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Large site prep tractors for fire line establishment in southern pine stands in Alabama

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ABSTRACT
Trials of fire line establishment with a mulcher were conducted with a 261 kW Caterpillar 586C site prep tractor and Cat HM825 mulcher head (2.5 m cutting path). The fire lines were intended for the application of prescribed fire. The trials were on three sites and in two stand types (cutover and thinned pine), and at three production speeds (0.6, 0.8, and 1.2 km h^{-1}). The slowest speed (0.6) was a two-pass application at 1.2 km h^{-1}. Treatments were applied in 16 blocks to 48 segments which ranged from 100 to 300 m in length. Mineral soil exposure ranged from 50% to 80% of the treatment width for all but one block. Slower speeds produced significantly greater mineral soil exposure with some significant interactions of site and treatment. Productive delays were caused by maneuvering and retreatment of skips, due to sudden changes in terrain or obstacles. Productive delays were 9% and 27% of the total time in cutover and thinned stands, respectively. Even with productive delays, most design speeds could be achieved. At the higher speeds, mulched fire line costs ($ km^{-1}) were near current costs for bladed trails. However, mulcher productivity (km h^{-1}) could be 2 to 3 times greater than dozers in open woodlands or young stands where the mulcher can easily navigate. Opportunities for using a wheeled mulcher to create fire lines might include locations that can take advantage of on-road travel between sites or locations that require spot treatments of high fuel loads in high-risk locations.

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Introduction

Management of fire in forests is important to both landowners and the public. Wildfire is a common occurrence, and landowners and the public are engaged in fire suppression efforts for public safety and health and to control economic losses. The application of prescribed fire is the principle means of hazardous fuel treatment across the southern USA with millions of acres treated annually (Marshall et al. 2008). Prescribed fire also contributes to both timber and non-timber management objectives.

The application of prescribed fire requires a network of fire lines, like forest roads, plowed or bladed trails, and sometimes low, moist areas. The lines may minimize damage from wildfires or allow managers to control the timing and intensity of fires. Fire lines can be constructed manually or with a variety of heavy equipment (Garcia and O'Brien 2018). In the southern USA, fire lines are often constructed by small- and medium-size dozers using the blade or a plow to expose mineral soil. The establishment of fire line with dozers is relatively inexpensive and the results are consistent. The limitation of dozers is that they are slow both in fire line construction and in travel between treatment areas. The treatment also scrapes and displaces at least a few inches of the thin A horizon on forest soils possibly affecting both soil erosion and revegetation (Christie et al. 2013). Using a mulcher to create fire lines by incorporating organic matter into the soil could increase the feasibility of mulching treatments for fire hazard reduction and the disruption of continuous fuels.

The availability of high capacity mulchers has resulted in their expanding use for hazardous fuel mitigation treatments. Mulching or mastication treatments disrupt fuel loads vertically and horizontally to reduce the risk of wildfire or allow the reintroduction of prescribed fire in the treated areas. In the southern USA a number of fuel mitigation studies which include mulching have been conducted (Brockway et al. 2009; Ottmar and Prichard 2012; Kreye et al. 2014b; Stottlemyer et al. 2015). Since treatments are typically completed in areas with high fuel loadings, there is often a deep layer of organic material on the surface (Kreye et al. 2014a). The fire intensity in treated areas depends on the fuel loading and moisture conditions, but the intent of the treatment is to reduce intensity, flame length and rate of spread compared to untreated conditions.

Mulching productivity to change fuel size and arrangement has been estimated on an area basis and some productivity estimates are 0.13 ha h^{-1} (Vitorelo and Han 2010), 0.23 ha h^{-1} (Halbrook et al. 2006), and 0.7 to 1.2 ha h^{-1} (Bolding et al. 2006). Productivity may be affected by machine type and size, tree removal, terrain, and the treatment of large diameter pieces. Most of the mulching studies to date have been fuel load reduction treatments which were measured on an area basis (ha h^{-1}). Mulching treatments to produce bare mineral soil areas which could act as fire line is feasible and the productivity measurement is linear (km h^{-1}). Using excavator-based machines, productivity estimates for fire line production were 0.1 to 0.25 km h^{-1} and 0.31 km h^{-1} (Halbrook et al. 2006) and 0.22 km h^{-1} (Dodson and Mitchell 2016).

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Since both the machines and the work accomplished are different, the comparisons between mulching and fire line productivity are difficult to make.

The objective of this research was to determine the performance and productivity of a large mulcher for fire line establishment under conditions where there was some likelihood of success. Those conditions could be described as upland sites, with limited shrub biomass, and fire line paths relatively free of large standing trees or downed woody debris.

Materials and methods

We used a Caterpillar 586C Site Prep Tractor (261 gross kW, hydrostatic transmission, and mass 17,440 kg) equipped with the HM825 mulcher head (cutting width 2.5 m, total width 3.2 m) for the trial. Before the trial, we operated the mulcher under varying machine parameters (head down pressure in float mode and speed in creep mode) to determine the performance in terms of mineral soil exposure in a single pass. We initially planned to complete treatments at three treatment speeds with a single pass, slow (0.8 km h^{-1}), medium (1.2 km h^{-1}) and fast (1.6 km h^{-1}) and a double pass (DP) at the medium and fast speeds. However, the fast treatment speed could not be sustained under field conditions and was dropped after the first site. Double-pass treatments at medium speed resulted in a treatment speed of 0.6 km h^{-1} and increased treatment width by limiting overlap during successive passes to 60–80% of the treatment width when possible. The double pass was planned to reduce the chances that brush or vines might fall into the fire line limiting effectiveness. Obstacles (e.g. standing trees or large stumps) sometimes restricted both passes to the same path. The operator managed designed speed by using the hydrostatic control in creep mode at 25% and 35% for the slow and medium speeds, respectively. Results of the few fast treatments on the Auburn site were coded as medium speed for analysis. Prior to the trial, we replaced two of the four rows of teeth so that no broken teeth remained on the head. We measured the length of each tooth across the top to the greatest dimension (Figure 1) and recorded the tooth position for re-measurement at the end of the trial.

We selected three sites on Auburn University forestland to represent a range in difficulty due to slope and surface rocks. Soil information was accessed by exporting stand shape files to the Web Soil Survey (NRCS 2018). At the Auburn site (32.675°, −85.523°), soils had sandy loam surface soils and clay or sandy clay subsoils with few surface rocks and slopes generally less than 10% (Gwinnett and Pacolet soils). At the Coosa site (32.846°, −86.019°), soils had sandy loam surface soils and sandy loam subsoils with frequent surface rocks and slopes mainly from 10% to 15% (Louisburg-Rion and Pacolet-Rion soils). At the Fayette site (33.814°, −87.812°), soils had fine sandy loam surface soils and sandy clay loam subsoils with few surface rocks and slopes mainly from 10% to 20% (Smithdale-Luverne soils).

We implemented the study in two general stand types that we termed cutover and thinned. The Auburn cutover was harvested in the previous year and surface cover was mainly herbaceous vegetation and logging slash. At Coosa and Fayette, the loblolly pine regeneration was 10 years old with uniform cover of woody vegetation and pine regeneration 4-m tall. In the cutovers, the treatment blocks were at the stand perimeter. In the thinned, mature pine stands, thinning had occurred more than 10 years before and stumps of removed trees were mostly decayed. The basal area exceeded 25 m^2 ha^{-1} in most locations, and understory shrub cover varied from 20% to 50% among the segments. The treatment blocks were skid trails and removal rows (fifth row thinning). During the trials (August–December 2018) soil moisture conditions were fresh with regular precipitation at each location. We avoided operation within 36 hours of rainfall.

Figure 1. Tooth from HSM825 head.

We used aerial imagery to identify treatment locations and paths of 1–2 km divided into two or three blocks. None of the paths were flagged in the cutovers, but we flagged specific trail points in thinned stands to help the operator avoid trails or rows which were dead-ends. Each block was divided into three segments which were randomly assigned one of the treatments. If the blocks were contiguous, we ensured that adjacent segments never had the same treatment. The Coosa site had enough space for just two blocks of the three treatments (double pass, slow, and medium) in both stand types.

The machine operator was employed by the project and had limited machine operation experience before the trial. The operator received about 30 hours of training and coaching before the trial began.

A GPS (SX-1) enabled Multidat and a VIO POV camera focused on the machine head were mounted in the mulcher cab. Prior to operation, the camera recorded the time from a handheld GPS to facilitate syncing the video recording to the location data. We used the video to identify delays (≤1 minute or >1 minute), the reason for the delay and operating time per segment. For most of the segments, we obtained distance with the GPS data. In a few cases, the GPS failed to record locations due to a loose cable and we measured those with a hip chain following the treatment. Operating time began when either the implement was activated or lowered to the ground. Mulching time ended when the mulching head was raised at the end of the segment. All delays where forward progress stopped were counted, but only delays exceeding 1 minute were timed. The time limit threshold varies by study, but the low limit ensured that we timed the vast majority of the occurrences and captured nearly all of the delay time. Shorter delays typically account for progressively smaller proportions of total delay time (Spinelli and Visser 2008; Acuna et al. 2012)

For assessment of mineral soil exposure, we mounted a camera on the mulching head and aimed it at the ground. The head and the camera were elevated to record the entire width of the path. The mulcher drove the entire length of each segment at about 1 km h^{-1}. For each trial, 30 transects were chosen at random by time. The surface was categorized at 10 or 12 points across the width of the head. Since we used landmarks on the head (mostly teeth) as transect points, the number of visible teeth varied in the center of the transect. Only observations where the sample point was located within the mulched path were included in the analysis.

Results

Productivity

Gross production data for the thinned and the cutover stands are presented in Tables 1 and 2, respectively. Total length per treatment ranged from 360 m to nearly 2000 m with a total treatment length of over 13 km. Total time spent mulching was just over 17 hours including productive and delay time. Delay frequency ranged from 24 to 71 km^{-1} with a mean frequency weighted by a distance of 47 km^{-1}. Since the operator was inexperienced, we tried to determine if there was a learning curve by completing a simple correlation between the order the segments were completed and both the delay frequency and speed (w/delay). Both were small, respectively, −0.04 and −0.15. Only the delay frequency has a sign that would indicate a positive effect of increased experience.

Speed with delay time (S-WD) varied by segment with no apparent trend between cutover and thinned stands (Figure 2). At higher design speeds, fewer segment observations (S-WD) exceeded the design speed. Speeds without delay (D-DF) were consistently at or above design speeds (Figure 3). Again, there was no apparent trend between cutover and thinned at any of the design speeds, but the medium design speed (1.2 km h^{-1}) for cutover was the only one with most observations lower than the design speed.

The delay distribution by frequency and time is presented in Figure 4. Most of the delays by frequency were reverse delays (reverse other and reverse to re-mulch) with about 70% of the total. The reverse to re-mulch delays often resulted from uneven terrain or obstacles that increased the head height. Once the operator noticed the change, the operator reversed and then treated that section of the segment again. Reverse other delays were usually components of some other maneuver to stay on the trail or select the correct path. The only other delay to comprise more than 5% of the frequency was Adjust head. Beginnings of segments, changes in trail location or conditions, or reverse would likely be associated with Adjust head delays. In many cases, head adjustment could be accomplished without a specific delay. Four of the delay categories each comprise more than 10% of the delay time and none were more than 20% of the total delay time.

Table 1. Gross production data for the treatments in thinned stands for the Auburn, Coosa, and Fayette sites.

Treatment	Site	Segments	Treated length (m)	Delay (count)	Speed w/delay (km h^{-1})	Speed wo/delay (km h^{-1})	Delay frequency (km^{-1})
Double	Auburn	3	394	24	0.40	0.85	61
Double	Coosa	2	360	18	0.67	0.85	50
Double	Fayette	3	733	30	0.74	0.86	41
Slow	Auburn	3	394	15	0.76	0.80	38
Slow	Coosa	2	514	20	0.99	1.08	39
Slow	Fayette	3	1042	36	0.67	1.02	35
Medium	Auburn	3	415	15	0.92	1.19	36
Medium	Coosa	2	443	19	1.45	1.45	43
Medium	Fayette	3	968	23	1.10	1.72	24

Table 2. Gross production data for the treatment in cutover stands for the Auburn, Coosa, and Fayette sites.

Treatment	Site	Segments	Treated length (m)	Delays (count)	Speed w/delay (km h^{-1})	Speed wo/delay (km h^{-1})	Delay frequency (km^{-1})
Double	Auburn	3	661	43	0.77	1.05	65
Double	Coosa	2	451	13	0.86	0.86	29
Double	Fayette	3	1511	76	0.74	0.79	50
Slow	Auburn	3	600	16	1.03	1.07	27
Slow	Coosa	2	461	23	0.64	0.78	50
Slow	Fayette	3	1613	113	0.57	0.79	70
Medium	Auburn	3	636	45	0.90	1.06	71
Medium	Coosa	2	397	23	1.12	1.18	58
Medium	Fayette	3	1939	92	0.81	1.25	47

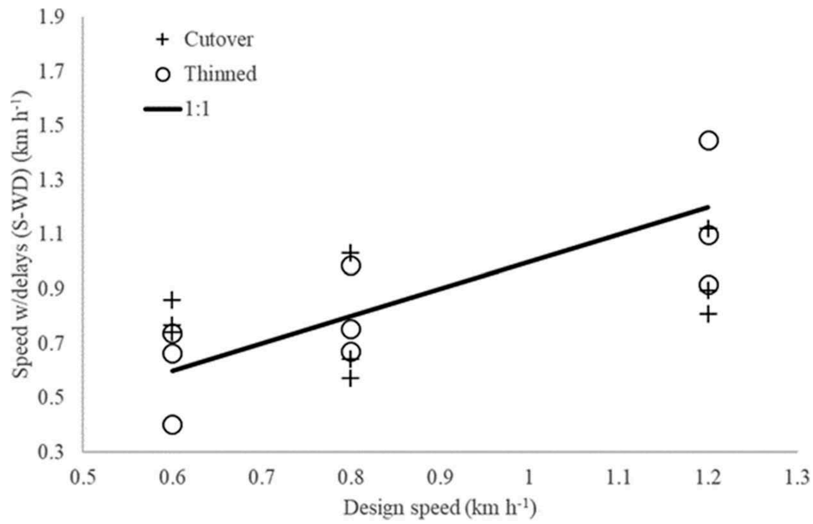

Figure 2. Treatment speed with delays for all segments by stand type. The line represents the design speed. The double-pass treatment is 0.6 km h^{-1}.

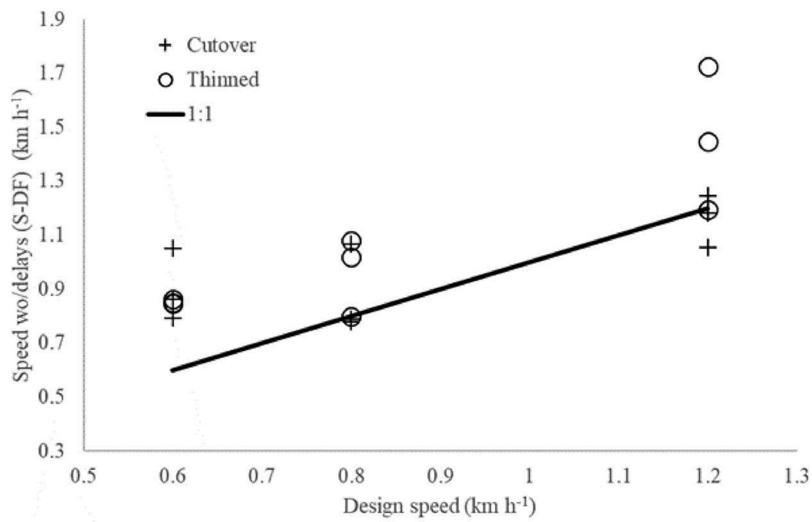

Figure 3. Treatment speed without delays for all segments by stand type. The line represents the design speed. The double-pass treatment is 0.6 km h^{-1}.

Two categories include aspects of route travel or location. Locate route and Travel off trail account for about 23% of the delay time. While we planned the routes, the operator would occasionally have to decide between options within the general direction of travel or deal with conditions not recognized in the planning process (e.g. insufficient clearance, excessive vines, etc.). Stuck or immobile delays included circumstances like insufficient traction on adverse grades, wet areas, or trapped between trees. Mulching on side slopes in thinned stands could result in the machine sliding sideways down slope. After the slide, if a tree was between the front and rear wheels, it would take some time for the operator to maneuver and free the machine. On two occasions, we needed recovery machines to pull the machine from wet areas. Both occasions involved travel between areas and not during the treatment. Debris cleaning either involved moving large branches off the top of the head or pulling vines from the drum. Delay time was 27% of the total time in thinned stands and 9% in cutover stands indicating the greater difficulty in reckoning and maneuvering among standing trees.

The general linear model results for speed (with and without delay), and delay frequency (time and distance) are presented in Table 3. Only four of the eight models are significant at $p < 0.05$ and none at $p < 0.01$. In the cutover stands, only the Speed – Delay Free (S-DF) model is significant, and in that model both block and design speed are significant. The parameter estimate for design speed was 0.82 (SE 0.235) and was significantly different from 0 ($p = 0.004$) but was not different from 1 ($p = 0.763$). A parameter estimate of 1 indicated design speeds were not different from the observed speed. Delay free speeds were similar to the design speeds and reflected the minimal influence of delay time in cutover stands. The operator managed speed with both an average and instantaneous speed indicator with the goal of completing the segment at the design speed. Delay (time or distance) was not significantly affected by any of the model parameters in the cutovers.

In the thinned stands, the model significance generally increased for each variable. In the Delay models, the only significant term was block. The significance largely resulted from

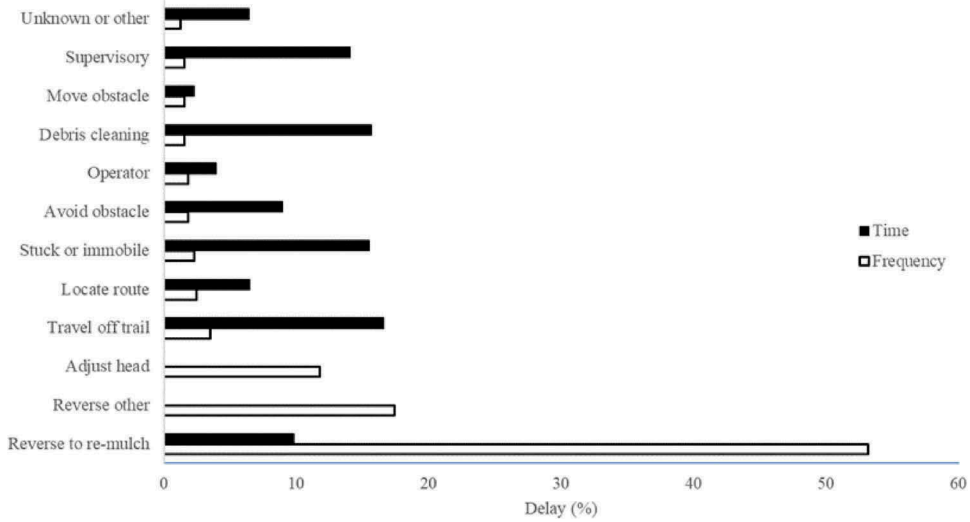

Figure 4. All delays summarized by time as a percent of total delay time (Time) or as a percent of total delay occurrences (Frequency).

Table 3. Model statistics for the productivity as delay free speed (S-DF) and speed (S-WD) and delay frequency as delays per unit time (D-T) and per unit distance (D-D) for each stand type.

		Model			Parameter – p values			
Stand type	Variable	N	F (p)	Mean square error (MSE)	Site	Block	Design speed (DS)	SitexDS
Cutover	S-DF	24	3.99(0.0112)	0.031	0.333	0.018	0.004	0.133
	S-WD	24	1.75(0.1695)	0.054	0.578	0.071	0.160	0.686
	D-T	24	1.39(0.2844)	285.3	0.599	0.531	0.062	0.154
	D-D	24	2.02(0.1166)	999.3	0.565	0.031	0.644	0.590
Thinned	S-DF	24	6.28(0.0015)	0.071	0.043	0.039	0.001	0.587
	S-WD	24	3.12(0.0292)	0.1397	0.102	0.119	0.004	0.376
	D-T	24	1.82(0.1541)	269.2	0.582	0.051	0.474	0.488
	D-D	24	3.69(0.0154)	1194.3	0.217	0.004	0.128	0.660

increased delays in one of the Auburn segments, which was the first site completed. The Speed – Delay Free (S-DF) model had the smallest p value among the thinned and cutover models. The net effect of the site, block, and the interaction of the site with design speed (S-DF) indicated that speeds on Coosa and Fayette were slightly faster than Auburn, respectively, 1.21, 1.33, and 0.95 km h^{-1}. The design speed parameter estimate for thinning was 1.36 (SE 0.356) and was also significantly different from 0 ($p = 0.002$), but not significantly different from 1 ($p = 0.169$). Again a parameter estimate of 1 indicated design speeds were not different from observed speed. For speed with delay (S-WD), the design speed was the only significant variable with a parameter estimate of 0.97 and SE of 0.499 ($p = 0.074$).

In total, the models indicate observed speeds were close to design speeds with an exception for speed with delays (S-WD) in cutovers. Site factors were not important for speed but might have impacted delay frequency. As might be expected, conditions by segment impacted both delay and speed, but we did not characterize aspects of segment variability which might have included slope, obstacle frequency, or ground cover.

Disturbance

The average number of points per treatment per site was 874 and the average number of transects was 86. Woody cover was consistently low (<3%), due to the treatments and our decision to avoid paths with heavy cover. Mineral soil exposure (MSX) ranged from a low of 54% to a high of 87%. Summing the point data from all the transects, the mineral soil exposure means for the design speeds were 78%, 69% and 66% for the 0.6 (DP), 0.8 and 1.2 design speeds. The design speed indicates the amount of soil tillage and comminution completed. The double-pass treatment, 0.6 design speed, allowed the mulcher to treat some of the area twice and extend the treated area width. The models show that the treatment was significant either as design speed or as a dummy variable for the double-pass treatment (Table 4). Site and block differences were more important in thinned than cutover stands. The variability among the thinned treatments can be seen in Figure 5. In the thinned stands, only block 15 (Fayette) has higher MSX values for the fastest treatment, while all the others show the expected relationship of lower MSX with increasing speed. In the cutover stands, nearly all the segments had similar trends between MSX and the design speed (Figure 6).

Tooth wear

Following the study, we remeasured 14 of the new teeth we installed and 14 of the teeth that were already on the machine. The new teeth had an average depth (Figure 1) of 71.9 mm and the wear during the study averaged 3.7 mm. The old teeth measured 65.6 mm and the wear averaged 1.5 mm. The

Table 4. Model results for mineral soil exposure (asin(MSX°.⁵)) for model with site, block (Blk), treatment (Tmt), site*tmt, and blk*tmt. Treatment is either design speed (DS) or a dummy variable for the 0.6 design speed, the double-pass (DP) treatment. P values ranges are indicated by * for <0.01 and + for <0.10.

		Model				Parameter – F values				
Stand type	Tmt	N	F (p)	MSE	R^2	Site	Blk	Tmt	Site* tmt	Blk* tmt
Cutover	DP	767	9.95(0.0001)	0.078	0.169	9.17*	8.1*	74.0*	0.0	3.3*
	DS	767	6.57(0.0001)	0.083	0.119	8.64*	7.59*	29.3*	1.3	2.3+
Thinned	DP	777	22.5(0.0001)	0.078	0.307	40.4*	33.4*	58.4*	1.5	5.7*
	DS	777	26.8(0.0001)	0.073	0.346	42.4*	35.4*	63.7*	13.9*	9.8*

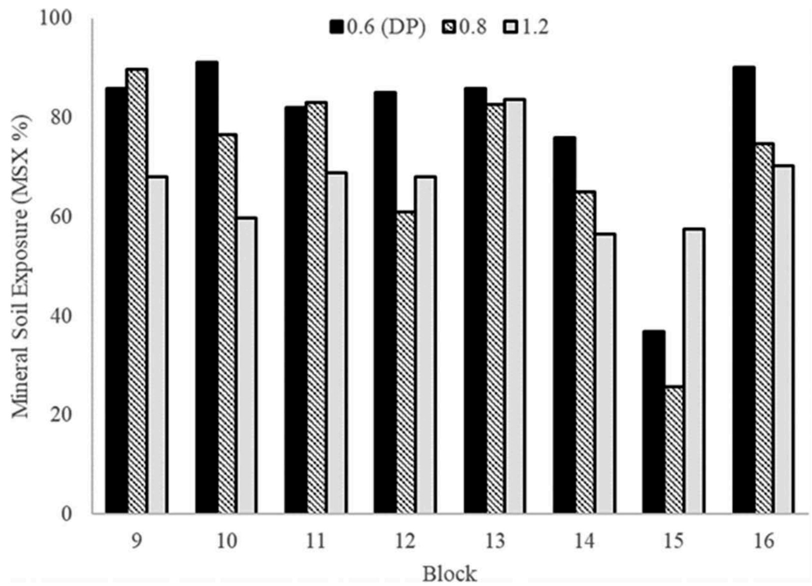

Figure 5. Mineral soil exposure in thinned stands for each block and segment by the design speeds 0.6, 0.8, and 1.2 km h^{-1}. The double-pass (DP) treatment is 0.6 km h^{-1}.

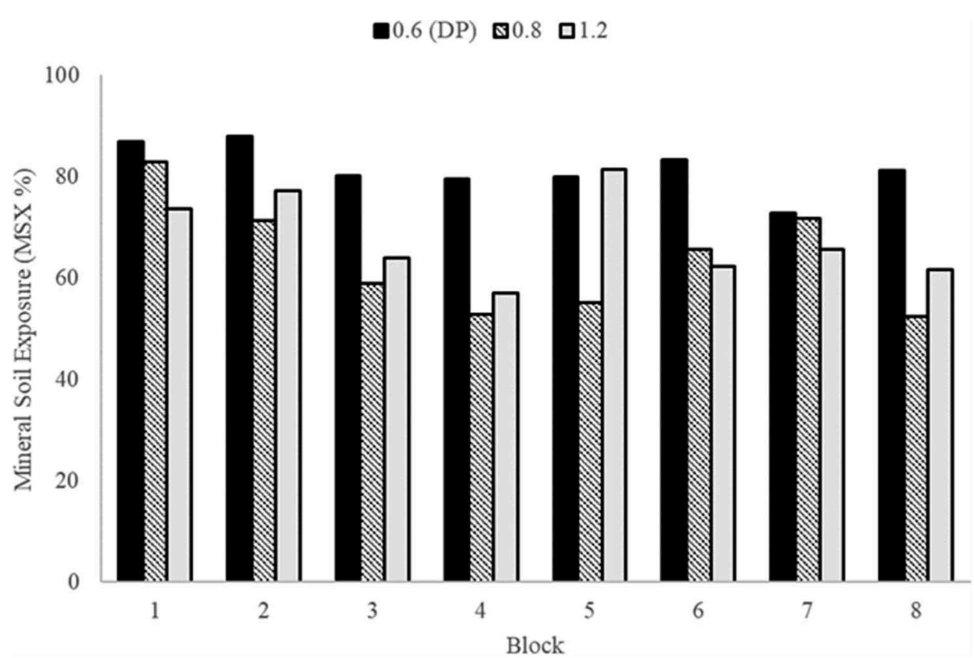

Figure 6. Mineral soil exposure in cutover stands for each block and segment by the design speeds 0.6, 0.8, and 1.2 km h^{-1}. The double-pass (DP) treatment is 0.6 km h^{-1}.

base of the tooth widens as it gets closer to the mounting bracket accounting for the difference. Only 1 of the 56 teeth on the head broke during the study.

We calculated the number of operating hours to erode each millimeter of the tooth by dividing the total number of machine hours by the change in tooth dimension over that time. The resulting relationship is Equation (1) which had an

R^2 of 0.84. The tooth wear (W) in h mm^{-1} is related to the tooth dimension (T) in mm at the beginning of the period. We estimated that the tooth life between 72 and 61 mm would be about 130 hours. Using the same relationship, a tooth would last about 370 hours to 51 mm. At 51 mm the shape of the wear surface changes more dramatically and harder material in the tooth is mostly worn away.

$$W = -1.1589(T) + 88.305 \quad (1)$$

Cost

Given the range utilization and variety in machine application, it is difficult to estimate the precise ownership costs. All costs are in USD($). We used a before-tax cash flow technique (Tufts and Mills Jr 1982) with purchase price of $400,000, discount rate at 15%, a machine life of 6 years, 20% salvage value, 4% insurance rate and 0% financed. The minimum Annual Equivalent Cost is $106,445 yr^{-1} and occurs when the machine is owned for the full 6-year machine life. The cost increases approximately 8% per year with fewer years of ownership. We estimated that operating costs including fuel, lube and oil, repair and maintenance, and tooth replacement would be $20, $10, $50, and $12 per productive machine hour (pmh^{-1}), respectively (Caterpillar Inc 1996). We estimated another $20 pmh^{-1} to account for moving and support cost and operator wage and fringe at $26 pmh^{-1}. The annual operating hours needed to break even (including the operator wage and 15% discount rate) at three levels of productivity (0.6, 0.8, and 1.0 km pmh^{-1}) and contract rates ranging from $210 to $330 km^{-1} are presented in Figure 7. We used 1.0 km pmh^{-1} in the cost analysis instead of 1.2 km pmh^{-1} since the analysis showed the latter was not consistently attainable. Annual productive machine hours exceeding 2000 per year likely violate assumptions of a 6-year machine life and assumptions used to generate maintenance costs. At 0.6 km pmh^{-1} income greater than $330 km^{-1} would result in positive net income. At 0.8 and 1.0 km pmh^{-1} most of the scenarios are likely to be profitable. Using the cutting path width of 2.5 m for all treatments, the productivity rates we achieved of 0.15, 0.20 and 0.25 ha pmh^{-1} for the three treatment speeds were similar to those from (Halbrook et al. 2006). The cost would range from $840 to $2200 ha^{-1} across the conditions displayed in Figure 7.

Discussion

Both the productivity and disturbance analyses show that operations are more difficult in the thinned stands. The difficulty in maneuvering made speeds with delay of 1.2 km^{-1} difficult to attain. In addition, it is likely that the variability in understory cover contributed to greater variability in mineral soil exposure. In application, operators would be likely to change speed to produce the desired fire line conditions. While that might mean that speeds would be slower than those tested for treating heavy understory, operators might be able to exceed 1.2 km h^{-1} in favorable conditions.

The fire lines we installed appeared to be adequate for most conditions where the prescribed fire might be applied (NRCS 2006; Weir et al. 2017), but specific performance attributes are linked to conditions (fire/ignition type, flame length, topography, etc.). Guidelines for fire line construction indicate the width based on expected fire and terrain conditions and mineral soil exposure across some portion of the width. Dodson and Mitchell (2016) found performance issues for mulching in the area designated for mineral soil exposure (0.3 to 1.0 m) inside a 3 m fuel break. All of our treatment areas had the 3 m fuel break and with more than 50% mineral soil across the transect, there would seldom be less than 0.3 m of continuous exposed mineral soil. The proportion of mineral soil exposure was 70% or higher for the double-pass treatments and greater than 60% for most of the single-pass treatments. Nearly all the woody material was masticated.

The mulched fire lines do not look like dozed lines since some organic material remains at the surface which might limit the acceptance of mulching. However, it is not uncommon for landowners and managers to use cultivation or mowing for fire lines (NRCS 2006) and mulching could be more effective than these options. Desired fire line widths greater than 2.5–3.0 m would have to be installed with a double-pass treatment. While we administered the double-pass treatment at the same speed for each pass, the same level of disturbance might be achieved by

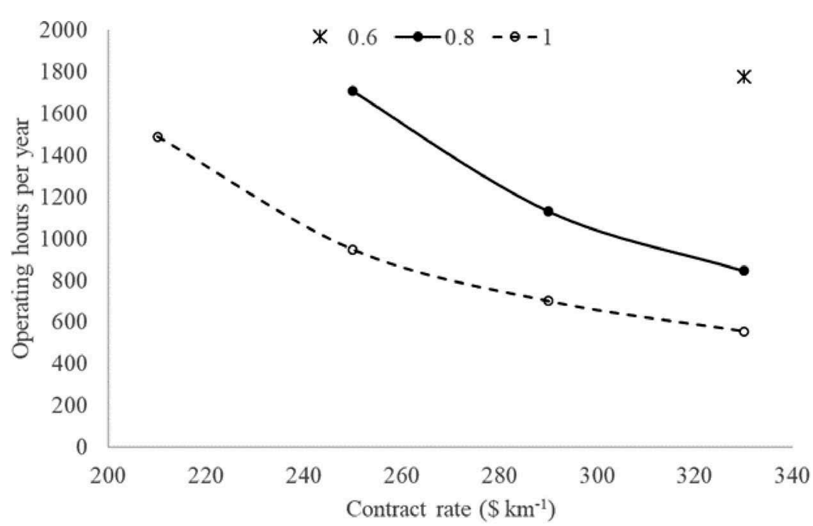

Figure 7. Annual operating hours needed for break-even at each of the contract rates and productivity levels (0.6, 0.8, and 1.0 km pmh^{-1}).

selectively treating only areas which need extra mastication or additional treatment width. This variation could achieve productivity of 0.8 to 1.0 km pmh^{-1}.

Published information for production rates for plowed or dozed fire line ranged from 0.1 to 0.3 km h^{-1} in the western US (Fried and Gilless 1989) and Spain (Garcia et al. 2018). A review by (Parker et al. 2007) indicated that average rates were between 0.25 and 0.50 km h^{-1} and rates were influenced by dozer size, stand and terrain conditions. Since conditions in the current study were among the best conditions reviewed in the literature, we would expect comparable dozer productivity near the high end of the range. In 2018 a USDA cost-share program allowed \$300 km^{-1} for light equipment and \$800 km^{-1} for dozer constructed line with a desired width of 2.4 m. The Alabama Forestry Commission provides small dozers for fire line construction at \$90 h^{-1} or fire line construction cost between \$180 and \$360 km^{-1} at average productivity levels (0.1 to 0.3 km h^{-1}).

In conclusion, both machine productivity and utilization are important in application costs. The more likely scenarios put fire line construction cost with mulching at the upper range of that for small dozers. Still fire line production with the mulcher would be cost competitive with the dozers as long as there is enough work at one location to control the higher transport costs and the conditions (terrain and understory) are similar to the study areas. For wheeled mulchers expansion of the work, area is possible by driving the machine between sites over public or private roads. As compared to dozers, wheeled mulchers are suited to road travel with high range speeds (>19 km h^{-1}) and rubber tires. Scenarios where the mulcher might be a better option than dozers are where the mulcher is used to treat heavy fuels in high-risk areas (e.g. near structures or public roads, up slope positions, or ownership boundaries, etc.) in addition to fire line preparation. On sites with potential for erosion, the mulching treatment avoids some issues created by bladed fire lines such as berms that might channel runoff, degradation of the seedbed, and the removal of surface organic matter.

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