turbulence conditions above and below closed canopies (b → 0 when LAI > 6, fig. 2b).

The traditional micrometeorological canopy parameters for \( u^* \) do not show a clear diurnal pattern. The drag coefficients are inversely proportional to the leaf area index. The canopy scale ranged from 3 m to 21 m and the radiation extinction coefficients ranged from 0.43 to 0.82.
Daytime CO₂ fluxes

Mean daytime net CO₂ fluxes above the canopy were all negative (net uptake) during summer. Net fluxes below the canopy were positive and dominated by respiration at eight of the eleven sites (maximum: 4.5 µmol m⁻² s⁻¹), while the remaining were negative and dominated by photosynthesis (minimum: -2.1 µmol m⁻² s⁻¹) (fig. 3a). The understory contribution to the net CO₂ flux above the canopy varied between 36% at Blodgett (dominated by photosynthesis) and -54% at the Jackpine site (dominated by respiration) (fig. 3b). Almost all the sites showed positive $GPP_B$ in the understory, except for Walker Branch (Wbr) and Tonzi2 (To2) where $GPP_B$ was equal to 0 (fig. 4a). While leaf area index of the understory at To2 was zero, Wbr reported 0.3 m² m⁻². The maximum understory $GPP_B$ of all sites was calculated for Tonzi1 (To1) with 4.7 µmol m⁻² s⁻¹ (fig. 4a). This site was characterized by mild temperature, high soil moisture, and the presence of a very active herbaceous understory ($LAI_B = 0.7$ m² m⁻²) during early summer. The understory contribution to total canopy $GPP_A$ varied between 0 and 39%, with an average of 14% across the studied sites (fig. 4b). Variations of this contribution across sites could not be explained by $LAI_B$ or $PAR_B$ at the forest floor alone (not shown). By taking into account variations of $LAI_B$ and $PAR_B$ in the understory together, a significant relationship was found with variations of photosynthetic uptake, both in absolute values and in relative contribution (fig. 5a and b). Scatter around this relationship indicates that other factors played a role. In particular, the Aspen site (Asp) showed a significant deviation from the main relationship found for the other sites: $GPP_B$ of the understory remained low despite relatively high penetration of radiation to the understory (~140 µmol m⁻² s⁻¹) and dense understory vegetation (hazelnut, $LAI_B = 3.2$ m² m⁻²) (Figures 5a and b). Thus, the Aspen site indicated minimal photosynthesis by the understory for the amount of radiation and leaf area.
Nighttime CO₂ fluxes

We calculated the probability \( p \) (see equation 15) for different \( u^* \) thresholds at the top of the canopy ranging from >0.3 to >0.6 m s\(^{-1}\). Irrespective of the \( u^* \) threshold, the probability of gas transport out of canopy, \( p \), seems to be inversely related with the leaf area index of the main canopy, as shown in figure 6 for a \( u^* \) of 0.4 m s\(^{-1}\). However, this relationship was not significant, even when discarding the outlier at Walker Branch. Discarding this outlier, \( p \) varied between 1.0 and 0.8 amongst sites, with most of the sites having \( p \sim 0.85 \). These data suggest that at most sites, at least 15% of the CO₂ produced in the understory was recycled and assimilated by leaves during the early hours of the day, without passing the level of the above canopy eddy-covariance system (fig. 6).

Mean nighttime fluxes of CO₂ above canopy varied between 2.3 and 8.4 µmol m\(^{-2}\) s\(^{-1}\), while fluxes beneath ranged between 0.7 and 5.4 µmol m\(^{-2}\) s\(^{-1}\) (fig. 7a). The understory flux contribution to the above canopy flux varied between 32% and 79%, with an average around 55% (fig. 7b). Understory in deciduous forests had higher contributions (62%) than in evergreen forests (49%) (fig. 7b). Boreal and temperate forests had a mean contribution of ~61% while arid/semi-arid forests generally had lower values (44%) (fig. 7b). At the oak savanna site, where the climate was the most arid, both above and below canopy fluxes were reduced in late summer (To2) compared to early summer (To1), while the understory contribution to the above canopy fluxes decreased from 48% to 32% (fig. 7b). At the Metolius ponderosa pine site, the understory flux contribution of 62% was higher than expected considering the location in a semi-arid climate with a very dry summer (Irvine et al. 2004).
In an attempt to explain variation in understory CO$_2$ efflux during night between the sites, we plotted mean summer below canopy fluxes as a function of mean soil temperature (fig. 8a). A negative relationship was found, but it was not statistically significant. Effluxes were normalized for short-term soil temperature changes and soil moisture variations at each site. For soil temperature, we used a $Q_{10}$ relationship established at each site during well ventilated summer nights to calculate $F_{CO2}$ at 20 ºC ($F_{CO2,B(20ºC)}$). For soil water, we divided $F_{CO2,B(20ºC)}$ by Relative Soil Moisture (RSM) during summer, which is the average soil moisture at 10 cm measured at each site divided by the soil moisture at maximum field capacity (Howard and Howard 1993). The normalized efflux for soil temperature and soil moisture was negatively and significantly correlated with soil temperature, suggesting a temperature acclimation of soil respiration, with higher normalized respiration at lower temperature ($r^2=0.64$, $p<0.01$, fig. 8b). However, soil carbon content was probably a confounding factor: we effectively found a positive relationship between carbon content of the first 10 cm of the soil (g C m$^{-2}$) and the normalized understory...
efflux for soil temperature and soil moisture $F_{CO2, B(20°C)/RSM}$ ($r^2=0.82, p<0.01$, fig. 9a). This indicates that soil respiration at constant temperature and soil moisture was higher where there was more substrate. While it is clear that, in general, boreal forests have both the lowest soil temperature and the highest soil carbon content, the relationships in figures 8b and 9a were partially independent because soil carbon content and soil temperature were not significantly correlated in our dataset ($r^2=0.26, p=0.11$, not shown). Some sites, such as Metolius, had low soil carbon content and lower than average soil temperature, while other sites, such as Tonzi, had high soil carbon content and a higher than average temperature. Differences between sites in long-term climate (e.g., annual precipitation), soil type, ecosystem management and disturbance history may explain these variations. However, the size of the database and the lack of standardized data for some of these factors preclude further analyses for the moment.

Another way to investigate these relationships is to look at the reciprocal of the relationship found in figure 9a, which shows the variation of the normalized efflux for temperature and soil carbon, as a function of Relative Soil Moisture (fig. 9b). The y-axis represents the understory flux per gram of carbon in the soil, at constant temperature of 20 °C: it gives an idea of the microbial metabolic activity, showing a decrease in efficiency when soil moisture decreases ($r^2=0.67, p<0.01$, fig. 9b). Finally, we found a significant positive relationship between whole canopy photosynthesis and understory efflux across sites. Thus, ecosystems that assimilated more carbon had higher respiration fluxes in the understory, with a ratio of 0.23 between both fluxes ($r^2=0.78, p<0.01$, fig. 10).
Soil Organic Matter Decomposition

Soil organic matter decomposition derived CO2 efflux

Carbon effluxes, when expressed as a function of exposed surface area ($F_a$) and are not subjected to water-limiting conditions (wet treatment), were the highest in soils from the understory oak savanna (fig. 11d) and the lowest in the trenches plot of the ponderosa pine site (fig. 11a). Except
for those in the trenched plot (fig. 11a) \( F_a \) decreased exponentially in time, with a faster decrease during the first month of the incubation.

**Figure 11.** Temporal evolution of decomposition-derived soil CO\(_2\) fluxes in the wet (open circles) and dry (closed triangles) treatments as a function of surface (Soil CO\(_2\) efflux, \( \mu \text{molC m}^{-2} \text{s}^{-1} \)) in the four studied soils: ponderosa pine trenched (a), ponderosa pine trenched (b) oak savanna open (c) and oak savanna understorey (d). Error bars represent the standard error of the mean.

**Figure 12.** Temporal evolution of decomposition-derived soil CO\(_2\) fluxes as a function of remaining soil C (Soil CO\(_2\) efflux, \( \mu \text{molC mg soil C}^{-1} \text{s}^{-1} \)) in the wet (open circles) and dry (closed triangles) treatments in the four studied soils: ponderosa pine trenched (a), ponderosa pine trenched (b) oak savanna open (c) and oak savanna understorey (d). Error bars represent the standard error of the mean.
Fast and slow C pools

The fast pool ($C_f$) and rate constants ($k_f$ and $k_s$) of fast and slow pool were calculated with a first order kinetic-two pool model (table 1). The model estimated no fast carbon pool in the trenched plot (table 1). In the non-trenched plots the size of this fast C pool ($C_f$) differed between soils, the largest observed in the oak savanna soils and the lowest in the ponderosa pine control soils (table 1). For non-trenched soils, the rate constant of the fast pool ($k_f$) was significantly higher than that of the slow pool ($k_s$). The rate constant for the fast pool was the same for both oak savanna soils, but slightly higher than $k_f$ from the ponderosa pine control (table 1).

Table 1. Calculated values and statistics ($t$ tail and $p$-value) of the coefficients ($C_1$, $C_2$, $k_1$ and $k_2$) obtained when flux data (expressed as $F_a$ and $F_m$, respectively) was fitted to equation 7. Adjusted correlation coefficient ($\text{Adj } R^2$) and $p$ value ($P$) of the regression are also reported. Asterisk (*) following values represent coefficients significantly different from 0 for a 95% confident interval.

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Soil turnover time

Turnover times for the bulk soil C ($T_{\text{soil}}$), were typically higher in ponderosa pine (fig. 12a and 12b) than in oak savanna soils (fig. 12c and 12d). $T_{\text{soil}}$ values of the trenched ponderosa pine plot were typically lower than those of the control plot, while no substantial differences were found in savanna soils $T_{\text{soil}}$. Turnover times of the remaining C increases as the labile C was burned off, but decreases again at late stages of the incubation (fig. 12).

Sensitivity of organic matter decomposition to temperature and drought

In general, lowest values of $Q_{10}$ for the wet treatment were recorded under soils from the ponderosa pine trenched plot (fig. 13a) and the highest under soils from the open areas of the oak savanna (fig. 13c). Values at the end of the incubation period were very similar for the four soils (around 1.5). In trenched soils $Q_{10}$ coefficients were always below 2. Except for early stages of the incubation, when the labile fraction of organic matter was still present in the control soils, $Q_{10}$ coefficients were very similar for both soils of the ponderosa pine site (around 1.5; see fig.
Correlation between soil decomposition and temperature was very weak for the dry soils. $Q_{10}$ coefficients for the dry treatment were typically around 1 for ponderosa pine sites (no sensitivity to temperature of the organic matter decomposition) and below 1 in the oak savanna sites (negative correlation between temperature and SOM decomposition). Soil respiration was negatively correlated to soil temperature at 5-cm depth during dry periods, under treatments with no roots present (fig. 13a and 13c) and with roots present (fig. 13b and 13d).

\[ \text{Figure 13. Temporal evolution of the sensitive to temperature of microbial decomposition (expressed as } Q_{10} \text{) in the wet (open circles) and dry (closed triangles) treatments in the four studied soils: ponderosa pine trenched (a), ponderosa pine trenched (b) oak savanna open (c) and oak savanna understorey (d). Error bars represent the standard error of the mean.} \]

\section*{Root Dynamics}

\section*{Meteorology}

The average precipitation recorded at our Blodgett Forest research site is 1,210mm/year. The total amounts of precipitation for 2003, 2004, and 2005 were 1,200mm, 1,025mm, and 1,800mm of rainfall, respectively (fig. 14). The timing of precipitation differed between these years as well, with the last day of measurable precipitation recorded in mid-May for 2003, mid-April for 2004, and in the beginning of June for 2005. In the time that we have maintained precipitation records at the site (eight years), 2004 was the driest, with 18% less precipitation than average and 2005 was the wettest, with 48% higher than average precipitation. As a result, we observed significant differences in soil water potential between the three years of observation, with 2004 showing rapid decrease in available soil moisture and reaching much lower soil water potential values than either 2003 or 2005. Although at the peak of summer the values for soil water potential were comparable between 2003 and 2005, the timing of water potential decrease was different, with an earlier onset of drying in 2003 compared with 2005 (fig. 15). Air temperature (fig. 16) and soil temperature (fig. 17) did not differ significantly between the three years of observation.
As has been previously noted by several researchers, the first year of minirhizotron observation often exhibits large compensatory fine root growth due to the installation effect of the minirhizotron tubes. In 2003, we observed a significant increase in fine root length and number across our plots which continued 1.5 months, with the onset of fine root growth being correlated with the increase of the daily minimum temperature above 5 degrees C, and the end of the growing season being correlated with the decrease in soil water potential below -0.28MPa (17%) (fig. 18). We attribute the large magnitude of the increase in overall root length to the installation effect. In 2004 we observed no significant net increase in overall fine root length (fig. 18), and the total growing period for fine roots was restricted to a two-week window in the beginning of May (fig. 19). In 2005, we observed a significant amount of net root length increase (fig. 8), and the total growing period where fine root length change was significantly greater than zero was 3.5 months (fig. 19). In 2005, the belowground growing season was punctuated by a week of cold temperatures in the beginning of the season (figs. 16,17), resulting in a bimodal growth pattern (fig. 19). The average longevity of fine roots at Blodgett Forest is 445 days, and almost a quarter of the roots survive past the three-year observation period (fig. 20). Fine root initiation appeared to correspond with the increase of soil temperature above 5 degrees C, although the data do not allow for a robust analysis of significance (not shown).
Figure 15. Average daily soil water potential recorded for the depths of 20 cm and 50 cm, 2003-2005.
Controls of Canopy Photosynthetic Activity on Roots and Soil Carbon Dynamics in Ponderosa Pine and Oak/Savanna Ecosystems—Goldstein

Figure 16. Air temperature at 12-hour intervals, 2003-2005.

Controlling factors of fine root development

The rates of fine root development are tightly coupled with belowground moisture availability. We have found a significant relationship between soil water potential and fine root growth ($R^2 = 0.383$, $p < .0001$) with an apparent threshold for root growth at -0.3 MPa soil water potential (fig. 21). The data points under high soil moisture and high mortality correspond to dates with soil temperatures lower than 5 degrees C. In all three years root growth, shoot growth, and stem thickening started growing concurrently, with needle growth initiating after the initial start of the flush. However, unlike the significant differences we have observed in the duration of the belowground growing period between different years, aboveground growth duration was not similarly affected by the differences in soil moisture between the years (fig. 22).

Discussion

Overstory Density Effect Analysis

In open forests, understory eddy-covariance flux measurements can be problematic at night due to the build up of a strong inversion layer, and in denser forests because the flux footprint above and below canopy is less similar than in open forests. We showed that the understory can contribute significantly to whole ecosystem photosynthetic sinks and respiration sources. However, variations between sites were important for both sinks and sources, and were related to difference in leaf area index, canopy composition (evergreen vs deciduous) and climate (boreal,
temperate, arid/semi-arid). Understory $GPP$ contribution ranged between 0% and 39% of total ecosystem $GPP$, and was related to understory $LAI$ and light penetration. Understory respiration ranged between 32% and 79% of total ecosystem respiration, and was related to substrate availability ($GPP$, soil carbon) and quality (soil C:N ratio), soil temperature and soil moisture content. Taking into account these factors and how they affect the flux partitioning between overstory and understory are crucial to fully understand, quantify, and predict the influence of forests on atmospheric composition and climate.

Figure 17. Soil temperature recorded at depths of 20cm and 50 cm, 2003-2005.
Figure 18. Total observed fine root length by plot, 2003-2005. Error bars represent standard error.

Figure 19. Changes in fine root length between observations per plot, 2003-2005. Error bars represent standard error.
Soil Organic Matter Decomposition

Our results suggest a necessity of further examination and increased understanding of the complex nature of soil organic matter decomposition patterns in order to better understand the response of soil organic matter decomposition to climate change. The large increase in turnover times when soils were incubated under the naturally dry conditions suggest that, although the low moisture levels during the dry season prevent soil organic matter decomposition, sporadic summer rains may significantly increase soil organic matter mineralization rates (up to five times in the oak savanna soils). A two-pool, first-order kinetic model was used to obtain estimates of the fast and the slow organic matter pool, as well as their respective turnover times. Our results indicate the existence of a small C pool, which we attribute to products of plant activity, which is rapidly mineralized (12-18 days), and that exerts a strong influence on soil organic matter decomposition rates and their response to temperature. Moreover, observed changes in the turnover times of soil organic matter and their response to temperature during the incubation period could not be entirely explained based on currently accepted models and theories. Here we hypothesize that the disagreement between observations and theory is likely due to the inability of the current models and theories to include the microbial community as an active component of the soil C dynamics.

Figure 20. Percent survival of fine roots as a function of time alive.

Root Dynamics

Our results demonstrate a close relationship between soil micrometeorological conditions and fine root development. At the Blodgett Forest research site, we have observed temporal
dynamics of fine roots that are very different than the majority of reported fine root research. The average longevity of fine roots at our site is longer than most reported results, and the development and mortality of fine roots is unusually closely coupled to soil temperature and moisture conditions. These results are significant because ecosystems such as the Western Sierra Nevada are projected to be significantly affected by regional climate change, with changes in precipitation patterns and temperatures. Changing soil moisture and temperature regimes will have a significant effect on belowground development, and are likely to affect whole ecosystem development in the long run, although we did not witness as strong a negative effect of adverse conditions on aboveground development. Judging by the fact that most phenological development occurs before photosynthetic tissue development, it is also likely that most growth utilizes carbon resources stored from the previous year, which may add a level of buffering capacity which allows these ecosystems to withstand temporary adverse conditions, but which may not be sufficient to mitigate long-term changes in precipitation and temperature patterns.

Figure 21. The relationship between change in length (net growth >0, net mortality <0) and soil water potential, 2004 and 2005, for corresponding 20cm and 50cm depths. Data from 2003 were excluded from the analysis due to the likely artificial nature of the magnitude of growth.
Figure 22. Aboveground growth. Changes in stem thickening, needle and shoot elongation 2003-2005

References


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