FORESTRY TIRE TRACTIVE PERFORMANCE: NEW, WORN, AND WITH CHAINS

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ABSTRACT. *The tractive performance of a new tire, a worn tire, and a worn tire with forestry tire chains was measured in four soil types. Two of the soil types simulated forest-floor conditions with one soil type having a surface cover of pine straw and the other having a surface cover of sod. The two remaining soil types were bare. The worn tire with and without chains had higher net traction than the new tire. Tractive efficiency was highest for the worn tire without chains in all soil types.*
Keywords. *Tires, Traction, Tractive performance, Forestry tire chains, Wear.*

The aggressiveness of forestry tire chains has the potential of increasing the tractive ability of a tire as well as extending its useful life. Chains have been shown to increase the tractive ability of off-road vehicles under a variety of conditions, including snow, wet areas, slopes, and on agricultural fields. Chains may improve traction by increasing the soil shear area through better penetration of the soil surface, without using wide tires or tracks to increase the contact area. No literature that quantitatively defined the effect of forestry tire chains on tractive ability, productivity, costs, site impacts, and vehicle loading was found. No direct comparison of performance was found between tires operated with and without chains under controlled, uniform conditions.

LITERATURE REVIEW

Several studies have reported the use of tire chains with agricultural tires under field conditions and on snow-packed roads. Some research with forestry tire chains has been reported. Skidding studies (Heidersdorf and Ryans, 1986) compared productivity and site damage between two skidders: one equipped with chains and the other with wide tires. No literature was found that quantitatively documented the effect of forestry tire chains on tractive performance.

Southwell (1962) investigated several kinds of traction aids including chains, wide tires, strakes, and half-tracks for agricultural applications. Using chains increased traction by 6%. A Norwegian study (Sellœg and Bakken, 1972) conducted on snow-packed roads showed a 10% increase in the friction coefficient for barbed or studded chains over ordinary chains.

Several qualitative reports on forestry tire chain performance have been published. Mesh forestry tire chains were field tested on a log loader in New Zealand. A subjective evaluation (Bonner, 1982) indicated that the main advantage associated with tire chains was greater loader efficiency due to enhanced traction on a wet clay site. However, the aggressive studded chains resulted in excessive site disturbance at the landing and damaged road surfaces when moving between sites. Another New Zealand report (Anon., 1981) subjectively noted that skidder performance was much improved with chains on sloping terrain and in weak soil conditions.

Heidersdorf and Ryans (1986) compared skidder performance using wide, high flotation tires (66×50-26) versus conventional tires (74×30.5-32) equipped with chains on a wet site with about 1 m of organic soil over wet clay. There were differences in productivity due to differences in ground clearance and differences in severity and distribution of ground disturbance due to operational differences.

The same report (Heidersdorf and Ryans, 1986) compared skidding on steep slopes with dry soil conditions using wide tires (66×50-26) and conventional tires (64×23.1-26) with chains. The case study showed that there were differences in skidding productivity and ground disturbance due to slope and maneuverability limitations of wide tires. This study suggested that the choice of tires and chains depended on both soil conditions and terrain factors.

Previous studies indicated that using tire chains increased tractive ability under certain conditions. Previous quantitative studies were conducted using agricultural tires and chains. Forestry tires equipped with heavier, more aggressive forestry chains may provide different tractive performance than agricultural tires with chains. Forestry field studies also indicated significant differences in site impacts, particularly in rutting, between tires alone and tires with chains. A quantitative assessment of the effect of forestry tire chains on tractive performance and site impacts is necessary for harvesting managers to make informed decisions when selecting among the many options of tires and traction aids.

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Objective

The objective of this research was to compare the tractive performance of typical forestry tires (new and worn) with and without chains under controlled conditions (Vechinski, 1993). For comparative purposes, tests were conducted using the same "typical" worn tire with and without chains and a new tire made by the same manufacturer and of the same size (without chains).

Methods and Materials

The experiments were carried out in the soil bins of the USDA-ARS National Soil Dynamics Laboratory (NSDL). The single-tire test vehicle (Burt et al., 1980) was used to conduct the experiment. This vehicle is instrumented to control and measure applied dynamic load, vehicle speed, tire rotational speed, slip, and inflation pressure.

The tire treatments used in this research were a new tire, a worn tire, and a worn tire with ring tire chains. Two Firestone 23.1-26 Forestry Special (10 ply, LS-2) tires, one new and one 80% worn (based on lug height), were used in the soil bin tests. The ring chains added at least 7 cm (2.8 in.) to the effective lug height in the center of the worn tire.

Data were collected on four soil conditions: a bare clay soil, a bare sandy soil, a clay with a pine straw cover 7 to 10 cm (2.8-4.0 in.) deep, and a clay sod. The four soils were selected to provide a range of soil and surface conditions (table 1). The Decatur clay loam, located in an enclosed building, was chosen as the bare surface clay soil. It was prepared to approximate a low-strength, undisturbed forest soil. Unlike an undisturbed forest soil, there was no ground cover or root mat that might modify the surface friction or shear strength of the soil surface. The Norfolk sandy loam was located in the same enclosed building. The Norfolk soil was prepared to approximate a firm soil surface providing favorable traction conditions. Like the Decatur soil, there was no groundcover or root mat. The two remaining clay soils were located in outside bins. The Oktibbeha clay was covered with pine straw. The Sharkey silty clay had been planted with a crop of winter rye grass about one year before the test occurred. The grass residue and new growth formed a layer of organic matter and root mat at the soil surface.

Following discussions with NSDL personnel and observing the soils, it was decided that there was more variation in soil strength and moisture along the length of the bin (76 m or 250 ft) than across its width (6.1 m or 20 ft). This is particularly true with the indoor bins where large doors near one end of the bins cause excessive evaporation of moisture from adjacent soil. Each soil bin was divided into four equally spaced lanes. Because of practical restrictions of mounting and dismounting a tire from the test car, all tests for each tire treatment were completed before changing to another tire treatment within each soil bin.

Testing progressed along the length of a bin for each tire treatment with each treatment conducted in a separate lane. When the end of each lane was reached, any remaining tests were completed in the fourth lane of that soil bin. The slip level was varied randomly for each tire treatment and soil bin.

Net traction and tractive efficiency were the primary dependent variables in a 3×2 randomized factorial experiment. Three tire treatments (a worn tire, a worn tire with chains, and a new tire) were tested at two levels of slip (10 and 20%) at the tire's rated dynamic load of 32 kN (7,200 lb) at an inflation pressure of 138 kPa (20 psi). Each of the six combinations of tire treatment and slip level at constant dynamic load was replicated three times (two times in the sandy soil). All tire treatments were completed for one soil condition before moving to the next soil condition. Gross traction and rolling resistance were measured in addition to net traction and input torque.

In addition to the designed experiment, the new tire was also run with chains in the Decatur soil. This soil bin had more useable length than the other bins and the designed experiment for each tire was completed within the first three lanes. The fourth lane was then used for the new tire with chains.

Variable load tests at zero net traction were first conducted to determine the rolling radius for that soil-tire combination. The dynamic load was varied from 0 to 32 kN (7,200 lb) over a distance of about 1.5 m (60 in.). All other variables were held constant. The calculated rolling radii were used in all subsequent calculations of slip for each tire and soil. The rolling radius is typically determined on a rigid surface but can be determined for the actual operating conditions. The rolling radius estimates were made on the actual soil conditions to obtain more realistic values (table 2).

The constant load tests provided point observations used for comparing tire treatments and soil conditions. The tractive performance based on the constant load test data was evaluated to determine if there were significant

Table 1. Selected soil properties for soil bins soils at the NSDL

	Decatur Clay Loam	Oktibbeha Clay	Sharkey Silty Clay	Norfolk Sandy Loam
Location	Inside	Outside	Outside	Inside
Composition*				
Sand	26.9%	20.6%	1.6%	71.6%
Silt	43.4%	18.3%	41.2%	17.4%
Clay	29.7%	61.1%	57.2%	11.0%
Gravel	0%	0.3%	0%	0%
Surface cover	None	Pine straw	Sod	None
Cone index at 140 mm, kPa	297	840	1418	487
(psi)	(43)	(122)	(206)	(71)
Moisture content†‡	17.5%	25.2%	28.3%	17.6%
Bulk density‡ (g/cm^3)	1.04	1.22	1.12	1.44

* Batchelor (1968).
† Dry basis.
‡ Average of at least 12 sample locations per soil collected at depths of 5 and 15 cm.

Table 2. Rolling radii (m) for each soil/tire combination

	Soil Type			
Tire	Decatur	Oktibbeha	Sharkey	Norfolk
New	0.847	0.822	0.826	0.833
Worn	0.844	0.800	0.813	0.826
Worn w/chains	0.862	0.820	0.833	0.833
New w/chains	0.877 *	---	---	---

* Data were not collected for this soil/tire combination.

differences in tractive performance due to the tire treatments and soil conditions, and to identify significant interactions. Analyses of Variance (ANOVA) on the constant load traction test data were conducted to determine significant differences between tire treatments. Tractive performance measures of net traction and tractive efficiency were analyzed by soil type.

Results and Discussion

Net Traction

The soil conditions had a significant effect ($\alpha = 0.01$) on the observed net traction. Within each soil type, the effects of tire treatment, slip, and the tire treatment-slip interaction were significant ($\alpha = 0.0001$). Net traction means were significantly different between tire treatments and between slip levels for all soils except the Decatur soil where there was no significant difference between the observed net traction of the worn tire with chains and the new tire with chains (table 3).

In the Decatur soil, adding chains to the new tire increased the average net traction by 10%. Chains decreased the average net traction for the worn tire by 2%. The worn tire averaged 14% greater net traction than the new tire. Overall, increasing slip from 10 to 20% increased net traction by at least 60%. In the Decatur soil, the worn tire averaged the highest net traction, while the new tire averaged the least net traction.

In the Oktibbeha soil, the worn tire had the highest net traction at 10% slip. At 20% slip, the worn tire with chains had the highest net traction. The average net traction was less in the Oktibbeha soil than in any of the other soils. Generally, the worn tire with or without chains averaged at least 8% higher net traction than the new tire in the Oktibbeha soil.

The worn tire with chains averaged the highest net traction in the Sharkey soil at both 10 and 20% slip. The new tire and the worn tire did not have significantly different net traction values at the two levels of slip. In the Sharkey soil, the worn tire with chains had 7% higher net traction than the new tire and 11% higher than the worn tire. Overall, the observed net traction was significantly higher in the Sharkey soil compared to the other soil types.

The worn tire and the worn tire with tire chains had higher net traction than the new tire at 10% slip in the Norfolk soil. At 20% slip, the worn tire averaged higher net traction than both the worn tire with chains and the new tire.

The performance of the worn tire without chains in all the soils agreed with the results of a study by O'Brien (1991) showing that artificially worn agricultural tires produced higher drawbar pull than new tires for slip less than 20%. The improved performance of the worn tire with chains in the Oktibbeha and Sharkey soils was due to the penetration of the surface cover by the chains.

Tractive Efficiency

The ANOVA of tractive efficiency by soil type shows that the main effects of tire treatment, slip, and the tire treatment-slip interaction were significant for all soils except one. In the Sharkey soil, there was no significant effect due to slip or the tire treatment-slip interaction. The highest values of tractive efficiency were measured in the Sharkey soil. Across all soils the worn tire consistently had the highest tractive efficiency and the new tire had the lowest (table 4).

Tractive efficiency increased when chains were added to the new tire but decreased when they were used on the worn tire in the Decatur soil. There was an average 5% loss in tractive efficiency when chains were used in the Oktibbeha and Sharkey soils and an average loss of 8% in the Norfolk soil. Generally, tire chains reduced the tractive efficiency except for the test using the new tire with chains in the Decatur soil.

Tractive efficiency increased between the 10 and 20% slip levels in the clay soils as shown by the Decatur and Oktibbeha soils. But at the higher values of tractive

Table 3. Summary statistics: Constant load test — net traction (kN) by soil

Soil Type	N	10% Slip	N	20% Slip
Decatur clay loam				
New	251	6.50 ± 0.69*	240	11.09 ± 0.42
Worn	244	7.54 ± 0.57	264	12.03 ± 0.37
Worn w/chains	252	7.79 ± 1.41	252	11.69 ± 0.71
New w/chains	247	7.20 ± 1.05	252	11.97 ± 1.13
Oktibbeha clay				
New	253	6.00 ± 0.59	262	10.81 ± 1.09
Worn	250	6.97 ± 0.67	239	11.31 ± 0.47
Worn w/chains	253	6.50 ± 0.81	261	11.94 ± 0.90
Sharkey silty clay				
New	162†	9.00 ± 0.43	236	14.85 ± 0.62
Worn	237	8.64 ± 0.70	270	15.14 ± 0.93
Worn w/chains	244	10.07 ± 1.11	270	16.39 ± 0.93
Norfolk sandy loam‡				
New	182	7.64 ± 0.45	175	10.76 ± 0.43
Worn	177	9.25 ± 0.48	166	12.91 ± 0.42
Worn w/chains	171	9.27 ± 0.79	177	11.68 ± 0.98

* Mean ± one standard deviation.
† One replication was not used in the analysis because of an unexplained trend in the data.
‡ Only two replications per tire treatment.

Table 4. Summary statistics: Constant load test — tractive efficiency (%) by soil

Soil Type	N	10% Slip	N	20% Slip
Decatur clay loam				
New	251	44 ± 5*	240	51 ± 4
Worn	244	52 ± 4	264	56 ± 4
Worn w/chains	252	50 ± 7	252	53 ± 4
New w/chains	247	47 ± 6	252	53 ± 4
Oktibbeha clay				
New	253	49 ± 4	262	55 ± 4
Worn	250	60 ± 4	239	61 ± 4
Worn w/chains	253	54 ± 7	261	59 ± 5
Sharkey silty clay				
New	162†	62 ± 3	236	63 ± 4
Worn	237	71 ± 5	270	71 ± 4
Worn w/chains	244	68 ± 7	270	68 ± 5
Norfolk sandy loam‡				
New	182	56 ± 4	175	55 ± 3
Worn	177	69 ± 5	166	64 ± 4
Worn w/chains	171	65 ± 6	177	58 ± 4

* Mean ± one standard deviation.
† One replication was not used in the analysis because of an unexplained trend in the data.
‡ Only two replications per tire treatment.

efficiency observed in the Sharkey soil, there was essentially no difference between 10 and 20% slip. In the Norfolk soil, tractive efficiency decreased between 10 and 20% slip levels. The observed tractive efficiency varied more between soil types than between tire treatments or travel reduction.

Summary

The constant load tests illustrate differences between “laboratory” and “field” conditions. The Decatur clay loam and the Norfolk sandy loam are typical laboratory test conditions. The Oktibbeha clay with a layer of pine straw and the Sharkey silty clay with sod cover approximated forest field conditions. This research showed there was a tractive advantage associated with using tire chains in the Oktibbeha and Sharkey soil bins but not in the other soil conditions.

On favorable traction conditions, it appears that good surface contact results in the highest net traction. Little benefit is gained from using traction aids in good traction conditions. The worn tire shows the benefits of good surface contact while the new tire and the worn tire with chains show reduced tractive performance. Traction aids improve tractive performance by increasing contact with the soil in unfavorable traction conditions. This was illustrated in the Oktibbeha and Sharkey soils where the tires operated over a layer of pine straw or sod.

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