United States
Department of
Agriculture

Forest Service

Northeastern Forest Experiment Station

Research Paper NE-664

Cycle-time Equations for Five Small Tractors Operating in Low-Volume Small-Diameter Hardwood Stands

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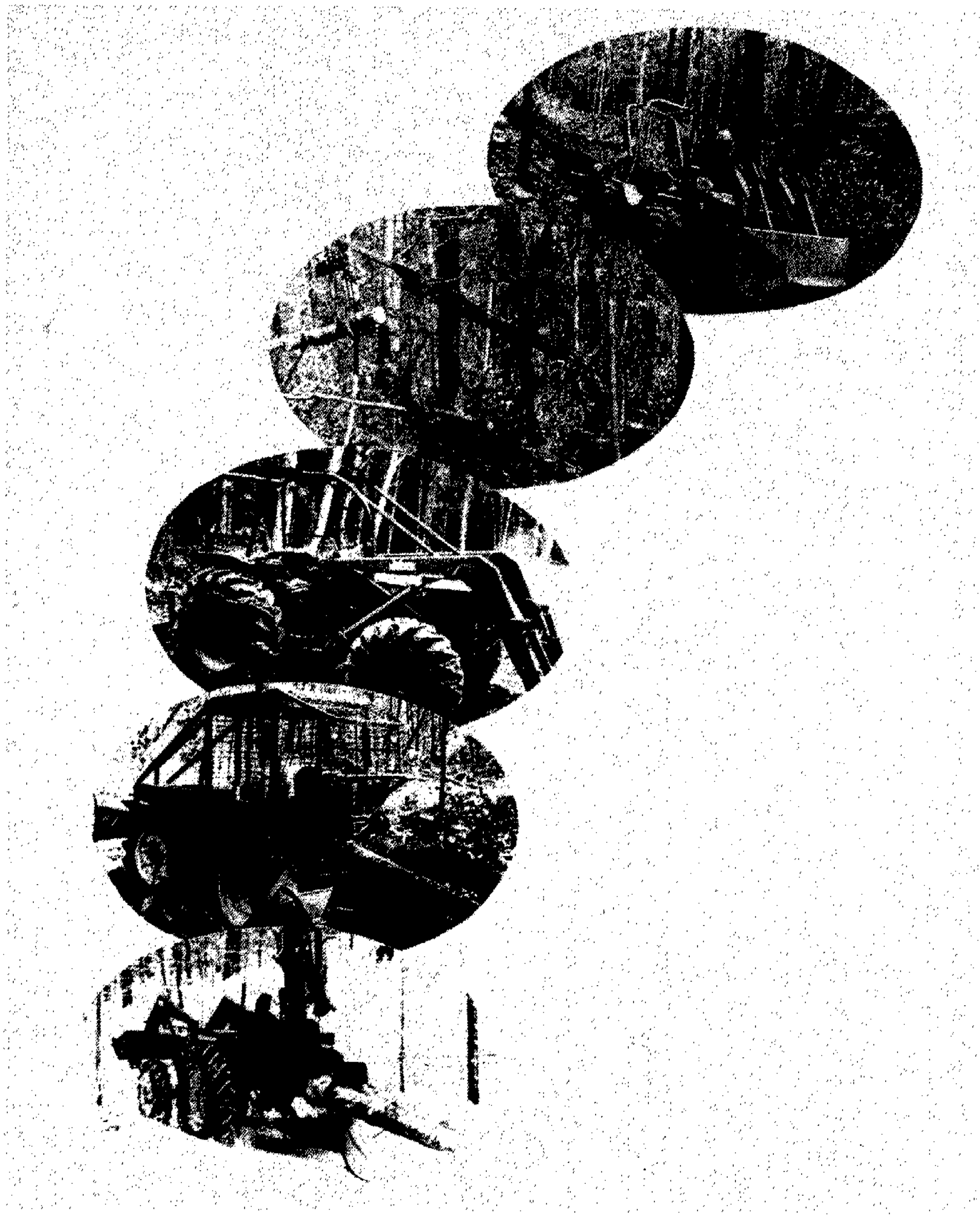

Abstract

Prediction equations for estimating cycle time were developed for five small tractors studied under various silvicultural treatments and operating conditions. Skidding costs were estimated based on the cycle-time equations. Using these equations to determine the incremental effect of log size on cost shows that hooking a 30-ft^3 log cost \$0.103/ft^3 while hooking six logs to form a 30-cubic foot turn cost \$0.234/ft^3, an increase of 127 percent. Cost relationships are illustrated for each tractor.

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Manuscript received for publication 14 April 1992.

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July 1992

Introduction

Several small tractors have entered the commercial market in the last decade. Designed for light farming, land cultivation, and forestry operations, they are relatively low cost with low horsepower (12 to 60).

Interest in using these tractors on small-scale logging operations in the northeastern and north-central regions has increased in recent years. Owners of small tracts of land see small tractors as an alternative to large skidding machines that may damage their woodlots. Also, fuelwood often is processed from small low-quality trees from stand thinnings, and harvesting such material with large equipment usually is not economical.

To evaluate and develop alternative harvesting systems, a series of time and motion studies were conducted on small-scale logging operations in the Northeast. Several small tractors were studied for a wide range of silvicultural treatments and operating conditions. The small tractors included the Pasquali 933, a Holder A60F, a Forest Ant Forwarder, a Massey-Ferguson, and a Samé Minitaurus.[1] This paper summarizes attributes, operating conditions, and cycle-time equations for these machines.

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Table 1.—Characteristics of the study sites

Tractor	Study site no.	Average tree d.b.h.	Basal area		Ave. skidroad slope		Loaded skid direction	Type of cut
			Precut	Postcut	Primary	Secondary		
		Inches	*ft²/acre*		*Percent*			
Massey-Ferguson	1	9.4	109	80	4	22	Downhill	Selection
Massey-Ferguson	2	10.3	90	0	6	17	Uphill	Regeneration clearcut
Massey-Ferguson	3	10.3	90	0	6	2	Uphill	Regeneration clearcut
Samé	4	11.0	110	85	5	15	Downhill	Selection
Pasquali	4	8.6	116	76	0	14	Uphill	Low thinning
Holder	4	8.6	116	76	0	14	Uphill	Low thinning
Forest Ant	5	8.4	96	71	0	12	Uphill	Low thinning

Table 2.—Summary of cycle-time elements for five small tractors

Item	Outhaul	Hookup	Inhaul	Unhook	Hook	Productive	Time Delay	Total
			MASSEY-FERGUSON (119/878)[a]					
Average time (minutes)	5.31	11.15	4.68	5.74	–	26.88	7.26	34.14
Standard deviation	2.02	11.58	2.15	2.81	–	12.86	9.09	15.54
Percent of total time	15.55	32.66	13.71	16.81	–	78.73[b]	21.27	100.00
			SAMÉ (29/2,183)[a]					
Average time (minutes)	11.58	13.69	10.73	7.39	–	43.40	17.74	61.14
Standard deviation	5.63	9.28	4.73	3.33	–	14.58	31.25	32.12
Percent of total time	18.94	22.39	17.55	12.09	–	70.98[b]	29.02	100.00
			HOLDER (45/627)[a]					
Average time (minutes)	2.50	10.30	2.50	4.20	.30	19.80	3.90	23.70
Standard deviation	0.57	2.45	0.65	1.20	0.59	–	4.96	5.95
Percent of total time	10.60	43.60	10.60	17.40	1.30	83.50[b]	16.50	100.00
			PASQUALI (65/402)[a]					
Average time (minutes)	2.70	9.60	2.70	1.70	.20	16.90	8.30	25.20
Standard deviation	1.08	3.71	.98	.64	.66	–	20.42	21.22
Percent of total time	10.70	38.20	10.70	6.70	.80	67.10[b]	32.90	100.00
			FOREST ANT (30/237)[a]					
Average time (minutes)	2.50	13.50	2.00	1.00	–	19.00	9.10	28.10
Standard deviation	1.03	4.24	1.00	.58	–	–	12.27	13.91
Percent of total time	8.90	48.20	7.10	3.50	–	67.70[b]	32.30	100.00

[a]Number of observations/mean skidding distance (ft).
[b]Machine utilization rate.

Logging Equipment and Sites

The Pasquali 993 tractor is manufactured in Italy and was designed for use on small farms, landscaping projects, and light construction work. It is powered by a 30-hp engine and has an articulated frame with four-wheel drive. The tractor was equipped with a three-point hitch, live power takeoff (PTO), and a JL-25 Farmi logging winch. The winch has a 5,500-pound line-pulling capacity, spooled with 100 feet of 3/8-inch cable. The Pasquali tractor is 4-1/2 feet wide and 8 feet long, excluding a 4-foot bucket. Safety options include liquid-loaded front and rear tires, rollbar, skid pan, and wheel chains.

The Holder A60F tractor is manufactured in Germany and was designed for farm use and light forestry operations. It is powered by a 48-hp engine with an articulated frame. The tractor is equipped with a 3-point hitch, live power takeoff, and an Igland Jones 3000 double-drum winch. The winch has a 6,600-pound line-pulling capacity, spooled with 120 feet of 3/8-inch cable. Safety options include wheel weights, forestry cab, rollbar, and skid pan.

The Forest Ant is manufactured in Sweden and was designed to forward stems to the main skid trails in large forest operations. This small four-wheel drive tractor has a 12-hp engine with an articulated frame. It is equipped with a knuckleboom loader and clam bunk. The tractor steering and speed are controlled by a tiller bar in front. The machine has no cab and the operator walks at a comfortable speed with the machine following.

The Massey-Ferguson 184-4, manufactured in the United States, is a medium-size, four-wheel drive farm tractor. It has a 60-hp diesel engine and is equipped with a three-point hitch and live power takeoff, and a JL-456 Farmi winch with a line-pulling capacity of 10,000 pounds. Tire chains were used on the rear tires and extra weight was added to the front tires. All tires were loaded with calcium chloride for weight.

The Samé Minitaurus 60 is manufactured in Italy and is designed for use on small farms. It is a medium-size, four-wheel drive tractor with a 60-hp engine. It is equipped with a three-point hitch, live power takeoff, and a JL30 Farmi logging winch. The winch has a 6,600-pound line-pulling capacity, spooled with 165 feet of 3/8-inch cable. Safety options include a bucket loader, front wheel weights, loaded rear tires, wheel chains, and rollover protection.

Attributes of the study sites are shown in Table 1 and detailed in Huyler et al. (1984); Turner et al. (1987); Huyler and LeDoux (1989); and Huyler and LeDoux (1991).

Skidder Production Rates

Table 2 summarizes cycle-production data for the five machines studied. The data were recorded by two technicians trained in continuous time-study techniques. One technician was located in the woods at the hookup site and the other was at the landing. Work-cycle elements were timed to the nearest 1/10 minute with a stopwatch, two-way radio communication was used. Individual logs were scaled at the landing or at the hooking point on a turn-by-turn basis. Other turn attributes such as slope yarding distance, were similarly recorded. Table 3 summarizes mean production data for each tractor. Figure 1 summarizes operating delays during the time-study operation as a percentage of total observed time.

Regression analysis was performed on the time-study data of each machine to develop prediction equations for estimating cycle time, excluding delays. Variables were selected such that each equation would be similar. Variables included slope yarding distance, turn volume, logs per turn, and volume per log. Table 4 lists the prediction equations obtained by regression analysis of the skidding production cycle for each of the five machines. The equations were chosen by comparing overall R^2 values and levels of significance of the estimated regression

Table 3.—Mean production data for each tractor

Tractor	Stems/turn	Volume/turn	Volume production/ hour[a]	Volume/ scheduled hour
	Number	*ft^3*	*Cords*	
Massey-Ferguson	3.78	46.9	1.32	1.04
Samé	3.98	66.2	1.12	.80
Holder	5.67	48.4	1.85	1.54
Pasquali	3.94	22.8	1.01	.68
Forest Ant	7.10	34.9	1.39	.94

[a]Without delay time.

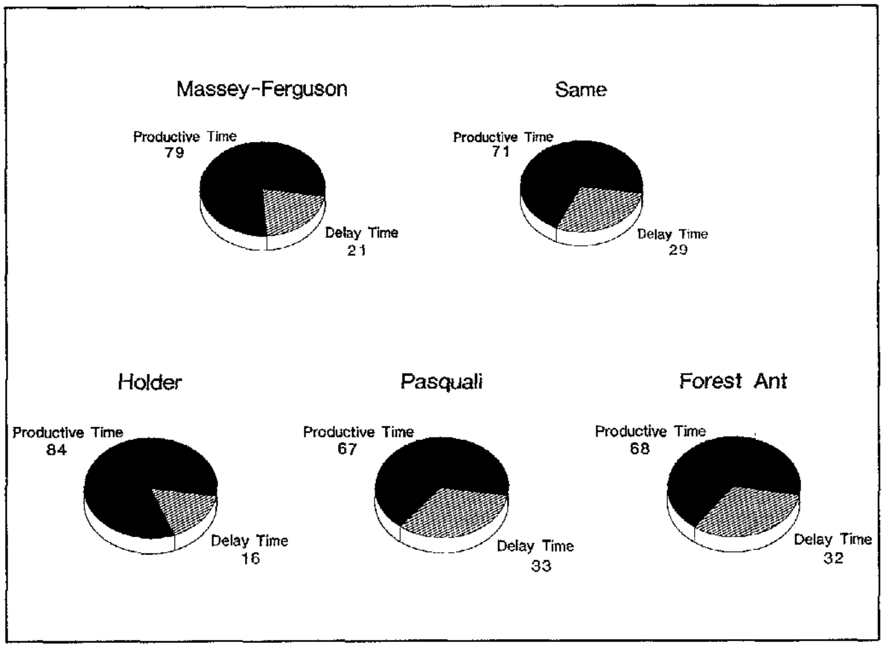

Figure 1.—Yarding delay as a percentage of total time observed.

coefficients. Although not all of the regression coefficients were statistically significant, we found it useful to include some of these variables in the equations for comparison purposes.

Skidding Costs

Skidding costs for each system listed in Table 5 are based on the total hours worked and the purchase of all new equipment. The costs do not include an allowance for profit and risk. Results for the Holder A60F are used in the examples that follow to illustrate the incremental effect of each variable on the cost of skidding small-diameter trees.

Data from Tables 4 and 5 were integrated using a computer program. The output was used to develop Figure 2, which shows the incremental effect of each respective variable in the regression equation on cost per volume produced. The variable of interest was allowed to change in value while other variables were held constant at the observed mean value.

Table 4.—Prediction equations obtained by regression analysis, excluding delays (estimates of cycle time in minutes) for five small tractors

	Equation									
Tractor	Constant		Slope yarding distance (ft)		Turn volume (ft^3)		Logs/turn (no.)		Volume/turn (ft^3)	R^2
Pasquali	Y=8.990**	+	0.009_{X1}**	+	0.318_{X2}[a]	-	0.110_{X3}	-	0.307_{X4}	51.2
Massey-Ferguson	Y=4.346	+	0.011_{X1}**	+	0.351_{X2}	+	0.810_{X3}	-	0.111_{X4}	29.0
Holder	Y=15.574**	+	0.007_{X1}**	+	0.141_{X2}	-	0.473_{X3}	-	0.540_{X4}**	64.2
Forest Ant	Y=4.948	+	0.005_{X1}	-	0.107_{X2}	+	1.762_{X3}**	+	2.672_{X4}**	59.2
Samé	Y=19.451	+	0.011_{X1}**	+	0.138_{X2}	-	0.894_{X3}	-	0.325_{X4}	33.6

[a]Significant at 0.10 percent level.

**$p<0.01$.

Figure 2A suggests that as slope yarding distance increases, cost per volume produced increased. For example, skidding costs at the average turn volume and logs per turn would be $0.194/ft^3 for a slope yarding distance of 500 feet. However, a distance of 1,000 feet would increase the cost by 21.1 percent to $0.235/ft^3.

Figure 2B shows the effect of varying the number of logs and volume/log skidded per turn while the other variables are at their mean values. For example, hooking one 30-ft^3 log would cost $0.103/ft^3. By contrast, hooking six logs to form a 30-ft^3 turn would increase the cost by 127.2 percent to $0.234/ft^3. The relationship illustrated is the result of holding turn volume constant and increasing the number of pieces to make up that volume.

Incremental costs associated with skidding various volumes per turn are shown in Figure 2C. The cost to skid a 20-cubic foot turn is $0.683/ft^3. Skidding a turn volume of 60 cubic feet would lower this cost by 67.9 percent to $0.219/ft^3.

Figure 2D shows the incremental effect of skidding logs of different sizes. The cost of skidding logs that average 5 ft^3 with all other variables at their mean values is $0.234/ft^3. Increasing log size to 20 ft^3 lowers the cost by 30.3 percent to $0.163/ft^3.

Table 5.—Owning and operating and labor rates for five small tractors

Tractor	Own and operate[a]	Labor[b]	Total hourly
	Dollars		
Pasquali	5.77	6.75	12.52
Forest Ant	4.27	6.75	11.02
Massey-Ferguson	5.62	6.75	12.37
Holder	14.42	6.75	21.17
Samé	5.41	6.75	12.16

[a]Based on 1988 new equipment cost, depreciation, insurance, taxes, interest, storage, operating cost (fuel, oil, lubricants, maintenance, and repair).
[b]Labor rate at $5.00/hour plus 35-percent fringe benefits.

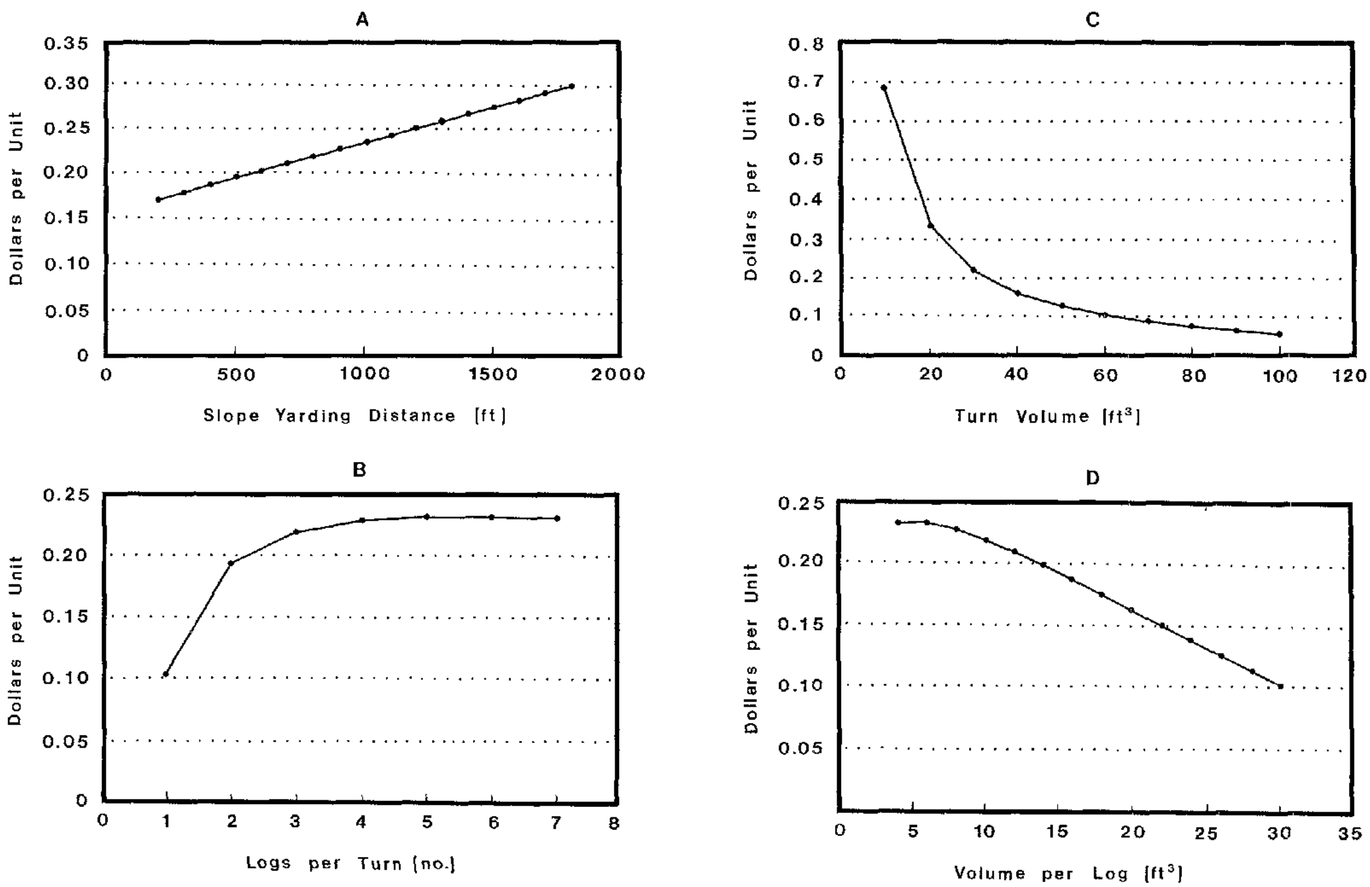

Figure 2.—Incremental effects of skidding variables on costs for Holder Tractor for following conditions (mean values): (a) slope yarding distance, 800 feet; (b) number of logs per turn, 3; (c) turn volume, 30 ft^3; (d) volume per log, 10 ft^3.

Discussion

Besides the prospect of increased revenue from the sale of selectively removed small-diameter stems, there are other benefits from removing wood of this size: fuel loadings on the site are reduced; one can enter young stands and conduct silvicultural thinnings and cleanings; habitat that promotes forest insects and diseases is removed; and visual management is enhanced. Additional research should focus on matching specific machines to stand and site conditions.

Cycle-time and production estimators by machine, along with the range of stand and forest conditions, could be used as input to select simulation models. Simulators would be run repeatedly over the range of conditions of interest. The resulting cost or production data points by machine and forest condition could be summarized in a mathematical equation suitable for incorporation into generalized stump-to-mill models that can be used by managers, planners, and loggers to estimate logging costs.

Forest-land owners and users are placing increased demands on the forest for a variety of uses. Often, the silvicultural treatment needed to bring the woodlot or forest to the desired condition generates associated logging and harvesting costs. Generally, the revenues needed to offset these costs are derived from the value of the wood harvested. The results presented here along with the results of research in progress should provide managers, planners, loggers, and landowners with detailed and accurate logging cost estimators that can be used to evaluate and quantify the tradeoffs posed by different forest uses and allow for comparison and selection of equipment.

Literature Cited

Huyler, Neil K.; Koten, Donald E.; Lea, Richard V.; Quadro, Anthony P. 1984. **Productivity and cost of three small fuelwood skidders.** Journal of Forestry. 82(11): 671-674.

Huyler, Neil K.; LeDoux, Chris B. 1989. **Small tractors for harvesting fuelwood in low-volume small diameter hardwood stands.** In: Proceedings of the 12th annual meeting of the Council on Forest Engineering; 1989 August 27-30; Coeur d'Alene, ID. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region: 61-66.

Huyler, Neil K.; LeDoux, Chris B. 1991. **A comparison of small tractors for thinning central hardwoods.** In: McCormick, Larry H.; Gottschalk, Kurt W., eds. Proceedings, 8th central hardwood forest conference; 1991 March 4-6; University Park, PA. Gen. Tech. Rep. NE-148. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 92-104.

Turner, Terry L.; Bousquet, Daniel W.; Huyler, Neil K. 1987. **Productivity and operating cost of two medium-size tractors harvesting northern hardwoods in Vermont.** Burlington, VT: University of Vermont, School of Natural Resources. 23 p.

LeDoux, Chris B.; Huyler, Neil K. 1992. **Cycle-time equations for five small tractors operating in low-volume small-diameter hardwood stands..** Res. Pap. NE-664. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

Prediction equations for estimating cycle time were developed for five small tractors studied under various silvicultural treatments and operating conditions. The tractors studied included the Pasquali 933, a Holder A60F, a Forest Ant Forwarder (Skogsman), a Massey-Ferguson, and a Samé Minitarus. Skidding costs were estimated based on the cycle-time equations. Using these equations to determine the incremental effect of log size on cost shows that hooking a 30-ft^3 log cost \$0.103/ft^3 while hooking six logs to form a 30-cubic foot turn cost \$0.234/ft^3, an increase of 127 percent.

Keywords: Harvesting, thinning, cost, production

☆ U.S. GOVERNMENT PRINTING OFFICE: 1992—648-139/40,022

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