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FIELD TRIALS OF A CANADIAN BIOMASS FELLER BUNCHER[1/]

Douglas J. Frederick, Bryce J. Stokes, and Dennis T. Curtin[2/]

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 $2.95 per green tonne.

INTRODUCTION

Major constraints to implementing operational, short-rotation hardwood energy plantations are development of efficient and economical 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, semi-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 must 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-Mech[3/] 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 (ha) sycamore *Platanus occidentalis* plantation and its potential for 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 research 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-Mech 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 duel 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.

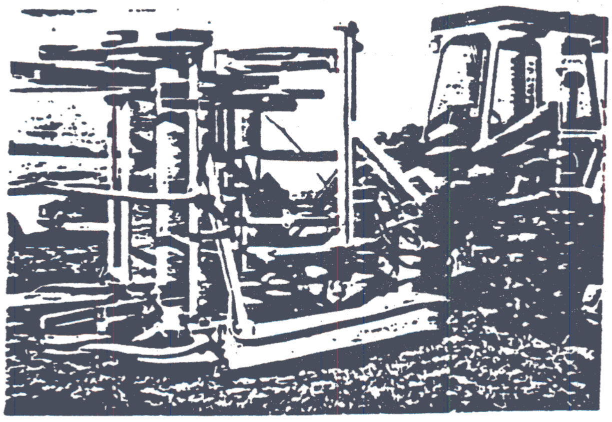

Figure 1. Hyd-Mech feller buncher head mounted on versatile tractor.

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 functions continued without interrupting forward travel.

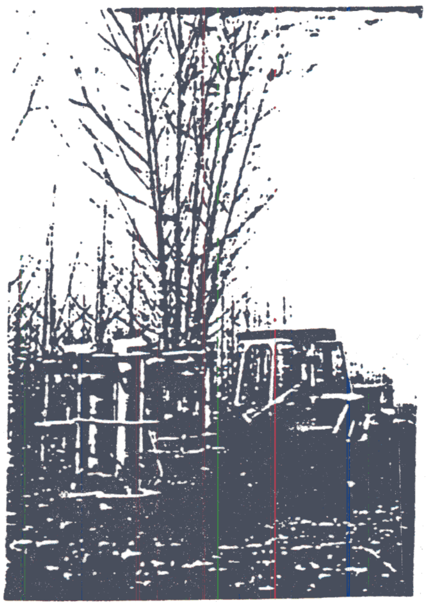

Figure 3. Hyd-Mech Feller Buncher with accumulation head full and ready to dump.

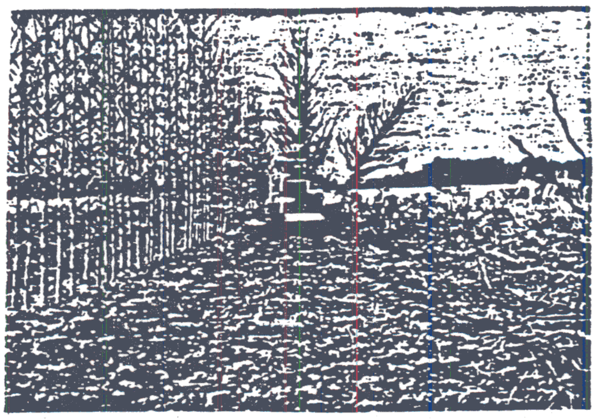

Figure 4. Hyd-Mech feller buncher cutting a row, accumulating and dropping bunched trees.

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.

During 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 the bunches during the next pass. This procedure resulted in every other row having bunches laying in opposite directions. The remaining rows were cut a progressive row method which required that the bunches in the first row cut in the middle of the stand had to be skidded before the adjacent row could be felled. This method resulted in nine adjacent rows each having bunches 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 turn around times recorded. These data were transferred to computer files for later analyses.

A machine rate analysis was completed for the Hyd-Mech feller buncher and estimates made for maintenance and repair costs, machine life and utilization efficiency.

After skidding, all trees from the 2 ha block were chipped and blown into vans. The biomass harvested from the site was calculated by weighing the vans loaded with green chips. After felling, stumps were evaluated for damage using methods modified from Gibson and Pope, (1985). Every tenth stump was sampled and inspected for three types of damage: cambial tissue, deformation, and stability. Cambial tissue was examined for percent of the circumference of the stump that was loosened or removed. A clear template 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 dislodged.

RESULTS

During the study, the Hyd-Mech feller buncher encountered some operating problems frequently associated with prototype machines. Besides the 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 computer components did not always work properly. The overheating problem was corrected by the addition of an oil cooler. Future problems with the computer components, sensor switches and build-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 kms/hr. The distance traveled during a cycle (distance between bunches) was approximately 8.8 m. For the study, the average spacing between the trees was 1.8 m and the average tree dbh was 6.4 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 1. Production summary for the Hyd-Mech prototype.1/

Item	No. of Observ.	Mean	Std. Dev.
Productive min. per cycle	56	0.298	0.095
Trees per cycle	56	5.1	1.5
Trees per productive hr.2/	56	1056.7	194.0
Distance per cycle (m)	56	8.8	2.26
Prod. cutting speed (km/hr)	56	1.74	5.05
Delays3/	6	0.289	0.173
Turn-around (min)	4	0.455	0.122
Tree spacing (cm)	559	1.79	1.15
DBH (cm)	568	6.30	1.60
Stump diameter (cm)	203	9.42	2.53
Green weight per tree (kg)	568	20.41	13.06

1/Summary for four rows in video study.
2/Does not include turn around time at end of row or delays; based on cycles.
3/Delays are only those where trees hung during cutting or dumping. Delays not included were mechanical delays such as hydraulic problems, broken switch pins, and cleaning head.

A complete time summary which incorporates the delays in production delays and the time to turn around at the end of the rows 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 rows was 8.8 percent of the operating time (0.4 minutes/row). Operating production was 850 trees per hour with a resulting 17.3 green tonnes per operating hour.

Table 2. Time summary for the Hyd-Mech prototype[1/]

Item	Minutes	Percent
Productive time	17.13	82.8
Delays[2/]	1.734	8.4
Turn-around	1.820	8.8
Total operating time	20.684	100.0

Total stems = 293

Trees/Operating Hour[3/] = 849.9

1/ Summary for four rows in video study.
2/ Same as footnote number 3 of Table 1.
3/ Does not include time to clean out head or other mechanical delays.

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 between trees 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 or slow 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 the variable. Once past the spacing in which the arms could be recycled without slowing 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 from dump-to-dump
Trees = stems per cycle

An increase in trees per cycle greatly improves production (Table 3). Using the developed total cycle equation, production was 1027 trees per hour when cutting 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 applicaton 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.[1/]

Trees	Minutes	Trees	Green tonnes[2/]	Dollars per Green tonne[3/]
-(per cycle)--		-----(per PMH)-----		
3	0.207	870	17.8	2.88
4	0.250	962	19.6	2.61
5	0.292	1027	21.0	2.45
6	0.335	1075	22.0	2.34
7	0.378	1112	22.7	2.26
8	0.420	1142	23.3	2.19

1/ Does not include turn around time at end or rows.
2/ Based on average tree weight of 20.41 kg.
3/ Explained in section on cost analyses.

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 $51.21 per productive hour (PMH) (Table 4).

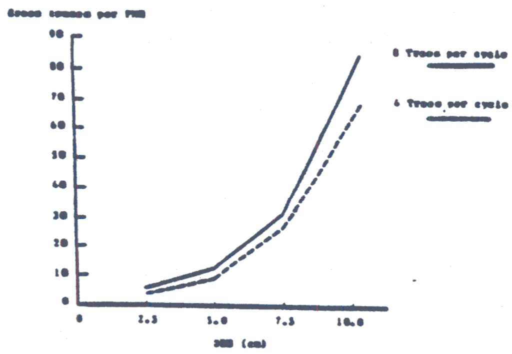

Figure 5. Estimated production of Hyd-Mech feller buncher as a function of tree diameter and trees per cycle.

Table 4. Value and costs for the prototype felling head and carrier.

Component	Purchase Price	Life	Salvage Value	Utilization
	($)	(yrs)	($)	
Felling Head	25,000	4	4,000	70
Carrier	40,000	8	4,000	80
Total	65,000			

	Fixed Cost ($/SMH)	Variable Cost ($/PMH)
Felling Head	10.54	11.20
Carrier	5.04	3.08
Total	15.58	14.28

	Labor Cost ($/SMH)	Total Cost ($/PMH)
Felling Head		31.06
Carrier		10.15
Total	10.00	51.21

Fixed costs and labor costs were calculated per scheduled hour (SMH).

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 green 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 16 days later, sampled trees had lost 15.5 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 bark being ripped, exposing the cambial tissue. The hydraulic problem was intermittent and therefore the damage resulting

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

Block	Stumps Sampled	Cambial Tissue: Stumps Damage	Cambial Tissue: Average Damage
I	133	9	12.2%
II	217	49 [1/]	13.3%

Block	Splitting: Stumps Damage	Splitting: Average Damage	Stability: Stumps Damage	Stability: Average Damage
I	5	25%	0	0
II	24	25% [2/]	1	1 [3/]

1/ Hydraulic problems caused speed loss in saw which resulted in higher damage. More typical damage from the Hyd-Mech is exemplified in Block I.

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.

from the saw stalling 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.

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 is this sycamore plantation during the test was $2.95. 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

Frederick, D. J., R. R. Resovsky and J. L. Orrell. 1984. Yields, efficiency and resources of harvesting two-year-old close-spaced sycamore in Alabama. Proc. Short Rotation Woody Crops Program Contractors Meeting. Michigan State University, EAst Lansing, MI. August. 10p.

Gibson, H. G. and P. E. Pope. 1984. Harvesting biomass plantations -- equipment design and impact on productivity. In: Saucier, J. R., ed. Proceedings of the 1984 Southern Forest Biomass Workshop. Sixth Annual Meeting of the Southern Forest Biomass Working Group; 1984 June 5-7; Athens, GA. Asheville, NC: U.S. Dept. of Agriculture, Forest Service, Southeastern Forest Exp. Station; 1985:101-109.