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MULCHING PRODUCTIVITY IN BLACK SPRUCE FUELS: PRODUCTIVITY AS A FUNCTION OF TREATMENT INTENSITY

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ABSTRACT:

This study investigated the effect of applying three distinct mulching treatment intensities on mulcher productivity and fuel bed characteristics. The results from these trials in conjunction with studies of fire behaviour in the resulting mulch fuel beds will assist fuel management practitioners in developing appropriate cost-effective mulching prescriptions.

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INTRODUCTION

Mulching, a mechanized forest fuel treatment, is often prescribed in Alberta as a technique to reduce aerial fuels, increase stem spacing, and reduce the crown bulk density of a stand, thereby reducing the potential for active crown fire in forested stands within or adjacent to a community or other values at risk. During these operations, the reduction of aerial fuels is achieved through the selective removal and mulching of unwanted stems to achieve desired crown spacing.

Mulching operations in boreal forest black spruce (Picea mariana) stands are typically conducted during the winter when the ground is frozen in order to permit access into areas with a high water table and to reduce ground disturbance. Mulching operations under winter conditions result in a layer of chips deposited on top of existing moss layers and other surface fuels. Depending on the depth of snow, dead woody debris and other surface fuels can be mulched as part of the fuel treatment. Experienced operators who are engaged in industry operations such as right-of-way clearing and maintenance are accustomed to creating a uniform fuel bed of fine and medium-sized chips with little residual round wood or intact stems remaining in the surface fuel layer. ‘Because of human nature to make things look tidy and neat, operators tend to grind material more than necessary to reduce the fire hazard and doing so they use more machine time which increases costs and can produce less than desirable soil and fuel conditions’ (Halbrook et al. 2006).

While mulching fuel treatment prescriptions do not generally specify mulch fuel bed characteristics, mulcher operators often default to an “industry standard” of fine and medium sized chips when conducting forest fuel treatments in the wildland–urban interface. To achieve a uniform bed of fine and medium-sized chips, multiple passes with the mulcher are often required, which can increase the cost of the operation. Fuel managers have concerns about the high cost of these treatments. A clearer understanding of the effects of various mulching intensities on wildfire behaviour can assist fuel managers in prescribing a mulching intensity that reduces wildfire risk and is economically viable. This project and future experimental fires will explore the cost-effectiveness of varying mulching intensities by measuring the productivity of each treatment, assessing the resultant fuel bed, and comparing fire behaviour in these fuel environments.

OBJECTIVES

Unit 2 at the Pelican Mountain FireSmart research area has undergone three mulching treatments at three distinct intensities. The unit was subdivided into three subunits, and we observed the operations and measured the productivity of the machine in each subunit. The objective of this study was to compare machine productivity in each subunit using the following performance metrics:

- Treated area (ha)/productive machine hour (PMH).
- Biomass (tonnes)/productive machine hour (PMH).

STUDY SITE AND METHODOLOGY

Study Site

The Pelican Mountain FireSmart Fuel Management Research Area[1] was developed by Alberta Agriculture and Forestry to conduct wildfire research that will contribute to the development of scientifically based community protection strategies and enhance knowledge about the effectiveness of forest fuel treatments in modifying fire behaviour. Unit 2 at this research area was dedicated to conducting varying intensities of mulch fuel treatments and studying the ability of these treatments to modify fire behaviour. Three subunits were mulched at low, medium, and high intensities.

Pre-treatment forest stand inventory

Prior to treatment, the Alberta Wildland Fuels Inventory Program (AWFIP) crew inventoried the research subunits. Pre-treatment stand measurements are presented in Table 1. Black spruce is the predominant species in Unit 2, and the most notable difference between these subunits is density of large and small trees (Figure 1).

Table 1. Unit 2 pre-treatment stand characterization (standard deviation in parentheses)

	Forest stand components						
	Large trees[a]			Small trees[b]			Seedlings[c]
Subunit (mulching intensity)	**Density[d]**	**Average DBH[e] (cm)**	**Average height (m)**	**Density**	**Average DBH (cm)**	**Average height (m)**	**Density**
2A (low)	362	10.8 (1.7)	9.2 (1.3)	15 735	3.2 (2.1)	3.6 (1.8)	14 361
2B (normal)	2001	11.7 (1.9)	10.9 (1.1)	4 995	3.7 (2.7)	4.6 (3.0)	6 494
2C (high)	575	10.5 (1.4)	10.0 (1.4)	25 100	3.0 (1.9)	4.2 (2.0)	11 614

[a]Large trees = Stems ≥ 9 cm dbh

[b]Small trees = Stems < 9 cm dbh and ≥ 1.3 m height)

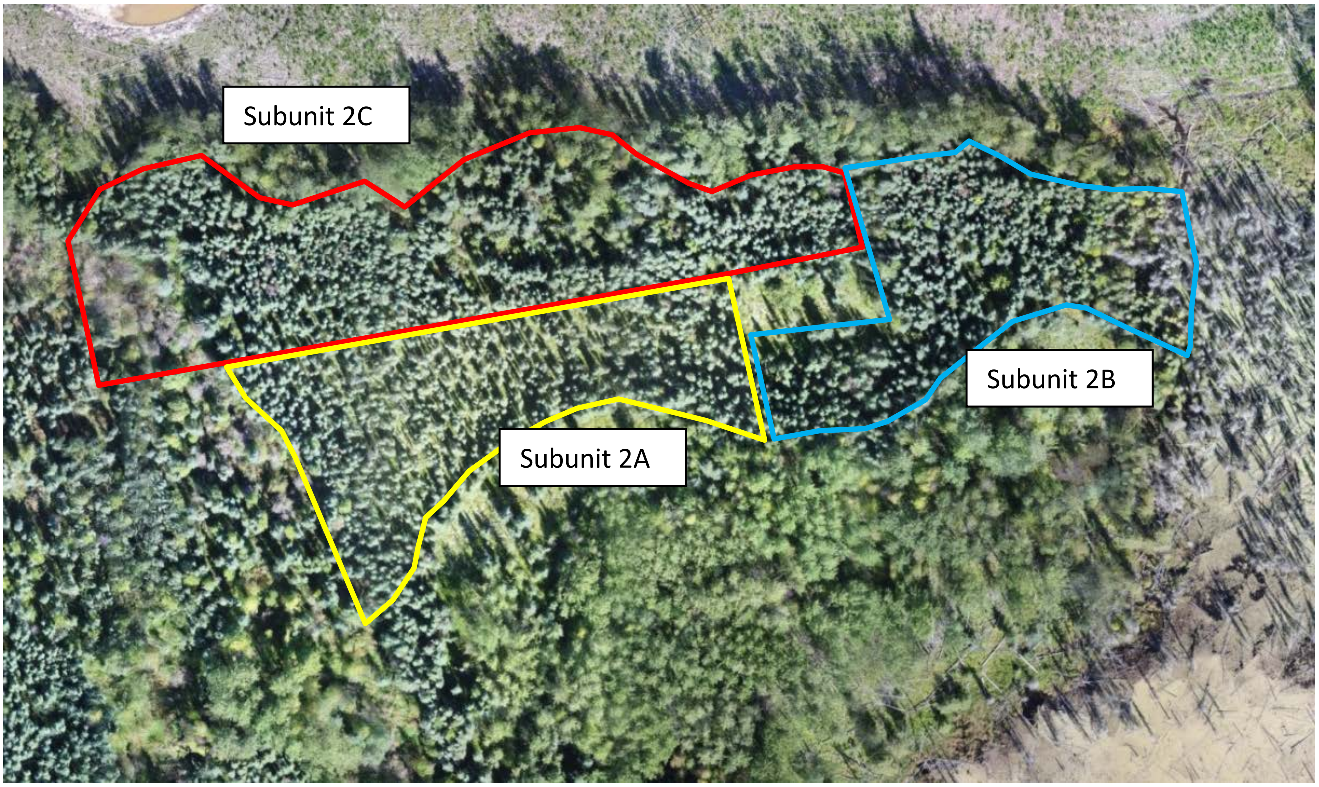
[c]Seedlings = Stems < 1.3 m height

[d]Density = Stems/hectare

[1] For more information about the Pelican Mountain FireSmart Research Area, see the Canadian Wildland Fire & Smoke Newsletter.

[e]DBH = Diameter at breast height

Figure 1. Varying stem density and forest stand maturity in Unit 2.



Machine description

The GyroTrac G-T 25XP (Figure 2) is a 201 kW (270 hp), low-ground-pressure (24 kPa or 3.5 psi) machine on belted tracks with cleats. The attached TOMA-AX 700HF cutter head has a mulching surface that is 2.2 m wide (Figure 3).

Figure 2. GyroTrac 25 XP mulcher.

Figure 3. Mulching head using "Sabre Tooth" cutting technology

Mulch treatments

Unit 2 was delineated into three subunits that were mulched at different treatment intensities to produce three distinct mulch fuel beds (Figure 4). A normal-intensity mulch treatment included knocking over stems and processing them using at least two passes. This resulted in a bed of uniformly sized chipped debris with a minimal amount of intact round wood.

Both the low- and high-intensity mulch treatments were exploratory treatments which are not commonly applied. The low-intensity treatment redistributed standing fuel to the surface and included only minimal mulching. The resulting coarse mulch fuel bed included a large volume of round wood debris and an undisturbed duff layer.

The high-intensity treatment redistributed standing fuel to the surface, thoroughly mulched all the treatment area, and intentionally mixed the mulch with the duff layer whenever possible to create a fine mulch fuel bed. This treatment intensity is not typically applied because of the additional cost and unknown benefits. In previous mulching studies, mulcher operators were reluctant to mulch below the surface fuel layer and mix duff fuels because of potential damage to the mulcher head.

The prescriptions for each fuel treatment of varying intensity did not specify quantifiable fuel characteristics (e.g., size class distribution or depth of mulching in duff layer) for the resultant fuel bed. Therefore, at the time of mulching, we assessed qualities of each fuel bed (e.g., amount of intact round wood, disturbance of duff layer, separation of branches) to subjectively label the treatment intensities as high, normal, and low intensity.

Figure 4. Fine (left), regular (middle), and coarse (right) mulch fuel beds resulting from the three treatment intensities applied in Unit 2.

Productivity measurements

We observed and documented mulching operations in the three subunits while the mulcher was applying the three mulch treatment intensities. The productivity of the mulcher was measured during each trial.

We attached a MultiDAT[2] motion sensor and datalogger to the mulcher and conducted time and motion studies to document machine productivity as a function of treatment intensity. This work took place from February 7 to 10, 2018. The temperature ranged between -20 and -35°C and there was a 40-cm layer of snow in the treatment area.

The same operator performed the mulching work in the three subunits. Before mulching operations in Unit 2 commenced, we briefed the operator on the objectives and qualities of the mulching intensity treatments, allowed time for practice, and provided feedback through this process.

Each subunit was flagged, and the operator worked within that subunit until the work had been completed. We manually recorded the initial start and final stop time for that subunit. In addition, the MultiDAT motion sensor provided a more detailed timing of delays by recording the stop and start time. Delays greater than 5 minutes were totaled and subtracted from the overall operating time to yield productive machine hours.

Productivity of forest fuel treatments is typically expressed as hectares per productive machine hours. With a large variability in stem height, diameter, and density across a forest stand or landscape, we felt that the volume of biomass processed per productive machine hour could be used as a meaningful productivity metric. We used stand inventory data (diameter at breast height [dbh]) for each subunit as an input to biomass equations (Lambert et al. 2005) to calculate biomass for each forest stand component. We used subunit area (ha), biomass per area (tonnes/ha), and mulching time (PMH) to calculate two productivity metrics: biomass/mulching time (tonnes/PMH) and area/mulching time (ha/PMH).

Post-treatment fuel bed inventory

During the summer of 2018, AWFIP crews conducted destructive fuel sampling in each mulch fuel bed in the three subunits. The AWFIP lab technician oven dried and sorted the material by size class and weighed the sorted debris samples to determine surface fuel bed properties, including size class distribution, overall loading, and bulk density.

Conventional field inventory techniques for measuring harvest debris (McRae et al., 1979) have been adapted to characterize mulch debris by size class. While this measurement is typically used to determine a slash fuel loading, this adaptation for measuring mulch debris particles is only for the purpose of sorting mulch particles in a sample and characterizing the sample by size class composition (percentage). For our purposes of size class characterization, each mulch debris particle was measured across the smallest diameter to determine the size class.

[2] MulitDAT is a system for recording and reporting information about the activities of forestry machines: http://www.castonguay.biz/

RESULTS

Fuel bed characteristics

The differences between each mulch fuel bed in the three subunits were visually obvious. The primary differences in the low-intensity treatment subunit were the relatively minimal amount of mulch debris particles, greater volume of coarse woody debris, and undisturbed moss layer (Figure 5). This surface fuel layer was classified as coarse mulch.

Figure 5. Coarse mulch fuel bed resulting from a low-intensity mulch treatment.

A normal-intensity mulching treatment typically results in a fuel bed with most aerial and surface fuels processed into chipped debris. Some disturbance of the duff layer occurs. The fuel bed qualities of mulching treatments are often determined by the type of mulching head, amount of snow cover, and number of passes that a machine makes in the treatment area. The fuel layer created in this subunit (Figure 6) was typical of the "industry standard" that is often applied in utility corridors. The fuel layer created by the normal-intensity mulch treatment was classified as regular mulch.

Figure 6. Regular mulch fuel layer resulting from the normal-intensity mulch treatment.

Key characteristics of the high-intensity treatment were the high percentage of mulched debris in size classes 1 and 2 with the greatest extent of mixing of duff and mineral soil (Figure 7). By comparison, the normal-intensity treatment resulted in a fuel layer with little mixing of the duff layer. Characterization of the three mulch fuel types by size class distribution is show in Table 2.

Figure 7. Fine mulch layer resulting from the high-intensity mulch fuel treatment.

Table 2. Post-treatment debris loading

Subunit (mulching Intensity)	Mulched debris loading (tonnes/ha) and percentage (%) of total					
	Diameter size class (cm)					Overall loading
	Litter and SC1 (0.00– 0.49)	SC2 (0.50– 0.99)	SC3 (1.00–2.99)	SC4 (3.00–4.99)	SC5 (5.00–6.99)	
2A (low)	32.9 (54.8)	7.8 (13.0)	8.2 (13.6)	9.3 (15.4)	1.9 (3.2)	60.1 (100)
2B (normal)	96.9 (58.3)	28.2 (17.0)	32.8 (19.8)	8.2 (4.9)	0.0	166.1 (100)
2C (high)	64.7 (69.1)	13.1 (14.0)	14.6 (15.5)	1.3 (1.4)	0.0	93.7 (100)

Productivity

The low density of large trees and relatively low volume of biomass in subunit 2A presented little challenge for the mulcher and this is reflected in both productivity metrics (Table 3) for the low intensity treatment.

Even though more time was required to process the larger area of subunit 2C using the high intensity treatment, the productivity rates measured in this subunit were similar to those recorded in subunit 2B mulched at the normal intensity.

The large differences in stand characteristics (most notably density of large trees and small trees) are suggested, in the discussion section, as contributing factors that equalized the productivity between the two subunits.

Table 3. Productivity based on biomass and area processed.

	Biomass (oven dry weight) (tonnes/ha)							Productivity	
Subunit (mulching Intensity)	Large trees ≥ 9 cm dbh	Small trees < 9 cm dbh	Seedlings < 1.3 m[a]	Total	Biomass per subunit (tonnes)	Area (ha)	Time (PMH)	tonnes/ PMH	(ha/PMH)
2A (low)	11.7	54.9	0.1	66.7	21.4	0.32	1.72	12.42	0.19
2B (normal)	77.2	25.5	0.1	102.8	36.0	0.35	6.15	5.85	0.06
2C (high)	17.1	71.3	0.1	88.5	51.3	0.58	9.80	5.24	0.06

[a] Seedling mass applied at 0.008 kg/seedling (Miao and Li, 2007)

DISCUSSION

An intuitive speculation about mulch fuel treatment intensities is that a higher intensity treatment requires more passes with the mulcher and, hence, results in lower productivity. The low intensity treatment supports this assumption; however the almost identical productivity rates measured for the regular and high intensity treatments suggests that further analysis of our results is required to evaluate the influence that different stand attributes have on productivity.

There was a broad variance in the densities of large trees and small trees between the three subunits with a more mature forest stand in the east end of unit (Figure 1). While subunit 2C had a very low density of large trees and a high density of small trees, the opposite distribution was measured in subunit 2B (Table 1). Subunit 2B was a more mature forest stand with a high density of large trees and low density of small trees relative to the other subunits. An increase in stem diameter results in increased mulcher operating time and reduced productivity (Coulter et al. 2002, Ryans and Cormier 1994, Vitorelo 2009). This may explain the reduced productivity in the normal intensity treatment in subunit 2B with rates similar to those in subunit 2C where the high intensity treatment was applied.

In the deep duff layer found in these trial sites, the intentional mixing of the duff layer appeared to be easy to incorporate in the high intensity treatment. However, with the 40 cm overlay of snow it was often difficult to determine how much of the mulch layer was being processed and how many passes were actually required to achieve an adequate mixing. Future mulching trials will be conducted at Pelican Mountain to determine an optimum number of passes required to achieve a mixing with the duff layer and minimize mulching time.

The treatments were applied across the entire subunit, with all stems processed and no deviations or manoeuvering to create a specific stem spacing or treatment pattern. Hence, the productivity rates derived through these trials do not accurately reflect those in treatment areas where stem retention is an objective.

Values for overall debris loading (Table 2) were similar to the calculated biomass (Table 3) for subunits 2A and 2C. However, the two values produced for subunit 2B showed a difference of 64 tonnes/ha. A possible explanation for this difference could be that the more mature forest stand in subunit 2B contained a greater volume of dead and down debris. Ground-truthing biomass estimates through measurement of mulch fuel load was not an objective of this study; however if biomass estimates can be shown to be a reliable indicator of mulch fuel loading, this may be an operationally viable method for predicting mulch coverage and depth.

During our observations of the machine, we noted that the size and volume of stems in these subunits presented no operational issues for the mulcher. The machine's productivity rates during this study represent only what is capable when mulching stands with similar attributes and objectives. Mulcher productivity in different stand types with different treatment objectives and prescriptions will differ.

NEXT STEPS

Further comparative trials will focus on stem diameter and stand density as productivity variables. Conducting productivity trials in more homogeneous forest stands will reduce the effects of the stand variability and enhance the productivity data set. Future trials will also attempt to develop a well-defined prescription for each treatment intensity in order to optimize machine time and increase productivity.

In August 2018, simultaneous fire behaviour trials were conducted in the three distinct fuel environments in Unit 2. Documentation of these experimental fires will be presented in a forthcoming technical report.

Vitorelo (2009) suggests that anecdotal observations indicate that 'the intensity of mastication affects resprouting and fuelbed depth, both factors that increase treatment efficacy and longevity'. The three unique mulch fuel beds created in Unit 2 provide good opportunities for long term comparative studies in vegetative regrowth and evaluation of temporal changes in fire behaviour potential.

CONCLUSION

We observed a GyroTrac mulcher conducting three mulch fuel treatments of varying intensities and compared the productivity rates at each intensity level. In addition to the standard performance metric of hectares/ productive machine hours, we measured the volume of biomass processed in each subunit and calculated tonnes/productive machine hours as a performance metric. Future applications of this metric can be further refined to include user-friendly stand inventory and data processing tools.

While the intensity of a mulch treatment has an impact on productivity, stem size will have a confounding influence on productivity. With the large variability of forest stand characteristics across a treatment area, individual environmental and operational factors should not be considered in isolation when estimating mulcher productivity.

When complete removal of all standing biomass by mulching operations is the objective of a fuel treatment, a lower productivity rate can be expected in forest stands with large diameter stems. However, in fuel treatments where the retention of larger stems and mulching of smaller stems and surface fuels are the treatment criteria, productivity can be expected to increase.

The relative economics of these treatment intensities can be weighed in a decision-making process for determining an appropriate treatment. Additionally, a decision-making process should include the relative fire behaviour potential (probability of ignition, rate of spread, and fire intensity) for the fuel beds created by the varied mulching treatment intensities. Continued productivity trials and experimental fires in mulch fuels of varying treatment intensities are necessary to enhance this preliminary data set in order to provide sound fuel management decision support.

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