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Long term consequences of a controlled slash burn and slash mastication to soil moisture and CO_2 at a southern Colorado site

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1. Introduction

Thinning of forest stands is frequently used to reduce the risk of catastrophic fire. But thinning requires that the refuse (or slash) be removed from the site, which can be done either by burning it or by mastication and dispersal. Either method has long term consequences to the soil and to soil moisture and soil CO_2 levels. For example, after the initial drying of the soil by a fire, soil moisture in burned areas tends to exceed that of unburned areas because the loss of vegetation reduces or eliminates transpiration (Neary and Ffolliott, 2005). This situation may persist until the vegetation is reestablished. In general, burning also tends to reduce soil respiration (Amiro et al., 2003) and, therefore, soil CO_2 amounts and fluxes. Nevertheless, some environmental conditions will allow the soil respiration of a burned area to exceed that of an unburned area (Andersson et al., 2004). In fact, exposing soil to a severe fire may actually increase heterotrophic respiration (Bisset and Parkinson, 1980; Richter et al., 2000). In this situation the consequences to soil CO_2 and soil fluxes is less clear because nearby unburned areas may still support autotrophic respiration. This increase in heterotrophic respiration in the burned area is thought to result from the stimulation of the soil microbiota by increased soil temperatures (Bisset and Parkinson, 1980; Richter et al., 2000) and/or elevated levels of bioavailable nutrients (Fyles et al., 2001; Choromanska and DeLuca, 2002; Certini, 2005).

The impact of masticated and dispersed residue on soils varies significantly depending on whether the residue is left as a mulch, burned, or tilled into the soil (e.g., Zabowski et al., 2000; Busse et al., 2005; Sanchez et al., 2000). The present study examines the mulch treatment. Generally speaking, the mulch (wood chips) tends to act as a barrier to moisture and heat depending on the depth of the mulch and the rainfall amounts and patterns at a specific site (Resh et al., 2006). However, microbial response is extremely varied (Resh et al., 2006), which suggests that soil CO_2 amounts and soil respiration fluxes can be influenced by more than just the physical barrier presented by the chips.

This study presents 2.3 years of continuous soil moisture and CO_2 measurements at two experimental slash treatment sites in the Rocky Mountains of southern Colorado: (i) a controlled slash-burn site and (ii) a site at which the slash was masticated and dispersed to form a layer of wood chips. Each experimental site has a separate control plot (with no treatment). Because the instrumentation was installed before treatment, the burn data include observations obtained, not only after the fire, but before and during as well.

2. Site and Soil Descriptions

The burn and mastication experiments were conducted in the Manitou Experimental Forest (MEF: 39° 04' N and 105° 04' W), in the central Rocky Mountains about 45 km west of Colorado Springs, Colorado, USA. MEF has a mean elevation of about 2400 m ASL. The annual mean temperature of the experimental forest is about 5 C and the annual precipitation is about 400 mm. Soils within MEF tend to have low available water holding capacity and moderately high permeability. The dominant parent materials of the soils within MEF are primarily Pikes Peak granite and secondarily weathered red arkostic sandstone.

The burn area is at the edge of a large grassy opening within the (dominant) ponderosa pine (*Pinus ponderosa*) forest. The vegetation within this site is predominantly grasses, forbs, and shrubs (including some non-native invasives). The soil at the treatment and control areas is a deep (> 1.0 m), fine-loamy, mixed, frigid, Pachic Argiustoll and is typical of soils throughout this experimental area. Soils within this particular area are approximately 66% sand, 21% silt, and 13% clay with bulk densities that usually increase with depth and range between 1.1 and 1.5 g cm^{-3}. Soil organic material comprises about 1–2% of the soil by volume. Previous grazing and mechanical harvesting throughout the area has resulted in a moderately disturbed soil.

The mastication experiment is about 0.5 km south of the burn area and has a ponderosa pine overstory, with an understory of artemesia, bunchgrasses, and other forbs and grasses. The soil at the treatment and control areas is a deep (> 1.0 m), loamy-skeletal, mixed, frigid, Aridic Haplustoll and is again typical of soils throughout this particular experimental area. Soils at this location are approximately 70% sand, 16%

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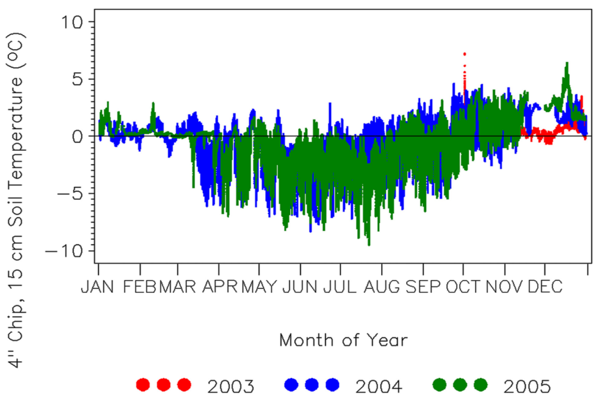

Figure 1: Time series of (0.15 m deep) soil temperature difference between the 0.102 m deep chip plot and the control from September 2003 to March 2006. All temperature data at the other soil depth and chip depth are similar.

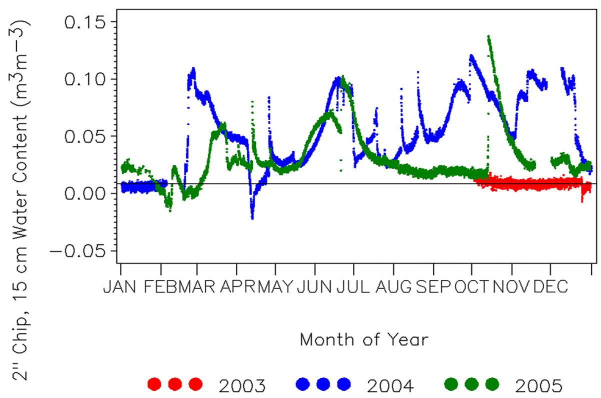

Figure 2: Time series of the (0.15 m deep) soil moisture difference between the 0.051 m deep chip plot and the control from September 2003 to March 2006. Other soil moisture data do not indicate that the chips have such a systematic affect on soil moisture; see text.

silt, and 14% clay with typical bulk densities ranging between 1.3 and 1.4 g cm^{-3} and also tending to increase with depth. Soil organic material at this location comprises about 0.5–1% of the soil by volume.

3. Instrumentation

All soil moisture, CO_2, and temperature data were measured at 0.05 and 0.15 m depths at all treatment locations. All data were logged using CR23X data loggers (Campbell Scientific; Logan, UT, USA), which were housed several meters from where the instruments were buried. The burn site instrumentation was installed in August 2003 at two control plots and two slash plots (center and edge of the burn area). The slash pile was constructed in March of 2004 and the slash was burned on April 26, 2004. The instrumentation at the chip site was installed in September 2003 and the chips were added in early March 2004. The chip site has one control plot, one plot with chips 0.051 m (2”) deep and one with chips 0.102 m (4”) deep.

Soil moisture at the slash pile burn site was measured using a specially designed high-temperature TDR (Zostrich Geotechnical; Pullman, WA, USA). The design of this particular probe is fairly standard, but the material used to house the steel needles and the connectors attaching them to the coaxial (data/signal) cables had a much higher melting temperature than normal. Additionally, those external portions of the coaxial cables that were likely to be exposed to high temperatures were wrapped in silicon tape.

Soil moisture at all other locations, none of which were exposed to high temperatures, was measured using a commercially available TDR (manufactured by Campbell Scientific; Logan, UT, USA). Soil CO_2 at the burn site was measured by drawing a continuous sample for approximately 0.5 minutes through 3/8-inch (id) decabond tubing into a LI-820 (LI-COR Inc.; Lincoln, NE, USA) that was housed about 27 m from the slash pile. Soil CO_2 at the chip site was sampled using the same approach, except the data were obtained with an LI-800.

Soil temperatures were measured with thermocouples (Omega Engineering; Stamford, CT, USA). To insure electrical isolation all thermocouple junctions were coated with epoxy (Omegabond 101) prior to insertion into the soil.

4. Chipping Site Results

An example of the effect chips have on soil temperature is shown in Figure 1. In general, the soil under the wood chips is cooler than at the control (no treatment) plot, except possibly for the period beginning early- to mid-October and continuing through December. Here the chips act as a barrier to daily and seasonal heat flow through the soil, thereby impeding heating during the summer and the cooling during the late fall and early winter. The temperature gradients at the chip plot (not shown), which are greatly reduced compared to the control, also support this conclusion.

Figure 2 shows the difference in soil moisture at a depth of 0.15 m between the 0.051 m deep treatment

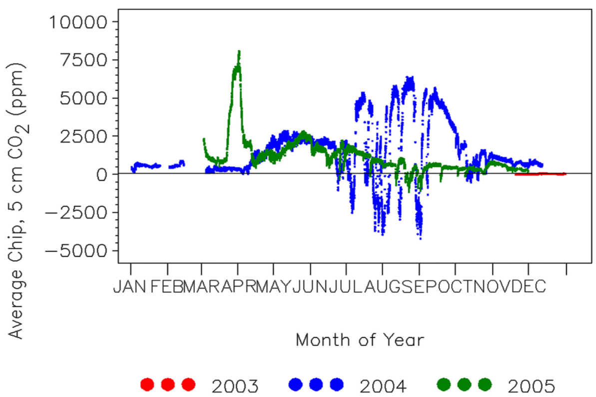

Figure 3: Time series of the difference between the average (0.05 m deep) soil CO_2 at the two chip treatments and the control from September 2003 to March 2006. All other CO_2 differences have a similar pattern, but are slightly greater at the 0.15 m depth.

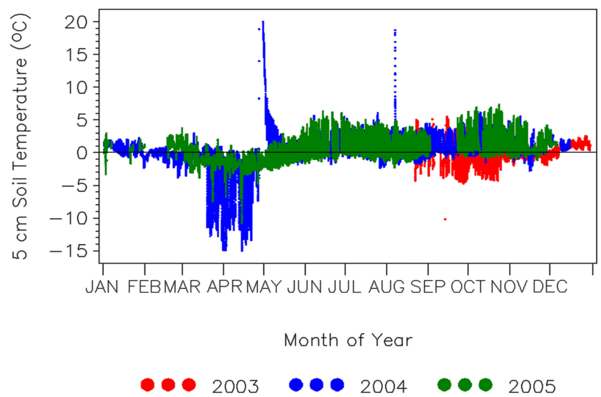

Figure 4: Time series of (0.05 m deep) soil temperature difference between the burn plot and the control from September 2003 to March 2006. The soil temperature data at the two burn plots have been averaged, as have been the two control plots.

and the control. At this depth and location the soil is considerably moister than at the control throughout most of the experiment. It is possible the chips have had some effect on soil moisture, but this cannot be proved conclusively for two reasons. First, the soil moisture differences for the other location and depth do not show such a systematic difference and second, this particular location is at the bottom of the slope, which may be affected by lateral subsurface water flow. Nonetheless, when taken as a whole, the data do indicate that the chips are acting as a barrier to the infiltration of water into the soil and to subsequent soil drying. However, the influence of the chips on soil moisture is somewhat variable and dynamic and depends on the amounts and patterns of precipitation. Figure 2 also indicates that the summer of 2004 was wetter than summer 2005. Finally, there is some evidence (not shown) that the deeper layer of chips reduced the soil moisture gradient more than the thinner layer did. This suggests that the deeper layer of chips was more effective at reducing soil evaporative losses than the thinner layer.

Except for a few erratic periods during July and August of 2004, Figure 3 shows that at a soil depth of 0.05 m the soil CO_2 under the chips exceeds that at the control. (The same is true at all soil and chip depths). During these exceptions the soil CO_2 at 0.05 m depth at the control plot was extremely variable and was likely responding to the frequent precipitation events that were occuring during the summer of 2004. Otherwise, Figure 3 suggests that chips can increase the amount of CO_2 within the soil, a likely consequence of the chips acting as a barrier to the normal CO_2 efflux from the soil. It is also possible that the soil microbial respiration has been affected by the chips, but nothing can be concluded from the data about this. Because soil temperatures are lower under the chips it seems reasonable to assume that microbial respiration under the chips has been reduced, however, because soil moisture is also an important driver of soil respiration and because it is somewhat erratically affected by the chips, this assumption is speculative at best. In general, the depth of the chips had much less influence on the soil CO_2 difference than did the depth of the soil. The rather remarkable increase in soil CO_2 under the chips that occured during March of 2005 (Figure 3) coincides with a cold period that may have caused the moisture in the chips to freeze, blocking the normal soil CO_2 efflux to the atmosphere and thereby causing the CO_2 under the chips to increase.

5. Burn Site Results

Figure 4 shows that at 0.05 m deep the soil within the slash pile burn area was heated significantly by the fire (end of April 2004). However, even after the fire had gone out and the soil had cooled, Figure 4 also indicates that the fire-heated soil has remained warmer than the control for most of the last year and a half. The 0.15 m deep temperature data indicate that this long-term burn-induced warming extends at least 0.15 m into the soil. This long-term warming may result from increased heating (lower albedo) of

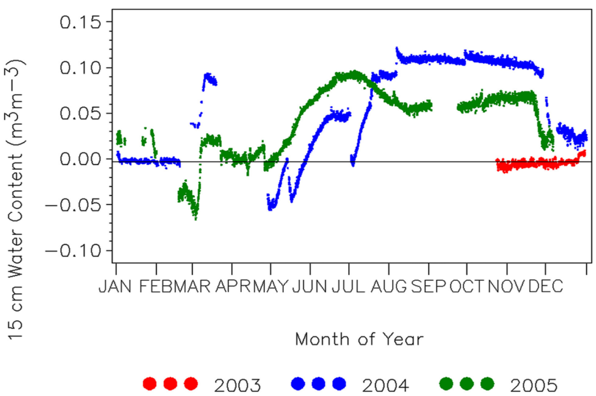

Figure 5: Time series of the difference in the (0.15 m deep) soil moisture between the burn plot and the control from September 2003 to March 2006. The soil moisture at the two burn plots have been averaged; as have been the two control plots.

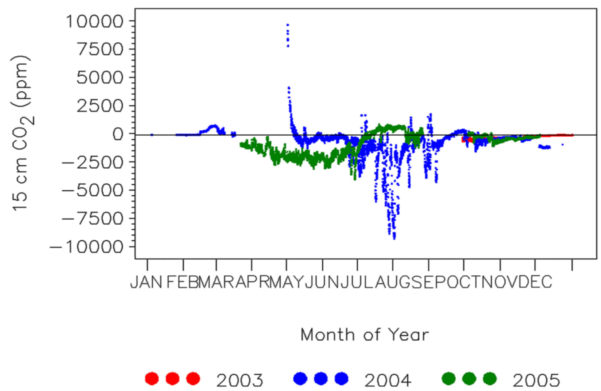

Figure 6: Time series of the difference between the average (0.15 m deep) soil CO_2 at the two burn plots and the only functioning control plot from September 2003 to March 2006. In general, the 0.05 m CO_2 differences have a similar temporal pattern.

the blackened soil surface at the burn site. It may also be related to changes in the soil thermal conductivity that resulted from this burn (Massman and Frank, 2006).

Figure 5 shows that the soil at a depth of 0.15 m is and has remained (nearly consistently) moister at the burn site than at the control for more than the last year of the experiment. Soils at the burn site are also usually moister than the control at the 0.05 m depth as well (data not shown). This result is consistent with the loss of plant cover and roots at the burn site, which would reduce transpiration and help maintain relatively high amounts of soil moisture (e.g., Neary and Ffolliott, 2005).

Figure 6 shows that the soil CO_2 in the burned areas is often quite different from that of the control. During and shortly after the burn (end of April 2004) the soil CO_2 under the slash pile far exceeded the control. However, by summer (July and August) of 2004 the soil CO_2 at the control site greatly exceeded the soil CO_2 in the burn area. This should not be too surprising as the burn heated the soil to over 200 C at 0.05 m so most of the microbial population have likely been destroyed in the burn area. Furthermore, the summer of 2004 was a relatively wet summer, so that the soil moisture in the control area was likely to have been very conducive to microbial growth and activity.

Nonetheless, by summer (July and August) of 2005 the burn area had begun to recover and the soil CO_2 there once again exceeds the control soil CO_2. This particular event seems even more surprising knowing that 2005 was quite dry in general and much drier than 2004 in particular. In addition, laboratory tests of the respiration potential of the microbes (under controlled and optimal conditions) indicate that the soil microbes in the control had significantly (2 to 5 times) greater respiratory potential than those found in the burn area. To account for this seeming discrepancy we propose that microbial activity in the burn area exceeds that in the control area largely because the soil in the burn area during the summer of 2005 is significantly moister at the 0.15 m depth than the control. During this period the volumetric soil moisture at this depth at the burn site was about 0.10, whereas at the control it was about 0.05. [The volumetric soil moisture at 0.05 m at the burn site was also greater than at the control by nearly a factor of two as well.] Therefore, the tendency of burn area soils to remain moister than unburned areas may also be responsible for the increase in heterotrophic respiration after a burn. This hypothesis is further supported by observations of CO_2 gradient within the control plots. Normally this gradient would show CO_2 increasing with depth. But during the summer of 2005 the soil CO_2 amounts at the control site are similar at both the 0.05 and 0.15 m depth and both are relatively low, which indicates that the soil respiration is quite low throughout the soil profile.

6. Conclusions

This study examines some long-term consequences of two different fuel reductions treatments on soil temperature, moisture, and CO_2 at Manitou Experimental Forest in the Rocky Mountains of southern Colorado. These treatments include the burning of slash and the mastication of the slash and the dispersal of the resulting wood chips over the study area. Results indicate that:

1A. Wood chips insulate the soil so that most of the time it remains cooler than it would without the chips; but there are periods, notably during the fall, when the chips by impeding heat loss will keep the soil warmer than the untreated soil.

1B. Wood chips can impede both infiltration of water into the soil and soil evaporation. But the effects on soil moisture depend on the amounts and patterns of rainfall.

1C. Wood chips impede the efflux of CO_2 from the soil, so that soil CO_2 amounts under the chips tends to exceed the amounts within untreated areas. Because the mastication experiment did not specifically examine microbial responses to the chip treatment or seek any associations with the measured soil CO_2, nothing can be concluded about the microbial or root respiration response to the chip treatments.

2A. Soil temperatures over a year and half after the experimental burn tend to be systematically higher than those in the control plots.

2B. Long-term soil moisture at 0.15 m depth tends to higher in the burn area than in the unburned control areas.

2C. Soil CO_2 amounts within the burned areas can vary significantly from the that in the soils of the control plots. For much of the year following the burn, CO_2 amounts in the burned area were well below that within the control area. However, during the dry summer of 2005, the additional soil moisture in the deeper levels of the burn plot, allowed microbial activity there to remain high enough so that the CO_2 amounts within the burn area exceeded that within the control for about 2 months.

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