Productivity and cost of conventional understory biomass harvesting systems

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Abstract

Conventional harvesting equipment was tested for removing forest understory biomass (energywood) for use as fuel. Two types of systems were tested — a one-pass system and a two-pass system. In the one-pass system, the energywood and pulpwood were harvested simultaneously. In the two-pass system, the energywood was harvested in a first pass through the stand, and the pulpwood was harvested in a second pass. These systems were tested over a range of understory biomass amounts. Equations were developed to estimate the cost per green ton of energywood. The two-pass system exhibited high harvesting costs when biomass amounts were low, but costs moderated as biomass amounts increased. The one-pass system harvesting costs were not sensitive to the amount of energywood present.

The harvest of woody biomass for hogged fuel (energywood) is becoming increasingly important in the forest industries. In 1981 wood fuel accounted for nearly one-half of the energy consumed by the pulp and paper industry and nearly three-quarters of that consumed by the solid wood industry (4). Wood energy consumption is expected to increase within the industry (2). The trend in the pulp and paper industry is toward self-sufficiency in cogeneration of power (1). In fact, wood accounts for about 3 percent of total domestic energy consumption (4), and the use of wood for energy is expected to rapidly increase (3). Much of this increase is provided by harvest operations totally dedicated to procuring energywood (6).

Several firms in the South harvest understory biomass for use as a hogged fuel source. Our cooperator in this study was Scott Paper Company, which has recently increased its consumption of energywood at its Mobile, Ala., operations. The major concern in such an operation is the amount of understory biomass necessary for an economically feasible operation. Understory biomass can range from as much as 60 green tons per acre on tracts that have not been prescribed burned, to amounts as little as 3 green tons per acre where prescribed burning is frequently practiced. This article reports on a study designed to evaluate the influence of understory biomass level on the cost of harvesting energywood.

Two types of systems for harvesting energywood were tested. In the one-pass system, the energywood and pulpwood were harvested simultaneously. In the two-pass system, the energywood was harvested in a first pass through the stand, and the pulpwood was harvested in a second pass.

In the one-pass system, feller-bunchers felled the pulpwood and energywood in one pass, separating pulpwood and energywood into different piles. Pine trees less than 6 inches in diameter at breast height (DBH) and all hardwood constituted energywood. The equipment spread consisted of three feller-bunchers, three grapple skidders, one 22-inch portable chipper, and one chain saw. The grapple skidders dragged alternate loads of pulpwood and energywood. The energywood piles were skidded directly to the chipper. The slideboom on the chipper was used to feed the energywood into the chipper.

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TABLE 1. — *Energywood and pulpwood tonnages per acre.*

Tract	No. of passes	Energywood (estimate)	Energywood (actual)	Pulpwood (actual)
		(tons/acre)		
I	2	4.05	9.94	34.95
I	1	4.83	25.89	42.08
II	2	22.26	23.11	22.74
II	1	20.27	35.64	27.69
III	2	32.40	37.77	30.33
III	1	25.59	46.06	38.17
IV	2	34.63	36.81	30.94
IV	1	45.00	49.71	30.80
V	2	6.85	3.23	--
VI	2	6.74	3.15	--

TABLE 2. — *Component productivity for one- and two-pass harvesting operations.*

Tract	No. of passes	Green tons/acre	Feller-buncher	Skidder	Chipper
			(green tons/productive hour)		
VI	2	3.15	7.26	17.91	30.29
V	2	3.23	6.67	20.72	42.50
I	2	9.94	6.79	15.63	52.32
II	2	23.11	14.21	25.51	54.25
IV	2	36.81	12.68	17.83	45.22
III	2	37.77	13.71	24.49	62.33
I	1	25.89	20.45	29.76	40.45
II	1	35.64	19.10	25.83	58.05
III	1	46.06	21.56	27.22	53.56
IV	1	49.71	19.18	29.28	47.16

In the two-pass system, the feller-bunchers felled energywood in a first pass through the stand, and pulpwood in a second pass. Only the portion of the study dealing with the energywood harvest will be discussed in this article. The equipment spread in the energywood pass consisted of three feller-bunchers, three grapple skidders, and one 22-inch portable chipper. The grapple skidders dragged energywood to the chipper. The slide-boom was used to feed the energywood into the chipper. After the pulpwood was felled, grapple skidders dragged it to the same deck. The tops were removed and the pulpwood was cold decked.

Methods

Six tracts were located in slash pine plantations in Escambia and Conecuh counties in Alabama. The plantations ranged in age from 17 to 23 years. Ten test blocks (5 chains by 10 chains) were established within the tracts. Six test blocks were allocated to the two-pass harvesting system and four blocks to the one-pass system. Four of the two-pass blocks were close to the one-pass blocks and had similar topographic positions and biomass volumes. A forest cruise was used to verify that the blocks were of similar understory composition (5). A deck was located at the midpoint of a 10-chain side on each test block. The 5-acre blocks were of the same configuration to maintain average skid distances between the tests. The various test blocks are described in Table 1.

Each test block was logged by one of Scott Paper Company's experienced energywood crews. The total productive time by block and piece of equipment was recorded by Servis recorders mounted on each machine. The recorder disks were collected daily to obtain the productive time for each machine on each test block. Each truckload of energywood was weighed at the mill to determine the total tonnage removed from the block. From these data, production of energywood in green tons per productive hour was determined.

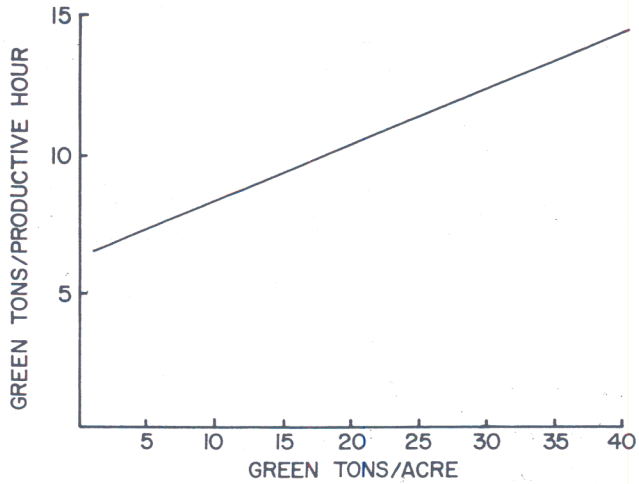

Figure 1. — Feller-buncher productivity (two-pass).

On the one-pass test blocks, to properly allocate the amount of time the skidders and feller-bunchers devoted to pulpwood and energywood, the percent of time producing each product was estimated from a detailed time study. Total feller-buncher time was allocated between products based on percentages developed by using two stopwatches to record the time spent on each product. The skidding time was similarly apportioned by counting the number of loads of energywood and pulpwood that were produced from each block.

Production studies

The average production of energywood in green tons per productive hour was calculated for each piece of equipment on each test block (Table 2). Regression analysis was used to analyze the relationship of production to volume of energywood per acre.

The feller-buncher was the only machine that was significantly affected by the amount of energywood present on the two-pass blocks (Fig. 1), due to the manner in which the feller-buncher was utilized. The feller-buncher always built a full bundle for the skidder. In a low tonnage stand, the feller-buncher spent more time moving from one stem to the next than it did felling and bunching stems. Conversely, in a high tonnage stand, production rates climbed because the feller-bunchers did not have to travel as great a distance to fell a sufficient number of stems to build a full bundle for the skidder. The regression equation for the feller-buncher energywood production was:

$$FB\ PROD = 6.33 + 0.205\ GTA$$
$$(n = 6, R^2 = 0.79)$$

where:

FB PROD = feller-buncher production in green tons per productive hour

GTA = green tons per acre

The grapple skidder production rate was not significantly affected by the tonnage of energywood per acre. The test block area and configuration was the same in each case, with decks located in the same spot on each block to maintain the same average skid distances among the test blocks. Also, energywood was required to be uniformly distributed over each block. The feller-bunchers built large piles of energywood in low tonnage stands as well as high tonnage stands. Since the productivity of the skidders was a function of skid distance and tonnage per load, regardless of energywood tonnage per acre, proportional numbers of equal size loads were made from the same skid distances. Thus, skidder production in tonnage of green energywood per productive hour was not significantly different over the range of tonnages tested.

The chipper production was not significantly affected by the energywood tonnage per acre. This is because the skidders were able to feed the chipper at a rate that was not significantly different over the range of tonnage of energywood tested.

Production bottlenecks could occur with the two-pass system, because skidder production is higher than feller-buncher production. This problem worsens with a reduction in energywood tonnage per acre, because the feller-buncher production was significantly lower as tonnage decreased, while there was not a significant reduction in skidder production. Production bottlenecks were eliminated between the skidders and feller-bunchers by allowing the feller-bunchers to complete a test block before skidding and chipping started.

No production bottlenecks occurred between the three skidders and chipper. The chipper produced at a faster production rate than the skidders in some cases. A potential bottleneck was eliminated by starting skidder production slightly ahead of the chipper startup and continuing skidder production during the time the chipper was waiting for chip vans to be moved into position.

Low-tonnage tracts can be harvested at a faster pace than the high-tonnage tracts, creating the need to move the system more often during a given time period. The movement of the system, even though it is very mobile, can take appreciable amounts of time. The chipper has to be prepared for the road. If the move is over 10 miles, the skidders and feller-bunchers should be hauled on a lowboy trailer. Before production can start, a deck must be constructed for the chipper, and turnaround roads cleared for the trucks and chip vans. This is expensive.

Small, low-tonnage areas within a high-tonnage tract can be harvested without an impact on the production rates. However, lower overall energywood tonnages do affect production rates. Intensive site preparation in recent years has led to lower energywood tonnages on site prepared land. Low-tonnage stands will become more important as the high tonnage energywood stands are depleted. The one-pass system, which utilizes the tops of the pulpwood trees for energywood, has advantages over the two-pass system for this reason.

The production rates can be misleading in the one-pass system. A part of the total energywood tonnage produced in the one-pass system is produced in the pulpwood phase of production. The felling and skidding of the pulpwood tops is essentially free because they are moved with the rest of the pulpwood to the chipper. Thus, production rates for felling and skidding energywood were increased due to this improved utilization of the pulpwood tree (Table 1).

In the one-pass system, production of the feller-buncher, grapple skidder, and chipper was not significantly different over the range of tonnages. Feller-buncher production was uniform due to the free tonnage of energywood contributed by the pulpwood tops. Skidders maintained stable production because the feller-bunchers accumulated energywood into large piles that could be efficiently skidded. This allowed the skidders to feed the chipper at an even rate.

Cost Analysis

A total cost to harvest each test block was calculated. Cost rate estimates for the various machines were made using the machine replacement cost instead of actual purchase prices (7). A labor rate of 10 dollars per loaded hour was assumed. The labor hours were calculated by dividing the utilization rate of the machine into the productive hours spent on each test block.

The component cost of producing energywood was calculated in dollars per green ton for each piece of equipment on each test block (Table 3). Regression was

TABLE 3. — *System and component costs for one- and two-pass harvesting operations.*

Tract	No. of passes	Green tons/acre	Feller-buncher	Skidder	Chipper	System	System with moving cost
			($/green ton)				
VI	2	3.15	8.02	2.92	2.66	13.60	19.95
V	2	3.23	8.74	2.50	1.90	13.14	19.33
I	2	9.94	8.59	3.34	1.55	13.48	15.48
II	2	23.11	4.10	2.06	1.49	7.65	8.51
IV	2	36.81	4.60	2.94	1.79	9.33	9.86
III	2	37.77	4.25	2.14	1.30	10.82	13.56
I	1	25.89	2.85	1.76	2.00	6.61	8.54
II	1	35.64	3.05	2.03	1.39	6.47	7.87
III	1	46.06	2.70	1.92	1.51	6.14	7.23
IV	1	49.71	3.04	1.79	1.71	6.55	7.56

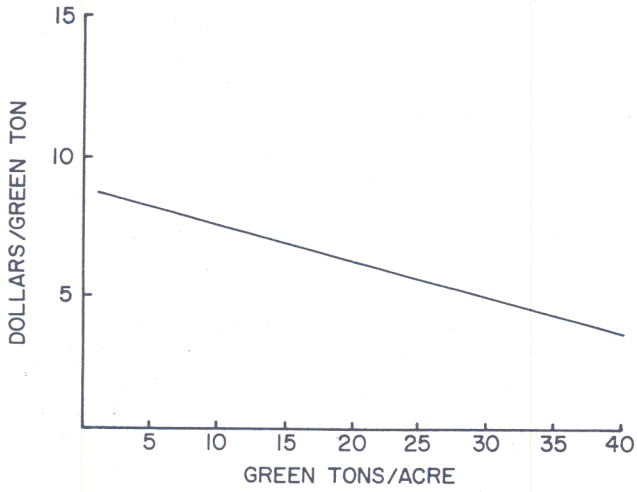

Figure 2. — Feller-buncher cost (two-pass).

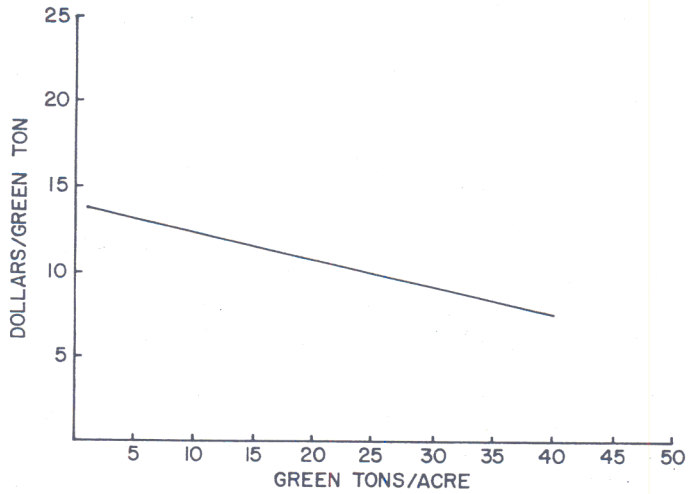

Figure 3. — Cost per green ton without moving cost (two-pass).

used to analyze the relationship of cost to the tonnage of energywood per acre.

The feller-buncher cost was the only cost that differed significantly over the range of tonnages tested on the two-pass test blocks (Fig. 2). The low production rates associated with the low-tonnage test blocks yielded a high cost per green ton.

The regression equation for feller-buncher cost was:

$$FB\ COST = 8.84 - 0.130\ GTA \quad (n = 6, R^2 = 0.82\%)$$

where:

FB COST = feller-buncher cost in dollars per green ton

GTA = green tons per acre

There were no significant differences in function costs or system costs with different harvest volumes per acre for the one-pass system. There was a significant difference in the total cost per green ton for the two-pass system over the range of tonnages tested (Table 3), due to the significant difference in the cost of felling the energywood separately. Estimates were developed using regression to predict cost in dollars per green ton from energywood tonnage per acre (Fig. 3). The equation for cost per green ton with no moving costs for the two-pass system was:

$$TOTAL\ COST\ WITHOUT\ MOVE, TWO\text{-}PASS = 13.90 - 0.160\ GTA \quad (n = 6, R^2 = 0.77)$$

This cost estimate demonstrates the increasing costs associated with harvesting a low-tonnage energywood stand, due to the high cost of felling and bunching the energywood. These costs are only for harvesting the energywood on each 5-acre test block and do not include trucking or deck preparation. The average cost per green ton of the two-pass system was $10.82.

Several assumptions were made to demonstrate the effect of moving and deck preparation on the cost estimates. To move the harvesting system and prepare the deck, a truck was needed for 30 minutes to move the chipper, at a cost of $15. The chipper operator and a utility man were needed for 2 man-hours at a cost of $10/man-hour. A skidder and a feller-buncher were used for 1 hour and 15 minutes to clear the deck at a combined labor and machine cost of $65. With these assumptions, a $100 cost was assigned to prepare a test block for harvest. Energywood crews often work on units as small as the test blocks, resulting in frequent moves. Figure 4 illustrates the influence of moving costs on the total cost estimate and demonstrates the ability of the high-volume tracts to carry this additional cost. The regression equation for cost per green ton with moving and deck preparation cost for the two-pass system was:

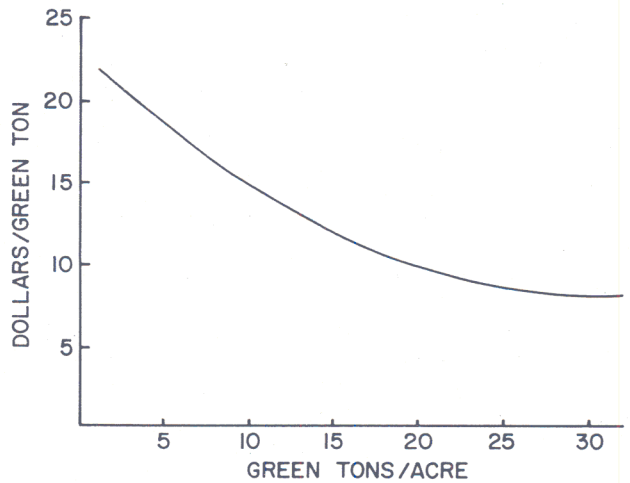

Figure 4. — Cost per green ton with moving cost (two-pass).

$$TOTAL\ COST\ WITH\ MOVE, TWO\text{-}PASS = 27.70 - 0.948\ GTA + 0.155\ GTA^2 \quad (n = 6, R^2 = 0.98)$$

In the one-pass system, the cost per green ton was decreased because a portion of the energywood tonnage

was produced in the pulpwood phase of production, and the felling and skidding of the pulpwood tops was essentially free (Table 3). For the same reasons, production rates for the feller-buncher, grapple skidder, and chipper did not significantly differ; costs also were not significantly different over the range of tonnages tested. The average cost per green ton of the one-pass system was $6.48.

A $50 deck preparation cost was added to the one-pass test to arrive at a total cost including moving. This was half that of the two-pass system because it was split with the pulpwood phase of the one-pass system. Regression analysis was also used to compare the cost per green ton with tonnage per acre. The cost per ton was not significantly different over the range of tonnages tested. The average cost per green ton with deck preparation was $7.80 for the one-pass system and $13.56 for the two-pass system.

Conclusions

Costs using the two-pass harvesting system depended mainly upon the feller-buncher productivity. As energywood tonnage decreased, the feller-buncher productivity decreased, and feller-buncher cost increased. This increased the system cost as stand tonnage decreased.

The one-pass harvesting system productivity and cost were not significantly different over the range of energywood tonnages tested. This was due to the free energywood tonnage gained from the pulpwood phase of the operation.

High-tonnage tracts defray moving costs much better than low-tonnage tracts. The average cost per green ton of the one-pass system was $6.48; or $7.80 with moving costs. These costs with the two-pass system were $10.82 and $13.56, respectively.

The productivity and cost of biomass harvesting operations influence management practices, site preparation, and logging management on forest tracts. Practices like prescribed burning and thinning affect biomass tonnage, biomass harvesting reduces site preparation costs, and biomass harvesting must be planned as one component of overall logging management. Forest managers should be aware of the differences in the productivity and costs of various biomass harvesting systems and the impact of these systems on forest management planning.

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