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Field Trials of a Short-rotation Biomass Feller Buncher and Selected Harvesting Systems

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ABSTRACT

A continuous-speed felling and bunching prototype machine was evaluated in harvesting a three-year-old, short-rotation sycamore plantation. A small tractor, grapple skidder, and large chipper were evaluated along with the prototype machine as complete harvesting systems. Prediction equations, production rates, and costs were developed for each component of the systems. Production of the feller buncher was about 850 stems an hour (17·3 green Mg), and felling cost for the test was \$3·29 green Mg^{-1}*. Total system cost was about \$11·50 green* Mg^{-1}*. However, cost could be reduced with a smaller chipper. A survey of stump damage showed little damage from the feller buncher when it was operating properly. The tractor caused minimal skidding damage, less than that of the large skidder.*

Key words: Biomass, yield, production, harvesting.

INTRODUCTION

Sycamore (*Platanus occidentalis* L.) has high promise as a short-rotation fiber and energy species on better quality sites in the Southeastern United States.[1–3] Favorable attributes include rapid early growth, prolific sprouting, high energy yields, and availability of genetically improved planting stock. The silvicultural technology for growing plantation sycamore under short rotations is well developed.

A major constraint to implementing operational, short-rotation plantations is the development of efficient and economical harvesting systems. There have been few studies on operational harvesting systems for hardwood plantations. In one such study, semi-mechanical and mechanical systems with conventional equipment were evaluated for harvesting sycamore plantation wood.[1] The authors concluded that mechanical systems perform better than semi-mechanical systems, but that machine size must be closely matched with tree size. For small trees, less than 15 cm in diameter at breast height (dbh), high production is necessary for economical felling. Bunching is essential for higher production in the subsequent harvesting functions.

For improved production, a specialized, high-speed feller buncher that better matched tree size was evaluated. The Hyd-Mech FB-7* prototype is a continuous-speed felling and bunching machine designed for high productivity in small diameter stands. This paper reports the field evaluation of this feller buncher in a sycamore plantation and includes analyses of selected short-rotation biomass harvesting systems.

STAND DESCRIPTION

An 8·1 ha sycamore plantation in south Alabama was used for the study.[4] The former agricultural site was operationally planted with 1-year-old sycamore seedlings at a 1.5×3 m spacing in January, 1982. The plantation was divided into four 2 ha blocks, with initial plans for harvesting one block each year beginning in 1984. Results of the first year harvesting have been reported;[1] harvesting information on the second 2 ha block, which was three years old in January, 1985, is presented here. At the time of this harvest, the test block had 1824 trees ha^{-1} and total standing biomass of 41·7 green Mg ha^{-1}.

*The use or mention of trade names is for the convenience of the reader. It is not an endorsement by USDA Forest Service, North Carolina State University, or Tennessee Valley Authority.

FELLER BUNCHER TEST

Machine description

The prototype felling unit is a continuous-speed feller buncher (Fig. 1) manufactured by Hyd-Mech Engineering Ltd, Woodstock, Ontario. Development of the machine was funded by the National Research Council of Canada for harvesting short-rotation bioenergy plantations with tree diameters up to 20 cm at continuous speeds of 2·4 km h^{-1}. The felling head is mounted on an articulated, four-wheel drive Versatile tractor having a 45 kW turbo-charged diesel engine. Each axle has dual 34·5 × 61 cm tires.

The cutting mechanism consists of two horizontal 61 cm saws, counter-rotating at 2000 rpm (Fig. 2). Cut trees were forced with hydraulic grabbing arms into either of two accumulators on each side of the head. Choice of accumulator was made by the operator and was controlled by use of a switching gate and hydraulic arms. The accumulator was rotated to dump the bunched trees parallel to the direction of travel and alongside the feller buncher without interrupting forward

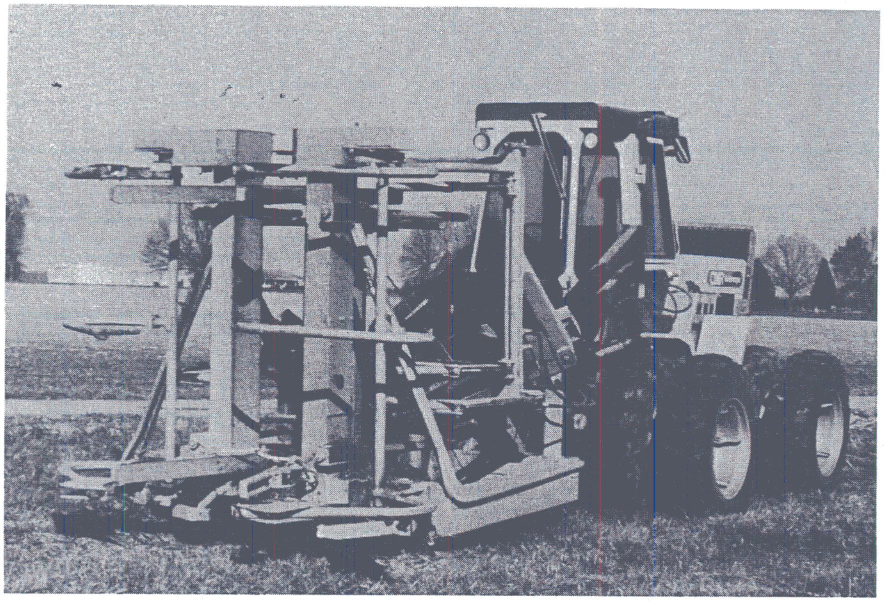
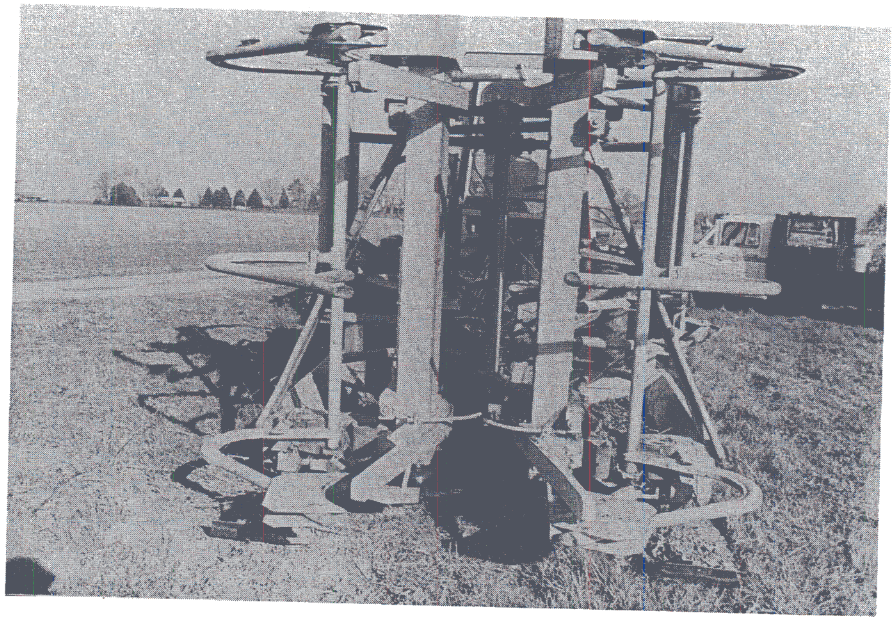
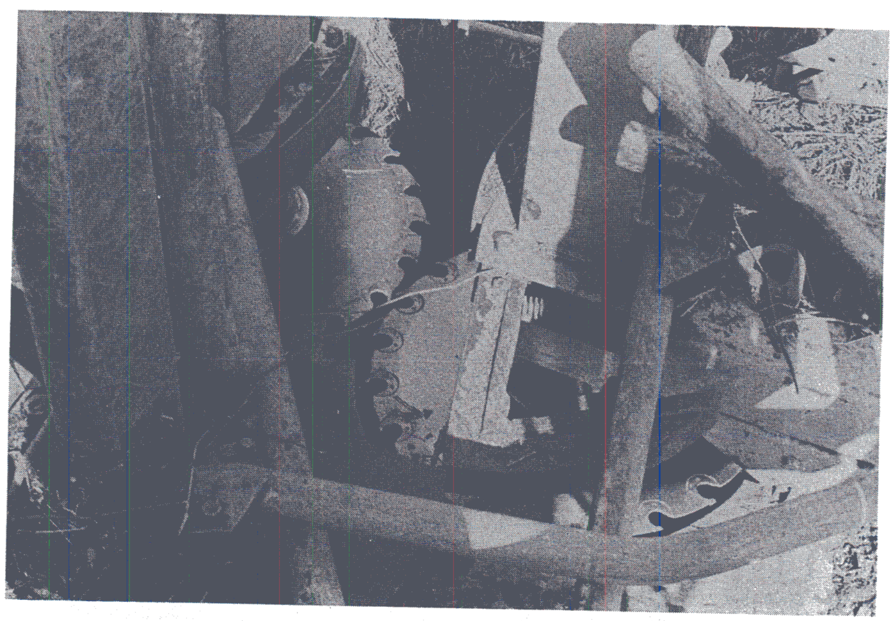


Fig. 1. Hyd-Mech felling head mounted on Versatile tractor.



(a)



(b)

Fig. 2. Felling head of Hyd-Mech feller buncher.

travel. The accumulators allowed unloading to either side, away from the stand for clearance on the next pass.

Operation of the felling head was controlled by an onboard computer system. An OMRON SYSMAC S6 programmable controller operated the arms that pushed trees from the cutting area into the accumulating area and also 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 drove the machine at a relatively constant speed, only slowing to insure that the push arms had reset before cutting the next tree. The dumping sequence was operated by the controller after the operator had initiated the sequence.

Methodology

Three felling plots, consisting of three adjacent rows approximately 142 m long, were selected, and every tree was tagged and numbered in the plots. Each tree was measured at dbh and sample trees were measured at stump level. The distance of each tree from an end reference point was measured. The cutting of each test row was video taped to obtain time study data. Delays and turn around times were also recorded.

During part of the cutting test, the operator cut a row, turned around, and then cut the next row. The remaining test areas were felled using a progressive cutting method. A five-row spacing was maintained between the completed cut row and the next row to be felled.

Analyses and results

The feller buncher encountered some operating problems usually associated with prototype machines. Besides the minor breakdowns with hydraulic components, sensor switches broke or failed, leaves and vines built up in the head, and the computer components failed. An overheating problem was corrected by the addition of an oil cooler. Other problems may be eliminated by some minor engineering changes.

The average cycle time from dump-to-dump was 0·298 min, with an average of 5·1 stems per cycle (Table 1). The maximum number of stems cut during a cycle was ten. Average production (not including delays and turn arounds) was 1057 trees h^{-1}. Production cutting speed averaged 1·74 km h^{-1}. The distance traveled during a cycle (distance between bunches) was about 8·8 m, and the average spacing between the trees was 1·8 m.

TABLE 1
Production Summary for Hyd-Mech Feller Buncher

Measurement	*Number of observations*	*Mean*	*Standard deviation*	*Range*
Productive minutes per cycle	56	0·298	0·095	0·179–0·600
No. trees per cycle	56	5·1	1·5	3–10
No. trees per productive hour[a]	56	1056·7	194·0	466·0–1457·0
Distance per cycle (m)	56	8·8	2·26	4·70–15·58
Productive cutting speed (km h^{-1})	56	0·74	5·06	0·68–3·04
Delays[b] in time (min)	6	0·289	0·173	0·036–0·405
Turn around time (min)	4	0·455	0·122	0·336–0·622
Tree spacing (m)	559	1·79	1·03	0·18–15·80
Diameter breast high (cm)	568	6·30	1·60	1·02–12·19
Diameter stump level (cm)	203	9·42	2·21	2·79–15·24
Green weight per tree (kg)	568	20·43	13·08	2·50–150·18

[a] Does not include turn around time at end of row or delays; based on cycles.
[b] Delays are only those where trees hung during cutting or dumping. Delays not included were mechanical delays such as hydraulic problems, broken switch pins, or cleaning head.

TABLE 2
Time Summary for Hyd-Mech Feller Buncher

Measurement	*Min*	*%*
Productive	17·13	82·8
Delays[a]	1·734	8·4
Turn around	1·820	8·8
Total operating time	20·684	100·0

Total no. stems = 293
No. trees per operating hour[b] = 849·9

[a] Does not include turn around time at end of row or delays; based on cycles.
[b] Does not include time to clean out the head or other mechanical delays.

The average tree had a dbh of 6·3 cm and weighed 20·4 kg. A complete time summary, with delays, is given in Table 2. The machine was productive (cutting trees, not mechanically delayed, or removing trash from the head) 82·8% of the available time. Therefore, production totaled 850 trees per productive machine hour (PMH), with a resulting 17·3 green Mg PMH^{-1}.

Regression techniques were used to analyze the total cycle time. Variables tested in the model were number of 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.

The inverse of spacing proved significant in the model; as the spacing increased, cycle time decreased. At close spacings, the operator had to stop or slow the travel of the machine to allow time for the grabbing arms to recycle. The higher cycle times occurred at spacings of 1·4–1·5 m. Unfortunately, the range of spacings between trees was limited, with the average spacing being 1·8 m. Once past the spacing for which the arms can be recycled without slowing forward travel, wider spacings would decrease production. However, the data range was insufficient to show this effect, and the effect of spacing was not included in the final model.

The number of trees per cycle was varied during the study to determine its effect on production. The number of trees per cycle in the analysis was restricted to 3–8 because of insufficient data outside this range. The final model was a linear function of trees per cycle. The developed equation predicts time per cycle and does not include turn around time. The final model was:

$$\text{time per cycle} = 0{\cdot}0787 + 0{\cdot}0427 \times \text{trees}$$

with $R^2 = 0{\cdot}34$, Root MSE (standard error of estimate) = 0·063, and $n = 51$, and where time per cycle = minutes of productive time from dump-to-dump, and trees = stems per cycle.

Increasing the number of trees per cycle greatly improves felling production (Table 3) and subsequent skidding operations. Using the

TABLE 3

Estimated Hyd-Mech Production and Cost Using Total Cycle Time Equation[a]

No. trees per cycle	*Green Mg PMH⁻¹* [b]			*Dollars green Mg⁻¹*		
	Lower[c] value	*Predicted value*	*Upper[c] value*	*Lower value*	*Predicted value*	*Upper value*
3	15·5	17·8	20·8	2·74	3·20	3·67
4	18·2	19·6	21·2	2·69	2·91	3·13
5	19·9	21·0	22·1	2·58	2·71	2·86
6	20·6	22·0	23·5	2·42	2·59	2·76
7	20·8	22·7	24·9	2·29	2·51	2·74
8	20·9	23·3	26·3	2·17	2·44	2·72

[a] Does not include turn around time at end of rows.
[b] Based on average tree weight of 20·4 kg. PMH = productive machine hours.
[c] 90% confidence internal lower and upper values.

developed cycle equation, production when cutting five trees per cycle (approximate average for study) is 1027 trees h^{-1}. An increase of three trees per cycle would improve productivity by about 11%. Actual production would be less than that in Table 3 because the prediction does not include turn around time at the end of the rows. In actual application in long rows (over 250 m), the turn around time is almost negligible in estimating daily production. The effect of tree diameter on production is shown in Fig. 3.

Since harvesting can only be completed during the dormant season to insure good coppice regeneration, the felling head can only be used approximately 3–4 months per year. The assumption was that the head was planned or scheduled to work 500 h $year^{-1}$. All other machines, including the Hyd-Mech carrier, were scheduled to work 2000 h $year^{-1}$ or fifty 40 h weeks on other harvesting activities.

In a machine rate analysis of the Hyd-Mech feller buncher, estimations were made of maintenance and repair costs, machine life, and utilization because the machine is a prototype (Table 4). The machine was estimated to cost \$29·86 per scheduled machine hour (SMH).

Using the average production and a machine cost of \$39·86 SMH^{-1}, which included \$10 for labor, the average cost for felling in the sycamore plantation was \$3·29 green Mg^{-1}. Cost estimates as a function of trees per cycle were developed using the prediction equation (Table 3). An increase from three to eight trees per cycle would decrease cost by 24%.

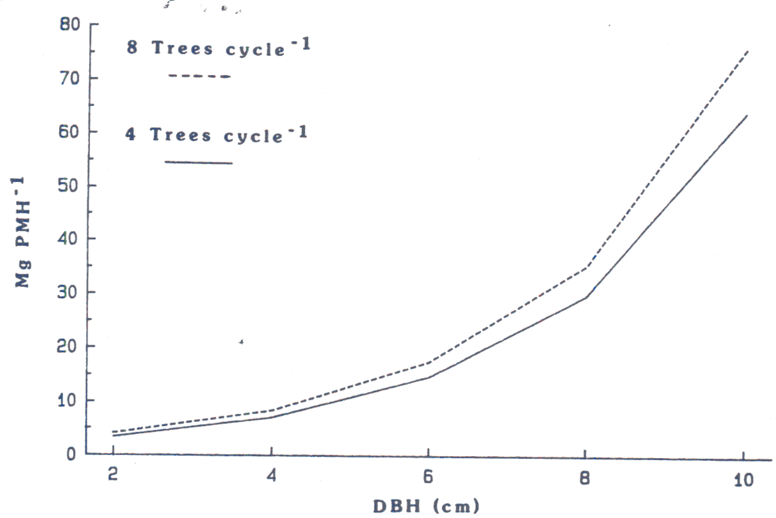


Fig. 3. Estimated production for Hyd-Mech feller buncher.

TABLE 4
Machine Rate Analyses for Each Machine in Study

Machine	*Purchase price ($)*	*Economic life (years)*	*Salvage value ($)*	*Utilization*[a] *(%)*	*Fixed cost*[b] *($ SMH^{-1})*	*Operating cost*[b] *($ SMH^{-1})*	*Total cost ($ SMH^{-1})*
Hyd-Mech							
Felling head	25 000	4	4 000	70	10·54	11·20	21·74
Versatile tractor	40 000	8	4 000	80	5·04	3·08	8·12
Total	65 000				15·58	14·28	29·86
Kubota tractor	15 000	5	3 000	80	2·44	2·17	4·61
CAT 518 skidder	88 000	4	17 600	80	15·14	10·94	26·08
Smaller (56 kW) skidder[c]	54 000	3	10 800	80	11·41	9·26	20·67
Chipper—RXL27	235 000	5	47 000	75	33·18	34·32	67·50
Smaller (261 kW) chipper[c]	132 000	5	26 400	75	18·64	19·61	38·25

[a] All machines except felling head (500 h) were scheduled for 2000 h annually; if not in hardwood plantation, then in other harvesting activities. Salvage value for Hyd-Mech was 16% of the purchase for the head and 10% for the carrier; all other machines were 20%.
[b] Operating costs exclude labor. SMH = scheduled machine hours.
[c] Smaller, lower horsepower skidder and chipper were not tested but were added for comparison.

SKIDDING AND CHIPPING TESTS

Machine descriptions

Skidding was completed with two different skidders — a small, four-wheel drive Kubota farm tractor and a large, articulated, rubber-tired Caterpillar grapple skidder. The Kubota 295DL with 26 kW engine had a small, three-point hitch hydraulic grapple with a 65 cm opening. The small tractor was equipped with a bucket loader from which the bucket had been removed and replaced with a straight blade. A canopy with a protective grill had been installed. The Caterpillar 518 with 97 kW engine had single 58·7 × 66 cm tires and was equipped with a 259 cm grapple.

Chipping was completed with a Morbark RXL27 chipper having a slide boom loader and a 447 kW diesel engine. Tree capacity was 69 cm in diameter. Chips were blown directly into vans for transport.

Methodology

The stand was divided into two blocks for the skidding tests. Bunches were tagged, and all the butt diameters were measured and recorded. The distance from the edge of the block to each bunch was measured.

The Kubota tractor operated between the rows of stumps in block 1, about 0·6 ha. The operator backed the tractor down the corridor and picked up the bunches. If more than one bunch was skidded in a cycle, the operator picked up the first bunch with the butts extended under the rear axle of the tractor, lifting the crown off the ground. Then the operator drove the tractor backwards to the next bunch and picked it up before skidding both bunches.

The large skidder was used to skid the remaining 1·4 ha in block 2. To avoid damaging the stumps, the skidder was operated while straddling each row of stumps. The skidder was backed down each row of bunches, over the first few bunches to the last bunch to be included in that cycle. Then the operator picked up that bunch, skidded it over the next bunch, picked it up, and repeated this procedure until all the bunches for that cycle were accumulated.

A time study was completed during the skidding operation. Elemental times were recorded along with the number of bunches skidded during the cycles. This information was used to develop the number of trees, load weight, and travel distance per turn.

During the skidding tests, the trees were skidded to the end of the rows and piled. After the tract was completely harvested, the chipper was moved on site. The large grapple skidder was used to re-skid the trees to the chipper. The productive time of the chipper was recorded. Non-productive time, such as delays while waiting for a skidder to bring wood, was recorded separately. The total productive time required to fill a van was measured. The weight of wood per van was used to determine productivity of the chipper.

Analyses and results

The Kubota tractor had an average skid cycle time of 2·3 min, at a 74 m average distance, with 5·9 stems per cycle (Table 5). Grapple time

TABLE 5
Skidding Production Summary[a]

Measurement	*Number of observations*	*Mean*	*Standard deviation*	*Range*
Kubota Tractor				
Travel-empty (min)	62	0·59	0·32	0·0–1·43
Travel-empty distance (m)	62	71	43	0–151
Load time (min)	68	0·86	0·86	0·09–5·50
No. stems per cycle	68	5·9	2·0	3·0–12·0
No. bunches per cycle	68	1·2	0·38	1·0–2·0
Travel-loaded (min)	67	0·45	0·25	0·0–1·09
Travel-loaded distance (m)	67	74	43	0–151
Turn around (min)	52	0·70	0·13	0·42–0·98
Time per cycle (min)	48	2·31	0·79	0·916–4·29
Grapple Skidder				
Travel-empty (min)	46	0·63	0·21	0·22–1·09
Travel-empty distance (m)	46	89	42	11–143
Load time (min)	46	1·98	0·91	0·63–4.17
No. stems per cycle	46	23·8	12·3	4·0–56·0
No. bunches per cycle	46	4·2	1·8	1·0–9·0
Travel-loaded (min)	46	0·35	0·27	0·0–0·83
Travel-loaded distance (m)	46	57	45	0–128
Drop load (min)	46	0·15	0·05	0·07–0·28
Turn around (min)	46	0·53	0·15	0·28–1·02
Time per cycle (min)	46	3·64	0·95	1·77–5·84

[a] Travel time and distance were from edge of block to bunches. Turn around time outside of block includes travel to pile and travel back to block. Dropping load was measured separately as shown. Operational skid distance would be longer than observed when measured to the pile.

increased by 62% when picking up two bunches instead of one. Total cycle time increased by 44% for two-bunch cycles, but the number of stems almost doubled to 9·5. Production potential of the Kubota was 184 trees h^{-1} when skidding two bundles. Therefore, the highest potential production of the Kubota was 3·7 green Mg PMH^{-1} if skidding two bunches per cycle.

Multiple regression techniques were used to develop an equation to predict productivity. Variables tested in the model were number of bunches and stems per cycle, and one-way travel distance per cycle. Distance was the average of travel-empty and travel-loaded distance and can be interpreted as the average one-way skid distance. The final model developed after testing these variables and their interactions was

$$\text{time per cycle} = 1{\cdot}1440 \times \text{bunches} + 0{\cdot}0144 \times \text{distance}$$

with R^2 (corrected) = 0·48, Root MSE (standard error of estimate) = 0·646, and $n = 48$, and where time per cycle = minutes of productive time, bunches = number of bunches in cycle, and distance = one-way skid distance (m).

The operator drove the large skidder slowly, avoided grappling stumps and, overall, did an excellent job of minimizing damage to the stumps. The average grapple skidder cycle was 3·6 min (Table 5) at an average one-way distance of 73 m. The average number of stems per cycle was 23·8, which resulted in an average production of 393 stems PMH^{-1}.

A specified number of bunches in a cycle, ranging from one to nine, were skidded from entire rows. Because the skidder was driven backwards over the bunches to the first bunch to be picked up in the cycle, the average travel-empty time increased with more bunches in the load. As the skidder was loaded, it was driven toward the end of the block where the stems were piled. The travel-loaded distances were always shorter than travel-empty distances.

The average cycle time increased from 2·5 min to 4·8 min when the number of bunches increased from two to six. The cycle time increased almost 92% and the number of stems per cycle increased by almost five times. Productivity peaked at 598 trees (12·1 green Mg) per operating hour when skidding six or more bunches. The largest load skidded was 56 trees. If the number of stems in a bunch were increased, then overall skidder production could be increased, even with wider spacing between bunches.

Multiple regression was used to develop a prediction equation for the Cat 518 cycle time. The number of bunches per cycle, number of stems per cycle, and average number of stems per bunch were tested in the model. Distance in the analysis was the average of travel-empty and travel-loaded distances for the cycle; this distance is the average one-way skid distance. The final model was

$$\text{time per cycle} = 0{\cdot}9635 + 0{\cdot}4178 \times \text{bunches} + 0{\cdot}0128 \times \text{distance}$$

with $R^2 = 0{\cdot}76$, Root MSE (standard error of estimate) $= 0{\cdot}472$, $n = 46$, and where time per cycle = minutes of productive time, bunches = number of bunches in cycle, and distance = one-way skid distance (m).

The productive time was measured for the grapple skidder re-skidding the wood from the ends of the tract to the chipper. Average re-skidding production was 14·2 green Mg PMH^{-1}. Maximum skid distance was 300 m.

The average time required to chip a van load (21·9 green Mg) was 49·09 min, resulting in 26·8 green Mg PMH^{-1}. There were many delays while waiting for wood at the chipper because only the one skidder was used. In an operational mode, actual production would probably have been improved by adding another skidder. Although the delays were removed from the data, a more continuous operation of the chipper would probably have improved production efficiency.

Machine rate analyses of the skidders and chippers (Table 4) were completed using standard machine rate techniques. Current purchase price information was obtained, and estimations were made on machine utilization for year-round logging. In addition, a smaller skidder and a smaller chipper were evaluated in the cost analyses. We felt that the grapple skidder and chipper used in the study were too large for the size of the trees in the tract.

The Kubota tractor cost per SMH was \$4·61. The large skidder cost was \$26·08 SMH^{-1}. A smaller skidder (56 kW) was estimated to be \$5·41 less, or \$20·67 SMH^{-1}. Estimated cost for the large 69 cm chipper was \$67·50 SMH^{-1}. A small chipper, 51 cm, was estimated to cost about \$38 SMH^{-1}. These are equipment cost estimates that exclude labor, crew transportation, and support equipment.

Using the average production for each machine from the study, costs for equipment and labor were determined for each function. We assumed that the functions were independent and not delayed by interactions. The felling function cost was \$3·29 green Mg^{-1} using the Hyd-Mech (Table 6). Using the Kubota tractor, the skidding cost of wood piled at each end of the block was estimated to be \$4·64 green Mg^{-1}. When the large grapple skidder was used, the cost of wood to roadside

TABLE 6
Harvesting Costs of Functions as Studied

Function	Production[a]				Costs SMH^{-1}			Cost, $ green Mg^{-1}
	Trees PMH^{-1}	Green Mg PMH^{-1}	Utilization (%)	Green Mg SMH^{-1}	Machine	Labor	Total	
Felling (Hyd-Mech)	850	17·3	70	12·1	29·86	10·00	39·86	3·29
Skidding (Kubota)	153	3·1	80	2·5	4·61	7·00	11·61	4·64
Skidding (Cat 518)	393	8·0	80	6·4	26·08	7·00	33·08	5·17
Re-skidding (Cat 518)	693	14·1	80	11·3	26·08	7·00	33·08	2·93
Chipping	1312	26·8	75	20·0	67·50	10·00	77·50	3·88

[a] Production estimates are the averages from the study over the specified test conditions. Based on average tree weight of 20·4 kg. PMH = productive machine hours; SMH = scheduled machine hours.

was \$5·17 green Mg^{-1}. Re-skidding with the large grapple skidder cost \$2·93 green Mg^{-1}. The chipping cost green Mg^{-1} was \$3·88.

SYSTEM ANALYSES

System analyses were completed for three balanced systems: (1) Hyd-Mech, Kubota, large chipper; (2) Hyd-Mech, Cat 518, large chipper; and (3) Hyd-Mech, small skidder, small chipper. Systems 1 and 2 were based on the field study, and system 3 was based on alternative equipment not studied. Production estimates for the Hyd-Mech, Kubota, and Cat 518 were determined from the developed equations. The production was based on 8 stems per bunch, which greatly increases the efficiency of the felling and subsequent functions for the study conditions. We also assumed that the trees were skidded directly to the chipper without any intermediate staging. Added travel distances were used to more closely predict this effect on the skidding function production.

For system 1, the cost of chips to roadside (no hauling) was \$11·38 green Mg^{-1} (Table 7). This cost includes equipment and labor costs, but excludes crew transportation, support vehicles and equipment, supervision, and profit. A balanced system included one feller buncher, one chipper, and five small tractors. Two grapple skidders were required for a balanced system (system 2) that produced wood to roadside for \$11·50 green Mg^{-1}. There were few differences between balanced systems 1 and 2 because the savings in machine cost using the Kubota tractors did not compensate for the difference in productivity of the skidders. The system costs could be reduced by 10–15% with a smaller, lower cost chipper.

Because the smaller grapple skidder and chipper (system 3) were not tested, production estimates were based on reductions of 20% and 25% for the skidder and chipper, respectively. The cost to roadside for such a balanced system was \$7·80 green Mg^{-1}, considerably less than that of the other two systems.

BIOMASS SUMMARY

For the 2 ha tract, 67·0 green Mg of total biomass were harvested for energy wood, and 3·5 Mg of rejects were separated by the chipper. From the day of felling to the time of chipping (16 days later), sampled trees had lost 15·5% of their weight from drying. Using this percentage, the total green weight yield at the time of harvesting was 83·4 Mg or 41·7 green Mg ha^{-1}.

TABLE 7
Estimated Production and Costs for Three Balanced Feller Buncher and Harvesting Systems

System	*Machine production*[a]			*Number of machines*	*System production*		*Cost SMH*$^{-1}$				*Total cost*[b] *\$ green Mg*$^{-1}$
	Green Mg PMH^{-1}	*Utilization (%)*	*Green Mg PMH*$^{-1}$		*Green Mg SMH*$^{-1}$	*Utilization (%)*	*Fixed*	*Operating*[c]	*Labor*	*Total*	
Hyd-Mech	21·0[d]	70	14·7	1	14·7	69	15·58	13·70	10·00	39·28	2·71
Kubota	3·6[e]	80	2·9	5	14·5	80	12·20	10·85	35·00	58·05	4·00
Chipper (large)	26·8[f]	75	20·0	1	20·0	54	33·18	24·71	10·00	67·89	4·67
					System 1 production = 14·5 green Mg SMH^{-1}						Total 11·38
Hyd-Mech	21·0	70	14·7	1	14·7	70	15·58	14·28	10·00	39·86	2·71
Cat 518	12·2[g]	80	9·7	2	19·4	61	30·28	16·69	14·00	60·97	4·14
Chipper (large)	26·8	75	20·0	1	20·0	55	33·18	25·17	10·00	68·35	4·65
					System 2 production = 14·7 green Mg SMH^{-1}						Total 11·50
Hyd-Mech	21·0	70	14·7	1	14·7	70	15·58	14·28	10·00	39·86	2·71
Skidder (small)	9·7[h]	80	7·8	2	15·6	75	11·41	8·68	7·00	27·09	~~1·84~~ 3·68
Chipper (small)	20·0[i]	75	15·0	1	15·0	73	18·64	19·08	10·00	47·72	3·25
					System 3 production = 14·7 green Mg SMH^{-1}						Total ~~7·80~~ 9·64

[a] PMH = productive machine hours; SMH = scheduled machine hours.
[b] Total costs are based on system production: lowest production for the functions in the system.
[c] Operating costs are based on system utilization of each function.
[d] Estimated from cycle production equation with eight trees per bunch and 10% reduction for turn arounds. Based on 20·4 kg per tree.
[e] Estimated from production equation with eight trees per bunch and skidding distance of 107 m.
[f] Based on average production for study and 20·4 kg per tree.
[g] Estimated from production equation with eight trees per bunch and six bunches per cycle. Skidding distance was 107 m without re-skidding. Trees were taken directly to chipper.
[h] Based on 20% reduction in productivity of the large skidder.
[i] Based on 25% reduction in productivity of the large chipper.

STUMP DAMAGE

After felling was completed, stumps were surveyed for damage using methods modified from Gibson and Pope.[5] Every tenth stump was sampled and inspected for three types of damage: cambial tissue, deformation, and stability. Cambial tissue was examined for percentage of the circumference of the stump that was loosened or removed. A clear template was used to classify tissue damage to the nearest 5% 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. After skidding, the same stumps were rechecked for additional damage.

Stump damage resulting from the felling is shown in Table 8. In block 2, the Hyd-Mech had hydraulic problems that caused speed loss of the saws during felling. The reduced speed, in turn, caused poor cutting, which resulted in the bark being ripped, thus exposing the cambial tissue. The hydraulic problem was intermittent; therefore, damage resulting from the stalled saw could not be separated from total felling damage to the stumps. The severity of the damage to the coppice production can only be evaluated after the stand regenerates. From the survey of the damage, the Hyd-Mech appears to do little damage when operating properly.

In block 1 (Table 8), 6·8% of the sampled stumps had some type of cambial tissue damage (exposure) that was caused by the felling function. The average amount of exposure along the perimeter of the damaged stumps was 12·2%. Only 3·8% of the stumps had any splitting, and all splitting amounted to less than 25% of the surface area of the stumps. No damage affecting the stability of the stumps was recorded. The results from block 1 are probably more representative of the operating characteristics of the Hyd-Mech felling machine than those from block 2.

Skidding with the Kubota caused no additional damage to cambial tissue of the stumps. The skidding operation resulted in splitting damage to 3% of the stumps. Stability of the stumps in the block was not affected, even after skidding.

In block 2, the large grapple skidder caused cambial tissue damage to an additional 10% of the stumps. The skidder also caused splitting in 3·7% of the stumps; in about 88% of these, splitting amounted to less than 25% of the surface area. In one occurrence, a stump was pulled loose from the ground. According to the survey of the damage, the Hyd-Mech does little damage when operating properly. The Kubota did a minimal amount of stump damage and certainly caused less damage than the grapple skidder.

TABLE 8
Summary of Stump Damage

Function	*Block*[a]	*No. stumps sampled*	*Cambial tissue*		*Splitting*		*Stability*	
			No. stumps damaged	*Average damage (%)*	*No. stumps damaged*	*Average damage (%)*	*No. stumps damaged*	*Average damage*
Felling	1	133	9	12·2	5	<25	0	0
Skidding	1	133	0	0	4[b]	<25	0	0
Felling	2	217	49[c]	13·3	24	<25[d]	1	1[e]
Skidding	2	217	21[b]	14·0	8	<25[f]	1	1[e]

[a] Block 1 was skidded with Kubota tractor and block 2 was skidded with large Cat 518 grapple skidder.
[b] Incremental damage caused by skidding function. Damage was either additional damage to stump with existing damage from felling or undamaged stump sampled after felling.
[c] Hydraulic problems caused speed loss in saw, which resulted in higher damage. More typical damage from the Hyd-Mech is probably exemplified in block 1.
[d] Almost 92% of stumps had splitting in only one quadrant of surface area.
[e] Stump was movable, not dislodged.
[f] Almost 88% of stumps had splitting in only one quadrant of surface area; other 12% of stumps had splitting in two quadrants.

CONCLUSIONS

The Hyd-Mech feller buncher proved to have much potential in 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 all the harvesting functions.

Production averaged 850 trees per productive machine hour. Cost per green Mg for felling in the sycamore plantation during the test was $3·29. Costs for the alternative systems, excluding highway transportation, crew transportation, and support equipment costs, were determined. There was little cost difference between the small tractor and large skidder systems. A 12% reduction in the cost of chips to roadside is obtainable with a smaller chipper than with the larger one tested. Costs can be reduced about one-third by using a smaller skidder and a smaller chipper.

A survey of stump damage showed little damage from the feller buncher when it was operating properly. The Kubota tractor caused minimal stump damage. Use of the large skidder resulted in more damage.

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