Above and below ground heating from the burning of masticated palmetto-gallberry fuel beds

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BACKGROUND

Fire is an important ecological process in many forest ecosystems of the southeastern United States and the maintenance of these ecosystems is often conducted with the use of prescribed fire. But as the spatial area occurring within the wildland-urban interface (WUI) increases it will become more difficult to use prescribed fire not only to maintain fire-dependant ecosystems, but also to mitigate threats associated with wildfire through the manipulation of fuel complexes. As prescribed burning becomes more difficult to employ, the mechanical treatment of fuels is likely to increase as an alternative to prescribed burning or as a pre-treatment option in conjunction with prescribed burning. While mechanical fuels treatments increase as a fuels management option several questions will need to be addressed to fully understand their applicability.

Mechanical mastication is a fuels treatment method that converts live shrubs and small trees into a dense fuelbed of dead fragments of vegetation (Fig. 1) in order to reduce fire intensity during a wildfire or a controlled/prescribed burn. Live fuels are chopped or cut using front end or boom mounted rotating equipment containing flailing cutters (Fig. 2) that sever branches, limbs, and stems. Important questions regarding mechanical fuels treatments are their effectiveness in reducing the threat of wildfire to communities, but It is also important to understand what potential ecological effects may result from the implementation of these types of treatments. Fully understanding the benefits as well as the consequences of using mechanical treatments as an alternative to or in conjunction with prescribed burning will be required to make sound management decisions.

Fig. 1 Repeat photos taken before (left) and after (right) mechanical mastication in pine flatwoods.

Pine flatwoods dominated by palmetto *(Serenoa repens)* and gallberry *(Ilex glabra)* shrubs in the understory is a widespread forest ecosystem in the southeastern United States where frequent low intensity fires are common. Since understory shrubs are the dominant fuel strata driving fire behavior in this ecosystem, energy release during combustion likely results in heat fluxes occurring at some distance above the forest floor surface due to the vertical fuel architecture of shrubs. When masticated, the conversion of shrubs into densely compact fuelbeds (Fig. 3) may reduce rate of spread and of energy release (intensity) during subsequent fire (Fig. 4), but heat release will likely be concentrated near the forest floor's surface. The slower rate of fire spread along with the concentration of heat fluxes at the ground's surface may result in lethal heating to the base of trees, to plant roots, to soil microorganisms, or have other undesired ecological consequences. Determining both the benefits and the potential consequences of these treatments are needed to fully understand their effectiveness at meeting management goals. In order to gain a better understanding of the effects of these treatments on fire behavior and potential effects we conducted experimental burning in collected fuels from masticated palmetto/gallberry dominated flatwoods to determine how fuel loading and fuel moisture influence fire behavior characteristics as well as above and belowground heating.

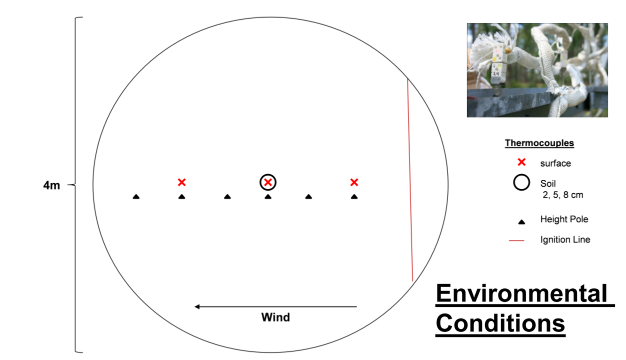
Fig. 2 Mastication equipment

Fig. 3 Surface fuels from mastication

Fig. 4 Fire behavior in pine flatwoods following mechanical mastication of understory shrubs and small trees. The photo on the right shows a pocket of un-masticated shrubs burning beneath a residual pine tree

METHODS

Surface fuels were collected from post-masticated treatment sites in the Osceola National Forest near Lake City, FL, USA in May 2010 and were used to develop fuelbeds for experimental burning. We burned 18 circular fuelbeds (4m diameter, Fig. 5) in a 3x2 full factorial experiment under 3 fuel loading (10, 20, & 30 Mgha-1) and 2 fuel moisture content (FMC) treatments (N=3). We measured flame length (at 6 locations, Fig. 5) and calculated rate of spread (ROS) from visual observations. Fuel consumption was determined from 4 pre and post-burn litter height measurements and fireline intensity ($kJ \cdot m^{-1} \cdot s^{-1}$) was calculated as the product of fuel heat content, fuel consumed, and ROS. Fuelbed surface as well as soil temperatures (0,2,& 8cm) were recorded every 3 sec using type K thermocouples. We compared fire behavior metrics, maximum surface temps, and duration of lethal surface heating (≥60˚C) across fuel load and FMC treatments and we compared maximum soil temperatures across fuel load, FMC, and soil depth using GLM ANOVA. The relationship of fire intensity and flame length was determined using non-linear regression assuming an exponential relationship.



Environmental Conditions

Temp: 28-34˚C
RH: 46-63%
Wind: 0.3-1.8 $m \cdot s^{-1}$
Soil moisture: 9.9±1.1%

$$I = h \cdot w \cdot r$$

I fireline intensity (kJ/m/s)
h heat content (kJ/kg)
w mass consumed (kg/m^2)
r rate of spread (m/s)

Fig. 5 Burning constructed fuelbeds using material collected from masticated shrubs from fuel treatment sites.

RESULTS

Flame length and fireline intensity both increased under greater fuel load and drier FMC, but ROS only increased under drier FMC (Table 1). Fuel consumption was high, but did not differ under either treatment. Interactions effects were not significant between fuel load and FMC on any fire behavior metric listed in Table 1.

Table 1. Fire behavior characteristics from experimental burning of masticated understory vegetation of southeastern pine flatwoods across fuel loading and fuel moisture content treatments. Marginal and cell means are listed along with p-values from GLM ANOVA.

		Flame Length *(cm)*		Rate of Spread *(m· min⁻¹)*		Consumption *(%)*		Fireline Intensity *(kJ·m⁻¹·s⁻¹)*	
		mean (SE)	P	mean (SE)	P	mean (SE)	P	mean (SE)	P
FMC[a]	Low	111 (14)	**0.001**	1.17 (0.12)	**0.007**	93.6 (1.9)	0.130	593(116)	**0.029**
	Moderate	67 (14)		0.61 (0.09)		97.0 (0.7)		317 (83)	
Fuel Load[b] (*Mg·ha⁻¹*)	10	49 (10)A	**<0.001**	0.75 (0.19)	0.446	94.2 (2.2)	0.387	183 (47)A	**0.003**
	20	91 (10)B		0.98 (0.16)		94.2 (2.2)		487 (81)AB	
	30	140 (14)C		1.00 (0.19)		97.6 (0.7)		773 (149)B	
FMC x Fuel Load	No interaction effects were significant across fire behavior metrics.								

[a] Fuel moisture content treatment: low (8.9±0.6%) and moderate (12.9±2.0%).
[b] Where fuel load was significant, similar letters within columns indicate no difference amongst means from the Tukey-Kramer post hoc comparison.

RESULTS (cont)

Surface temperatures, ranging from 274 to 503˚C, and duration of lethal heating (≥60˚C), ranging from 9.5 to 19.9 min, both increased with fuel load (Fig 6 a, P<0.001; Fig 6b, P=0.002), but did not differ between FMC (P=0.887) during the burning of masticated palmetto-gallberry. However, maximum soil temperatures were influenced by both fuel load (Fig 6c, P<0.001) and FMC (Fig. 6d, P<0.001), although differences were not detected between the 20 and 30 Mg/ha fuel loads using a Tukey-Kramer post hoc comparison. Soil temperatures differed across soil depth (Fig 6 c&d, P<0.001), and the effects of fuel load and FMC were consistent across depth as no interaction effects between factors were detected. Lethal temperatures were never reached within the soil profile.

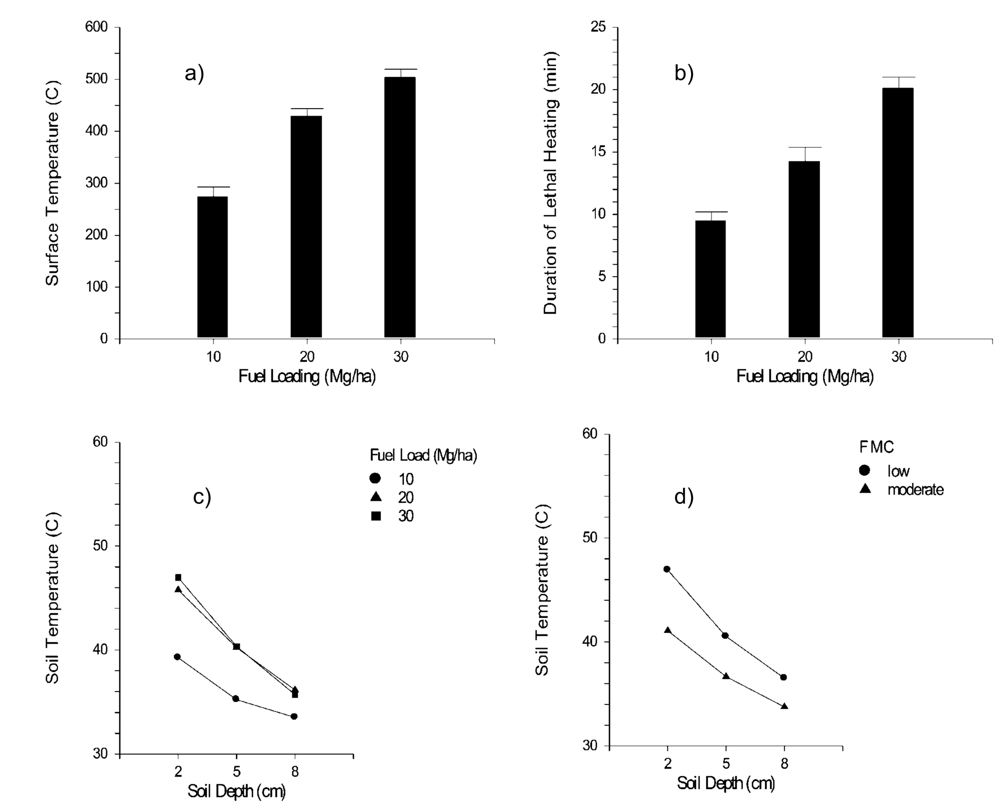


Fig. 6- The effect of fuel load on maximum surface temperatures (a) and the duration of lethal surface heating (b), as well as the effect of fuel load (c) and fuel moisture content (d) on maximum soil temperatures recorded at 3 soil depths (2, 5, and 8cm) during the burning of masticated palmetto-gallberry shrubs. .

The empirical relationship of fireline intensity and flame length fit an exponential model (R=0.81) and is described in Fig. 7. Byram's(1959) fireline intensity equation (Fig. 7) is currently used in several fire behavior and fire effects prediction modeling programs and was included here for comparison. Fireline intensity was greater across flame lengths in our study compared to that of Byram's equation.

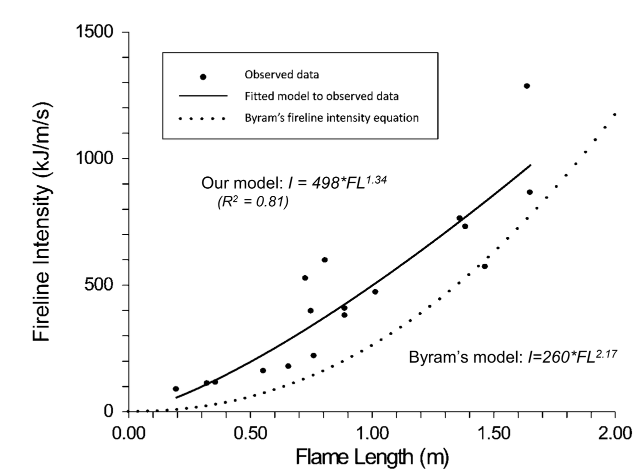


Fig. 7- The relationship of fireline intensity and flame length from the burning of masticated palmetto-gallberry shrubs (solid line) compared with that of Byram's fireline intensity equation (dotted line) used in fire behavior prediction models.

DISCUSSION

The results of this study indicate that fuel loading in masticated palmetto-gallberry shrubs influences fire intensity and both surface and soil heating when fuelbeds are burned. These effects were consistent across 2 fuel moisture contents (9 & 13%). Higher maximum surface temperatures and longer durations of lethal heating as a result of burning in higher fuel loads may indicate a greater potential for ecological damage when fuel treatments occur in areas with high pre-treatment shrub biomass. Although soil temperatures did not reach those considered lethal to plant tissues, the risk of damaging the basal cambium of trees or fine roots in surface duff layers is a concern. The compaction of fuel biomass at the surface of the forest floor from mastication in these forests may lead to unforeseen consequences when burned due to concentrations of heat flux occurring at or near the forest floor's surface.

The greater fire intensity across flame lengths compared to Byram's equation may indicate the effect of residual combustion following the passage of the main flaming front. The greater overall energy output per unit area may result in increased surface heating that may be not be predicted under currently used fire behavior and fire effects models. The burning behavior of these novel fuelbeds will need to be better understood for managers to have the ability to predict both fire behavior and potential fire effects, e.g. tree mortality, in order to evaluate trade offs between the benefits of mitigating fire hazard and potential undesired ecological consequences from the use of these fuels treatment methods.

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