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Effect of particle aging on chemical characteristics, smoldering, and fire behavior in mixed-conifer masticated fuel

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ABSTRACT

Mastication is a silvicultural technique that grinds, shreds, or chops trees or shrubs into pieces and redistributes the biomass onto the forest floor to form a layer of woody debris. Unlike other fuel treatments that remove this biomass, masticated biomass often remains on site, which increases total fuel loading and causes concern over how the masticated particles may burn if exposed to prescribed fire or wildfire. Central to the question of how these particles may burn is how the time since mastication affects the decomposition of the wood particles comprising the fuels. We conducted controlled laboratory experiments to investigate how the particles changed chemically over the time since they were masticated and how those chemical changes affected fire behavior characteristics. The objectives were (1) to quantify the chemical differences of masticated materials from different climates and different decomposition stages, (2) determine whether chemical changes occurred similarly in all fuel particles, and (3) describe the fire behavior characteristics exhibited by these fuels. Masticated materials came from mixed-conifer forests at fifteen different sites throughout the Rocky Mountains. Paired stands from these sites were of similar vegetation and forest stage. They represented wet and dry climates, different stages of wood decomposition, and variable piece sizes based on the type of machine used to masticate the biomass.

Time since mastication and piece size affected the rate of chemical changes in the masticated particles. Fragmented particles had less heat value, N, and C than intact particles from the same site. C decreased and N increased with time since treatment. In most cases, cellulose decreased as decomposition occurred. Age of the particles, tree species, climate, and quantity of fuel load were all important factors influencing chemical change and burn characteristics. In the smoldering experiments, age was not a significant factor but soil substrate was. Soil surface temperatures in the smoldering tests differed significantly between dry sand and dry duff, and most of the smoldering burns in dry duff easily reached temperatures and durations at the surface between the fuel and the soil that would kill soil plants, microbes, and fauna and severely affect soil ecology. When planning prescribed burns in these treatments, managers need to consider not only the moisture of the fuels, air temperature, and wind, but also the dryness and type of soil, the amount of decomposition (time since mastication) of the fuel particles, fuel depths, fuel loads, and the spatial distribution of the fuel loads left by the masticator.

1. Introduction

Mastication is an important silvicultural technique in which trees and shrubs are ground, shredded, or chopped, thereby converting ladder fuels into surface fuels. This biomass is redistributed to form a layer of woody debris on the forest floor. Mastication is a popular fuel treatment because it (1) redistributes fuel from the tree canopy to the ground, changing canopy base height, reducing fire intensity, and reducing crown fire potential in tree and shrub canopies (Battaglia et al., 2010); (2) affects the probability of fire occurrence across landscapes by changing spread rates (Cochrane et al., 2012; Kreye and Kobziar, 2015); and (3) may reduce detrimental effects from smoke on humans during prescribed burning (Naeher et al., 2006; Weinhold, 2011). It is also used to change or remove competing vegetation in areas requiring natural or artificial regeneration (Jain et al., 2012). Currently, mastication has become important in areas where using

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prescribed burning may pose danger to adjacent properties, such as in the wildland urban interface (WUI), or where thinning trees may be difficult and costly (Berry et al., 2006).

The physical, chemical, biological, and mechanical effects of mastication have been well studied since masticators were first developed to treat forest biomass (e.g., Ritter, 1950; Pokela, 1972; Busse et al., 2006; Kane et al., 2009). Although these studies have provided vital information for managers on implementing mastication treatments, previous research related to particle fragmentation and fire behavior in masticated fuelbeds is most relevant in this paper. A literature review to this effect, investigating studies related to fire behavior in masticated fuels, was completed by Kreye et al. (2014). It provided insights into a variety of factors that affect burn characteristics, including fuel characteristics (Kane et al., 2009) and relationships between particle size, fuel load and moisture content (e.g., Rothermel, 1972; Rothermel and Deeming, 1980). Important studies on the effects of particle fracturing and moisture content on fire behavior in masticated fuels have been conducted by Kreye et al. (2011), while the importance of fuel load has also been addressed by Battaglia et al. (2010). The impacts of prescribed burning on masticated fuels have been documented in field studies by Glitzenstein et al. (2006), Knapp et al. (2011), Wolk and Rocca (2009), Reiner et al. (2009), Kreye and Kobziar (2015) and Brennan and Keeley (2015). These studies have investigated fire behavior characteristics in a variety of ecosystems from forests to shrubs. Together the studies found that masticated materials produce low intensity, slow-moving fires; that fuel depth of the chips is important to burning; that flame length and height are much smaller in masticated materials than in wildland fires; and that these materials form novel fuel beds that defy easy classification in fuel models to describe their burn characteristics.

Several studies have also been done on the chemical changes that occur in wood during decomposition. Dobry et al. (1986), Boddy and Watkinson (1995), Creed et al. (2004), and Mattson and Swank (2014) all found that heat value and C generally decrease with longer decomposition times and N generally increases. N content has also been found to increase with progressive decomposition in several other studies (e.g., Kielak et al., 2016; Jurgensen et al., 2006). Kielak et al. (2016) and Larsen et al. (1978) hypothesized that increases in N content may relate to fungal and bacterial activities. For example, white-rot fungus *Hypholoma fasciculare* was recently shown to be able to translocate N into decomposing wood from soil under the colonized wood (Philpott et al., 2014). Similarly, Cowling and Merrill (1966) found that wood-inhabiting N-fixing bacteria were suggested to support fungi in fulfilling their N requirements (Hoppe et al., 2014). Increased N into the wood from either translocation or by active bacterial action is important because increased N accelerates decomposition of surface and buried wood (van der Wal et al., 2007). It also provides the N fungi need to increase their populations and breakdown wood cellulose during the decomposition process. Goldman et al. (1987) found that lignin decomposes more rapidly in soils when high amounts of easily degradable C and high concentrations of N are present because of an associated high metabolism and fast growth of microbial populations.

Heat value has been found to vary in response to lignin content and fungal activity (Demirbas, 2001). Dobry et al. (1986) found a difference in the combustion heat of wood depending on whether the wood samples were affected by white rot or brown rot. In samples affected by white rot, combustion heat ($Q_{exp} \times (J\ gm^{-1})$) remained virtually unchanged during decomposition and the relative portions of the main chemical wood components remained essentially the same. With brown rot, however, combustion heat was unchanged only in the initial stages of decomposition. After a weight loss of 30%, combustion heat and lignin content changed considerably (Dobry et al., 1986). The persistence of lignin and its role in the combustion heat of wood is well known to be determined by the type of fungal decay present (e.g., Kirk and Cowling, 1984; Dobry et al., 1986; Kielak et al., 2016). White-rot fungi are able to degrade lignin in order to get access to other polysaccharides within woody material. They also usually destroy all wood components during decomposition. Alternately, brown-rot fungi are specialized in degradation of holocellulose and usually destroy cellulose early in the decay process without removing lignin (Kielak et al., 2016). In 2016, Venugopal found that fungal wood decay was affected by temperature, humidity, substrate quality and fungal diversity; but, wood quality and fungal assemblage composition can modify the influence of climatic factors on fungal decomposition rates.

Missing from the past studies on mastication and decomposition is how masticated particles change chemically as they lie on the ground during decomposition and, further, how these chemical changes may affect fire behavior characteristics if the masticated materials burn and how this burning in masticated fuels might affect soil. Therefore, the objective of this study was to determine how leaving masticated materials on the surface of the ground for varying lengths of time affects their chemical composition and fire behavior characteristics. Because decomposition is central to the aging process, four specific questions were addressed to explore the changes that may occur over time. Does the chemical composition of fragmented and intact particles of the same age differ? What chemical changes occur within the materials left on the ground during decomposition over time? What effect does time since mastication or chemical decomposition have on the smoldering and surface fire behavior characteristics of masticated fuel? And finally, which of the measured chemical properties and fire behavior characteristics are most influenced by time since mastication treatment?

2. Methods

2.1. Study area and sampling design

This study employed a spatial and chronological sequence sampling strategy where we sampled sites that had different times since masticated treatments. Within mixed-conifer forests across the western U.S., 15 sites were selected that represent masticated fuel treated 6 months to 10 years prior to sampling (Table 1). Within these sites, sample areas having the same forest ages, forest structural stages, vegetation composition, geographic area, and climatic conditions were paired based on their times since mastication to determine the extent of changes that had occurred during the time they laid on the ground. Often the paired sites were located in close proximity within the same experimental or national forest so their species composition was similar. All of the sites had merchantable timber removed, followed by masticating both the remaining overstory trees and understory. Shreds of understory vegetation were not a dominant component of the masticated material, and deciduous trees were rare at all sites.

Geographically, sites were located from Idaho to New Mexico in the US Rocky Mountains and to South Dakota in the Great Plains. Within this wide distribution, the sites varied from mesic to xeric based on their annual rainfall. Sites in northern Idaho had more than 40 cm annual average precipitation and were composed of a variety of tree species, including western redcedar (*Thuja plicata* Donn.), western white pine (*Pinus monticola* Dougl.), western hemlock (Tsuga heterophylla (Raf.) Sarg.) and western larch (*Larix occidentalis* Nutt.). Sites in the remainder of the study area were drier and composed mainly of mixed ponderosa pine (*Pinus ponderosa* Dougl.) and Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) stands. Prior to treatment, each site consisted of dense pole or mature stands that could experience increased fire behavior, including higher crown fire potential. Pretreatment stand summaries were not available for many of the sites. All areas were treated using four general types of mastication equipment (Keane et al., 2017). These included a vertical rotating shaft cutting head with fixed teeth (6 sites), a horizontal drum head with fixed teeth (6 sites), a mowing horizontal shaft with swinging knives (2 sites); and a chipping head (1 site). All sites had a history of frequent fires prior to European settlement; but since the early 1900s, fires had been successfully suppressed creating dense canopies and heavy surface fuel