Comparison of site impacts due to conventional and mechanical harvesting systems

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Abstract

The trend in forest harvesting systems has been towards increased mechanization. The objective of this study was to determine the extent and the causes of soil surface disturbances and compaction due to conventional (hand faller/hand delimber/line skidder) and mechanical (feller-buncher/grapple skidder/stroke delimber) harvesting operations on a site in central Saskatchewan. Results showed that under both operations, about 51% of the cutblock area had been trafficked. Causes and extent of impacts were similar under both systems. Average compaction in both cutblocks appeared to be within published limits for root growth. However, the intensity of compaction (final bulk density profiles) under the mechanical system was significantly greater than under the conventional system to depths of about 300 mm. Detrimental compaction levels occurred on about 15% of the sites. Severe impacts were generally associated with slopes and the wetter areas of the site and were attributed to excessive weight transfer of machinery and/or high slippage.

Introduction

In recent years there has been a trend in ground-based harvesting systems away from hand falling and line skidding toward a fully mechanical system involving feller-bunching, grapple skidding, and mechanical road-side processing. The mechanical system has significantly greater productivity than the conventional system and lower worker safety risks, but has a potential increase in site impacts.

The two most important characteristics related to the fertility of a site are the organic matter (in the forest floor and upper mineral layer) and the soil porous structure (von der Gönna and Sanders 1994). Organic matter contains the bulk of the soil nutrients essential for forest productivity and regeneration, and helps retain soil moisture and the soil porous structure. The forest floor also helps protect the underlying soil from structural damage. A good porous soil structure is important for water, air and nutrient transport, for rapid root growth, and for healthy soil biological activity. Water moves more freely through large pores and roots require less energy to expand and move through larger pores (Karr and Guo 1991).

Two major types of soil disturbance are associated largely with the operation of machinery on sites: compaction and soil displacement due to slippage. Compaction increases the bulk density and reduces macroporosity. The effects of soil compaction due to forest machinery traffic in the boreal forest may persist for several decades (Corns 1988). Excessive slippage may remove the forest floor and upper mineral horizon, limiting nutrient supply to seedlings, and increasing the risk of water erosion, and may expose unfavourable material with higher acidity and carbonate levels. The extent of these impacts depends on initial soil characteristics, and on the amount and type of applied mechanical force. These forces depend on machine configuration, machine loading, vibration, and number of machine passes.

The objectives of this study were to compare the impact of traffic under conventional and mechanical harvesting operations on forest soil disturbance and to relate the observed impacts to machine parameters.

Site and System Description

The site was located in the Whiteswan Mid-Boreal Upland Region - Mixedwood section about 110 km northeast of Prince Albert, Saskatchewan. The cut block area was located within Weyerhaueser's FMLA just south of Beaver Lake and east of Whiteswan Lakes at 54°10.5'N, 105°04.3'W. Dominant tree species included black spruce *(Picea* ***mariana)*** and white spruce *(Picea* ***glauca),*** jack pine ***(Pinus banksiana)*** and trembling aspen ***(Populus tremuloids).*** The estimated pre-harvest stand descriptions are based on Ministry of Forestry cruise information. With the exception of a tA - wS zone which had a distinct litter layer, most zones were dominated by heavy moss coverage (feather mosses, reindeer lichen). The average depth of mosses was 90 mm (range 20 - 440 mm).

Topography was variable with 46.5% of the area having slopes <5%, 28.5% slopes of 5-19%, 17.8% slopes of 20-39%, and 14.4% having slopes of 40%+ (Wulfsohn 1996). The soils of the site were moderately well to well drained Eluviated Eutric Brunisols and Gleyed Eluviated Eutric Bnmisols. The dominant soil texture in the top 400 mm was loamy sand. Average water content in the O-150 mm soil depth at the time of harvest was 14.6% + 8.0%. Organic matter content was 1.5-2.0% in the upper 150 mm soil depth, and negligible in the mineral soil below. Total nitrogen and total phosphorus levels in the mineral soil were very low (less than 0.05%). Soil pH levels ranged between 4.0-5.8, indicating acidic conditions.

The 25-ha cutblock area was divided up such as to distribute the variations in topography and forest type in similar proportions between both harvesting systems allowing for the greater productivity of mechanical felling compared to handfelling. About two thirds of the area was harvested using a mechanical system while the remaining third was harvested conventionally.

The mechanical harvesting operation comprised felling and bunching with a tracked Caterpillar 325 feller-buncher, skidding to the block roads with a rubber-tired John Deere 748G grapple skidder, and roadside processing. A ProPac stroke delimber mounted on a Caterpillar 320 carrier delimbed, topped, bucked sawlogs, and decked and sorted the wood for loading. Loading onto trucks was done with a Caterpillar 980B front-end loader. After harvesting, slash was redistributed over the site using the front-end loader. Specifications of the off-road equipment are provided in Table 1.

Table 1. Specifications of the off-road machinery.

Conventional System			
Clark 664B Cable-Skidder	Tire size (4WD)		18.4 - 34
	Approx. weight[a]		75.6 kN
Clark 664C Cable-Skidder	Tire size (4WD)		24.5 - 32
	Weight[b]	front	46.1 kN
		rear	33.8 kN
		total	79.9 kN
Mechanical System			
Caterpillar 325 Feller-Buncher	Engine power		125 kW
	Track dimensions	L 5.69 m	W 0.6 m
	Approx. weight[a]		329.6 kN
John Deere 748G Grapple-Skidder	Engine power		123 kW
	Tire size (4WD)		30.5L-32
	Inflation pressure	front	135 kPa
		rear	205 kPa
	Weight[b]	front	60.8 kN
		rear	71.6 kN

[a] Estimated from manufacturer's specifications. [b] Measured. All weights are maximums, including weight of operator and a full fuel tank.

The conventional harvesting operation comprised handfalling, delimbing at the stump, and then skidding to the landing by the main block road. Sawlogs were bucked to length at the landing, whereas, pulp logs were pulled directly onto the pulp pile. Three rubber-tired cable skidders, one Clark 664B and two Clark 664C (Table l), were used.

Experimental Procedures

The feller-buncher and the grapple skidder used in the mechanical system were instrumented to measure typical applied load distribution. Strain gauges were mounted on top of the two axle casings on both left and right sides of the grapple skidder to monitor axle load, and on the feller-buncher frame structure supporting the track assemblies.

For purposes of site impact assessment, a 60 m x 60 m sampling grid was laid out resulting in 42 points in the mechanical site and 27 points in the conventional site. At each grid point, two 30-m transects originating at the grid point, one extending in a random orientation and the second laid 90∞ to the first, were surveyed for type, depth and cause of disturbance at l-m intervals. To assess soil compaction by the two harvesting operations over the site, 2 m x 2 m sampling areas (quadrats) with one comer positioned at each one of the 69 grid points were established. Within this sampling region two sets of wet bulk density versus depth readings were taken using a CPN density gauge. If the area was partially disturbed (e.g. a rut crossed within the boundaries of the quadrat), a paired reading of undisturbed and in the rut density was made. Where the quadrat area was either totally undisturbed or completely covered by a disturbance, two sets of readings were taken as replicates, Water content was also determined using a TDR unit to enable calculation of dry bulk density.

Results and Discussion

Results of the site disturbance survey are summarized in Table 2. In both the mechanical and conventional cutblocks, roughly 49% of the areas were untrafficked (undisturbed). Of the 5 1% of disturbed areas similar proportions were organic-compacted (i.e. compaction without humus removal) and mineral-compacted (i.e. soil compaction with forest floor removal). There was substantially more gouging with mineral soil exposure (3.2% vs 0.6%) on the mechanical site because of the significantly larger bunches hauled by the grapple skidder compared to the cable-skidders. The average depth of rutting was consistently greater in the mechanical area (Table 2).

Root growth begins to be inhibited at a soil strength of 2 MPa (Greacen and Sands 1980) which occurs at about 1.5 Mg m^{-3} for most medium to coarse textured soils (Wronski and Murphy 1994). Bulk densities exceeding 1.47 Mg m^{-3} and 1.69 Mg m^{-3} for Douglas fir and lodgepole pine, respectively have been found to severely restrict root growth (Wass and Smith 1994). Based on the literature and the in-situ range of undisturbed bulk densities we used 1.6 Mg m^{-3} dry bulk density to indicate a critical level of soil compaction.

Average undisturbed and disturbed dry bulk densities versus depth over the sites are presented in Table 3. Dry bulk density was significantly increased to depths of 300 mm, with possibly excessive compaction occurring from a depth of 200 mm in the mechanical system, as opposed to 300 mm in the conventional system. Overall, approximately 85% of the total area on both cutblocks were uncompacted or non-detrimentally compacted.

Table 2. Post-harvest disturbance by soil surface condition.

Disturbance	*Conventional** % of area	*Conventional** Av. rut depth (mm)	*Mechanical*** % of area	*Mechanical*** Av. rut depth (mm)
Undisturbed	48.8		48.9	
Disturbed				
Organic-compacted	36.3	-38	30.5	-47
Mineral-compacted	3.8	-70	5.2	-86
Mineral-gouged	0.6	-53	3.2	-53
Other	10.5		12.2	
Total	100.		100.	

* 1540 sample points. ** 2185 sample points.

Table 3. Undisturbed and disturbed dry bulk densities.

Depth mm	Undisturbed Mean Mg/m^3	Undisturbed CV %	Disturbed Mean Mg/m^3	Disturbed CV %
Conventional				
50 **	*1.24*	*12.1*	*1.38*	11.6
loo *	1.37	10.9	1.46	9.6
200 *	1.46	10.3	1.55	8.4
300 *	1.52	10.5	1.60	7.5
Mechanical				
50 ***	*1.30*	*8.5*	1.40	11.4
100 ***	1.42	8.5	1.52	9.9
200 **	1.53	9.2	1.62	9.9
300 ***	1.58	8.9	1.68	8.3

*,**,*** disturbed vs. undisturbed dry bulk densities significantly different at 5%, 1%, and 0.1% levels, respectively.

The predominant cause of organic-compacted and mineral-compacted disturbance was single-pass traffic. Generally, single passes of vehicles in both systems did not cause excessive compaction. Areas of concern were predominantly in wet areas and on the slopes. Slippage of tracks and wheels often exposed mineral soil, and these disturbances were generally associated with increased compaction. In some of the wetter zones on the edge of boggy areas, puddling was observed.

Figure 1 shows dynamic load data obtained for the front left and rear left wheels of the grapple skidder. The grapple skidder has a neutral static balance (Table 1). The plot shows that the grapple skidder was not properly ballasted for operating in these conditions. During operation most of the weight was transferred from the front to the rear wheels. This was confirmed by observation, *i.e.* the skidder front wheels were often lifted off the ground. In contrast, the load distribution was found to be more balanced for the feller-buncher (data not shown). Wästerlund (1990) observed that unsuitable load distribution of machinery is a major problem causing forest site damage.

Although the dynamic load of the feller-buncher was much greater than that of the skidder, the load is carried over a much larger contact area, so that the estimated average static ground pressure beneath the feller-buncher (-48 kPa based on weight of machine) is lower than that applied by the skidders (-52-56 kPa). Our data showed that the machines may apply 1.5 to 2 times their weight to the ground, due to load transfer and vibration. Actual pressures transmitted to the ground by tracked machines can be up to three times greater than the average ground contact pressure, depending on the spacing of the track road and the strength of the soil (Wong 1989). Thus, the applied ground pressures can be expected to be on the order of 70- 130 kPa. These values agree with ground contact pressures of 30-200 kPa reported by Greacen and Sands (1980) for various logging machines. Contact ground pressures significantly affect compaction near the surface but have less effect at greater depths, where the total weight of the machine governs the degree of compaction (Chancellor 1987). The fluctuating (vibrating) nature of the forces can be highly damaging; however, the thick moss layer would have provided some measure of protection (Soane 1990).

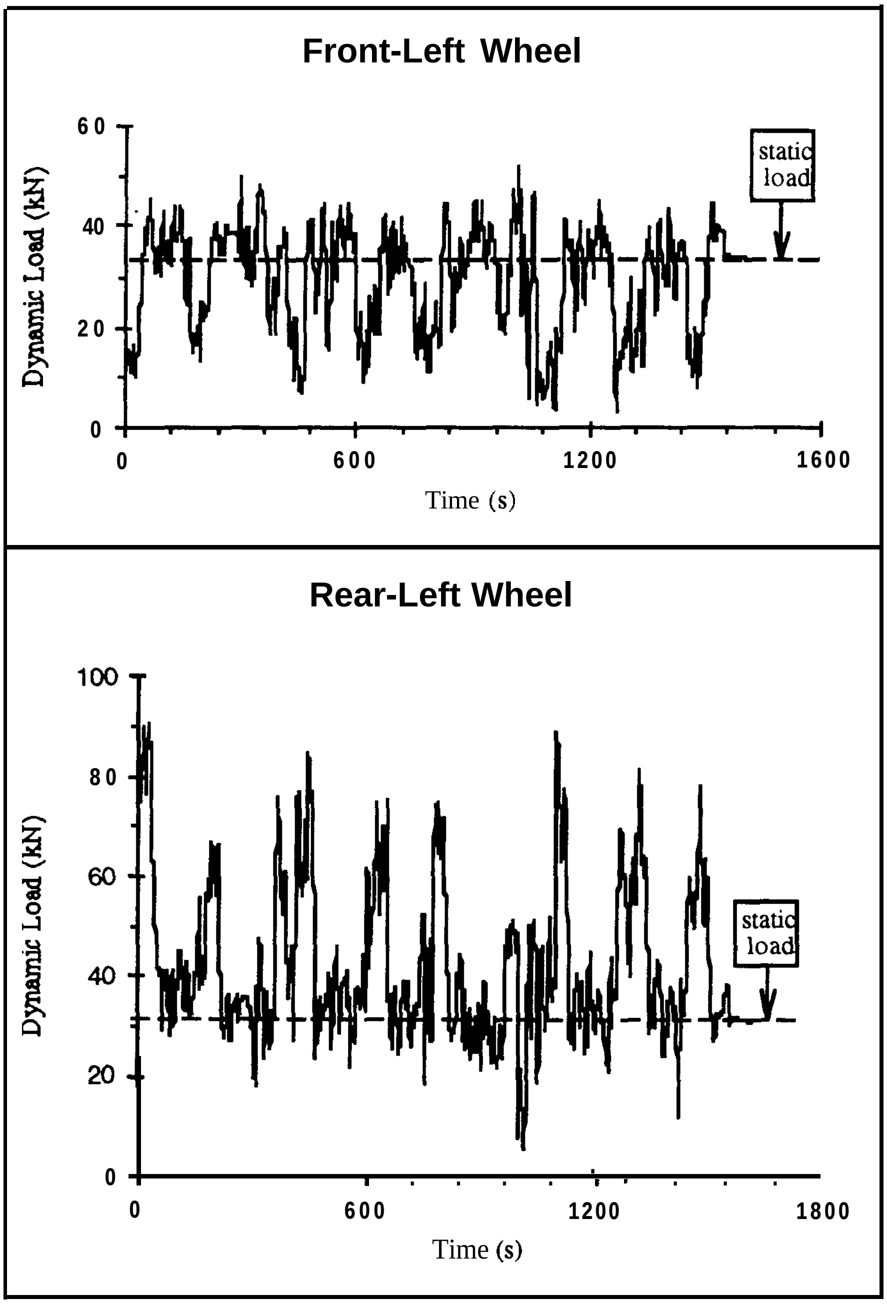

Figure 1. Typical dynamic loads for JD748 grapple skidder during operation.

Conclusions

Both conventional and mechanical harvesting systems resulted in trafficking over 5 1% of the respective cutblock areas. The compacted bulk density was significantly higher in the mechanical treatment over 200 - 300 mm soil depths. Increases in bulk density under both treatments appears to be non-detrimental over approximately 85% of the site. Increases in bulk density under both treatments appears to be non-detrimental over approximately 85% of the site. The remainder of the cutblock areas experienced moderate to high compaction and forest floor displacement. Severe compaction was generally associated with machine operations on steep slopes and in wet areas. Compaction by the grapple skidder used in the mechanical system was magnified due to unfavourable dynamic load distributions. To reduce site impacts, there is a need for machine designs that provide better load distributions during operation.

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