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Load and inflation pressure effects on soil compaction of forwarder tires

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ABSTRACT

A standard forwarder tire (600/55-26.5) was tested to determine its range of soil compaction with various inflation pressures and dynamic loads. Past research has shown that compaction of heavier equipment can be somewhat mitigated by operating with lower inflation pressures. Results indicated a significant effect of both load and inflation pressure on bulk density. rut size. and soilcone index.

INTRODUCTION

For a given set of conditions. several factors in combination affect the level of soil disturbance of a particular machine operating in the forest. Choosing the combination of factors that minimizes soil disturbance is a difficult problem because of the interactions between. most notably, vehicle weight. and tire inflation pressure. size. and construction. and their resultant impact on soil compaction Of all factors that can influence the level of disturbance of a machine, inflation pressure is perhaps the easiest to change in order to adapt to site specific conditions. It is important, therefore, to understand how inflation pressure affects soil compaction.

Several studies have shown reductions in soil impacts from operating at lower inflation pressures. Many of these studies were focused on agricultural tractor tires. ordinarily of radial-ply construction. and the problems associated with running this type of tire at higher inflation pressures. Raper and others (1995) examined the relationship between dynamic load and inflation pressure on rut size and soil-tie interface stresses. Although linear measurements of rut size (width or depth) changed with inflation pressure. rut cross-sectional area was related to only dynamic load. Contact length and area of the contact patch increased with decreasing inflation pressure. Higher inflation pressures tended to concentrate soil-tire contact stress at the tire center line. As inflation pressure was decreased. the increased deformation in the tire tended to increase contact stress towards the outer edge of the tire. and reduce stress near the center of tbe tire. This resulted in a more even stress distribution across the tire width. In earlier work (Raper rind others 1994) it was found that increasing dynamic load tended to concentrate soil stress near the outer edge of the tire. Results also indicated that higher inflation pressures also tended to increase soil stress to a greater depth for the same dynamic load. It was concluded that lowering inflatioa pressure could compensate to some degree for increased dynamic load. Myhrman (1996) reached a similar conclusion from a study in which rut size was measured for two different forwarders at varying inflation pressures. His findings showed that rut sizes were similar for a large forwarder (19.9 t gross vehicle weight. GVW) operated with an inflation pressure of 200 kPa and a smaller (12.9 t GVW) machine operated at 400 kPa.

Past research has shown the benefits of operating at lower inflation pressures. but results linking lower inflation pressure with a specific decrease in soil compaction are not available for forestry tires. Ties used in forestry applications are generally of bias-ply construction and may not respond to variation in load and inflation pressure the same manner as typical radial-ply agricultural tractor tires. This study investigated the changes in soil compaction of a typical forwarder tire when inflation pressure and dynamic ioad were varied.

METHODS

The experiment was conducted at the National Soil Dynamics Laboratory (NSDL), a facility of the USDA Agricultural Research Service in Auburn, Alabama. USA. using the NSDL single wheel Traction Research Vehicle (TRV) operating in a soil bin (Burt and others 1980; Lyne and others 1983). A Trelleborg[1] Twin 421 Mark II 600/55-26.5 forwarder drive tire was operated at four dynamic loads (10. 20. 30. and 40 kN), each at three inflation pressures (100. 240. and 380 kPa), resulting in 12 treatment combinations. Load capacities at two inflation pressures recommended by the tire manufacturer are shown in Table 1.

The experiment was conducted in the Davidson clay (*Rhodic Paleudults*) soi lbii at the NSDL. The composition of the soil was 25 percent sand. 31 percent silt and 44 percent clay. The soil was prepared by rotary tilling to a depth of about 300 mm and a hardpan was formed across the bin using side-by-side passes of a single moldboard plow followed by a weighted. cylindrical. steel wheel operating in the plow furrow. The soil above the hardpan was compacted and the surface leveled with a scraper blade. The mean depth to the top of the hardpan beneath the untrafficked soii surface was 270 mm. Selected initial physical properties of the soil are show-n in Table 2.

A randomized complete block experimental design was used with two replicates. The tire was operated so the 12 plots in each block were completed in one day.

Table 1. Tire load capacities at two inflation pressures recommended by the tire manufacturer.

Inflation	Terrain	
Pressure (kPa)	Light[a] (kN)	Heavy[b] (kN)
100	34.2	23.9
200	51.3	35.9

[a] -Terrain free of rocks and stones that may damage tire. Maximum speed = 10 km h^{-1}.

[b] -Terrain with rocks or stones. Maximum speed = 10 km h^{-1}, or 30 km h^{-1} for short distance road service.

[1] Use of wade names in this paper is for identification of sources only and does not constitute an endorsement by the United States Government or the US Department of Agriculture to the exclusion of other, suitable products.

Table 2. Pre-traffic soil physical properties. Each value is based on the mean of 30 samples.

Depth Below Untrafficked surface (mm)	Moisture Content (% dry basis)	Dry Bulk Density ($Mg\ m^{-3}$)
O-50	11.7	1.35
75 - 125	15.2	1.43

The entire soil profile within each plot was considered an experimental unit. and soil measurements taken at different depths were treated as independent observations in the statistical analysis.

Within each plot. the computer control of the TRV maintained constant inflation pressure. constant dynamic load. a constant slip of 5 percent and a forward velocity of 0.15 m/s. Zero conditions for slip calculations were established with the tire operating at zero net traction on concrete.

After the tire was operated, two soil samples were collected at the tire track centerline beneath a lug imprint in each plot to determine post-traffic soil dry bulk densities. Depth ranges of the soil samples were 0 to 50 and 75 to 125 mm beneath the lug imprint. Soil samples were also collected in undisturbed soil at the same depth ranges relative to the untrafficked soil surface. Each soil sample was cylindrical with a height and diameter of 50 mm.

Soil cone indices were measured in a lug imprint at the centerline of each tire track. and in undisturbed soil adjacent to each plot (ASAE 1995). The cone had a 323 mm' base area and depth resolution of the penetrometer was 3 mm.

Rut profiles were measured using a profilometer with horizontal resolution of 3.5 cm. and vertical resolution of 1 cm. The profile was measured across the entire width of the track. and these data were used to calculate maximum and average depth and total cross-sectional area of the rut.

RESULTS

Changes in bulk density as a function of load and inflation pressure are summarized in Tables 3 and 4 for depths of O-50 and 75-125 mm. respectively. Block effects were not significant and pooled results are presented. All treatments caused a significant increase in bulk density over the undisturbed condition. Differences between treatments, however. were not as consistent. For surface soils (O-50 mm depth). the pooled mean bulk density of the 10 and 20 kN loads was significantly lower (P < 0.001) than the pooled mean of the 30 and 40 kN treatments. Deeper in the soil profile (75- 125 mm depth).

Table 3. Means and standard deviations for bulk density by treatment for depth O-SO mm.

Treatment			Bulk Density	
Load (kN)	Inflation Pressure (kPa)	N	Mean ($Mg\ m^{-3}$)	Std. Dev. ($Mg\ m^{-3}$)
	100	8	1.4575	0.0523
10	240	5	1.4440	0.0447
	350	9	1.4611	0.0761
	100	8	1.4575	0.0623
20	240	5	1.4913	0.0357
	380	6	1.5300	0.0493
	100	5	1.5575	[illegible]
30	240	5	1.5950	0.0546
	350	5	1.6275	0.0752
	100	10	1.5220	0.0650
40	240	10	1.5640	0.0645
	380	9	1.5522	0.0705
Control		30	1.3456	0.0714

mean bulk density of the 10 kN load treatment was significantly lower than the pooled 20-40 kN mean. No other significant differences were observed.

A consistent effect of inflation pressure on bulk density was found only at dynamic loads of 20 and 30 kN. At those dynamic loads. bulk density of the 100 kPa treatments was significantly lower ($P < 0.001$) than for the 380 kPa treatments at both sampling depths.

Table 4. Means and standard deviations for bulk density by treatment for depth 75- 125 mm.

Treatment			Bulk Density	
Load (kN)	Inflation Pressure (kPa)	N	Mean ($Mg\ m^{-3}$)	Std. Dev. ($Mg\ m^{-3}$)
	100	9	1.4025	0.0462
10	240	5	1.5162	0.0496
	350	9	1.4633	0.0625
	100	9	1.5525	0.0541
20	240	5	1.6175	0.0512
	350	5	1.6459	0.0795
	100	9	1.6313	0.1131
30	240	5	1.6175	0.0471
	350	5	1.6755	0.0573
	100	10	1.5550	0.1131
40	240	10	1.6730	0.0631
	350	9	1.5411	0.1151
Control		30	1.4323	0.0623

There were more definite trends in the effects of both load and inflation pressure on rut formation and soil strength. Regression equations of rut size measures as a function of dynamic load were determined for each inflation pressure. All measures of rut size (maximum depth. average depth across the width of one tire, and cross-sectional area of displaced soil) increased linearly with dynamic load ($P < 0.001$ in all cases. average $R^2 = 0.79$). Tests of homogeneity of regression coefficients (Steel and Torrie 1980) were made between the rut depth and cross-sectional area equations for different inflation pressures. Results showed that. for both rut depth and area, regression coefficients were not the same ($P < 0.001$). meaning the response was statistically different between inflation pressures. Figure 1 shows regression-predicted rut cross-sectional area as a function of dynamic load and inflation pressure. The regression equations diverge at higher dynamic loads. indicating that lowering inflation pressure for heavy vehicles has the potential to decrease soil impacts. A similar result was found for rut depths.

Soil cone index for the 30 kN dynamic load treatment at all inflation pressures is shown in Figure 2. Also shown is the pre-traffic mean cone index. There was an increase in soil cone index after traffic in all cases, although it was smaller for the 100 kPa treatment. with the 240 and 380 kPa responses being very similar. Peak impedance values also occurred at a slightly lower depth for the two highest inflation pressures. probably because the ruts themselves were deeper. The increase in impedance for all inflation pressures occurred mainly from about 200 to 400 mm in depth. or from 40 mm above to 130 mm below the hardpan. The largest increase in impedance occurred just above the initial hardpan, nearly tripling the cone index for the 350 kPa treatment.

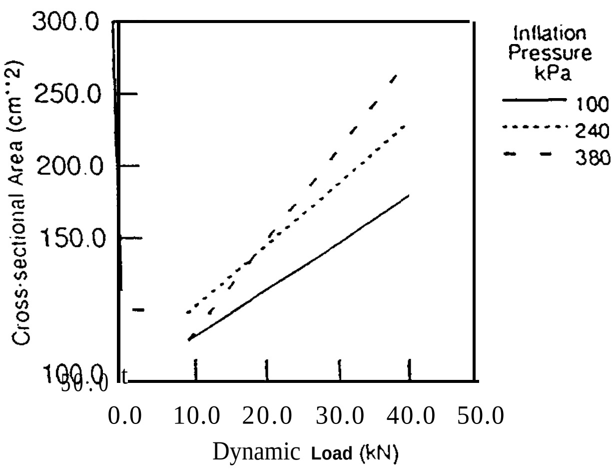

Figure 1. Predicted rut cross-sectional area as a function of dynamic load.

Figure 3 shows soil impedance as a function of depth and load for the 240 kPa treatment. Impedance in the range of 200 to 400 mm depth increased nearly linearly with dynamic load from 10 to 30 kN. Tbe 40 kN treatment however. produced impedances only slightly higher than the 30 kN response.

It appeared that reducing inflation pressure tended to decrease bulk density. soil cone index. and rut depth at a given dynamic load. Decreases were not always consistent, mainly for bulk density. and tended to be more related to dynamic load than inflation pressure. More research is needed to fully understand the interactions of inflation pressure with other variables. particularly soil moisture and texture.

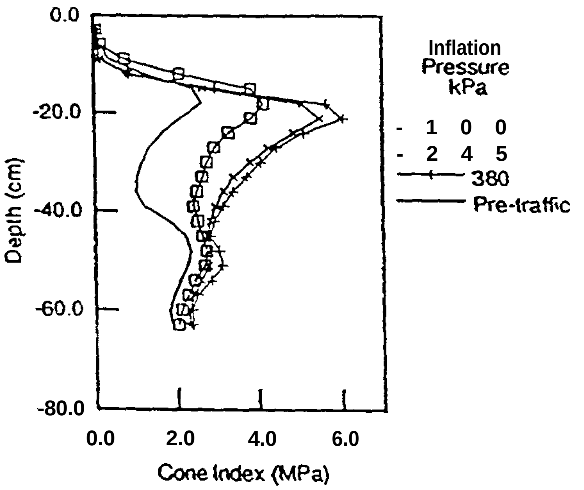

Figure 2. Soil impedance as a function of depth and inflation pressure. Data are from the 30 kN treatments.

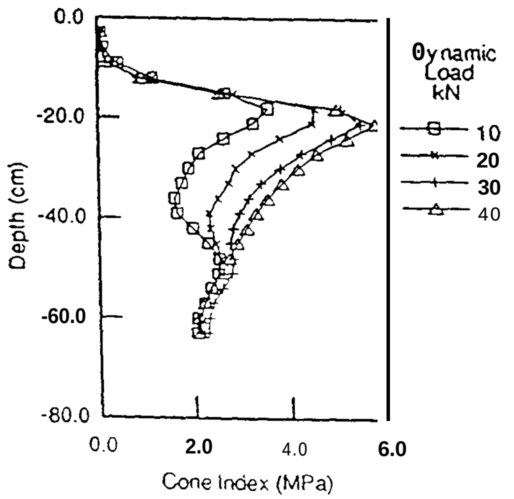

Figure 3. Soil impedance as a function of depth and dynamic load. Data are for the 240 kPa treatments

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