SOIL DISTURBANCE AND PRODUCTIVITY FROM WIDE-TIRED SKIDDER TRIALS IN MINNESOTA ASPEN HARVESTS

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Abstract—The soil disturbance and productivity of wide-tired and narrow-tired skidders was compared on aspen harvests in east-central Minnesota. Split plot comparisons showed that wide-tired skidders (73-44.00x32 tires) had cycle times 16 percent greater than the narrow-tired skidder (30.5Lx32 tires) for an average travel distance of 160 meters. The increased total cycle time for the wide-tired skidder came partly from significantly greater load building time. Since adequate traction and flotation were available throughout the harvest trials, wide-tired skidders had no advantage in any of the cycle elements. No significant difference was detected for production (tonnes/productive machine hour) partly due to small sample size. The mineral soil upland sites used in the study did not present any difficulty in operability for either skidder. The area in shallow depressions and ruts ranged from 2 to 23 percent (mean = 12 percent) with no significant difference due to tire size. During the study the application of the wide-tired skidder was affected by 1) poor truck access over haul roads and landings which restricted activity when soils were wet and 2) other production bottlenecks such as trucking limitations and volume quotas which limited operation productivity.

INTRODUCTION

In the Lake States, harvesting operations are often restricted during and following the spring snow melt (often referred to as spring break-up) because of the potential of soil damage and low harvesting productivity. Operators can be idle for as long as three months in this period. In an effort to recover productive time during this period and decrease soil impact throughout the growing season loggers are experimenting with wide tires.

A number of production trials comparing skidders with wide tires to those with conventional tires reported increased skidder productivity for wide-tired skidders on wet, level terrain (Hassan and Gupta 1988, Heidersdorf and Ryans 1986, Mellgren and Heidersdorf 1984, Novak 1988). In addition to productivity benefits, the increased mobility of skidders equipped with wide tires was also an important production benefit (Meek 1994, Mellgren and Heidersdorf 1984, Novak 1988).

Comparison of rutting in operational trials on swampy sites showed that while wide tire application reduced rut depth, the total coverage of ruts was only slightly lower for wide-tired skidders (Groot 1987, Heidersdorf and Ryans 1986, Novak 1988). Although wide-tired skidder use reduced soil compaction and maintained higher infiltration when compared to the narrow-tired skidder use, Aust and others (1991) cautioned that operation of skidders on wet sites made possible by wider tires could produce greater soil impact due to the increased site access not possible with narrow tires.

While the primary motive of wide tire use may be to decrease site disturbance, production comparisons may provide loggers and foresters with decision criteria for wide tire application. The objectives of this research were to compare a) the production of wide-tired and narrow-tired skidders on upland aspen sites and b) the soil disturbance resulting from the trials.

SITE DESCRIPTION

Research sites were established in northern Kanabec and Mille Lacs counties of east-central Minnesota. Each of the five sites were between six and eight hectares in size. The forest cover was generally aspen and mixed hardwood forest that varied slightly in composition, topography, and drainage. Tree volume, volume per acre, and stand basal area varied slightly among the sites (table 1).

The gently sloping sandy loam soils on the research sites were derived from glacial till. The soils were generally classified as having moderate drainage, but the dense till layers about 50 to 100 centimeters below the surface restricted drainage. Each site included small wetland or low areas with organic surface horizons. Site 1 had slightly better drainage than sites 2, 3, and 4. Site 5 had the poorest drainage and approximately 40 percent of the site was covered by poorly drained soils with organic surface horizons. Sites 1 and 4 had the most topographic relief (5-20 percent slope), sites 2 and 3 were gently rolling (5-10 percent slope), and site 5 was nearly flat (0-5 percent slope).

METHODS

The sites were divided into approximately equal halves or harvest areas for application of either the wide-tired or narrow-tired skidder. The harvest of sites 1 and 2 began in mid July and was completed at the end of August in 1991. In 1992 harvesting commenced on site 3 on May 25 and all sites were harvested by July 17. Efforts were made to begin harvesting as early as possible, but the poor condition of site access roads delayed harvesting in both years to the dates listed.

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Citation for proceedings: Stringer, Jeffrey W.; Loftis, David L., eds. 1999. Proceedings, 12th central hardwood forest conference; 1999 February 28-March 1-2; Lexington, KY. Gen. Tech. Rep. SRS-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 293 p. [Peer-reviewed paper].

Table 1—Stand variables for each harvested site

Stand variable	Site 1	2	3	4	5
Volume/tree (m^3)[a]	0.20	0.29	0.21	0.30	0.27
Merchantable trees (#/ha)[a]	449	480	380	395	296
Volume/hectare (m^3/ha)[a]	88	138	80	119	80
Basal area (m^2/ha)[b]	24.7	32.5	22.8	31.1	24.4

[a] Northern red oak was excluded. Merchantability standards were dbh > 15 cm, top diameter >10 cm (dob), and merchantable height > 5 m.
[b] Included all trees with dbh > 2.5 cm.

In 1991 the logging firm had two skidder operators, one operator for each skidder-tire combination. In 1992 a single operator was used for both skidders. All operators had extensive experience (> 5 years) in skidder operation and at least one year of experience with the wide-tired skidder.

Trees were skidded to the landing in tree-length form on all sites except site 5 where it was full-tree skidded and chipped at the landing. A John Deere (JD) 640D grapple skidder was employed for most of the study with limited use of a JD 648D grapple skidder (site 1 and 4). The narrow-tired skidder was equipped with 30.5Lx32 tires, and the wide-tired skidder was equipped with 73-44.00x32 tires. The JD 648D was used only as the narrow-tired skidder. In 1991 felling was accomplished with a JD 643 equipped with 64-34.00x26 tires in wide-tired configuration and 28Lx26 tires in the narrow-tired configuration (sites 1 and 2). In 1992 a Case tracked excavator with a feller-buncher head was used for felling all harvests (sites 3, 4 and 5).

Soil Conditions

Forty-four permanent plots were located randomly throughout each site prior to harvest for collection of soil information. On the same day that the area around the plot was skidded, soil samples were collected with a probe from undisturbed soil near the permanent plot markers from 0 to 20 centimeter and 20 to 40 centimeter depths. The soil samples were dried for 24 hours at 105° C and the gravimetric soil moisture was calculated.

The soil disturbance sampling technique was based on that described by Howes and others (1983). The permanent plot markers were used as starting points for the transects. Ten points, 3 meters apart, were located along the transect which was oriented at a random azimuth. The area below each point was categorized as undisturbed, slash covered, rutted, mineral soil exposure, water covered, rocks, or stumps. The points with possible soil compaction were categorized as shallow depressions (< 5 centimeters), moderate ruts (≥ 5 and < 15 centimeters), and deep ruts (≥ 15 centimeters). Mineral soil exposure included conditions ranging from mixed mineral soil and organic matter to complete removal of the surface organic layer.

The proportion of area compacted (shallow depressions and all ruts), moderate and deep ruts combined (≥ 5 centimeters), no disturbance, and all disturbance (all compacted classes plus mineral soil exposure) were the dependent variables modeled with a transformed logistic model (Neter and others 1985). The model included site, treatment (wide-tired or narrow-tired skidder harvest), and the interaction of site and treatment. The surface soil moisture (0 to 20 centimeters) for each sampling point was included as a covariate. The F ratio for the treatment was formed by the ratio of treatment mean square to the interaction mean square appropriate for nested designs.

Continuous Timing and Production

During the narrow- and wide-tired skidder harvests, 50 to 100 entire skidding cycles were timed midway though each harvest. The major skidding elements timed were unloaded travel, loaded travel, load building, delay, piling, and trail building. Load building included all maneuvering and hookup activities to build the load. Location of landmarks and permanent plot locations were used to estimate the loaded travel distance or travel distance(from the landing to the first bunch collected). Travel distance was collected for each cycle regardless of continuous timing. Missing data resulted in different sample size for elements. During continuous timing load size was measured only as trees per load.

The cumulative production data were collected over 2 to 5 days of production from each harvest area. To make up for the small number of sites, additional cumulative production samples were created from each site when the operation stopped completely due to circumstances like serious breakdown or poor weather conditions. A total of 15 production samples were collected. Data collected included total production (stick or weight scaled in tonnes), total productive time, number of cycles, and fuel use, and the travel distance for each cycle. From those data total cycle time, average load size, average travel distance, production per hour, and fuel consumption were calculated.

The dependent variables from continuous timing and cumulative production data were modeled using the GLM procedure (SAS Institute 1988) with the expanded model: site, treatment (tire: narrow or wide), travel distance (covariate), and the interactions tire*site and tire*travel distance. If the F value (type III sums of squares) for the interaction, tire*travel distance, was not significant ($P < 0.10$), it was deleted from the model and a reduced model was used.

RESULTS AND DISCUSSION

Soil Disturbance

Soil moisture conditions on sites 1, 3, 4, and the narrow-tired area of 5 had similar average soil moisture at both soil depths (table 2). Organic areas within the wide-tired area of site 5 had increased average soil moisture, and the August harvest date of site 2 resulted in considerably drier soil during the harvest.

Tire size was not a significant factor in any of the disturbance measures ($P < 0.10$), and site was largely the only significant term in the models. Even with moist soil conditions throughout the sites, soils provided generally adequate support for the equipment as indicated by the low coverage of deep ruts across all sites (table 3). The low level of soil disturbance on site 2 could be related to the dry soil. The low soil disturbance on site 5 was produced in part by the concentrated skidding pattern present. Relatively high levels of disturbance, especially on sites 1 and 4, resulted from the high skid trail density produced by unplanned skid trails. The change from wheeled (sites 1 and 2) to tracked feller buncher (sites 3, 4, and 5) was not obvious from the site totals, but was correlated with generally drier (sites 1 and 2) and generally (sites 3, 4, and 5) wetter soil conditions in the successive harvest years.

Continuous Timing and Production

Model P values were generally lower for the cumulative production data than for continuous timing data due in part to the smaller sample size and the increased error

Table 2—Completion date and average soil moisture data for the harvest areas harvested by the wide-tired (W) or narrow-tired (N) skidder

Site	Harvest date	Harvest area	Gravimetric soil moisture	
			0 to 20 cm	*20 to 40 cm*
1	7/91	W	0.38	0.22
		N	0.38	0.22
2	8/91	W	0.18	0.12
		N	0.20	0.14
3	6/92	W	0.39	0.26
		N	0.33	0.19
4	6/92	W	0.39	0.26
		N	0.39	0.24
5	7/92	W	0.69	0.36
		N	0.36	0.25

Table 3—Soil disturbance categories for the narrow-tired (N) and wide-tired (W) skidder harvest areas for each site. Totals do not equal 100 percent since coverage of natural water filled depressions, stumps, and rocks was omitted

	Site									
	1		2		3		4		5	
Disturbance class	W	N	W	N	W	N	W	N	W	N
1) Shallow depressions (<5 cm)	18	10	5	7	8	8	14	12	7	2
2) Moderate ruts (> 5 cm,< 15 cm)	5	2	2	1	2	5	3	6	0	0
3) Deep ruts (> 15 cm)	0	1	1	0	1	1	1	1	0	0
Total depressions (TD)(1 + 2 + 3)	23	13	8	8	11	14	18	19	7	2
Slash cover	17	20	20	20	14	17	15	22	15	21
Mineral soil (MS)	27	40	33	41	36	38	36	30	25	29
Total disturbed (MS + TD)	50	53	41	49	47	52	54	49	32	31
Total undisturbed	18	26	37	27	36	26	30	30	49	43

explained by the covariate, travel distance, in the continuous timing models (table 4). In the continuous timing data each cycle had a travel distance estimate whereas in cumulative production data the total cycle time and travel distance where averages for that cell. In the continuous timing models, significant ($P < 0.10$) differences for tire size were found for load building time and for travel distance and tire interactions for total cycle time and delay. In the cumulative production data a significant difference was found for only total cycle time.

With the continuous timing data the difference between wide-tired and narrow-tired skidder total cycle time increased with increasing travel distance. This was indicated by the significant interaction, tire*travel distance. The total cycle time for the wide-tired skidder increased with travel distance about 22 percent faster than the narrow-tired skidder total cycle time (figure 1). The delay model also had a significant interaction, tire*travel distance, and produced results similar to the total cycle time model with respect to the wide-tired skidder. Although the delay model is significant, the R^2 is only 0.055 compared to over 0.30 for all other element models. The interaction term was not significant for any other element, but the model predicted load building times 0.38 minutes/cycle greater for the wide-tired skidder across all travel distances.

In trials on wet terrain the cycle time advantage for wide-tires was produced during the travel elements of the cycle (Hassan and Gupta 1988, Heidersdorf and Ryans 1986, Mellgren and Heidersdorf 1984, Novak 1988). The similarity of unloaded and loaded travel times in this trial might indicate that the wide-tires were not able to produce improvements in traction or reduction in slip because of the relatively firm soil conditions present throughout the harvests. Similar or smaller increases in load building time for wide-tired skidders over narrow-tired skidders have been reported in the previous trials. The delay time

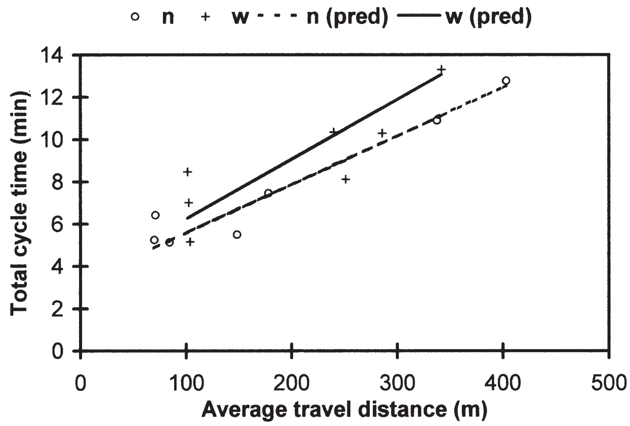

Figure 1—Average observed total cycle time from the harvest areas and predicted total cycle time from the continuous timing model for wide-tired (+) and narrow-tired (o) skidders versus average travel distance.

difference is difficult to explain since reasons for the delays in this study were not completely specified. The significant differences might result partially from confounding among site, delay time, and travel distance. Travel distance and site are somewhat confounded since a few sites contribute the majority of very long travel distances. The confounding problem is greater with the continuous timing data since most of the data for a site is taken over the more limited range of travel distances traversed in one or two days.

The high R^2 in the cumulative production models were mainly the result of limited replication within the harvest areas on each site. Only one model, total cycle time was significant at even a high P value of 0.10. The estimate of total cycle time was calculated as the total productive time divided by the number of cycles in the sample period (figure 2). These estimates were larger for a given travel

Table 4—Model R^2, N, and P value and tire, travel distance (TD), and tire*travel distance interaction P values for continuous timing and cumulative production data. If the tire*travel distance interaction was not significant ($P < 0.10$), model, tire, and travel distance interaction P values are from the reduced model without that interaction term

	Model			P values				Model			P values		
Continuous timing	P value	N	R^2	Tire	TD	Tire*TD	Cumulative production	P value	N	R^2	Tire	TD	Tire*TD
Unloaded travel	0.0001	737	0.85	0.422	0.0001	0.549	Total cycle time	0.006	15	0.96	0.093	0.003	0.737
Load building	0.0001	760	0.30	0.020	0.0001	0.631	Production	0.246	15	0.79	0.128	0.191	0.359
Loaded travel	0.0001	776	0.85	0.565	0.0001	0.400	Load size	0.448	15	0.70	0.693	0.365	0.388
Delay	0.0001	894	0.06	0.186	0.0001	0.001	Fuel use (l/t)	0.310	13	0.87	0.359	0.065	0.812
Total cycle time	0.0001	703	0.50	0.370	0.0001	0.001	Fuel use (l/pmh)	0.626	13	0.74	0.271	0.412	0.506

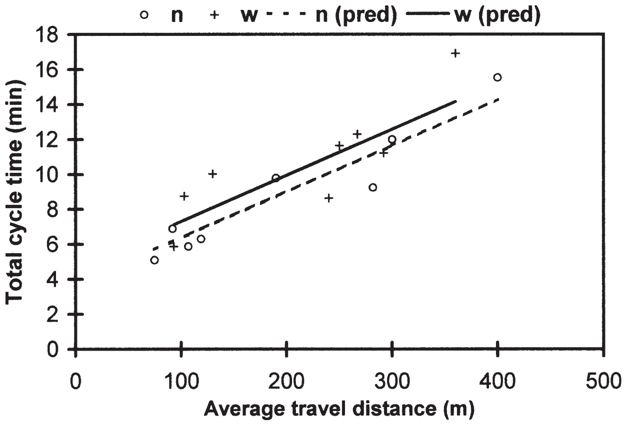

Figure 2—Predicted total cycle time from the cumulative production model and observed sample average total cycle time for wide-tired (+) and narrow-tired (o) skidders versus average travel distance.

distance than those from the continuous timing data, probably because cumulative production data contained the slower production periods that occurred at the beginning and end of the harvests. Total cycle time estimates for the wide-tired skidder were 0.92 minutes/cycle greater than those for the narrow-tired skidder across all travel distances. Significant total cycle time differences did not translate into significant differences in production (figure 3). Variation in load size could have introduced enough variability into production to mask the significant difference observed in total cycle time.

CONCLUSIONS

The relatively dry to moist soil conditions present throughout the study period prevented, for the most part, the demonstration of the advantages of wide-tires evident when used on softer, moister soil. However, wide tires did not produce any significant disadvantage in the travel elements of the cycle. The increased total cycle time for the wide-tired skidder seemed to be the result of accumulated insignificant differences in unloaded and loaded travel time and the significant differences in delay and load building times.

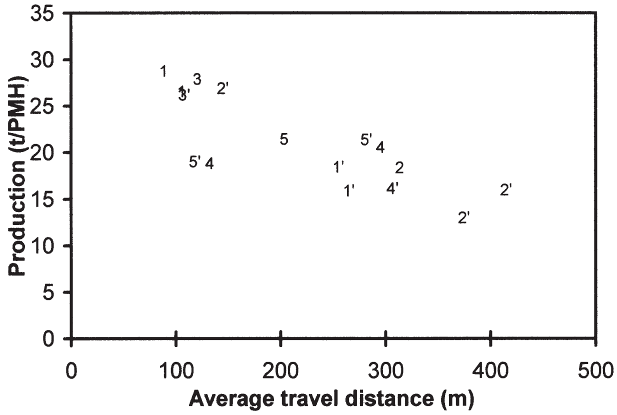

Figure 3—Production estimates versus average travel distance. Observations from narrow-tired harvest areas are indicated by the site numbers (1 - 5) alone. Observations from wide-tired harvest areas are indicated by the site number followed by an apostrophe. 1 and 1' represent narrow-tired and wide-tired skidder observations, respectively, from site 1.

Operators commented that it was more difficult to maneuver around stumps and rocks in the harvest areas due simply to the extra width of the tires. They were operating the wider tires with inflation pressures near 210 kPa due to dealer recommendations to prevent the bead separation from the rim. With the high pressure in the wide tires, jolts from running over obstacles were transferred to the operator rather than at least partially absorbed by the tire. The rougher ride may have been less important in travel element than load building since a relatively obstacle-free path could be chosen for repeated use.

Production bottlenecks might have had considerable effect on both production and total cycle time. Although landing placement emphasized access to all weather roads, the inability of trucks to get to the landing and remove stored wood inhibited production for as many as several days following rains that occurred throughout the study period. Since landing space was constantly limited due to either restricted road access or the supply of trucks, operators had no incentive or ability to increase production. As an example site 5 had similar production across a wide range in travel distance caused by the limited chipper capacity and inadequate supply of chip vans (figure 3).

Differences in site disturbance were also muted somewhat by the firm soil conditions during operation. The near absence of deep rutting indicated the soil's ability to provide both flotation and thrust for both machines. However, the lack of significant difference in areal extent of rutting is a result similar to other studies on much softer and moister terrain. The majority of differences in the areal extent of disturbance and rutting among sites was probably due more to uncontrolled factors such as feller-buncher type and activity, topography, and harvest layout.

The results of this study did not help to significantly clarify issues of comparative productivity of wide-tired and narrow-tired skidders on upland soils similar to these. Unless wet season road and landing access is addressed in harvest planning of upland sites, the operations may be restricted even when the wide-tired machines can provide a production advantage over conventional machines.

Inability to provide access or the lack of production advantages on upland sites would leave the cost of wide tires to be recouped mostly through decreases in site disturbance. The shallow aspen roots which provide the sucker regeneration are severely damaged even by the shallowest ruts (Bates and others 1992, Smidt 1996). Differences in areal extent of disturbance which are controlled mostly by planning on dry and moist upland sites are more critical than disturbance severity.

ACKNOWLEDGEMENTS

This project was supported by the Central Minnesota Initiative Fund, Champion International Corp., Lake States Paper Industries, Inc., Legislative Commission for Minnesota Resources, the Minnesota Department of Natural Resources, Minnesota Forest Products, Inc., Potlatch Corp., Rajala Timber Co., and the University of Minnesota, Department of Forest Resources and the Minnesota Agricultural Experiment Station under Project MN 42-42.

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