Biomass chipping for eastern redcedar

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Abstract

Eastern redcedar expansion is a significant economic and environmental problem in much of the Great Plains. Mechanical control measures are quite common and widely available, but application is costly and the often large piles of trees are significant issues for landowners. Biomass production from redcedar has the potential to lower costs and dispose of the material. Following field harvesting trials in 2015 and 2016, we developed production and costing tools to determine the cost and productivity for available production systems which might produce biomass chips at a cost that could be supported by biomass value for energy. Significant issues in the production systems include both low volume per tree and low density in the stands. While hot systems are typically more efficient in biomass harvesting, cold felling, processing, or transportation may be ways to overcome production constraints and increase material value. The lack of conventional timber harvesting in these regions also adds to the cost in terms of available equipment and expertise.

Keyword: Logging, eastern redcedar, biomass, productivity, Oklahoma

Introduction

Very little harvesting productivity and cost data is available for treatment of invading eastern redcedar (*Juniperus virginiana*) in the Great Plains. Treatment through mechanical and chemical removal has been a priority due to both the financial losses and environmental consequences of redcedar invasion. Removal costs are high and typically do not include material utilization that would offset costs (Drake and Todd, 2002). The roundwood harvest of red cedar across the region is very low and the likely market for additional material is comminuted material for mulch or bioenergy products. However, recent surveys of the supply chain indicate only a small percentage of wood is sent to the mulch market (Gold et al., 2005). While markets and harvesting/transportation costs both affect the application of harvest versus treatment, local contacts indicate that high cut and haul costs are an impedance to further market development.

The primary issues in redcedar harvesting include: 1) large branches near the stem base, 2) low volume per tree, with a high proportion of branch to stem volume, and 3) low stand density. The objectives of this study were to estimate productivity of currently available equipment and estimate the costs of full systems (with chipped biomass delivered to a market) to address problems with raw material availability identified by Gold et al. (2005).

Methods

We collected continuous time study data on a pasture site near Morrison, OK with about 30% redcedar cover. It was felled in the summer of 2015. The contractor transported trees to a grinder using a skidsteer loader (Caterpillar 277D) with a grapple attachment. We placed a point of view (POV) camera pointed at the grapple and installed a Multidat recorder with a Garmin 15 GPS receiver and antenna. We used GPS points collected at approximately every 10 seconds to estimate the total distance traveled per

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cycle. The straight line distance was estimated for each cycle by the distance from the center of the landing to the pickup element furthest from the landing. If the speed (km/hr) exceeded the maximum speed of the skidsteer (13 km/hr), we assumed that it was an errant location and set the distance traveled to the maximum possible distance for the duration. Elements and cycle variables were observed from the video for both the skidsteer and excavator. The skidsteer operators had several years of experience with this system.

We leased a Caterpillar 312 excavator (bucket and thumb) to conduct a shoveling trial for 8 machine hours. The operator had excavator and forest machine experience, but had never shoveled. We placed a POV camera pointed at the attachment and installed a Multidat recorder with a Garmin 15 GPS receiver and antenna.

We developed production models for a skidsteer and shovel based system, and the model approach is summarized in Table 1. The skidsteer and shovel equations were developed from the current study. The remaining productivity estimates are regression equations from previous studies. The truck cycle time excluding loading and delays was 3.5 hours and approximated a 60 to 80 mile one-way haul. Most of the modeled systems performed felling in a previous operation and those costs were not included in the models. In fact, landowners are so motivated to remove redcedar from rangeland, that they may pay for the felling operations and leave the felled stems in place. On one of the shovel systems an excavator (shear) was included in the equipment mix to fell and windrow trees prior to shoveling since standard felling leaves the trees scattered or in small bunches. In hot systems the productivity of all phases were balanced. In cold systems the productivity of the chipper and the loader were balanced and the other phases were scaled (machine number) so the productivity was similar to the chipper. With cold systems it is important that phase productivity is similar to avoid eventual bottlenecks. We capped system productivity at 7 loads per day since it is unknown whether the tract volume, infrastructure (mill systems), or demand could support 10 to 15 load per day systems. We estimated productivity in two types of stands; a relatively dense stand with 140 trees per acre (32 tons/acre) and a relatively open stand with 75 trees per acre (13 tons/acre). The stand characteristics for the dense stand was developed from a 15 acre stand near Cushing, OK. The stand characteristics for the open stand was derived from stand data in Starks et al. (2011).

We used a machine rate analysis to compare costs (Miyata, 1980). While machine rate analysis is not adequate to predict contractor costs, it provides for comparison of potential systems. Assumptions for machine costing are presented in Table 2. Machine life, interest rates, insurance and taxes, lube rate, and salvage values were 6 years, 10%, 5%, 36.78% and 20%, respectively. For labor costs we assumed an annual wage of $55,000 for the owner/supervisor and $40,000 for the machine operators and a fringe benefit rate of 30%. There was one supervisor on each operation and the remainder (two to four) was machine operators. We assumed system fixed costs of $400 per day for hot systems and $600 per day of cold systems to account for the increased cost of moving the terrain chipper and managing more than one harvesting location. For all systems we assumed that there were 180 10-hour shifts per year.

Tree volume and energy content were based on our analysis of local stands (weight equations and energy content). Stands harvested and chipped while green had moisture content of 46% and field dried stands had a moisture content of 15%. Energy contents were estimated at 10.7 and 15.0 MMBTU per ton, respectively.

Results and Discussion

Regression equations for the skidsteer and shovel were determined by stepwise regression (p entry = 0.15) are presented in Table 3. While both models were significant ($p < 0.05$), the cycle time equation for the skidsteer (F=216, MSE=1978.0, R^2=0.76) had a better fit than the shovel (F=8.97, MSE=715.0, R^2=0.27). We used the GPS data to estimate the wander factor which was needed to use the skidsteer model for production estimates. For the average cycle the straight line distance from the landing to the load was 40% of the round trip distance.

Productivity, in tons/pmh (productive machine hour), was estimated for each task performed by each machine and is presented in Table 4. Variations in productivity were the result of stand density, tree size, and moisture content. For the chipper and the loading phases productivity was affected by stem moisture content since productivity was estimated on a dry basis. Felling, shoveling, and skidding productivities depended largely on travel time and tree spacing, so larger distances between trees or piles increased cycle times and lowered productivity.

Table 1. Model sources and assumptions used in the production models.

Component	Machine	Model source	Adaptation	Assumption
Felling	12-15 ton excavactor with shear attachment (25 ft. reach)	(Schweier et al., 2015) (#5)	Move time between stumps scaled to lower density using ratio of modeled stand to test stand	Felled trees bunched in windrow
Shovel	12-15 ton excavator with shear attachment (25 ft. reach)	Current study	Cycle productivity for pile-to-pile and field-to-pile for felled but not windrowed trees	With felling no trees are moved field to pile. All trees shoveled to linear landing in the middle of the tract
Skidsteer	80 hp compact terrain loader with grapple loader	Current study		Trees moved to central landing
Loader	Either excavator or skidsteer	90% of chipper production	-	Loaders used to augment shovel or skidsteer production in hot systems
Chipper	600 hp horizontal chipper with live feed deck	Data gathered from (Smidt and Mitchell, 2014)	Output in dry tons per pmh and adjusted for moisture content	Tracked in cold systems and wheeled in hot systems
Trucking	Regular chip van (100 yd^3)	Cycle time from travel, unload and delay time (4 hr/cycle), and loading time (from chipper).	Estimated loads green (25 t) and dry (16 t) using (Thompson and Klepac, 2012)	Trucking was limited to 7 loads per day

Table 2. Costing assumptions and sources for machine rate analysis.

Machine	Purchase Price ($)	HP	M&R rate (%)	Fuel use (g/hp*hr)	Source
Skidsteer	100,000	70	90	0.0357	(Caterpillar, 2009)
Excavator (shovel)	175,000	79	90	0.0220	(Caterpillar, 1996)
Excavator (felling)	200,000	79	90	0.0220	(Caterpillar, 1996)
Chipper	360,000	600	100	0.0517	(Brinker et al., 1989)
Chipper (terrain)	450,000	600	100	0.0517	(Brinker et al., 1989)

Table 3. Parameter estimates and models statistics for regression equations for skidsteer and shovel transport to the landing. Dependent variable is delay free cycle time in seconds. The mean values for the independent variables are listed.

Machine	Item	Parameters			
		B_0	B_1	B_2	B_3
Skidsteer	Description	Intercept	Travel distance (km)	Trees per cycle	
	Estimate	27.5	446	6.9	
	Mean value		0.209	3.6	
Shovel	Description		Large trees per cycle (> 20 cm)	All trees per cycle	Field trees per cycle
	Estimate	18.0	29.3	8.19	21.5
	Mean value		0.14	1.4	0.51

Table 4. Productivity of each machine by task for each stand (dense and open) and moisture content (green and field dried) in green tons per PMH.

Stand	Moisture Content	Excavator-felling	Excavator- shoveling	Skidsteer-skidding	Loading	Chipper
Dense	Green	24	10	13.2	34.8	38.7
	Dry	20.1	8.4	11.1	22.1	24.6
Open	Green	13.6	8.2	12.2	34.8	38.7
	Dry	10.8	6.4	9.7	22.1	24.6

Since landowners may pay for operations on a per-acre basis we estimated those costs (Table 5). In general, high costs are reflective of more volume per acre. The objective in including the Felling/Shovel operations was to determine if a system with felling might be justified by biomass value. While another analysis anticipated that felling would be paid for by the landowner (Ramli and Epplin, 2017), it seems unlikely that a viable industry could be based on negative stumpage rates. The systems with felling have among the lowest per acre costs and may provide an alternative to the skidsteer systems. Green material costs below \$35/ton and field dried costs below \$45/ton are likely to be feasible and result in \$/MMBTU costs that are near the current price for natural gas (EIA, 2017).

Stump to truck costs (\$/MMBTU) ranged from 1.60 to about 2.50 for the green and field dried harvests in dense stands (Figure 1). In open stands most of these costs were greater than \$2/MMBTU (Figure 2). Much of the difference was related to caps on system productivity, thus increasing the labor cost per unit. Labor costs were the largest component of most systems. We started with annual average labor costs that were just lower than the mean for construction and extraction occupations (SOC 47-0000) and logging equipment operators (SOC 45-4022), but higher hourly wage (\$22/hr for operators). System success will be dependent on finding labor for difficult outdoor work and competitiveness with other machine operator opportunities.

To compare with other biomass system costs we projected costs in \$/dry ton for all of the systems (Figure 3). The costs were similar to that projected by (Ramli and Epplin, 2017) at \$38.82/dry ton with the same material and a 3 skidsteer system. Several differences in assumptions and costs could produce this difference. The Billion Ton Report (USDOE, 2017) estimates the harvesting costs for forest biomass in the south between \$20 and \$30 per dry ton for clearcuts and \$30 to \$36 for thinnings. Published harvesting costs for competitive woody crops in the region like mesquite (Wang et al., 2014) were developed from production models for other species and were not compared. While western juniper harvesting operations might be similar to eastern redcedar, the harvest of solid wood products makes the comparison difficult (Dodson, 2010; Dodson et al., 2006).

Table 5. Delivered costs for each of the systems and both stand densities in \$/ton (green), \$/acre and \$/MMBTU (million BTU), based on a hauling distance of 80 miles.

		Cost		
Stand	System	\$/ton	\$/acre	\$/MMBTU
Dense	Cold/Green (fell-shovel)	30.80	1001	2.05
	Cold/Dry (fell-shovel)	45.54	1239	3.04
	Cold/Green (shovel)	38.71	1259	3.62
	Cold/Dry (shovel)	53.65	1460	3.58
	Hot/Green (Skidsteer)	29.92	973	2.80
	Hot/Dry (Skidsteer)	42.80	1165	2.85
	Cold/Green (Skidsteer)	29.37	955	2.75
	Cold/Dry (Skidsteer)	44.17	1202	2.95
Open	Cold/Green (fell-shovel)	33.96	450	2.26
	Cold/Dry (fell-shovel)	51.32	539	3.42
	Cold/Green (shovel)	35.09	465	3.28
	Cold/Dry (shovel)	53.08	557	3.54
	Hot/Green (Skidsteer)	32.91	436	3.08
	Hot/Dry (Skidsteer)	44.55	468	2.97
	Cold/Green (Skidsteer)	31.28	415	2.93
	Cold/Dry (Skidsteer)	49.82	523	3.32

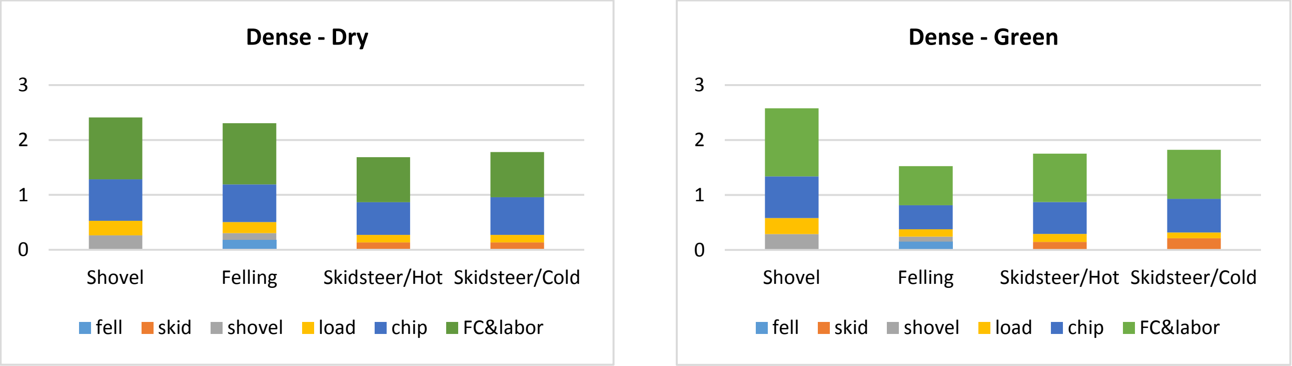

Figure 1: Cost (\$/MMBTU) of material (chipped and loaded) for the dense stand with field dried (dry) or green (harvests).

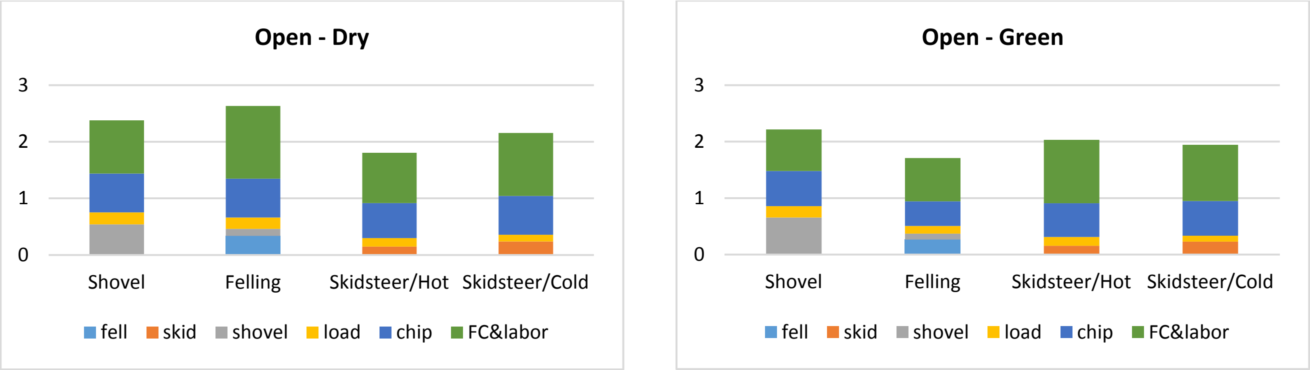

Figure 2: Cost ($/MMBTU) of material (chipped and loaded) for the open stand with field dried (dry) or green (harvests).

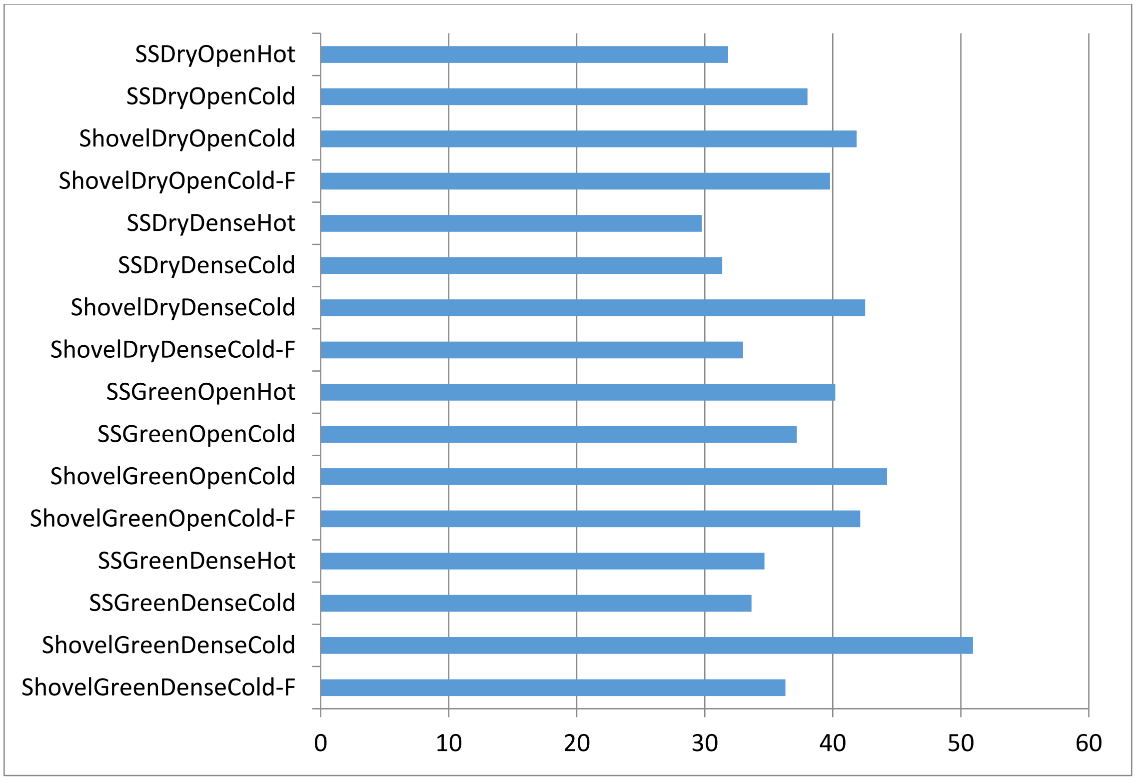

Figure 3: Cost ($/bone dry ton) of production for each harvesting system.

Conclusion

We developed speculative costs and productivity for eastern redcedar harvest systems across the likely range in stand density. While we developed harvesting systems without felling, we do not believe that a sustainable production system can be based on a negative stumpage rate (felling costs borne by landowner). Harvesters would be dependent on the supply of landowners willing to fell and store trees on site, the economics of rangeland, or the availability of cost share payments. Felling with skidsteer mounted shears would be about 12 green tons per PMH (50-60 trees per PMH) and increased piling activity would decrease productivity even more. Felling and transport systems would be efficient if the transport could take advantage of piled or bunched stems more typical with purpose built feller-bunchers. We coupled felling with shoveling, but it could be coupled with forwarding (Klepac and Rummer, 2012) or some other type of industrial truck (Stokes et al., 1992) for transport.

The difference in cost between green and field dried harvesting does not seem to justify the increased logistics challenges it presents unless mill specifications require field dried material. If systems required felling the systems would have to bear the risk and capital costs of carrying felled wood until it can be chipped and delivered.

We received anecdotal reports that chipping productivity would be lower and machine wear would be greater for redcedar that other eastern species. Those considerations are not used in the analysis. While smaller chippers are often justified in low production systems, they have significant drawbacks. In eastern redcedar a live feed deck (typically available on whole tree chippers) would be needed if loading was with a skidsteer since the large butt with horizontal lower branches make it difficult for the feed roller to grab the stem. Small chippers would also likely require jump butts on some trees to stay within chipper diameter specifications.

We did not make provision for harvesting solid wood products in these systems. In a felling system one potential method would be to shear the tree at log height and harvest logs in a second stage. The objective would be to prevent butt shatter and avoid the expense of purpose built sawhead feller buncher while harvesting most of the biomass.

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