FIELD TRIALS OF A CANADIAN BIOMASS FELLER BUNCHER

Douglas J. Frederick, Bryce J. Stokes, and Dennis T. Curtin

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Abstract — A prototype, continuous felling and bunching machine was evaluated in harvesting a three-year-old sycamore short-rotation energy plantation in Alabama. Prediction equations, production rates, and costs were developed for the harvester.

Production of the feller buncher was approximately 850 stems per hour (17.3 green tonnes). Estimated total cost of the machine was $51.21 per hour. Felling cost for the test was 52.95 per green tonne.

INTRODUCTION

Major constraints to implementing operational, short-rotation hardwood energy plantations are development of efficient harvesting systems. There have been numerous studies on harvesting systems for hardwood plantations but none have been thoroughly tested on an operational scale. During 1984, in a plantation adjacent to the current study, mechanical and mechanical systems with conventional equipment were evaluated for harvesting sycamore plantations (Frederick et al., 1984). The major outcome was that the mechanical system which included a tractor mounted shear was more economical and efficient than a backpack circular saw system, but that the harvesting machine size be closely matched with tree size. This is especially true for the felling function, which is greatly affected by tree size. With small trees less than 15 cm dbh, high production is necessary for economical felling. Bunching is essential for efficient production in the subsequent skidding or forwarding functions.

In February, 1985, a specialized, high-speed feller buncher was evaluated. The Hyd-Mach prototype is a continuous felling and bunching machine designed for high productivity in small diameter stands. This paper reports the field evaluation of the feller buncher in a 2 hectare sycamore Platanus occidentalis plantation and its potential use in short-rotation biomass harvesting. This work is part of a larger study funded by the U.S. Department of Energy which includes all aspects of short-rotation silviculture and management in the southeastern United States.

STAND DESCRIPTION

An 8.1 ha sycamore plantation owned by Scott Paper Company in southern Alabama was used for the study. The former agriculture site was operationally planted with 1-0 sycamore seedling at a 1.5 x 3 m spacing in January 1982. The plantation was divided into four 2.0 ha blocks with initial plans of harvesting one block each year beginning in 1984. Results of harvesting 2-year-old trees during 1984 have been reported (Frederick et al., 1984). This paper reports harvesting results for the second 2 ha block which was 3 years old.

MACHINE DESCRIPTION

The felling unit was a prototype continuous feller buncher (Figure 1) manufactured by Hyd-Mach Engineering, Ltd., of Woodstock, Ontario. Development was funded by the National Research Council of Canada to harvest short-rotation bioenergy plantations of hybrid poplar. The machine was developed to harvest trees with diameters up to 20 cm at continuous speeds of 2.4 km/hr.

The felling head was mounted on an articulated, four-wheel drive tractor with dual tires on each axle. The carrier, manufactured by Versatile Farm Equipment Company of Winnipeg, Canada was equipped with a 60-hp turbo charged diesel engine.

Two horizontal, 61 cm saws, counter-rotating at 2,000 rpm, constituted the prototype felling head (Figure 2). There were two stem accumulators, one on each side of the head. Cut trees


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3/ The use of mention of trade names is for the convenience of the reader. It is not an endorsement by North Carolina State University, USDA Forest Service. or Tennessee Valley Authority.
Figure 1. Hyd-Mech feller buncher head mounted on versatile tractor.

Figure 2. Hyd-Mech feller buncher head.

were forced with hydraulic arms through holding gates into either accumulator (Figure 3). Choice of the accumulator was controlled by the operator using a switching gate and hydraulic arms. When an accumulator was full, it was rotated to dump the bunched trees parallel to the direction of travel, alongside the feller buncher (Figure 4). The two accumulators allowed unloading to either side, away from the stand for clearance on the next pass. All accumulating and dumping func-

Figure 3. Hyd-Mech Feller Buncher with accumulation head full and ready to dump.

Figure 4. Hyd-Mech feller buncher cutting a row, accumulating and dropping bunched trees.

Operation of the felling head was controlled by an on-board computer system. An OMRON SYSMAC S6 programmable controller operated the arms that pushed trees from the cutting area into the accumulating area and the arms that held them upright. Sensors located in the cutting opening
and on the accumulators initiated operating cycles of the accumulating devices. The operator was relatively free to drive the machine at a continuous speed. The dumping sequence of the accumulated stems was operated by the controller after the operator initiated the sequence.

PROCEDURES

Three felling plots, consisting of three adjacent rows, were selected and every tree was tagged and numbered. Each tree was measured at breast height and sample trees were measured at stump level. Distance of each tree from an end reference point was measured. The cutting of each test row was video taped and the tree number was audibly recorded.

Owing the cutting test, the operator cut a row, turned around, cut the next row and then the third row. Turn-around times were recorded along with delays. Bunches were laid to the side away from the next row to cut in order to have sufficient space to clear bunches at the end. This procedure resulted in every other row having bunches laying in opposite directions. The remaining rows were cut in a progressive row method so that the bunches in the first cut in the middle row of the stand had to be skidded before the adjacent row could be felled. This method resulted in nine adjacent rows each oriented in opposite directions.

The video of the rows being cut was used to obtain time study data. The video tapes were replayed with the cycle time, stem numbers, delays and around times recorded. These data were transferred to computer files for later analyses.

A machine rate analysis was completed for the feller and for maintenance and repair costs, and utilization efficiency.

After skidding, dill trees from the 2 ha block were chipped and blown into vdns. The biomass harvested from the site was weighed and by weighing the vans loaded with green chips. After felling, stumps were evaluated for cambial tissue and intensity, and stability. Cambial tissue was examined for percent of the circumference of the stump that was loosened or removed. A clear was used to classify tissue damage to the nearest five percent of the circumference. Splitting was classified into quadrants of the stump and summed for total splitting. Stumps were checked to see if they were movable or not dislodged.

RESULTS

During the study, the feller encountered some operating problems frequently associated with the machines. Some minor breakdowns with hydraulic components, the machine hydraulic oil overheated, sensor switches broke or failed, leaves and vines accumulated in the cutting head, and the machine did not always work properly. Future problems with the components, sensor switches and leaf-up of leaves can be reduced by some minor engineering changes.

A summary of the production information is shown in Table 1. A complete cycle was defined from dump to dump. The average cycle time was 0.298 minutes with an average of 5.1 stems cut per cycle. The maximum number of stems cut during a cycle was ten. Average production based on a productive cycle (not including delays and turn arounds) was 1057 trees per hour. Production cutting speed averaged 1.74 km/hr. The distance traveled during a cycle (distance bunches) was approximately 8.8 a. For the study, the average spacing between the trees was 1.8 m and the average tree dbh was 13.4 cm. Total average green weight per tree was 20.4 kg. The production rate for the study was 21.6 green tonnes per productive hour.

<table>
<thead>
<tr>
<th>Item</th>
<th>No. of Std.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observ.</td>
<td>Mean</td>
</tr>
<tr>
<td>Productive min. per cycle</td>
<td>56</td>
</tr>
<tr>
<td>Trees per cycle</td>
<td>56</td>
</tr>
<tr>
<td>Trees per productive hr.</td>
<td>56</td>
</tr>
<tr>
<td>Distance per cycle (m)</td>
<td>56</td>
</tr>
<tr>
<td>Production cutting speed</td>
<td>56</td>
</tr>
<tr>
<td>Delay row</td>
<td>5</td>
</tr>
<tr>
<td>Turn-around (min)</td>
<td>4</td>
</tr>
<tr>
<td>Tree spacing (an)</td>
<td>559</td>
</tr>
<tr>
<td>DBH (cm)</td>
<td>568</td>
</tr>
<tr>
<td>Stump diameter (cm)</td>
<td>203</td>
</tr>
<tr>
<td>Green weight per tree (kg)</td>
<td>566</td>
</tr>
</tbody>
</table>

For four rows in video study. Does not include turn around or delays; based on only those trees hung during cutting or row delays; indicates mechanical delays such as hydraulic switch pins, and cleaning need.

A complete time summary which incorporates delays and row turn around at the end of the cycle is shown in Table 2. The machine was productive (cutting trees) 82.8 percent of the available time (not
including mechanical delays and trash removal from the head). Delays for lodged trees accounted for 8.4 percent of the operating time. Turning around at the end of the row was 8.8 percent of the operating time (0.4 minutes/row). Operating Production was 850 stems per hour with a resulting 17.3 green tonnes per operating hour.

Table 2. Time summary for the Hyd-Mech prototype

<table>
<thead>
<tr>
<th>Item</th>
<th>Minutes</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productive time</td>
<td>17.13</td>
<td>82.8</td>
</tr>
<tr>
<td>Delays</td>
<td>1.734</td>
<td>10.4</td>
</tr>
<tr>
<td>Turn-around</td>
<td>1.820</td>
<td>8.8</td>
</tr>
<tr>
<td>Total operating time</td>
<td>20.694</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Total stems = 293
Trees/Operating Hour = 849.9

Regression techniques were used to analyze the total cycle time. Variables tested in the model were trees per cycle, average spacing between trees in the cycle, and total distance traveled. Average tree dbh per cycle was not tested because of the limited range of the average diameters in the cycles.

Distance traveled during the cycle and average spacing were highly correlated. Distance was also correlated with the number of trees in a cycle. The inverse of spacing proved significant in the model. As the within row spacing increased, cycle time decreased due to the time required to cycle the accumulating arms after severing the tree. At close spacings, this required the operator to stop the machine to allow time for the arms to recycle. The higher cycle times occurred at the 1.4 - 1.5 m between tree spacings. Unfortunately, the range of multiple observations of different spacings between trees was very restricted with the average spacing being 1.8 m. The close spacings between trees took less time compared to the wider spacings, which were only slightly wider because average spacing for the cycle was a major variable. Once past the spacing in the row, the machine could be recycled without stopping forward travel. Wider spacing had a dramatic decreasing effect on production. However, the data range was insufficient to show this effect so the effect of spacing was not included in the model.

During the trees per cycle analysis there were insufficient observations associated with the lower and higher limits of the number of trees per cycle, thus data were restricted to observations within a range of three to eight trees per cycle. The final model was a linear function of trees per cycle. The final equation predicted time per cycle (excluding turn around time):

\[
\text{Time/cycle} = 0.0787 + 0.0427 \times \text{trees} \\
(R^2 = 0.34, \text{Root MSE} = 0.063)
\]

where:

- Time/cycle - minutes of productive time
- Trees - stems per cycle

An increase in trees per cycle greatly improves production (Table 3). Using the developed cycle equation, production was 1027 tonnes per hour when five trees per cycle which was the average for the study. An increase of three trees per cycle would improve productivity by approximately 11 percent. Actual production would be less than that in Table 3 because the prediction does not include turn around time. However, in actual application in long rows (over 240 m), turn around time is almost negligible.

Table 3. Estimated production for the Hyd-Mech prototype using the total cycle time equation

<table>
<thead>
<tr>
<th>Trees (per cycle)</th>
<th>Minutes</th>
<th>Trees (PMH)</th>
<th>Green tonnes (per tree)</th>
<th>Dollars per 4 rows</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.207</td>
<td>870</td>
<td>17.8</td>
<td>2.2</td>
</tr>
<tr>
<td>5</td>
<td>0.260</td>
<td>962</td>
<td>19.6</td>
<td>2.45</td>
</tr>
<tr>
<td>6</td>
<td>0.322</td>
<td>1015</td>
<td>21.8</td>
<td>2.8</td>
</tr>
<tr>
<td>7</td>
<td>0.383</td>
<td>1073</td>
<td>23.3</td>
<td>3.14</td>
</tr>
<tr>
<td>8</td>
<td>0.445</td>
<td>1135</td>
<td>24.9</td>
<td>3.64</td>
</tr>
</tbody>
</table>

\[1/\text{Does not include turn around time at end or between rows.}\]
\[2/\text{Based on average tree weight of 20.41 kg.}\]

The effect of tree diameter on production is shown in Figure 5. As expected more trees per cycle in all size classes gave the highest production.

Cost Analysis

The Hyd-Mech feller buncher was estimated to cost 551.21 per productive hour (PMH) (Table 1),
Estimated production of Sycamore cutting was evaluated. The long-term data determine the damage sustained by the bunches can result in a cycle, from three CO
and 3.5 tonnes of rejects separated. Four percent had splitting in one stump. From the day of felling to the time of chipping, 15.5 trees had lost 25 percent of their weight by drying. Using this percentage, the total green weight at the time of harvesting was 83.5 tonnes or 41.8 green tonnes per hectare.

Stump Damage

Stump damage resulting from the felling is shown in Table 5. In Block 2, the Hyd-Mech was experiencing hydraulic problems. These problems caused speed loss of the saws during felling. The reduced speed caused poor cutting and resulted in some stumps being ripped, exposing the cambial tissue. The hydraulic problem was intermittent and therefore the damage resulting from the saw stall could not be separated during the stump damage evaluation. The long-term effect of the damage to the coppice production can only be evaluated at a later date after the stand regenerates. From the survey of the damage, the Hyd-Mech appears to do little damage when operating properly.

Table 5. Stump damage summary for felling with the Hyd-Mech prototype.

<table>
<thead>
<tr>
<th>Block</th>
<th>Stumps</th>
<th>Stumps Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sampled</td>
<td>Damage</td>
</tr>
<tr>
<td>I</td>
<td>133</td>
<td>91</td>
</tr>
<tr>
<td>II</td>
<td>217</td>
<td>24</td>
</tr>
</tbody>
</table>

1/ Hydraulic problems caused speed loss in saw which resulted in higher damage. More typical damage from the Hyd-Mech is exemplified in Block 1.
2/ Almost 92% stumps had splitting in only one quadrant of surface area. The other 8% of the stumps had splitting in two quadrants of surface area.
3/ Stump was movable but not dislodged.

An assumption was made that the felling function was independent and operated at full utilization. Using the average production from the study (850 trees per PMH), the average cost for felling in the sycamore plantation was $2.95 per green tonne. Production estimates with the developed equation were used to determine cost at different levels of production (Table 3). An increase of five trees per cycle, from three to eight trees per cycle, would decrease cost by 24 percent.

Biomass Summary

For the 2 ha tract, there were 67.0 tonnes of total biomass harvested for energy wood and 3.5 tonnes of rejects separated by the chipper. From the day of felling to the time of chipping, 15.5 trees had lost 25 percent of their weight by drying. Using this percentage, the total green weight at the time of harvesting was 83.5 tonnes or 41.8 green tonnes per hectare.

CONCLUSIONS

The Hyd-Mech feller buncher has considerable potential for harvesting short-rotation biomass plantations. Production is greatly improved over alternative conventional felling methods. Using the machine to develop large bunches can improve the efficiency of the felling and the subsequent skidding function.
Production averaged 850 trees per productive hour. Cost per green tonne for felling the sycamore plantation during the trial was 52.95. The plantation is very productive and in the future by matching machine and stem size, even more favorable cost and efficiency can be expected.

ACKNOWLEDGEMENTS

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LITERATURE CITED
