Harvesting Short Rotation Woody Crops with a Shear

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Abstract
A time and motion study was performed on a skid steer equipped with a 14-inch tree shear attachment. The machine was used to install initial coppice harvesting treatments on three stands across the south. The study included one willow and two cottonwood sites. The stands averaged from 2 to 4 years old. Approximately 200 trees were shear harvested from each of the stands. This paper examines the operational characteristics for the felling operation.

Keywords: harvesting, felling, coppice management, SRWC

Introduction
Woody biomass is a renewable form of energy with multiple industrial uses. These could be applied as feedstock for pulp, paper industry, but also planted to feed the energy and biofuels industries. Wood biomass energy has some advantages over fossil energy, the most important is that woody biomass is a renewable resource.

Coppice management is a common method used for short rotation woody crop silviculture. Under a coppice management system, stems re-sprout from the stumps, and are harvested on a planned schedule, such as every 2 or 3 years. After several such rotations, a final harvest is planned followed by site preparation and replanting. Management costs are reduced as compared to single-stem management because site preparation and planting doesn't occur between rotations, only after the final harvest. Environmental impacts associated with site preparation, such as tilling and removing stumps, are less frequent with coppice management systems than they are with single-stem management.

Initial felling is required to move a stand from single stem management to coppice management. Once young stems are cut, multiple stems emerge from each stump. Given the short time between rotations, multiple stems per stump should result in a higher volume per acre as compared to single stem management.

With the growing demand for woody biomass, a high production with low cost method will be essential for producing a cost effective product. Traditionally, initial coppice felling is accomplished with manual labor and saws or machetes. Alternatives to manual felling are desired. This is primarily driven by safety regulations regarding manual labor and a declining

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workforce. Traditional logging equipment is generally unsuitable for this work task because of the size and weight of the equipment, the low production rates associated with harvesting tiny stems, and the high cost of traditional equipment.

For this study, a small machine with a tree shear attachment is tested for installing initial coppice harvests on short rotation woody crops. This combination of a smaller, less expensive machine with an attachment has the versatility to be used with other attachments for other uses when not harvesting short rotation woody crops. This paper provides a time-and-motion study using a small machine to perform initial coppice felling of short rotation woody crops.

Methods

Study Sites

The study was installed in March, 2014. The study sites are located in two different places, one is in Stoneville, Mississippi in the Mississippi River Delta and the other site is near Scott, Arkansas close to the Arkansas River. The Arkansas site was very wet, which is typical of harvesting short rotation woody crops during the dormant winter seasons found in the southern United States. Two stands were located on the Mississippi site; Stand 1 was planted with Cottonwood (Populus spp.), and had been in the ground for four growing seasons (4 years old). Stand 2 was planted with Willow (Salix spp.) and was also 4 years old. Both Stands 1 and 2 were planted in single rows on a 5 feet x5 feet spacing. The Arkansas site contained just one stand (Stand 3) of Cottonwood that was 4 years old. This stand was planted in dual rows with 2.5 feet between the dual trees. Spacing between the rows was 6 feet and spacing within a row was 2 feet between each set of dual trees. The cruise summary is included in Table 1.

Table 1. Stand Descriptions

Site	Stand	No. of Plots (n)	Species	Avg. DBH* (inches)	DBH Range (inches)	Avg. Height (feet)	Height Range (feet)
Mississippi	1	11	Cottonwood	3.0	0.6-6.2	23	9-33
Mississippi	2	7	Willow	1.5	0.4-3.0	19	7-33
Arkansas	3	3	Cottonwood	1.4	0.5-2.6	29	15-40

*Diameter at breast height (DBH)

All stands were located on flat terrain, but the numbers of treatment trees available per site were not equal. Stand 1 contained a high level of mortality and a few trees had previously been removed for research purposes, leaving just 47% of the 180 stems available for this study. Of the 140 stems that should have been available in Stand 2, only 74% were actually on the site for the shear treatment. Stand 3 had the lowest amount of mortality and testing, resulting in approximately 91% of the 206 stems available for treatment.

Operation

This study utilized a Fecon 14 inch Shear Head attached to a Caterpillar Skid Steer 279D and a 289C. Different prime movers were used on the two sites because the same equipment model was not available in both locations. The same shear head attachment was used on all sites. These machines have rubber tracks, and a ground pressure (with shear attached) of 4.86 lbs/in^2.

The shear head was selected for this study because it has an accumulation pocket and should also have lower maintenance costs as compared to a saw head. In addition, the shear should cause less impact on the root system because it slices through the trees rather than using a pushing or sawing mechanism.

The operational felling characteristics were different when felling single versus dual rows. The single rows were harvested by cutting each tree, accumulating stems, and placing accumulations into bunches. The dual row was harvested by essentially zigzagging between the dual rows. The first tree on the left would be cut, then the machine would back up and move to the first tree on the right. Next, the machine moved to the second tree on the right, then back to the second tree on the left. Using a small machine was crucial for harvesting the dual rows in this cutting pattern because the small machine was easily maneuvered. Accumulating and bunching was the same between all stands. The same operator was used on all study stands.

Data Collection

A digital video recorder was used to gather data for the time-and-motion study. Video data were collected for the entire mechanical felling operation on all three stands. The data were analyzed using TimerPro software (Applied Computer Services, Inc. 2014. TimerPro Professional, Version 10. Englewood, CO).

Results and Discussion

A cycle was identified as the time it takes to cut, accumulate one or more trees, and dump them, essentially dump to dump. Cycle elements were identified and analyzed. The elements identified were:

Table 2. Cycle Element Descriptions

Cycle Element	Description
Move to first tree	This element began when the machine tracks begin to move to a plot, or when the tracks move after dumping. This element ends when the tracks stop at the first tree.
Fell/Accumulate	This element begins when the tracks stop and the shear head positioning begins and ends when the tracks begin to move.
Move between trees	This element begins when the tracks begin to move and ends when the tracks stop at the next tree. Several occurrences of this element may occur within a single cycle.
Move to dump	This element begins when the tracks start to move after cutting the last tree in an accumulation and ends when the tracks stop moving.
Dump	This element begins when the tracks stop and ends when the tracks begin to move away from the bunching site.
Delay	This element is used to account for delays that occur in association with the operation. This element does not include administrative delays caused by study implementation.

The elemental cycle analysis is displayed in Figures 1, 2 and 3. The move between trees element on Stand 3 was much larger than that same element in the other two stands. This can be explained by the dual row planting. The zigzag pattern that was used in harvesting the dual rows requires more moving than the single row straight pattern used in Stands 1 and 2.

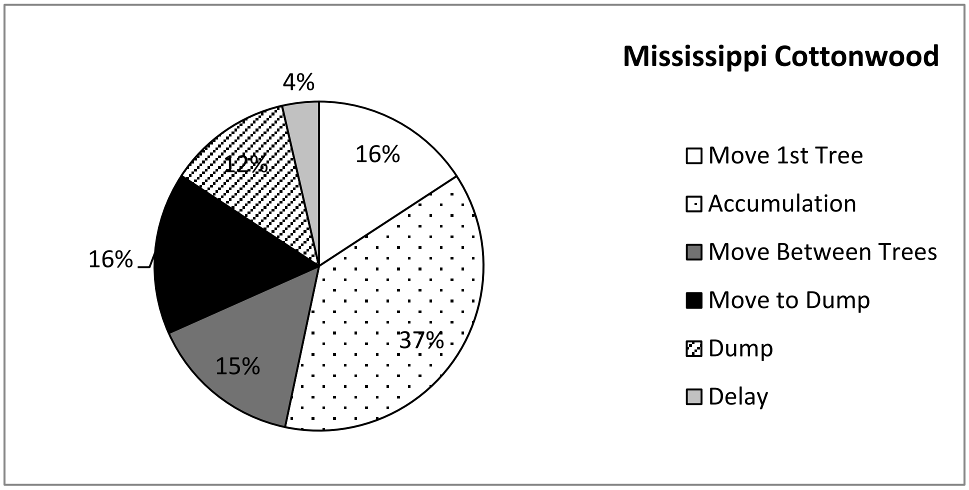

Figure 1. Elemental Cycle Time (%) for Stand 1

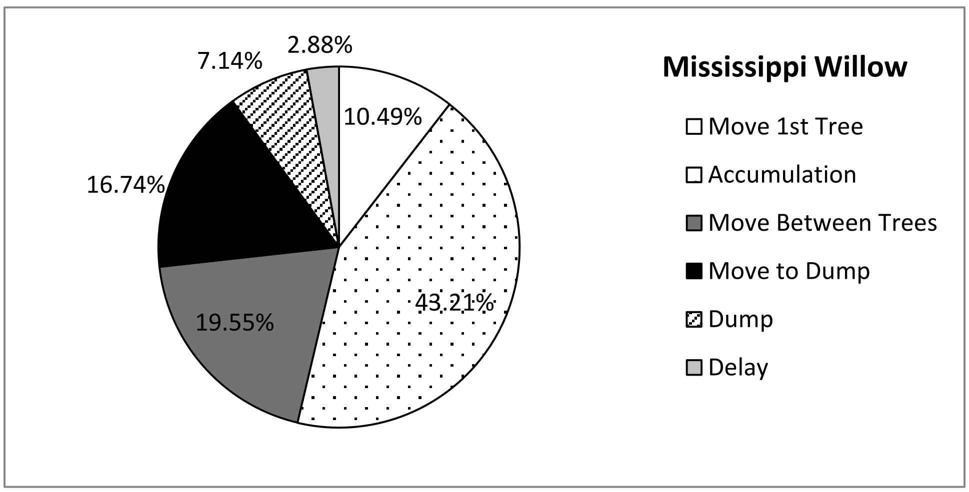

Figure 2. Elemental Cycle Time (%) for Stand 2

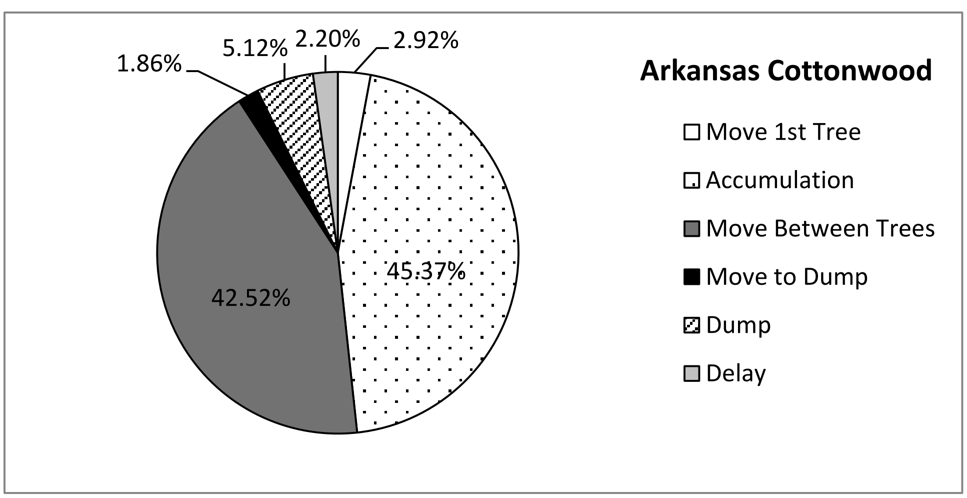

Figure 3. Elemental Cycle Time (%) for Stand 3

The move to dump element took more time in Stands 1 and 2 than in Stand 3. In Stands 1 and 2, the skid steer travelled to a nearby dumping location rather than dumping next to the rows as was done in Stand 3. This dumping location also explains why the move to first tree cycle element was longer on Stands 1 and 2 as compared to Stand 3.

The total time spent performing the felling operations in the three stands was similar. Felling took 56.48 minutes in Stand 1. In Stand 2, felling took 64.28 minutes. Stand 3 was felled in 65.09 minutes. Due to mortality, prior research removals, and a machine trial in Stand 3, the number of trees felled per stand varied. Stand 1 contained 84 trees, Stand 2 contained 104 trees, and Stand 3 contained 188 trees.

An Analysis of Variance (ANOVA) was used to determine if there was a significant difference between the stands in the time it took to cut a tree (Table 3) using total time / number of trees for the average time it took to cut a tree. Using SAS (SAS. 2013. SAS Version 9.4. Cary, NC), a significant difference (α=0.05) was found and additional analyses were performed. A Duncan's Test found that the two Mississippi plots were similar in the total time it took to fell a tree. The average time for felling a tree in Stand 1 was 0.67 minutes and Stand 2 was 0.62 minutes. In contrast, the time to fell a tree in the Arkansas stand (Stand 3) was different. The average time to fell a tree in Stand 3 was 0.35 minutes.

Table 3. Analysis of Variance between the Treated Stands

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr>F**
Model	2	0.28213900	0.14106950	15.28	0.0001
Error	18	1.16615785	0.00923099		
Corrected Total	20	0.44829685			

The time to fell a tree in Stand 3 is nearly half (52 – 56%) that of the time it took to fell trees in Stands 1 and 2. However, the operational characteristics help explain this difference. As stated earlier, the move to dump and move to first tree cycle elements in Stands 1 and 2 accounted for much more of the total cycle time as compared to Stand 3. In Stands 1 and 2, these cycle elements accounted for 27-32% of the cycle time. In Stand 3, the move to dump and move to first tree cycle elements only accounted for 4.8% of the total cycle time. Even when the move to dump and move to first tree elements in Stands 1 and 2 are adjusted to match those observed in Stand 3, the average time per tree is still faster in Stand 3 as compared to Stands 1 and 2.

Single row Stand 2 and dual row Stand 3 contained similar sized trees, but still differed in the time to cut a tree. The willows in Stand 2 had many branches that extended nearly to ground level. These branches impacted the move between trees element because the equipment operator was much more cautious in moving to the bole of a tree in order to avoid branches that could poke into the open cab. In addition, the numbers of trees per accumulation in these two stands also differed. In Stand 3, the average number of trees per accumulation was 23 (range 14 – 37). In Stand 2, the average number of trees per accumulation was 7 trees (range 4 – 12). The larger accumulations in Stand 3 contributed to faster felling cycle time per tree because fewer move to dump and move to first tree elements were needed. This, combined with the branch effect further explains the felling time variability between Stands 2 and 3.

Conclusion

We performed a time-and-motion study in three different stands. Stand 3 was planted in dual rows and Stands 1 and 2 were planted in single rows. The time to cut a tree was significantly faster in the dual row stand (0.35 minutes/tree), however this was confounded by both operational and stand characteristics. Operationally, two cycle elements were impacted by the distant dumping location on Stands 1 and 2. Even after adjusting for these operational differences, the time per tree was still lowest in the dual row stand (Stand 3). Stand characteristics, such as willow branches, also negatively impacted the cycle time for trees in Stand 2. The stand with the largest trees, Stand 1, required the most time to cut a tree.