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Forest Management Note 66

Canadian Forest Service • Northern Forestry Centre

Mulch fuels in boreal forests: structure, moisture, and initial fire behaviour observations

INTRODUCTION

Vegetation management (or fuel management) is one important component of wildfire risk mitigation outlined by the FireSmart program in Canada (Partners in Protection 2003). Treating fuels can alter how they react to fire. Mechanical mastication involves shredding aerial and understory fuels to reduce the likelihood of fires (specifically crown fire initiation), and thus reduce extreme fire potential. Fuel treatments, such as mulching, generate stand and surface characteristics that are significantly different from the standard fuel types described within the Canadian Fire Behaviour Prediction System (Forestry Canada Fire Danger Group 1992). These differences pose challenges for forestry and fire management practitioners. In addition to FireSmart treatments, mulching is a widespread activity in utility corridors such as electrical transmission and oil and gas development. Roadside mulching is also practiced in some jurisdictions. There is ongoing research to study this novel technique; Kreye et al. (2014a) produced a review of the topic focusing on forests of the western and southeastern United States. The objective of this Forest Management Note is to highlight some of the results from recent mulch research conducted in Alberta and British Columbia that can be applied and used by forestry and fire management practitioners.

FUEL COMPLEX

The fuel complexes (sites) targeted for mechanical mastication treatment (or mulching) in the boreal tend to be forested stands with closed canopies and plenty of forest biomass that is arranged along a vertical plane in such a way as to promote lighting and burning of a crown fire (which is referred to as strong vertical connectivity of ladder fuels). This fuel type normally supports a crown fire regime (i.e., fire in the tops of trees). The process of mechanical mastication uses heavy equipment fitted with rotating drums and cutters to shred aerial fuels and redistribute them into a compact mass of fractured particles called a fuel bed. Hand thinning may be completed first to achieve a specific reduced density, and the fallen stems are subsequently mulched on the ground. Certain types of shredders are capable of knocking trees over directly before mulching, or in some cases mulching standing stems using a boom-mounted attachment.

Canada

. Treatment intensity usually refers to the target reduction in stem density (either as a percent reduction in stems, in basal area, or as a desired inter-tree spacing distance); it also refers to the physical characteristics of the fuel bed after treatment (typically the particle size resulting from repeated mowing of the fallen stems). Treatment design and layout vary according to fuel type, slope, aspect, and surrounding natural features that may affect potential fire behaviour. At sites with standing timber or tall shrubs, common treatment designs include mulched corridors laid out in a grid pattern with residual patches of intact, standing stems; or individually spaced stems interspersed by mulch (Figure 1). In other cases, all standing vegetation may be masticated. Follow-up treatments of pruning will sometimes also occur depending on stand composition and the prevalence of ladder fuels. (Ladder fuels refer to forest biomass that enables fire to burn from a forest floor layer into a canopy layer.) Stand characteristics and treatment objectives (e.g., corridor widths) are important considerations for the selection of appropriate mechanized equipment. An inappropriate choice of machinery may result in not obtaining the intended objectives and potentially increasing residual stem damage.

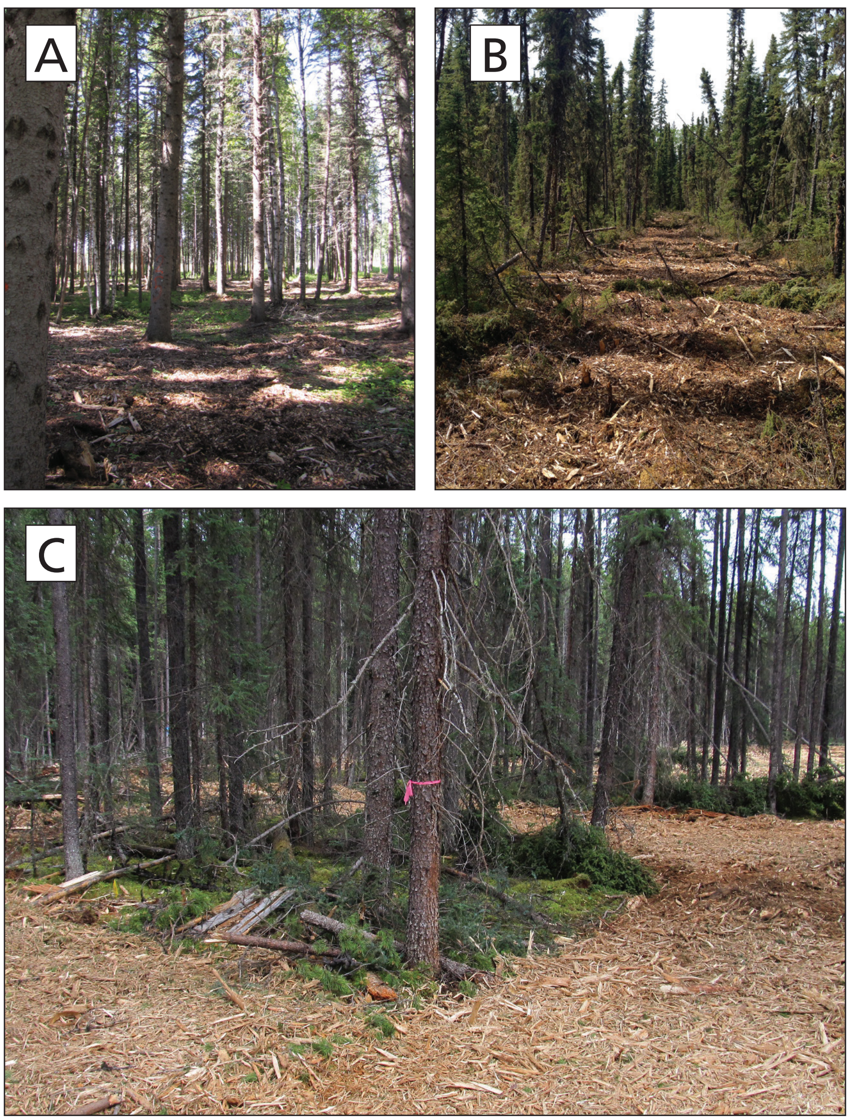

Figure 1. Photographs of common treatments A) inter-tree spacing, B) strip mulching, and C) checkerboard.

The thickness of the fuel layer that is created by mulching is influenced by the amount of biomass being treated (shredded): it may generate thin or thick layers of chipped fuel, sometimes mixed with fine fuels, coarse woody material, duff, and even underlying soil. Approximate mulch depths, based on the proportion of stems removed and stand volume, are given in Figure 2. (The term 'rails' has been used by some in industry to describe partially mulched stems that are still somewhat intact and lying at the surface of the fuel bed.) The fuel beds might be highly variable even within a given site, especially where high concentrations of fuels (known as jackpots) have been mulched in place. In more sparse treatments or in low-density stands, a mosaic of mulch mounds and uncovered, intact forest floor may result. Crews or machinery can be used to spread the material around the site to create a more continuous layer.

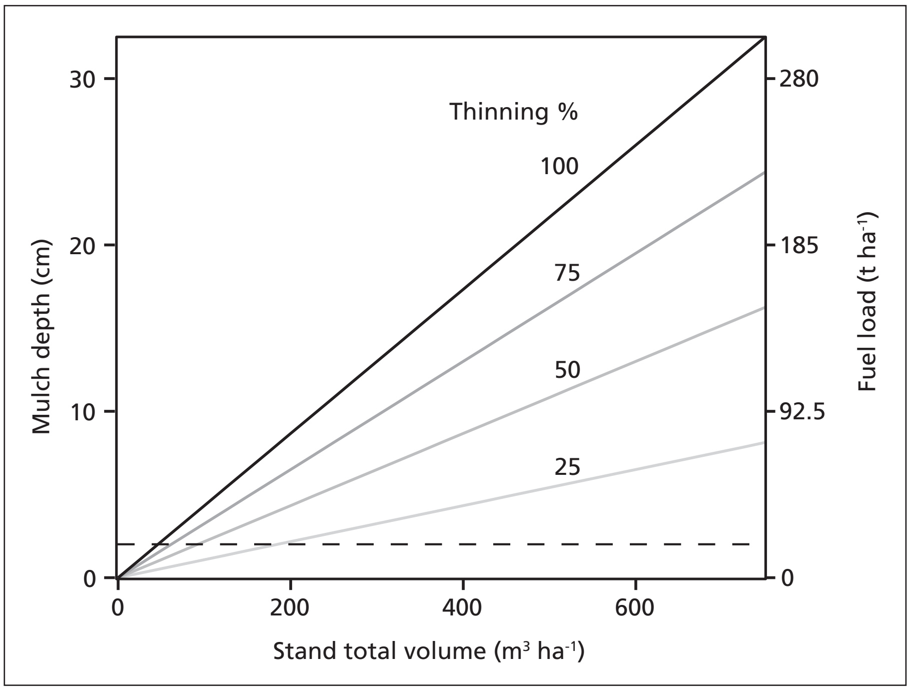

Figure 2. Estimated thickness of the mulch bed as a function of stand volume under variable thinning regimes. Mulch properties were estimated from Schiks (2014). The dashed horizontal line indicates a 2-cm depth of mulch in which the moisture content follows the MAST fuel moisture model (Schiks and Wotton 2015b). The approximate fuel loading in tonnes per hectare is given on the right axis, assuming a density of 400 kg m^{-3} of black spruce wood (Zhang and Morgenstern 1995). For comparison, the standard S-1 (jack or lodgepole pine) slash fuel type in the Canadian Fire Behaviour Prediction System has a total fuel load of approximately 40 t ha^{-1} (Forestry Canada Fire Danger Group 1992).

The physical properties of the fuel complex may change over time due to regeneration of vegetation, as well as the decomposition of the mulch particles. Though few direct studies of the timelines of re-vegetation on mulch-treated areas exist, utility companies such as BC Hydro often re-treat their stands at roughly 2- to 3-year intervals for surface fuels and 4- to 12-year intervals for tree regeneration (British Columbia Hydro 2010; Hvenegaard and Schiks 2013). Re-treatment intervals in regions with longer growing seasons and a more favourable climate will be shorter than those in cooler climates or on poorer sites. Further research needs to be conducted on both the re-vegetation dynamics and the changes to the moisture regime and flammability of aged mulch particles. A recent paper from Kreye et al. (2014b) suggests that reductions in potential fire behaviour are only short-lived for treatments in Florida, but more studies should be conducted for fuel types or ecosystems present in Canada. The Alberta Wildland Fuels Inventory Program has a network of study sites across Alberta for monitoring fuels and maintains all records in a database for reporting purposes. Maintenance of the fuel treatments is an important consideration for potential fire behaviour and operational budgets.

Fuel treatments, such as mulching, produce stand and surface characteristics that are significantly different from the standard fuel types described within the Canadian Fire Behaviour Predictions System (Forestry Canada Fire Danger Group 1992). For instance, thinning produces lower canopy bulk density and alters the gaps between aerial fuels in ways that cannot be accounted for in the current system. Furthermore, the mulched surface fuels differ from slash fuel types, especially in terms of bulk density of the fuel bed and size of fuel particles. Mulched fuels contain greater amounts of small-diameter particles, which would seem to increase the proportion of flammable biomass; however, arranging the fuels into a thick and highly compacted fuel bed reduces its susceptibility to burn by retaining fuel moisture for longer periods of time and limiting the supply of oxygen.

MOISTURE DYNAMICS

On the eastern slopes of the Rocky Mountains, an initial study near Carldale, Alberta, compared moisture observations in the mastication treatments to the standard Fire Weather Index (Van Wagner 1987) prediction of surface moisture, the Fine Fuel Moisture Code (Schiks 2014). With certain stand types and density, moisture is retained for longer periods than for a thin layer of pine needles in a closed canopy site (as predicted using the Fine Fuel Moisture Code). However, as the fuel beds become increasingly exposed to wind and solar radiation, the fuels dry out faster than predicted by the Fine Fuel Moisture Code. Active mulch drying at rates faster than

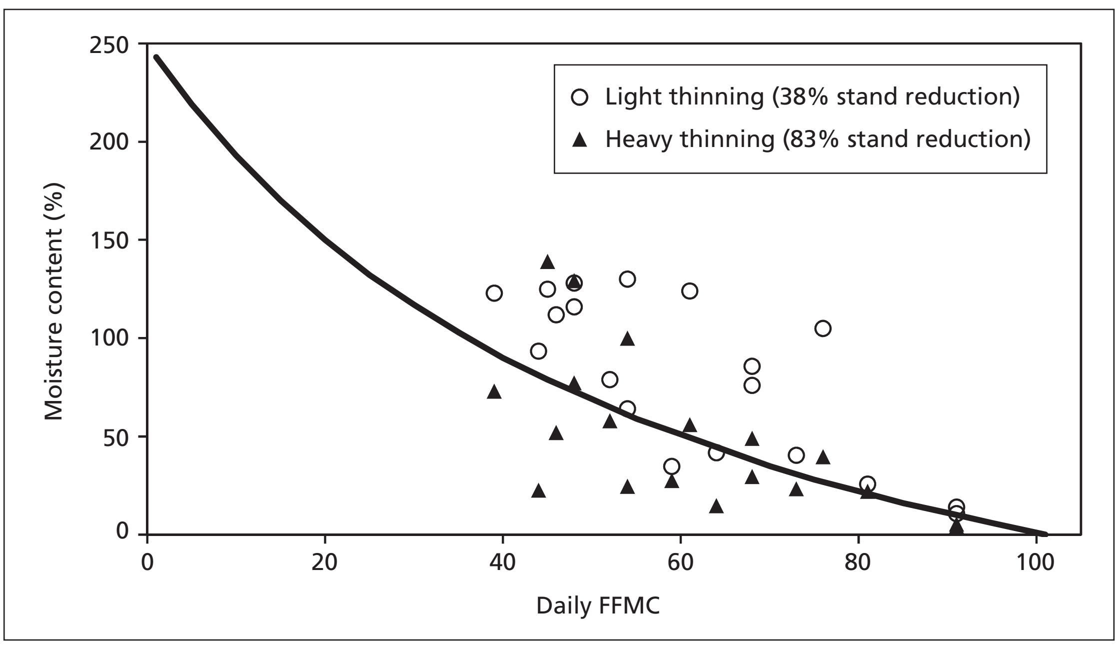

Figure 3. Moisture content and daily Fine Fuel Moisture Code (FFMC) for two levels of thinning achieved with mastication equipment in a mixedwood stand. The solid black line indicates the standard relationship between moisture content and Fine Fuel Moisture Code. After the light-thinning treatment there were 2016 stems/ha and 557 stems/ha in the heavy-thinning treatment compared to an adjacent, untreated stand. Figure adapted from Schiks (2014).

rates predicted by the Fine Fuel Moisture Code was only observed for the upper 2 cm. Moisture content in deeper layers of mulch (>5 cm) were not significantly correlated to the Duff Moisture Code or Drought Code predictions from the Fire Weather Index System; however, the deep layers tended to maintain wetter fuels, typically ranging from 150 to 250% moisture content (Figure 3).

In their MAST fuel moisture model, Schiks and Wotton (2015b) modified the Fine Fuel Moisture Code model to predict moisture content in masticated surface fuels. The MAST model was created to predict fuel moisture for small-diameter (< 1 cm) woody particles located within the top 2 cm of a masticated fuel layer that does not have standing residual trees or surface vegetation (this is one extreme end of the treatment intensity spectrum). Predictions were validated using fuel moisture observations from the Horse Creek Research Site, located in the foothills of Alberta. The MAST model predictions were more accurate than those predicted by the hourly Fine Fuel Moisture Code. The results highlight that the post-treatment exposure to solar radiation influences drying, particularly at the surface of fuel beds. An operational computer program to calculate MAST predictions is in development. A calibration factor was devised that would permit quick estimation of moisture content for a masticated surface fuel, based on the current day's Fine Fuel Moisture Code. The calibration factor was applied to historical weather data (Obed Tower, May–October, 2004–2013) to estimate the annual frequency of days when the surface moisture content fell below certain thresholds of dryness that would permit ignition (Figure 4).

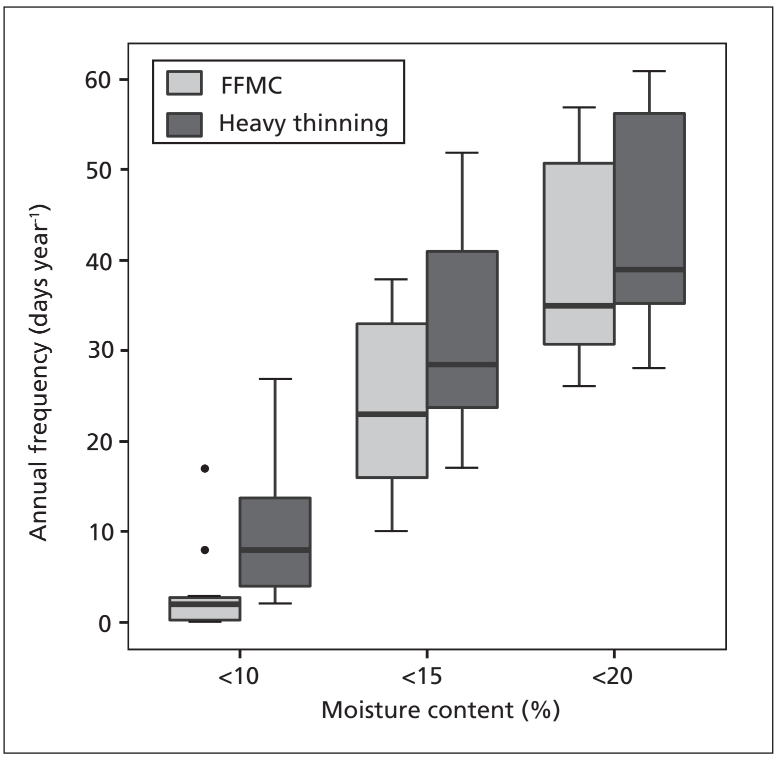

Figure 4. Estimated annual frequency of days having a given moisture content based on the Fine Fuel Moisture Code (FFMC) and a calibration for a heavily thinned mulching treatment. The heavily thinned mulching treatment is predicted to increase the annual number of days for which the moisture content of the surface is less than 10% and less than 15%. Standard error bars represent variability among years. Figure adapted from Schiks (2014).

Another study was conducted at the Horse Creek Research Site to observe fuel temperature and fuel moisture using the profile of masticated fuel beds (Schiks et al. 2015). Moisture in the deeper layers of mulch (5 and 13 cm below surface) was retained for extended periods, and drying at 5 cm was only apparent during a 10-day rain-free period. There are some notable differences between moisture dynamics of deep mulch and the assumptions of duff drying within the Duff Moisture Code. First, maximum moisture content is lower in wood particles (~250%) relative to duff (>400%). Second, drying rates were slower for deep mulch, which was likely driven by the densely compacted mulch that did not expose deeper layers to air movement or solar radiation. This slow drying is in contrast with more porous fuels beds, such as fuels cribs (which are sticks arranged in a crisscrossed, three-dimensional structure for use in fire experiments) or logging slash, through which air can move more freely. Overall the Duff Moisture Code may not be a suitable model to predict moisture content of deep mulch layers (Figure 5).

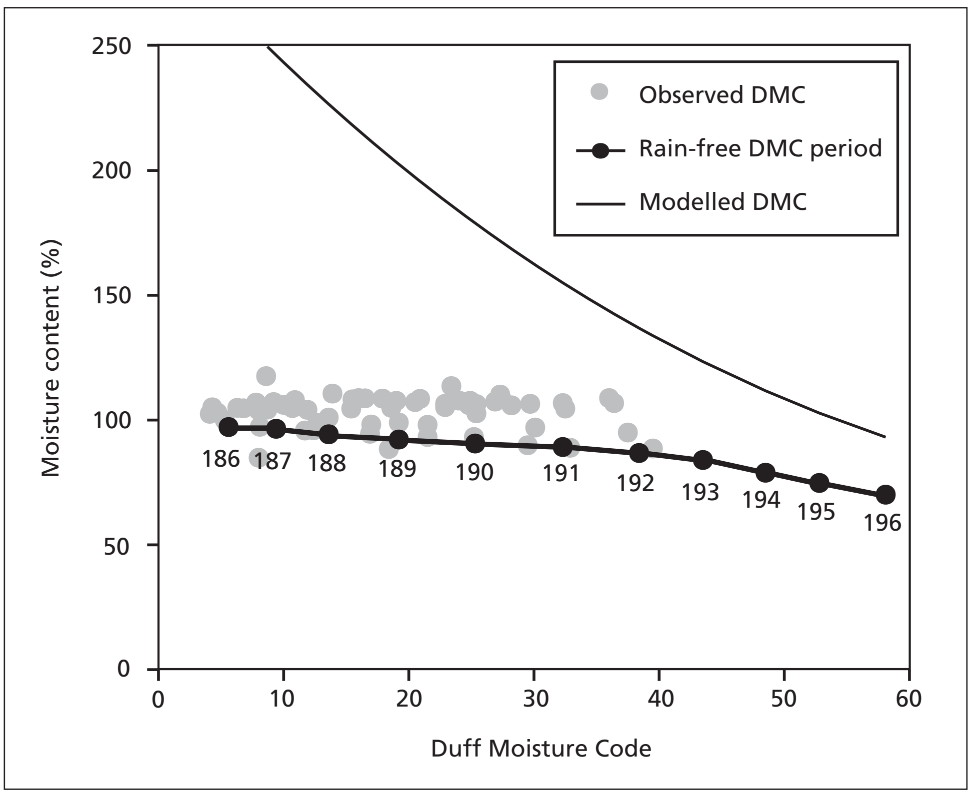

Figure 5. Moisture content of mulch at a 5-cm depth (in a 13-cm deep mulch bed) during the summer of 2012 at Horse Creek Research Site, Alberta (Schiks et al. 2015). Gray dots represent Duff Moisture Code (DMC) values plotted against moisture content of measured mulch, and black dots represent DMC in a rain-free period in July (numbers are day of year for each measurement). The solid line (DMC modelled) is the predicted moisture content of duff as a function of Duff Moisture Code following Van Wagner (1987). Figure adapted from Schiks et al. (2015).

MULCHING EFFECTS ON GROUND-LEVEL WIND, SUN EXPOSURE, AND RAIN INTERCEPTION

Increasing treatment intensity (at least in terms of stem reduction) will influence the exposure of the fuel bed to both wind and sun, which will have consequences for wetting and drying of fuels. Compared to slash fuels, which often exist in cut blocks that extend for hectares, mulching for FireSmart or other purposes takes place near intact tree canopies. Given the strong effect that sun exposure has on increasing the drying rate of mulch (Schiks and Wotton 2015b), fuel treatments can be designed to minimize sun exposure through east-west orientations, as well as partial retention of the overstory by using inter-tree spacing.

Mulching with the objective of increasing inter-tree spacing (as opposed to strip mulching) can significantly affect the amount of rainfall reaching the forest floor and mulch surface, as the amount of canopy interception of rain is decreased. For small rainfall amounts (~2 mm) in closed-canopy forests, rainfall intercepted by the canopy is close to 60% (Price et al. 1997), which is reflected in the Fire Weather Index System. The minimum rain event to cause the Duff Moisture Code to decrease is 1.6 mm, and 2.9 mm of rain is required for the Drought Code to decrease. Mulching to increase inter-tree spacing will be most effective in turning small rainfall events from having no effect on duff and mulch moisture into events that increase moisture content at the surface. In regions where daily rain events of ≥10 mm are more frequent, the effect of rain on the moisture content of surface mulch is likely less pronounced. To achieve an increase of ≥10 mm of rain reaching the forest floor, a reduced mulching intensity (measured by percent stems removed) is required in climates typified by large rainfall events compared to smaller, more frequent events (Figure 6).

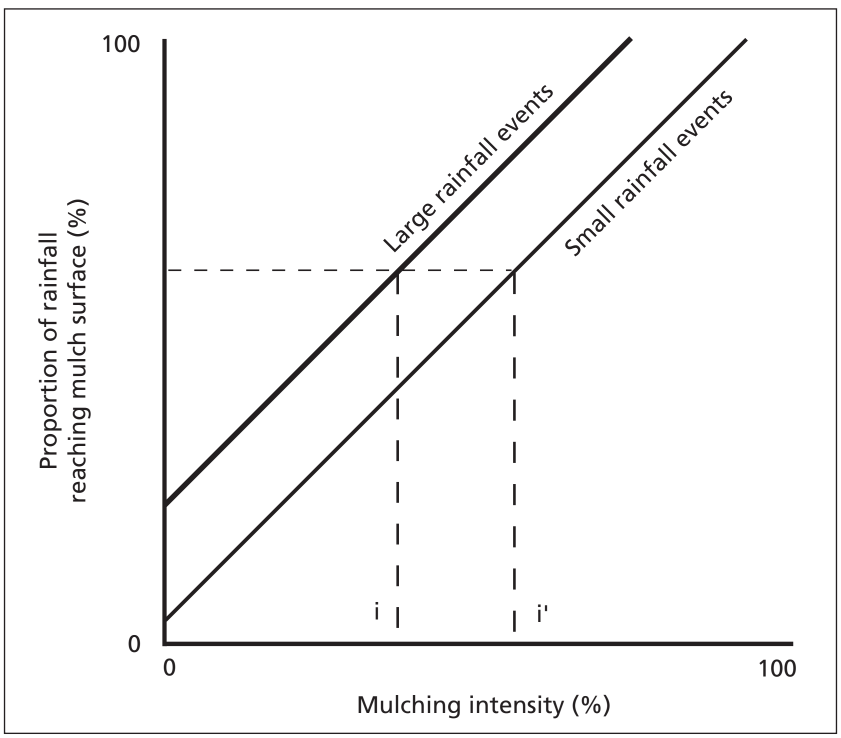

Figure 6. Conceptual diagram showing the relationship between mulching intensity and the ability of a rainfall event to increase surface fuel moisture. Greater mulching and/or thinning intensity (indicated by i’ relative to i) is required to achieve the same increase in rainfall reaching surface fuels in a climate with smaller average rainfall events.

FIRE BEHAVIOUR IN MASTICATED FUEL BEDS

An investigation of the probability of sustained burning of mulch fuels was performed in both laboratory and field settings, using the common 2-minute match drop test (Schiks and Wotton 2015a). Field observations from Horse Creek Research Site indicate that mulch fuels ignite and burn sustainably at similar moisture contents to several other common forest fuels (Figure 7). However, highly exposed mulch fuels may dry out more rapidly than other surface fuels (particularly those in closed-canopy forests), and they will ignite and burn sooner.

Temperatures of surface mulch were often much greater than air temperature on sunny days, which is an indication of low moisture content and increased likelihood of ignition. When there is time and equipment available, using an infra-red camera to detect surface temperatures in excess of air temperature may be useful in prescribed burning operations.

There is limited documentation of fire behaviour in masticated fuels for all regions of Canada. The existing models of the Canadian Fire Behaviour Prediction System do not incorporate masticated surface fuels, and the current level of data is not sufficient to develop new relationships using Fire Weather Index System inputs. However, data have been collected on point and line ignitions, which are lighting techniques used by crews in prescribed burning operations, for several field-based burning trials in the Northwest Territories, Alberta, and British Columbia (Hvenegaard, S.H.; Schroeder, D.; Thompson, D.K. 2014. Fire behaviour in mulched fuel beds: data collection in a unique fuel type. Poster presentation. Wildland Fire Canada Conference 2014, October 6–9, 2014. Halifax, Nova Scotia, Canada.).

Results from a laboratory study of mulch burning (Thompson et al. 2016) showed that the rate of flaming and smouldering combustion (a proxy for suppression effort) was a function of moisture content alone, and was not affected by the inclusion of larger mulch particles 1–3 cm in diameter in addition to smaller particles of only <1 cm. However, the proportion of remnant charcoal (a desirable soil additive) was significantly greater when larger mulch particles were added. In the laboratory study, particles of all diameters had the same moisture content, in comparison to field studies where larger diameter woody debris took longer to dry (Nelson 2000). While industrial standards for mulch particles may call for the smallest possible particle size in order to maximize decomposition rates and improve aesthetic appeal, retention of larger diameter debris in mulching operations appears to have the benefit of higher moisture content (and therefore easier suppression) as well as lower rates of fuel consumption.

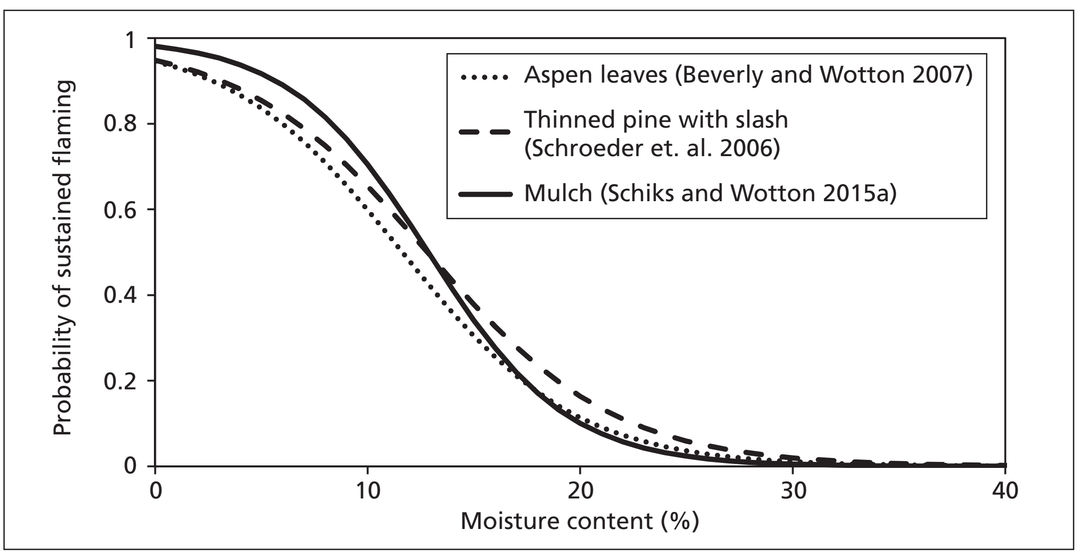

Figure 7. Ignition probability of mulch and other fuels as a function of moisture content. The ignition thresholds for each of these fuel types were similar. Reproduced from Schiks and Wotton (2015a).

CONCLUSIONS

The moisture dynamics of the mulch layer are influenced greatly by the uppermost 2 cm of mulch, which rapidly dries from surface winds and sun exposure. The potential of mulch fuels to start a flaming surface fire is the same as other forest materials given the same moisture content, though the drying rate of wind and sun-exposed mulch fuels is consistently higher than most materials found on an unaltered forest floor. Documentation of fire spread rates and flame heights in mulch fuels are found to be limited in quantity, but preliminary data are similar to logging slash. Laboratory experiments on charcoal (black carbon) production in mulch fuels shows that charcoal production is highest when larger diameter (1–3 cm) mulch particles are retained instead of being ground into finer particles.

KEY RESEARCH OUTCOMES THAT MAY HAVE MANAGEMENT IMPLICATIONS

1) Full characterization of a mulch fuel bed includes measuring the mass of fuels above and below size class 2 (1 cm diameter), as well as total mulch bed depth.

2) Moisture content in the upper 2 cm of mulch behaves similarly to the hourly Fine Fuel Moisture Code, with additional drying from increased sun exposure.

3) Deeper mulch depths dry slowly and retain moisture content above 100% until the Duff Moisture Code exceeds 60.

4) Ignition occurs at the same range of moisture content in mulch as other surface fuels, but mulch can begin to burn quicker than fuels under an intact forest canopy.

5) The production of charcoal and black carbon (a useful soil amendment) is increased when a higher content of fuel pieces have a diameter of ≥3cm in the mulch bed.

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