LETHAL SOIL HEATING DURING BURNING OF MASTICATED FUELS: EFFECTS OF SOIL MOISTURE AND TEXTURE

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INTRODUCTION

The potential for soil damage during burning of masticated fuels is substantial. Recent evidence suggests that temperatures between 100 and 300 ^{o}C in the upper soil horizon may result if masticated fuel beds are ignited (Busse et al. 2005). Of immediate concern is the survival of roots and soil organisms. The lethal threshold for roots is approximately 60 ^{o}C while that of many soil organisms is between 50 and 200 ^{o}C (Neary et al. 1999).

Whether soil temperatures will unavoidably exceed these thresholds when masticated fuels are burned is not clear. Heat transfer in soils is a complex process regulated by numerous soil physical properties (moisture, texture, porosity, pore continuity) and fuel characterisitics (mass, size class, moisture, surface area, structural arrangement). Our previous study examined only a limited set of these conditions, leaving doubt as to the true potential for soil heat transfer during burning (Busse et al. 2005). Here we expand the previous findings by assessing soil moisture and soil texture as regulators of heat transfer. Our overall objective was to provide managers with a comprehensive predictive model of soil heating that encompasses most soil and fuel conditions. Results are presented from a replicated experiment testing the effects of soil moisture (from maximum water availability to dry summer conditions) and texture on temperatures in the upper soil profile during burning of masticated fuels. In addition, validation results from several field burns of masticated fuel beds are summarized.

METHODS

Forty-eight controlled burns were conducted on the grounds of the Redding Silviculture Laboratory in Redding, CA. Factorial treatments included three soil textures (pumice sand, loam, clay) in full combination with four soil moisture contents (approximately 10, 20, 30, and 40% on a volumetric basis). The moisture contents were equivalent to water potentials of -3.0; -0.3; -0.1; and -0.01 MPa, respectively. Four replications of each treatment combination were included.

Soil temperatures were measured at 0, 1, 2, 4, and 6 inch depths in undisturbed soil using thermocouples (K type) connected to temperature data loggers. Large intact soil cores (12 inch diameter, 6 inches high) were collected from field sites representative of the three soil textures. Upon return to the Redding Lab, the cores were saturated with water and allowed to dry slowly to the desired moisture contents. When ready, each core was placed in the center of a 10.8 ft^2 plot and packed with loose soil, filling the entire plot except for a narrow opening to allow access for installing the thermocouples horizontally into the center of each core. Soil was then gently filled in the small opening with minimal disturbance to the thermocouple wires. Masticated residues (60 tons/acre) were added to the soil surface at a bulk density matching the conditions found at our field sites (8.42 lbs/ft^3) immediately before igniting the downwind side of the fuel bed.

Air temperature, relative humidity, wind speed, wind direction, flame length, and rate of spread were recorded during each burn. Soil temperatures were measured for 24 hours following ignition, providing sufficient time for the soils to recover to ambient temperature. Data from all burns were used in multiple regression analysis to predict maximum soil temperature as a function of soil moisture, soil texture, soil depth, and heat load (degree hours above the ambient temperature at 1 inch soil depth).

Soil temperatures were also measured during field burning of masticated residues to validate the results of our controlled burns. Four experimental units (~ 1 acre each) were burned in spring 2005 at the Challenge Experimental Forest and an additional four units were burned in spring 2006 near Whitmore, CA. The units had been masticated for control of understory shrubs and trees 2 to 3 years prior to burning. Thermocouples were placed at 0, 1, 2, and 4 inches in the soil profile at multiple locations within each unit prior to prescription burning. Fuel load, fuel moisture, and soil moisture in the vicinity of each thermocouple station were recorded prior to burning.

RESULTS AND DISCUSSION

Maximum temperatures on the soil surface ranged from 350 to 1080 ^{o}C during burning. As expected, an incremental drop in temperature was found with increasing soil depth. Temperatures ranged from 43 to 370 ^{o}C at 1 inch; from 35 to 308 ^{o}C at 2 inches; from 29 to 74 ^{o}C at 4 inches; and from 27 to 51 ^{o}C at 6 inches.

Soil temperatures were strongly affected by soil moisture but not by soil texture. An example of the influence of soil moisture on heating is presented in Figure 1. Regression analysis identified soil moisture ($p < 0.0001$), soil depth ($p < 0.0001$), and surface heat load ($p < 0.0001$) as significant independent variables. In contrast, soil texture was not signficant ($p = 0.872$). The final model in stepwise regression analysis provided a good prediction of soil temperature (r^2 = 0.77) and was applicable for all soil textures: ln (temperature) = 4.689 – (0.196*soil depth) – (1.06*soil moisture) + (0.00038*heat load), where heat load is the degree hours above ambient temperature at a depth of 1 inch in the soil profile. This dampening of heat transfer by soil moisture supports previous studies of natural fuels that emphasize the importance of burning when soils are moist in order to avoid excessive temperatures (Frandsen and Ryan 1986; Valette et al. 1994).

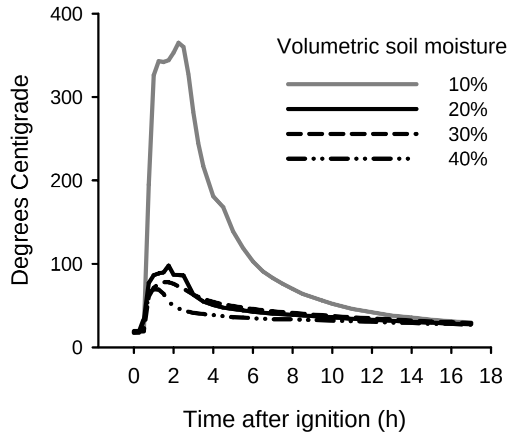

Figure 1. Effect of soil moisture on maximum soil temperature. Response curves are for the pumice soil at a soil depth of 1 inch and a masticated fuel load of 60 tons/acre.

Results from our experiment were limited to a single fuel load of 60 tons/acre, and are thus fairly confined in their practicality. To address this limitation, we combined the experimental results with previous findings of soil heating (Busse et al. 2005) to develop soil temperature response curves for a broad range of fuel loads (Figure 2). These data confirm that lethal temperatures (> 60^oC) are mostly superficial when soils are moist. Temperatures exceeded the lethal threshold only to a depth of 1-2 inches in moist soil regardless of fuel load, yet surpassed this threshold to a depth of 4-6 inches in dry soil. In addition, the temperatures in dry soil were highly responsive to increasing fuel loads, whereas moist soils only showed a slight response. We are currently testing a range of fuel moistures and fuel materials in order to expand our predictive model.

From a practical standpoint, these results suggest that most roots and soil organisms will be unaffected by burning of masticated fuels in all but the driest of soils. Burning when soils are moist (> 20% volumetric moisture) should inhibit damaging temperatures below 1 to 2 inches in the mineral soil. On the other hand, wildfires or prescribed fires may produce considerable soil heating when soil moisture is low. Results from our field burns support this concept. Eight spring burns were conducted when soils were moist, ranging from 18 to 45% volumetric soil moisture content. Corresponding soil temperatures in nearly all cases were well under the lethal threshold, averaging 36 ^oC at 1 inch and 28 ^oC at 2 inches in the mineral layer.

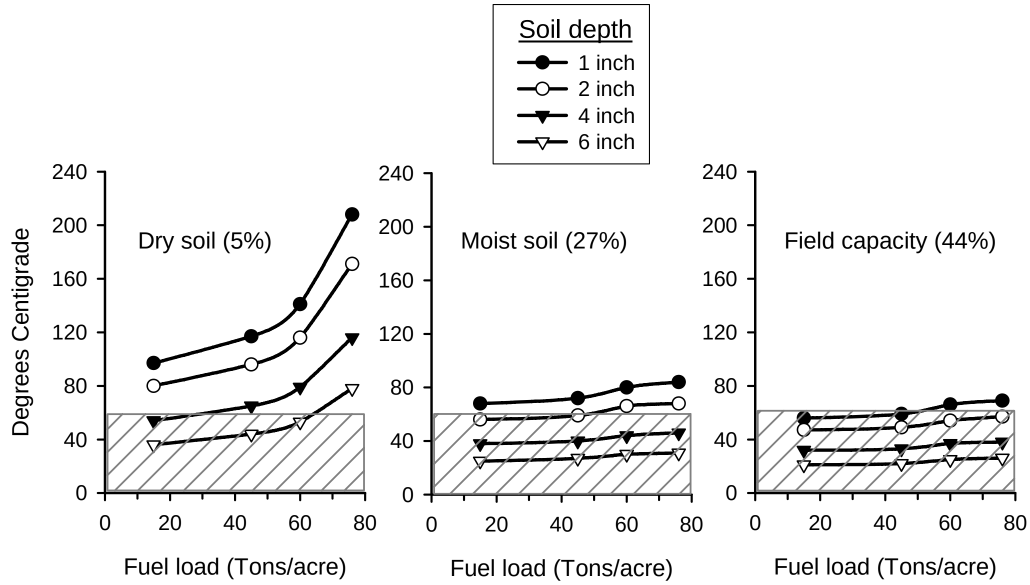

Figure 2. Predicted maximum soil temperatures during burning of masticated fuels as a function of soil moisture, soil depth, and fuel load. The gray-shaded area in each graph represents sub-lethal temperatures for roots. Volumetric soil moisture content is shown in parentheses in the graph titles. Field capacity is equivalent to the maximum available water content found within 24 hours of a saturating rainfall.

SUMMARY AND CONCLUSIONS

We developed a predictive model of soil temperature maxima during burning of masticated fuels. The model was well explained by three factors: soil moisture, soil depth, and fuel heat load. Soil texture, in contrast, was unrelated to the temperature profiles, suggesting a single model is applicable for all tested soils (pumice sand, loam, clay). Soil moisture as low as 20% by volume was sufficient to quench soil heating and inhibit the progression of lethal soil temperatures below the surface inch. Thus, burning of masticated fuels when soils are moist is recommended to avoid damaging roots and soil organisms.

LITERATURE CITED

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