PROCEEDINGS
VOLUME I

FIRST BIOMASS CONFERENCE OF THE AMERICAS:
ENERGY, ENVIRONMENT, AGRICULTURE, AND INDUSTRY

AUGUST 30-SEPTEMBER 2, 1993

BURLINGTON, VERMONT

Sponsored by:
U.S. Department of Energy
Energy, Mines, and Resources Canada
U.S. Department of Agriculture
Environmental Protection Agency

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado USA 80401-3393

NREL/CP-200-5768
DE93010050
UC Category: 241

NREL is operated for the U.S. Department of Energy by Midwest Research Institute.

Cover: printed with renewable source ink on paper containing at least 50% waste paper.
Interior: printed on paper produced from the kenaf plant, made and grown in the United States/recyclable.

DEVELOPMENT AND ANALYSIS OF SRIC HARVESTING SYSTEMS

Bryce J. Stokes, Ph.D., Project Leader, Southern Forest Experiment Station, Auburn, AL 36849 U.S.A.
Bruce R. Hartsough, Ph.D., Associate Professor, University of California, Davis, CA 95616 U.S.A.

ABSTRACT

This paper reviews several machine combinations for harvesting short-rotation, intensive-culture (SRIC) plantations. Productivity and cost information for individual machines was obtained from published sources. Three felling and skidding systems were analyzed for two stands, a 7.6-cm (3-in) average d.b.h. sycamore and a 15.2-cm (6-in) average d.b.h. eucalyptus. The analyses assumed that whole trees were chipped at roadside.

Costs and production were summarized for each system. The systems were: (1) Continuous-travel feller-buncher, skidder, and chipper; (2) 3-wheel feller-buncher, skidder, and chipper; (3) chainsaw, skidder, and chipper. In the 7.6-cm stand, system productivities were 9.9, 7.3, and 7.5 BDLT/SMH, and costs were $20.9, $20.8, and $18.0 per BDLT for the three systems, respectively. System production rates for the 15.2-cm stand were 24.3, 10.2, and 12.5 BDLT/SMH, and costs were $8.7, $10.9, and $13.2 for systems 1, 2, and 3, respectively.

INTRODUCTION

Timber harvesting consists of several functions that must balance to assure efficiency. Harvest and transport costs depend in part on tree size, volume removed, transport distance, and type of product. But total cost per unit of product is influenced by machine cost and system efficiency.

This paper reviews several machine combinations for harvesting short-rotation, intensive-culture (SRIC) plantations. Several machine combinations are incorporated into systems and costs are estimated. The analysis is based on studies and simulations conducted in 7.6-cm (3-in) d.b.h. sycamore (*Platanus occidentalis L.*) stands in south Alabama and 10.2-cm (4-in) to 15.2-cm (6-in) d.b.h. eucalyptus (*Eucalyptus camaldulensis*) plantations in central California (Stokes et al. 1986; Woodfin et al. 1987; Hartsough 1990; Hartsough and Nakamura 1990).

MACHINE REVIEW

Harvesting small stems requires highly efficient felling and bunching. Bunching stems facilitates subsequent wood removal. Chainsaw felling may cost less than machine felling but, without bunching, may increase total cost. Also, chainsaw felling is more hazardous and less productive than mechanical felling, making it more difficult to recruit and retain workers. Moreover, mechanical felling and bunching are more commensurate with the other mechanical functions in the system.

For this analysis we used three felling options: chainsaw, 3-wheel feller-buncher with shear, and a continuous-travel feller-buncher with saw. The 3-wheeler has two drive wheels in front and a free castering wheel in the rear. A continuous-travel feller-buncher with a sawhead was represented by a prototype unit tested in 1985 (Stokes et al. 1986) for harvesting SRIC plantations with tree diameters of about 17.8 cm (7 in) at the stump.

A small (77 hp) and a medium (100 hp) grapple skidder were used for skidding. Two farm tractors, approximately 35 hp, were used; one was equipped with a grapple and the other with a winch. Farm tractors may be a low-cost option for seasonal operations where they can be used for other work the rest of the year.

A medium chipper (400 hp) was used for all processing, producing whole-tree chips (wood, bark, and foliage).

METHODS

Productivity and cost information was obtained from published sources. The information was compiled to develop harvesting systems for two representative short-rotation stands: a 7.6-cm (3-in) and a 15.2-cm (6-in) average d.b.h. Various options for felling, extracting, and processing were combined into systems. Then the systems were balanced, by adjusting the number of machines.

The production rate for a system composed of several machines is limited to the least productive function in the system. There are several ways to balance the functions in a system. One way is to increase productivity or increase SMH of the limiting function. Another way is add machines. Balanced systems have lowest costs.

In the analysis, scheduled machine hours (SMH) is the time a machine is scheduled to work - 8 hrs per day. Productive machine hours (PMH) is the time a machine actually does productive work. The ratio of productive time to scheduled time is utilization. Harvesting machines operating year-round generally have utilization rates of 65 to 95 percent. In this analysis units of production were BDLT, bone dry long tons (BDST, bone dry short tons); 50 percent moisture content (wet basis) was used in the conversion.

Machine costs depend on the utilization rate of the machine and how it is utilized in the system. In this analysis, a machine rate is used. Machine rate is the average owning-and operating-cost based on assumed use over the life of the machine (Miyata 1980; Brinker et al. 1989).

COST AND PRODUCTION SUMMARY

In the analyses, some piling time was added for the chainsaw felling when cutting in the 7.6-cm (3-in) trees. All trees were assumed to be taken to the deck whole and chipped with a medium-sized chipper.

Table 1 summarizes the production and cost for each function by machine type and tree size. Costs include labor at $10.00 per SMH. The highest cost machines per SMH were the continuous-travel feller-buncher, medium-sized skidder, and chipper. The lowest were the small tractor and manual felling. These were the individual costs for one machine only, and do not reflect the costs in a balanced system.

The effect of system balancing is demonstrated in Table 2. In this example, for 15.2-cm (6-in) d.b.h. trees, the 3-wheel feller-buncher, small skidder, and chipper are used. When only one machine is used in each function (upper section of table), the system production is 3.7 BDLT/SMH (4.1 BDST/SMH) and the system cost is $27.6/BDLT ($24.6/BDST).

Table 1. Estimated Machine Production and Cost

	Util.		BDLT/SMH (BDST/SMH)				$/BDLT ($/BDST)			
	(%)	$/SMH	7.6 cm (3 in)		15.2 cm (6 in)		7.6 cm (3 in)		15.2 cm (6 in)	
Felling										
Continuous FB	70	39.9	6.0	(6.7)	27.5	(30.8)	6.6	(5.9)	1.5	(1.3)
3-Wheel FB	70	25.3	3.7	(4.1)	10.2	(11.4)	6.9	(6.2)	2.5	(2.2)
Chainsaw	60	11.3	2.8	(3.1)	3.1	(3.5)	4.0	(3.6)	3.6	(3.2)
Extraction										
Small skidder	80	26.0	3.7	(4.1)	-	-	6.9	(6.2)	-	-
Medium skidder	80	36.2	4.8	(5.4)	12.1	(13.6)	7.5	(6.7)	3.0	(2.7)
Small tractor w/grapple	80	14.6	1.2	(1.4)	-	-	11.6	(10.4)	-	-
Small tractor w/winch	80	23.2	2.8	(3.1)	4.6	(5.1)	8.4	(7.5)	5.2	(4.6)
Processing										
Medium chipper	75	49.5	9.9	(11.1)	13.0	(14.6)	5.0	(4.5)	3.8	(3.4)

Note: SMH is scheduled machine hours; BDLT is bone dry long tons and BDST is bone dry short tons; Costs include labor ($10/SMH); Chainsaw felling also includes hand piling. Tractor w/winch includes hook setter.

Table 2. Balancing a Typical System

	Machine			System					
	BDLT /PMH	(BDST /PMH)	Util. (%)	No. mach.	BDLT /SMH	(BDST /SMH)	$/ SMH	$/ BDLT	($/ BDST)
3-Wheel FB	5.3	(5.9)	70	1	3.7	(4.1)	25.3	6.9	(6.2)
Small skidder	4.7	(5.3)	80	1	3.8	(4.2)	26.0	7.1	(6.4)
Medium chipper	13.2	(14.8)	75	1	9.9	(11.1)	49.5	13.5	(12.1)
System					3.7	(4.1)	100.8	27.6	(24.6)
3-Wheel FB	5.3	(5.9)	70	2	7.3	(8.2)	50.6	6.9	(6.2)
Small skidder	4.7	(5.3)	80	2	7.5	(8.4)	52.0	7.7	(6.4)
Medium chipper	13.2	(14.8)	75	1	9.9	(11.1)	49.5	6.8	(6.0)
System					7.3	8.2	152.2	20.9	(18.6)

Note: BDLT is bone dry long tons; BDST is bone dry short ton; PMH is productive machine hours; SMH is scheduled machine hours; Utilization is PMH/SMH; Costs are rounded to nearest whole numbers and summations may not add.

There is excess chipping capacity and a high chipping cost. By adding two felling and two skidding units, (lower section of table), the balanced system's productivity is 7.3 BDLT/SMH (8.2 BDST/SMH) and the system cost is $20.9/BDLT ($18.6/BDST).

This process was used to develop balanced systems for other options. A summary for the 7.6-cm (3-in) d.b.h. stand is shown in Table 3 for the three felling options and small skidder. The small skidder was used because it was more cost efficient. Other machine combinations from Table 1 can be used to derive costs for other systems.

All the systems in Table 3 were balanced with only one chipper. Two felling units were required when using mechanical felling and bunching. Three chainsaw operators were needed to balance the manual system. Three skidders were needed to balance the continuous-travel feller-buncher system; only two were required to balance the other systems.

The chainsaw system was more cost effective with the medium chipper. It was assumed that the skidding productivity was the same for chainsaw-felled trees as for mechanically-felled trees. The chainsaw option assumed hand piling, although it may be impossible to maintain such productivity using hand piling. Also, there are safety problems associated with chainsaw use.

Table 3. Systems for 7.6-cm (3-in) D.b.h. Stands

	Machine			System					
	BDLT /PMH	(BDST /PMH)	Util. (%)	No. mach.	BDLT /SMH	(BDST /SMH)	$/ SMH	$/ BDLT	($/ BDST)
Continuous FB	8.5	(9.5)	70	2	12.0	(13.4)	79.7	8.0	(7.2)
Small skidder	4.7	(5.3)	80	3	11.2	(12.6)	78.1	7.9	(7.0)
Medium chipper	13.2	(14.8)	75	1	9.9	(11.1)	49.5	5.0	(4.5)
System					9.9	(11.1)	207.3	20.9	(18.7)
3-Wheel FB	5.3	(5.9)	70	2	7.3	(8.2)	50.6	6.9	(6.2)
Small skidder	4.7	(5.3)	80	2	7.5	(8.4)	52.0	7.1	(6.4)
Medium chipper	13.2	(14.8)	75	1	9.9	(11.1)	49.5	6.8	(6.0)
System					7.3	(8.2)	152.2	20.8	(18.6)
Chainsaw	4.6	(5.2)	60	3	8.3	(9.3)	33.8	4.5	(4.0)
Small skidder	4.7	(5.3)	80	2	7.5	(8.4)	52.0	6.9	(6.2)
Medium chipper	13.2	(14.8)	75	1	9.9	(11.1)	49.5	6.6	(5.9)
System					7.5	(8.4)	135.3	18.0	(16.1)

Note: BDLT is bone dry long tons; BDST is bone dry short tons; PMH is productive machine hours; SMH is scheduled machine hours; Utilization is PMH/SMH; Chainsaw felling also includes hand piling; Costs are rounded and summations may not add.

Table 4 summarizes the options used for the 15.2-cm (6-in) d.b.h. stand. Again, the same three felling options were used with the medium-sized chipper. The chainsaw system was matched with a small tractor using a winch. This combination was used because it is very difficult to hand bunch such large stems, and a winch is more efficient than a grapple for unbunched stems. Two chippers were required to balance the continuous-travel felling option. A larger chipper could probably be used in lieu of the two medium-sized chippers. Only one chipper was needed in the other systems. The high-production, continuous-travel feller-buncher system also required two skidders. The chainsaw system needed three tractors to balance it.

The system costs ranged from a low of $8.7/BDLT for the continuous-travel feller-buncher to a high of $13.2/BDLT for the manual system.

CONCLUSIONS AND COMMENTS

The least expensive harvesting system for the 7.6-cm d.b.h. stand used chainsaw felling. This system was cost effective but not highly productive and is hazardous to chainsaw operators. In the 15.2-cm d.b.h. stand, the lowest cost combination included a specialized continuous-travel feller-buncher. It cost 40-140 percent more to harvest the 7.6-cm d.b.h. stand than the 15.2-cm d.b.h. stand.

This analysis examined only cost to roadside. It did not include overhead for moving equipment, crew transportation, service truck and tools, profit, or transportation to the mill. It was based on several assumptions and limited data on operating systems. The systems were also limited to the production of whole-tree chips.

The analysis was based on year-round logging. It may be necessary to harvest SRIC stands only in the dormant season to ensure good coppice. Reducing the working period or working only part-time would increase costs unless the equipment could be used in other applications.

Table 4. Systems for 15.2-cm (6-in) D.b.h. Stands.

	Machine			System					
	BDLT /PMH	(BDST /PMH)	Util. (%)	No. mach.	BDLT /SMH	(BDST /SMH)	$/ SMH	$/ BDLT	($/ BDST)
Continuous FB	39.4	(44.1)	70	1	27.5	(30.8)	39.9	1.6	(1.5)
Medium skidder	15.3	(17.1)	80	2	24.3	(27.2)	72.3	3.0	(2.7)
Medium chipper	17.3	(19.4)	75	2	26.1	(29.2)	99.0	4.1	(3.6)
System					24.3	(27.2)	211.4	8.7	(7.8)
3-Wheel FB	14.6	(16.3)	70	1	10.2	(11.4)	25.3	2.5	(2.2)
Medium skidder	15.3	(17.1)	80	1	12.1	(13.6)	36.2	3.5	(3.2)
Medium chipper	17.3	(19.4)	75	1	13.0	(14.6)	49.5	4.9	(4.3)
System					10.2	(11.4)	111.1	10.9	(9.7)
Chainsaw	5.2	(5.8)	60	4	12.5	(14.0)	45.0	3.6	(3.2)
Small tractor w/winch	5.7	(6.4)	80	3	13.7	(15.3)	69.8	5.6	(5.0)
Medium chipper	17.3	(19.4)	75	1	13.0	(14.6)	49.5	4.0	(3.5)
System					12.5	(14.0)	164.3	13.2	(11.7)

Note: BDLT is bone dry long tons; BDST is bone dry short tons; PMH is productive machine hours; SMH is scheduled machine hours; Utilization is PMH/SMH; Chainsaw felling also includes hand piling; Tractor w/winch includes hook setter; Costs are rounded and summations may not add.

LITERATURE

Brinker, R.W., D. Miller, B.J. Stokes and B.L. Lanford. 1989. Machine rates for selected forest harvesting machines. Circular 296. Alabama Agricultural Experiment Station, Auburn University, Al. 24 p.

Hartsough, B.R. 1990. Product/harvesting options for agroforestry plantations in the San Joaquin valley, California. Paper No. 90-7546, American Society of Agricultural Engineers, St. Joseph, MI. 23 p.

Hartsough, B.R. and G. Nakamura. 1990. Harvesting eucalyptus for fuel chips. California Agriculture 44(1): 7-8.

Miyata, E.S. 1980. Determining fixed and operating costs of logging equipment. USDA Forest Service General Technical Report NC-55. St. Paul, MN. 16 p.

Stokes, B.J., D.J. Frederick and D.T. Curtin. 1986. Field trials of a short-rotation biomass feller-buncher and selected harvesting systems. BIOMASS vol. 11, Elsevier Applied Science Publishers Ltd, England. p. 185-204.

Woodfin, S., D. Frederick and B. Stokes. 1987. Selected harvesting machines for short rotation intensive culture biomass plantations. Paper No. 87-1567, American Society of Agricultural Engineers, St. Joseph, MI. 18 p.