PAPER NO. 87-6012

FACTORS AFFECTING POWER REQUIREMENTS FOR CHIPPING WHOLE TREES

by

Bryce J. Stokes, Research Engineer
USDA Forest Service
Auburn, Alabama 36849

William F. Watson, Associate Professor
Department of Forestry
Mississippi State, Mississippi 39762

Donald L. Sirois, Project Leader
USDA Forest Service
Auburn, Alabama 36849

and

R. Kenneth Matthes, Professor
Agricultural/Biological Engineering Department
Mississippi State, Mississippi 39762

For presentation at the 1987 Summer Meeting
Baltimore, Maryland
June 28 - July 1, 1987

SUMMARY: Large and small in-woods disk chippers were used in field tests to determine the power requirements for chipping whole trees. Hardwood and softwood species were evaluated over a range of diameter classes and moisture contents.

KEYWORDS: Power, Chipper, Whole-tree

ASAE
American Society of Agricultural Engineers
St. Joseph, MI 49085-9659

FACTORS AFFECTING POWER REQUIREMENTS FOR CHIPPING WHOLE TREES

INTRODUCTION

Woody biomass is becoming a significant source of fuel and is currently supplying much of the energy required at pulp and paper processing facilities in the forest industry. Also, wood residues are becoming a more prevalent source of energy for kilns at sawmills. Moshofsky (1980) indicated that wood energy consumption was increasing at rates of 10 to 15 percent annually. Much of the wood for fuel is currently derived from manufacturing residues; however, these residues can no longer fill the demand for woody biomass for fuel. Thus, more and more firms are utilizing residues left after logging for an additional energywood source.

Studies have shown that only 50 to 60 percent of the aboveground biomass is removed during harvesting operations utilizing conventional merchantability standards (Watson et al. 1986). These studies have also shown that an additional 18 to 27 tonnes (20 to 30 tons) of biomass per acre can be recovered with conventional equipment if the residual undesirable species and small stems are utilized. Harvesting these materials for boiler fuel can be economical if the stems are felled with a high-speed feller-buncher, skidded to the deck with a grapple skidder, and chipped.

The chipper is the dominant machine in an energywood harvesting system because it has the highest single hourly production capability and cost. All other machines (feller-bunchers, skidders, and haul trucks and vans) in the system are balanced to the chipper to ensure high utilization and production with low unit costs. Selection, implementation, and management of a whole-tree chipping operation depend on a good knowledge of the application of chipping systems for a wide range of stand conditions.

Tree diameters, stand volumes, species, and production goals affect the size of chipper required in a system. Chippers vary in infeed-opening size from 25 to 94 cm (10 to 37 in) and in power sources from 22 to 895 kW (30 to 1200 hp). Hardwood species generally require more power for chipping than softwood species. It has been speculated that trees with lower moisture contents and larger diameters require more power during chipping.

Several laboratory studies have been completed to determine the factors that affect the power requirements for chipping. Much of the research has concentrated on the chipper design and knife characteristics (Rogers 1948; Papworth and Erickson 1966). Important design and operating factors studied have been the angle of cut, knife sharpness angle, speed of cut, chip length, and knife dullness. Other research has identified wood properties and characteristics that affect chipping power. Papworth and Erickson (1966) found wood density (difference among species) to significantly affect power requirements during chipping. Other variables that have been studied include the volume and diameter of logs and environmental conditions (McKenzie 1970; Papworth and Johnson 1968).

This study was performed to evaluate some of the factors affecting the power requirements for chipping whole trees in the South for energywood. Results are presented for the effects of tree size, moisture content, and species on power requirements.

METHODS AND MATERIALS

The field tests were conducted in south Alabama during the summer of 1985. Several weeks before chipping was begun, trees were felled and separated in bunches according to DBH (diameter breast high) and species. The DBH classes were in 5-cm (2-in) increments, ranging from 2.5 to 38.1 cm (1 to 15 in). Species categories were pine, soft hardwood, and hard hardwood. The soft hardwood species were sweetgum, red maple, and black gum. The hard hardwood species were red oak, water oak, and dogwood. Separate bundles were prepared over a 6-week period so that transpirational drying could take place, providing a range of moisture contents for the stems to be chipped.

Chippers used in the study were Morbark[1] Models 27 and 20. The larger Model 27 had a 69-cm capacity opening and a 447-kW (600-hp) engine (Table 1). The smaller Model 20 chipper had a 51-cm opening and a 261-kW (350-hp) engine. The chippers were used in structured tests rather than operational to control the flow of bunches through the chipper. Chipper knives were changed after each van load of chips to reduce the effect of knife sharpness on productivity or power requirements.

Table 1. Description of chippers in study.

Item		Model 27	Model 20
Engine size	kW	447	261
	(hp)	(600)	(350)
Disk diameter	cm	211	147
	(in)	(83)	(58)
No. knives		3	3
RPM		450	738
Lineal feed rate	m/min	31	49
	(ft/min)	(100)	(162)
Throat opening			
Height	cm	69	51
	(in)	(27)	(20)
Diagonal	cm	109	61
	(in)	(43)	(24)

[1] The use of a trade name is not an endorsement by the USDA Forest Service or Mississippi State University.

Two engine performance parameters were needed to determine the power requirements for a bunch of trees. Rail pressure (fuel pressure) and engine speed were measured simultaneously to determine power requirements using the engine manufacturer's engine performance graph. The pressure was measured with a Bell and Howell transducer (type 4-326-001) having a pressure range of 0-345 Pa (0-500 psi). Engine rpm was monitored with a Reliance engine tach adaptor (SP 182) and a Servatech DC generator (SN 763A-Z). The measuring devices were connected to a Gulton 6-channel analog recorder (TR 6000).

During the tests, individual bunches of trees were batched through the chipper. For bunches with few stems or single, large-diameter stems, only one grapple full of trees was required to feed the entire bunch into the chipper. Larger bunches with many stems required several grapple loads to feed the bunch into the chipper. In such cases, the procedure was completed in an operational mode, with the operator continuously picking up trees from a single bunch and feeding them into the throat of the chipper when there was sufficient room in the opening. In some cases, such as for short, small-diameter trees, the stems were completely chipped before another grapple load could be fed into the chipper. For larger trees, the butts of another grapple load were fed into the opening while the tops of the preceding grapple load were still being processed.

Rail pressure and engine speed were recorded on strip charts as the bunches were fed through the chipper. This information was digitized from the charts into computer files for analysis. The average, minimum, and maximum rail pressures, with their associated engine speeds, were used to determine power requirements. Engine performance graphs, furnished by the manufacturer, displayed power as a function of rail pressure for a range of engine speeds (Bretz 1986).

During the chipping of a bunch, chip samples were taken. These samples were placed in airtight bags and later used to determine the average moisture content of the bunch by weighing and oven-drying.

Regression analyses were used to develop prediction equations for maximum power requirements. Dummy variable techniques were used to test the effects of qualitative variables such as chipper and species. Other variables tested in the analysis were average tree diameter, number of stems in a bunch, and the moisture content of the trees.

ANALYSES AND RESULTS

An attempt was made to use the average power requirements in the analysis, but apparently these requirements were influenced by the number of grapple loads in a bunch and by the method the operator used to feed the trees into the chipper. Whenever the operator failed to continuously feed the trees into the chipper opening before the preceding batches were chipped, there were lulls in the power requirements, resulting in unrepresentative averages. Therefore, the maximum power requirement was used to evaluate the influence of the bunch characteristics.

Table 2 shows the maximum power requirements in the study for both chippers by species. A total of 159 observations were made, and the average maximum power requirement for the tests was 203 kW (272 hp). The highest power requirements measured were 383 kW (514 hp) for the large chipper and 244 kW (327 hp) for the small chipper. There were 91 observations for the small chipper and 68 for the large chipper. The average maximum power requirements for the small and large chippers were 158 kW (212 hp) and 262 kW (352 hp), respectively.

Generally, the hard hardwoods required more power than the pine and soft hardwood species. Surprisingly, the average maximum power measured for the large chipper was less for the soft hardwood than for the pine. This may have resulted from the number of stems fed into the chipper during the tests. Pine was only tested up to the 13-cm (5-in) diameter class, whereas the soft hardwood tests included the 18- to 33-cm (7- to 13-in) diameter classes.

In the study, less than 16 percent of the tests were conducted with pine species; soft hardwoods and hard hardwoods accounted for 41.5 and 42.6 percent, respectively. The moisture contents ranged from 21 to 100 percent for the study (Table 3). There was a wide range of moisture contents for both chippers in the study.

Although the hard hardwoods required somewhat higher maximum power than the other species, the differences did not prove to be significant. Moisture content, though having strong influence with different combinations of tree diameters and number of stems, was not significant in the final equation. Interaction effects were tested in the model.

The number of stems in the bunch did not affect the power requirements directly because in many cases only part of a bunch was fed at one time into the chipper. When a grapple load completely filled the infeed area, the power requirements were higher than for a smaller load of a given tree size, species, and moisture content. However, the number of stems in a grapple load was not recorded. The number of stems in a bunch was not a good indicator of how many stems were being fed at one time and was not useful for predicting expected power requirements. Therefore, the only significant variable in the model when all the data were used was DBH. As expected, the maximum power requirement was significantly different between the small and large chippers. A final model was developed with dummy variables for type of chipper. The model, separated by chipper for clarity, was:

<u>Small chipper</u>

$$\text{Max kW} = 100.13 + 3.94 \times \text{DBH(cm)} \qquad (1)$$
$$\text{Max hp} = 134.30 + 13.42 \times \text{DBH(in)}$$

<u>Large chipper</u>

$$\text{Max kW} = 209.47 + 3.94 \times \text{DBH(cm)} \qquad (2)$$
$$\text{Max hp} = 280.94 + 13.42 \times \text{DBH(in)}$$

R^2=0.42 n=159, C.V.=35.26, and Root MSE=95.75
(Statistics are for combined equation.)

Where: DBH = average tree diameter (cm or in).

Table 2. Summary of maximum power requirements by chipper, species, and DBH.

Species	DBH class cm (in)	Small chipper No. of obs.	Small chipper Mean	Small chipper Std. dev.	Small chipper Range	Large chipper No. of obs.	Large chipper Mean	Large chipper Std. dev.	Large chipper Range
			-------- kW --------				--------- kW ---------		
			(------- hp -------)				(-------- hp --------)		
Pine	2.5	-	-	-	- -	2	209	45	177 - 242
	(1)	-	-	-	- -		(280)	(61)	(237 - 324)
	7.6	5	116	24	87 - 148	5	190	111	34 - 335
	(3)		(156)	(32)	(117 - 199)		(255)	(149)	(46 - 449)
	12.7	7	168	14	155 - 194	6	350	36	282 376
	(5)		(225)	(19)	(208 - 260)		(470)	(48)	(378 - 504)
	All	12	146	32	87 - 194	13	267	106	34 - 376
			(196)	(43)	(117 - 260)		(358)	(142)	(46 - 504)
Soft hardwood	2.5	6	107	28	76 - 143	7	133	86	31 - 293
	(1)		(144)	(37)	(102 - 192)		(178)	(116)	(42 - 393)
	7.6	6	172	16	145 187	6	252	100	88 - 373
	(3)		(231)	(21)	(194 - 251)		(338)	(134)	(118 - 500)
	12.7	9	157	50	60 229	5	315	90	155 - 375
	(5)		(210)	(67)	(81 - 307)		(423)	(121)	(208 - 503)
	17.8	8	141	46	86 - 218	5	308	97	138 - 376
	(7)		(189)	(62)	(116 - 293)		(413)	(130)	(185 - 504)
	22.9	7	175	41	125 - 230	3	220	101	150 - 336
	(9)		(235)	(55)	(167 - 309)		(295)	(135)	(201 - 450)
	27.9	1	221	-	- -	-	-	-	- -
	(11)		(296)	-	- -	-	-	-	- -
	33.0	1	224	-	- -	2	271	37	245 - 297
	(13)		(301)	-	- -		(363)	(50)	(328 - 398)
	All	38	155	46	60 - 230	28	242	110	31 - 376
			(208)	(62)	(81 - 309)		(324)	(147)	(42 - 504)
Hard hardwood	2.5	6	116	45	69 - 174	3	160	152	30 - 328
	(1)		(156)	(61)	(93 - 243)		(215)	(204)	(40 - 440)
	7.6	5	140	34	75 - 174	5	309	93	149 - 369
	(3)		(188)	(53)	(100 - 243)		(414)	(125)	(200 - 495)
	12.7	7	165	45	89 - 230	4	299	113	136 - 383
	(5)		(221)	(61)	(119 - 309)		(401)	(151)	(183 - 514)
	17.8	10	138	34	93 - 210	7	245	102	104 - 371
	(7)		(185)	(46)	(125 - 281)		(328)	(137)	(139 - 497)
	22.9	6	201	22	170 - 226	4	295	70	226 - 374
	(9)		(269)	(29)	(228 - 303)		(395)	(94)	(303 - 502)
	27.9	4	217	9	206 - 227	2	369	4	365 - 373
	(11)		(291)	(12)	(276 - 304)		(495)	(6)	(490 - 499)
	33.0	3	236	7	230 - 244	1	368	-	- -
	(13)		(316)	(10)	(309 - 327)		(493)	-	- -
	38.1	-	-	-	- -	1	377	-	- -
	(15)	-	-	-	- -		(506)	-	- -
	All	41	164	50	69 - 244	27	281	105	30 - 383
			(220)	(67)	(81 - 327)		(377)	(141)	(40 - 514)

Table 3. Summary of wood moisture contents for the study.[1/]

Chipper		No. of obs.	Mean	Range
			--- Percent	---
Small	Pine	12	62	34 - 83
	Soft hardwood	38	50	21 - 85
	Hard hardwood	41	50	22 - 78
	All	91	51	21 - 85
Large	Pine	13	74	49 - 100
	Soft hardwood	28	57	34 - 85
	Hard hardwood	27	56	38 - 71
	All	68	60	34 - 100

1/ Moisture content was determined on a green weight basis.

Another approach to analyzing the data was to restrict the data to only the observations that included one stem or one grapple load where the number of stems being fed into the chipper was known (Table 4). This way, the effect of the number of stems on the required power could be determined. Unfortunately, the number of observations of pine species for the smaller chipper were too few to determine if there were conclusive differences between the pine and hardwood species. However, there were a sufficient number of observations to test for differences between chippers for the hardwood species, diameter classes, moisture contents, and the number of stems being fed into the chipper. There were 45 observations for the small chipper and 35 observations for the large chipper. The final prediction equation from these data sets, separated by chipper for clarity, was:

Small chipper

$$\text{Max kW} = -49.64 + 8.75 \times \text{DBH(cm)} + 1.26 \times \text{DBH(cm)} \times \text{Stems} \quad (3)$$
$$\text{Max hp} = -66.57 + 29.83 \times \text{DBH(in)} + 4.29 \times \text{DBH(in)} \times \text{Stems}$$

Large chipper

$$\text{Max kW} = 1.45 + 8.75 \times \text{DBH(cm)} + 1.26 \times \text{DBH(cm)} \times \text{Stems} \quad (4)$$
$$\text{Max hp} = 1.54 + 29.83 \times \text{DBH(in)} + 4.29 \times \text{DBH(in)} \times \text{Stems}$$

R^2=0.70, n=80, C.V.=25.92, and Root MSE=64.41
(Statistics are for combined equation.)

Where: DBH = average tree diameter (cm or in),
Stems = number of stems in chipper infeed.

Stem diameter, again, had a significant effect on power requirements. Larger stems required more power for chipping. The analysis showed that the interaction of DBH and number of stems was significant in the model. As the number of stems increased with larger size trees, more power was required for chipping.

Table 4. Summary of number of stems of hardwood species chipped per test for restricted data.

DBH class cm (in)	Small chipper No. of obs.	Mean	Range	Large chipper No. of obs.	Mean	Range
2.5 (1)	3	50.0	34 - 65	10	49.9	9 - 100
7.6 (3)	2	8.0	7 - 9	4	7.2	3 - 15
12.7 (5)	5	3.2	1 - 5	2	6.0	3 - 9
17.8 (7)	15	1.1	1 - 2	7	2.4	1 - 2
22.9 (9)	12	1.1	1 - 2	7	1.0	1 - 1
27.9 (11)	4	1.0	1 - 1	1	1.0	1 - 1
33.0 (13)	4	1.0	1 - 1	3	1.0	1 - 1
38.1	-	-	-	1	1.0	1 - 1

DISCUSSION

The maximum power requirements as a function of the number of stems being chipped and DBH (equations 3 and 4) is plotted in Figures 1 and 2. Note that for the small chipper handling 20.3-cm (8-in) stems, the maximum available power of the chipper is being predicted as needed when approximately five stems are being fed into the chipper (see Figure 1). Likewise, when the large chipper is handling 20.3-cm (8-in) stems, the maximum power requirement is predicted when eight stems or more are being fed into the chipper (Figure 2).

However, the maximum opening size of the chippers also determines the number of stems that can be fed in at one time. For example, the small chipper has a throat area of about 0.3 m^2 (3.5 ft^2). The throat size of the large chipper is about 0.5 m^2 (5.7 ft^2). The maximum percentage of chipper opening that could be occupied by trees can be estimated. In a neatly stacked cord of wood, about 70 percent of the cross section is solid wood (based on 2.5 m^3 (90 ft^3) of solid wood per stacked cord that comprises 3.6 m^3 (128 ft^3). Assuming that the same degree of packing occurs in the chipper, one can surmise that the maximum proportion of the throat area of the chipper that could be occupied by stems is about 70 percent. Thus, the area actually occupied by stems would be 0.22 m^2 (2.4 ft^2) in the small chipper and 0.37 m^2 (4.0 ft^2) in the large chipper.

The diameters of stems fed into the chipper were measured at breast height; thus, the stems would be about 20 percent larger at the butt. Therefore, assuming that the butts are circular, the following empirical relationships were derived for the number of stems that would be required to fill the throat of the chipper for a given DBH class:

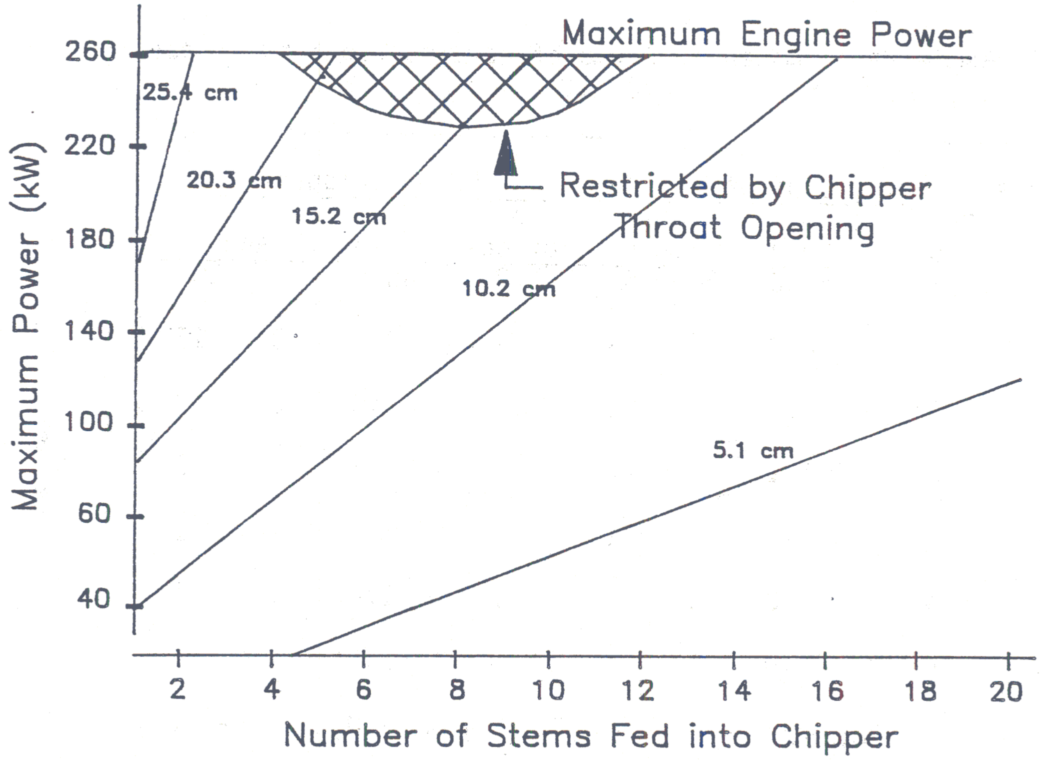

Figure 1. Maximum power requirements for the small chipper as a function of number of stems being fed and stem diameter.

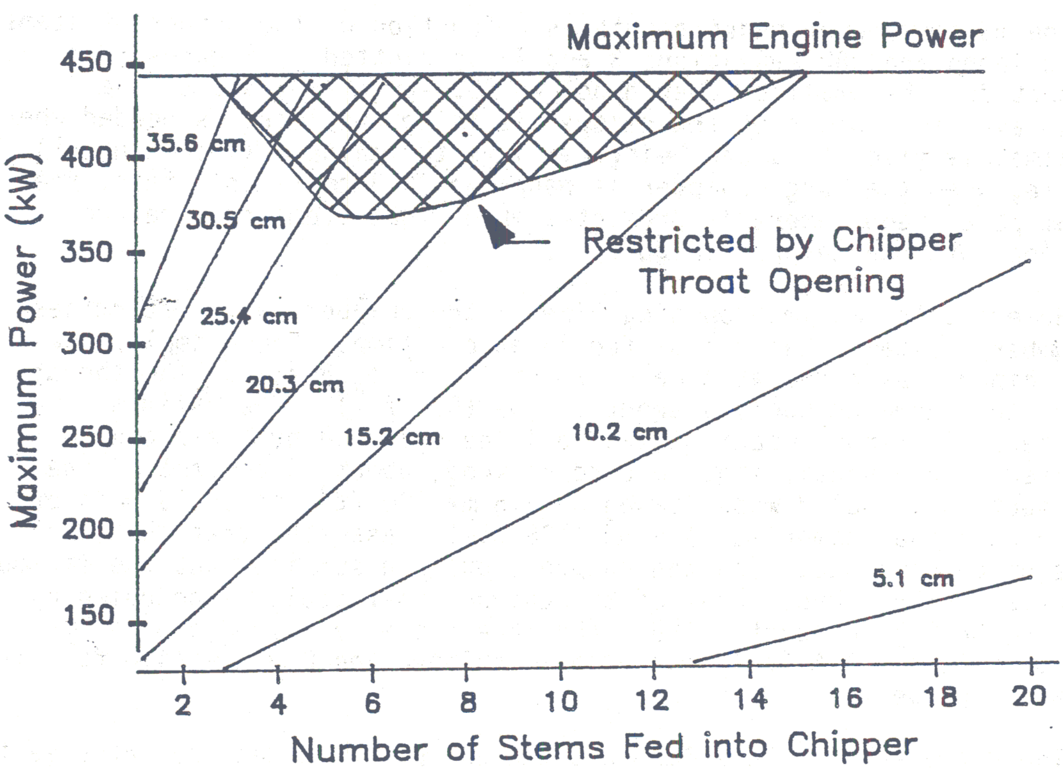

Figure 2. Maximum power requirements for the large chipper as a function of number of stems being fed and stem diameter.

Small chipper

$$\text{Number of stems} = \frac{0.22\ \text{cm}^2}{\left[\frac{1.2 \times \text{DBH(cm)}/100}{2}\right]^2 \times 3.14} = \frac{1946.2}{[\text{DBH(cm)}]^2} \qquad (5)$$

$$\text{Number of stems} = \frac{2.4\ \text{ft}^2}{\left[\frac{1.2 \times \text{DBH(in)}/12}{2}\right]^2 \times 3.14} = \frac{305.5}{[\text{DBH(in)}]^2}$$

Large chipper

$$\text{Number of stems} = \frac{0.37\ \text{cm}^2}{\left[\frac{1.2 \times \text{DBH(cm)}/100}{2}\right]^2 \times 3.14} = \frac{3273.2}{[\text{DBH(cm)}]^2} \qquad (6)$$

$$\text{Number of stems} = \frac{4.0\ \text{ft}^2}{\left[\frac{1.2 \times \text{DBH(in)}/12}{2}\right]^2 \times 3.14} = \frac{509.3}{[\text{DBH(in)}]^2}$$

Where: DBH = average tree diameter (cm or in).

When the estimated maximum number of stems required to fill the throat of the chipper are used with the power requirement estimates for the same diameter class, the chipper infeed capacity may be more limiting than chipper power. Figures 1 and 2 show the combinations of diameters and number of stems that cannot be accomodated in the chipper, even though there is sufficient power. However, the difference in the number of stems that cannot be fed and the number of stems restrained because of power requirements is small, indicating that the manufacturer has provided the necessary power for the opening size of the chipper, which is determined by the size (diameter) of the chipper disk.

REFERENCES

Bretz, Lyle R. 1986. Personal correspondence. Cummins Engine Company, Inc. Columbus, IN.

McKenzie, W. M. 1970. Chipping for pulp production. Aust. Timber J, May. p. 21-31.

Moshofsky, W. J. 1980. Timber demand - the future is fiber. Proc. of the Forest Product Research Society Conference. New Orleans, LA, No. P-80-29. p. 158-160.

Papworth, R. L. and J. R. Erickson. 1966. Power requirements for producing wood chips. For. Prod. J. 16(10):31-36.

Papworth, R. L. and K. R. Johnson. 1968. Power requirements for producing wood chips with a parallel knife chipper. For. Prod. J. 18(10):42-44.

Rogers, H. W. 1948. The wood chipper. The Paper Industry and Paper World. Sept. p. 883-888.

Watson, W. F., B. J. Stokes, and I. W. Savelle. 1986. Comparisons of two methods of harvesting biomass for energy. For. Prod. J. 36(4):63-68.