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Belts vs Tires, Belts vs Belts, Tires vs Tires

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Abstract. *Tractive performance comparisons among two different width rubber belt tracks, 46 cm (18 in.) and 81 cm (32 in.) wide, and two different size rear tires, 710/70R38 and 18.4R46, were made on two different surface conditions. The belts were tested on a Caterpillar 55 tractor equipped with the Mobil-trac™ system and the tires on a John Deere 8400 mechanical front-wheel-drive (MFWD) tractor. The performance tests were completed on two surfaces, one being a non-tilled wheat stubble field and the second, the wheat stubble field tilled approximately 23 cm (9 in.) deep with a Noble blade sweep. Performance comparisons using tractive efficiency, dynamic traction ratio, and slip were made. Results of these performance comparisons between the belts and tires indicate that, in general, the belts performed better. The performance differences between the two belt widths were less defined. The performance differences between the two tires suggests that the narrower tire had a slight traction advantage.*

Keywords. *Tractors, Rubber belt tractors, Tractive performance, Tractive efficiency.*

Caterpillar, Inc. entered the row crop agricultural tractor market with the introduction of a mid-sized tractor in 1994. This tractor has rubber belt tracks in lieu of the rubber tires found on conventional agricultural tractors or steel tracks on crawler tractors.

The use of rubber belt tracks on tractors was introduced in 1987 by Caterpillar, Inc. Prior to that, most published research results compared the performance of wheel tractors to steel tracked crawlers. Domier et al. (1971), Taylor and Burt (1973), and Brixius and Zoz (1976) compared the performance of steel tracked crawlers to two-wheel or four-wheel-drive tractors equipped with conventional rubber drive tires. In all instances, the tracks had higher tractive efficiencies than the tires. One disadvantage to the use of steel tracks was the slow travel speed and high maintenance costs of the track.

Taylor and Burt (1973) also tested a pneumatic track which consisted of a circular-shaped, nylon-reinforced flexible tire stretched over a track frame. They reported that the tractive performance of the pneumatic track greatly exceeded the tractive performance of a regular tire. Evans and Gove (1986) compared the tractive performance of a rubber belt track and a four-wheel-drive tractor. The results of their tests indicated that the rubber belt track developed higher tractive efficiencies and higher dynamic traction ratios than did the four-wheel-drive tractor. Esch (1987) and Esch et al. (1990) were probably the first to conduct extensive tests on the comparisons between the new rubber belt tracks and conventional rubber tires. They conducted tests on four ground surface conditions ranging from firm to soft. In all instances the tractive performances and dynamic traction ratios were higher for the rubber belt track than the rubber tires. In general, the softer the surface conditions the greater the performance differences between the two types of traction devices.

The new row crop rubber belted tractors have a different track drive configuration than the original Caterpillar rubber-belted track tractors introduced in 1987. The new tractors have a rear drive wheel with a much larger diameter than the front idler wheel, where the original rubber belt tractors had rear drive and front idler wheels approximately the same diameter. Zoz (1997), Shell et al. (1997), and Turner et al. (1997) reported on their cooperative effort to define field performance comparisons of tractor efficiency between the new rubber belt agricultural tractor and a mechanical front-wheel-drive tractor in southern Alberta soils and on Texas soils. Their comparisons were limited to fuel efficiency and power efficiency. Because axle power was not determined, they could not make any comparisons as to the tractive efficiency of the two different types of traction devices.

Shell et al. (1997) used a laboratory power take-off (PTO) dynamometer to determine PTO power and torque. Fuel consumption was measured using a positive displacement fuel transducer during the laboratory work. This information was then used to predict fuel flow and PTO torque during the field tests. They reported that the rubber belted tractor had a slightly higher power delivery efficiency than the wheel tractor. Their conclusion was that there was very little difference in fuel efficiency or power delivery between the two tractors.

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In similar laboratory and field tests in Canada, Turner et al. (1997) concluded that there was little performance difference between a rubber belted tractor and a radial tire equipped MFWD tractor with correct tire pressure.

OBJECTIVES

No published literature was found where tractive performance comparisons between a row crop rubber belted tractor and a conventional tire MFWD tractor included the determination of axle power. Therefore, the primary objective of this research effort was to compare the field tractive performance of four tractive devices: two different width rubber belts and two different size radial tires. A row crop rubber belted tractor and a conventional MFWD tractor of similar PTO power and weight were used as the test platforms for testing the tractive devices.

TRACTION ANALYSIS

Performance was determined by calculating the dynamic traction ratio (DTR), tractive efficiency (TE), and slip for each of the belts and tires. These terms are defined in *ASAE Standards*: ASAE S296.4. Esch (1987), Esch et al. (1990), and Bashford et al. (1987) reported on their use of curve fitting analyses to describe tractive relationships for performance comparisons. Esch (1987) and Esch et al. (1990) used a more sophisticated DTR relationship for the belt which was different than for the wheel. Bashford et al. (1987) used a simple relationship for DTR as reported by Wismer and Luth (1974). For the comparisons for this research effort, the DTR model proposed by Wismer and Luth (1974) was used and is in the form:

$$DTR = B0\left(1 - e^{B1 \cdot S}\right) + B2 \qquad (1)$$

with the regression coefficients, B0, B1, and B2, and slip, S, in decimal form.

The TE model used for the two tractors was:

$$TE = \left(1 - S\right)\left(1 - \frac{C0}{1 - e^{C1 \cdot S}}\right) \qquad (2)$$

with the regression coefficients, C0 and C1, and slip, S, in decimal form.

The Gauss-Newton method of nonlinear regression was used to estimate the regression coefficients for DTR and TE. These coefficient estimates and respective 95% confidence intervals were calculated assuming the coefficient estimates were normally distributed. These equations were used only to assist in comparing tractive performance among the belts and tires. The regression coefficients are not interchangeable between equations 1 and 2.

The slip measured in the field is relative to a loaded wheel radius determined on a reference surface at zero drawbar pull. The reference surface used was the concrete track at the Nebraska Tractor Test Laboratory. At zero drawbar pull and on surfaces other than that used to establish the zero conditions, slip is evident in propelling the tractor. Therefore, the measured slip consisted of the slip required to overcome motion resistance, provide drawbar pull and some implied slip because of the differences in loaded wheel radius while the tractor was under load on the test surface to that established on a reference surface at zero drawbar pull.

EQUIPMENT AND PROCEDURE

A Caterpillar 55 tractor equipped with the Mobil-trac™ system and a John Deere 8400 mechanical front-wheel-drive (MFWD) tractor were instrumented to measure axle torque, engine speed, drawbar pull, and ground speed. Calibration procedures and transducers described by Esch (1987) were used in this study. The front wheel speed for the MFWD tractor was calculated from the rear wheel speed and the wheel speed ratio of 1.3188. The axle torque of the front drive wheels was calculated from the torque measured at the drive shaft to the front planetary and the speed ratio in the front planetary.

The two tractors were set up in two configurations. The row crop configuration included the 46-cm (18-in.) belt on the rubber-belted tractor and the 18.4 rear tires on the MFWD tractor. The field configuration included the 81-cm (32-in.) belt on the rubber-belted tractor and the 710/70 rear tires on the MFWD tractor. The specifications for the tractors as tested are listed in tables 1 and 2. The 18.4R46 and 16.9R30 tires were Goodyear Dyna Torque Radials. The 710/70R38 and 600/65R28 tires were Goodyear DT820 Radials. Dual units are not used for the tire size designations to avoid confusion. The rubber belt tracks were manufactured by Caterpillar. Both tractors were equipped with a 16-speed powershift transmission. Both tractors were ballasted to the manufacturers' recommendations. A series of gears in each tractor was selected to permit slips up to 50%. Drawbar loads were obtained by towing two load-unit tractors in series behind the test tractor.

Tractive performance tests were performed on two surface conditions. The soil was a Sharpsburg silty loam. The surface conditions are described in table 3.

A wheat stubble field of approximately 24 ha (60 acres) was divided in half. After harvesting, the straw was baled and removed from the field leaving only about 20 cm

Table 1. Specifications for the MFWD tractor

MFWD Tractor Specifications		
	Row-crop	Field
Tires	Front: 16.9 R30 Rear: 18.4 R46 duals	Front: 600/65 R28 Rear: 710/70 R38 duals
Inflation pressure	Front: 207 kPa (30 psi) Rear: 83 kPa (12 psi)	Front: 124 kPa (18 psi) Rear: 41 kPa (6 psi)
Tractor weight	Front: 4941 kg (10,892 lb) Rear: 7987 kg (17,608 lb) Total: 12 928 kg (28,500 lb)	Front: 5017 kg (11,060 lb) Rear: 8233 kg (18,150 lb) Total: 14 250 kg (29,210 lb)
Drawbar height	47.2 cm (18.6 in.)	41.1 cm (16.2 in.)

Table 2. Specifications for the rubber-belted tractor

Rubber-belted Tractor Specifications		
	Row-crop	Field
Belt width	46 cm (18 in.)	81 cm (32 in.)
Weight	11 630 kg (25,640 lb)	11 787 kg (25,985 lb)
Drawbar height	48.0 cm (18.9 in.)	50.8 cm (20.0 in.)

Table 3. Test soil conditions and properties

Surface	Depth cm	Depth (in.)	Cone Index kPa	Cone Index (psi)	Bulk Density Mg/m³	Bulk Density (lb/ft³)	Water Content (% db)
Non-tilled	0-8	(0-3)	135	(20)	1.20	(75)	21
	8-15	(3-6)	228	(33)	1.41	(88)	21
	15-23	(6-9)	410	(59)	1.45	(91)	20
	23-31	(9-12)	486	(70)	1.45	(91)	15
Tilled	0-8	(0-3)	—	—	1.03	(64)	21
	8-15	(3-6)	—	—	1.28	(80)	23
	15-23	(6-9)	231	(34)	1.28	(80)	20
	23-31	(9-12)	437	(63)	1.48	(92)	21

(8 in.) of standing stubble. One-half of the field remained in this original stubble condition and the other half of the field was tilled with a Noble sweep plow to a depth of 23 cm (9 in.) with residue remaining on the surface. No rain was experienced during the entire testing program.

The test tractor was operated at full throttle in each selected gear in a straight pass across the field while towing the two load tractors. Data were collected starting at minimal drawbar loads and drawbar loads were increased by 8900 to 17 800 N (2000 to 4000 lb) increments until the test tractor was limited by power, exceeded 50% slip, or some other limiting factor such as power hop occurred.

Once one of the limitations was exceeded, the tractor was turned around and the same loading and sequence repeated going in the opposite direction. After the required series of gear runs was finished, the test tractor was moved to the second surface and the tests repeated. After the series of tests was completed on the second surface, the instrumentation was moved to the second test tractor and the series of tests repeated on the two surfaces. Both tractors were tested in parallel adjacent passes through the field to minimize the possible changes in soil or grade. A minimum of three sets of 25 observations was recorded at each drawbar load in each gear. Data were later downloaded to a computer and the average for each set of 25 observations calculated. Therefore, each data point in the analysis was the average of 25 data observations.

Results and Discussion

Model coefficients and correlation coefficients for the nonlinear regression analyses on the tractive efficiency and dynamic traction ratio for the rubber belts and the tires are presented in tables 4 and 5.

The correlation coefficients for the dynamic traction ratio for the tires were all higher than 0.98, indicating a very good fit of the DTR model to the data. The correlation coefficients for the dynamic traction ratio for the rubber belts were not as high as for the tires, but all were higher than 0.95. In general, the data obtained from the rubber belts had a tendency to be more dispersed than the data from the tires.

TE vs DTR

Comparisons of tractive performance were made between the 46-cm (18-in.) belts and 18.4 rear tires and the 81-cm (32-in.) belts and the 710/70 rear tires on the non-tilled surface and on the tilled surface. Figure 1 illustrates the comparisons between the 46-cm (18-in.) belts and 18.4 rear tires on the non-tilled wheat stubble field. It was apparent that the belt performance enveloped the tire performance. The maximum tractive efficiency for the tire was approximately 0.8 at a dynamic traction ratio from 0.3

Table 4. Non-linear regression coefficients and the 95% confidence intervals for the belts

		Dynamic Traction Ratio				Tractive Efficiency		
Belt in. (cm)	Surface	B0 (95% CI)	B1 (95% CI)	B2 (95% CI)	r	C0 (95% CI)	C1 (95% CI)	r
18 (46)	Non-tilled	1.14 (1.02, 1.26)	–7.34 (–9.04, –5.64)	–0.03 (–0.06, 0.01)	0.952	0.11 (0.10, 0.12)	–29.47 (–33.45, –25.50)	0.436
	Tilled	1.17 (0.98, 1.36)	–6.99 (–9.62, –4.36)	–0.07 (–0.14, 0.00)	0.953	0.11 (0.09, 0.13)	–15.22 (–19.39, –11.05)	0.593
32 (81)	Non-tilled	1.02 (0.94, 1.10)	–10.02 (–12.76, –7.29)	–0.08 (–0.14, –0.02)	0.966	0.11 (0.08, 0.13)	–20.09 (–27.67, –12.51)	0.564
	Tilled	1.10 (1.00, 1.19)	–13.00 (–15.21, –10.79)	–0.30 (–0.41, –0.19)	0.956	0.10 (0.08, 0.11)	–10.41 (–13.10, –7.73)	0.822

Table 5. Non-linear regression coefficients and the 95% confidence intervals for the tires

		Dynamic Traction Ratio				Tractive Efficiency		
Tire	Surface	B0 (95% CI)	B1 (95% CI)	B2 (95% CI)	r	C0 (95% CI)	C1 (95% CI)	r
18.4	Non-tilled	0.75 (0.73, 0.76)	–6.87 (–7.38, –6.36)	0.03 (0.02, 0.05)	0.987	0.11 (0.10, 0.12)	–21.42 (–23.97, –18.87)	0.912
	Tilled	0.72 (0.70, 0.74)	–8.13 (–8.75, –7.52)	–0.08 (–0.10, –0.05)	0.988	0.13 (0.12, 0.14)	–12.00 (–13.84, –10.16)	0.804
710/70	Non-tilled	0.67 (0.64, 0.70)	–6.49 (–7.64, –5.34)	0.04 (0.01, 0.08)	0.981	0.17 (0.15, 0.19)	–46.58 (–58.34, –34.82)	0.827
	Tilled	0.76 (0.72, 0.79)	–5.11 (–5.84, –4.38)	0.02 (0.00, 0.04)	0.984	0.19 (0.17, 0.21)	–18.39 (–21.66, –15.11)	0.696

to 0.35. The maximum tractive efficiency of the belt was approximately 0.82 at a dynamic traction ratio from 0.3 to 0.45. The general shape of the performance curves indicated that the belt had a higher tractive efficiency than the tire over a dynamic traction ratio from 0.15 to 0.75. This meant that the belt was more efficient over a wider range of drawbar pulls than the tire.

Comparisons for the 81-cm (32-in.) belts and the 710/70 rear tires for the non-tilled surface are illustrated in figure 2. The maximum tractive efficiency for the tire was approximately 0.77 over a dynamic traction ratio range of 0.2 to 0.3. The maximum tractive efficiency for the belt was approximately 0.8 over a dynamic traction ratio range of 0.4 to 0.5. The general shape of the performance curves indicates that the belt had a higher tractive efficiency than the tire over a dynamic traction ratio range from 0.3 to 0.65. As in figure 1, the belt system was more efficient over a wider range of drawbar pulls than the tire. For the dynamic traction ratio range of approximately 0.13 to 0.3, the tire had a higher tractive efficiency than the belt. However, this was the only time that this occurred during the tests.

Comparisons for the 46-cm (18-in.) belts and the 18.4 rear tires on a tilled wheat stubble surface are illustrated in figure 3. The performance of the belts and tires were similar over the dynamic traction ratio range from 0.1 to 0.2. At higher DTR values, the tractive

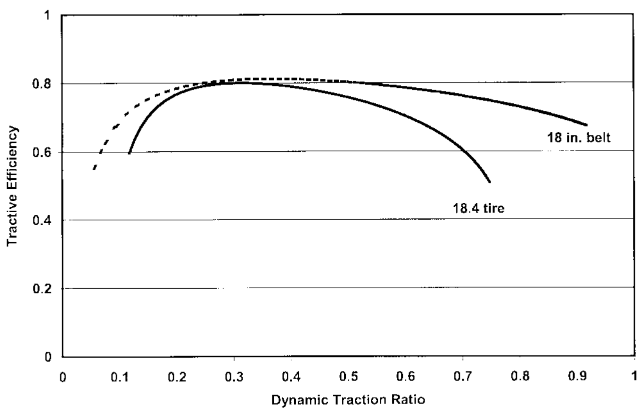

Figure 1–Tractive efficiency vs dynamic traction ratio for the 46-cm (18-in.) belt and 18.4 rear tires on a non-tilled wheat stubble field.

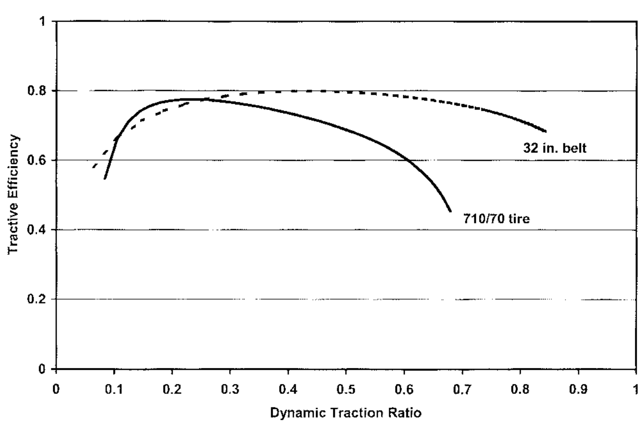

Figure 2–Tractive efficiency vs dynamic traction ratio for the 81-cm (32-in.) belt and 710/70 rear tires on a non-tilled wheat stubble field.

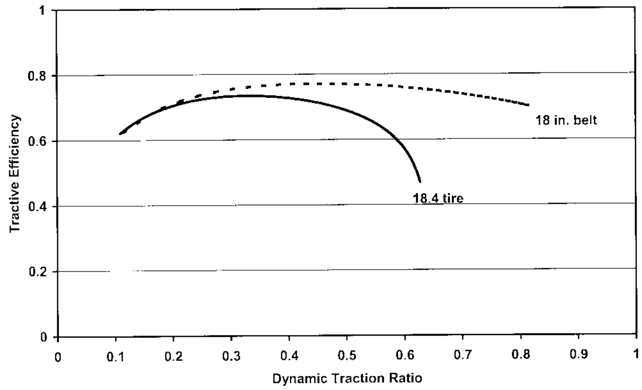

Figure 3–Tractive efficiency vs dynamic traction ratio for the 46-cm (18-in.) belt and 18.4 rear tires on a tilled wheat stubble field.

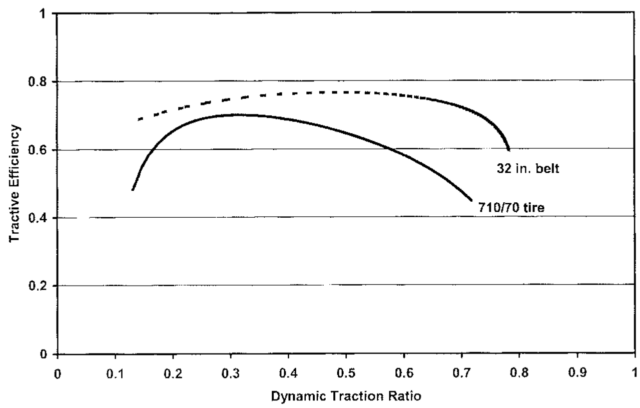

Figure 4–Tractive efficiency vs dynamic traction ratio for the 81-cm (32-in.) belt and 710/70 rear tires on a tilled wheat stubble field.

efficiency for the belt was higher than for the tire, as was true on the untilled stubble surface. The maximum tractive efficiency for the belt was approximately 0.76 over a DTR range from 0.4 to 0.6. The maximum tractive efficiency of the tire was approximately 0.74 over a DTR range from 0.25 to 0.4. The belt had a higher tractive efficiency than the tire over a DTR range from 0.25 to 0.65.

The largest differences between a belt and tire are illustrated in figure 4, where a comparison between the 81-cm (32-in.) belts and the 710/70 rear tires was made on the tilled surface. The maximum tractive efficiency for the tire was approximately 0.7 over a DTR range from 0.25 to 0.35. The maximum TE for the belt was approximately 0.76 over a DTR range from 0.35 to 0.6. The belt had a higher TE than the tire over a DTR range from 0.15 to 0.7.

In general, the tires reached peak TE at low DTR values with TE dropping off at higher DTR values. The belts reached peak TE at medium DTR values, and maintained high TE over a wider range of DTR than the tires. This resulted in a pattern of the largest TE advantages for the belts over the tires occurring at the high end of the range of DTR values.

DTR and TE vs Slip

Figures 5 to 8 illustrate tractive performance comparisons between the belts and tires on the two surfaces. Illustrated in figure 5 are the comparisons of DTR and TE as a function of slip for the 46-cm (18-in.) belts and

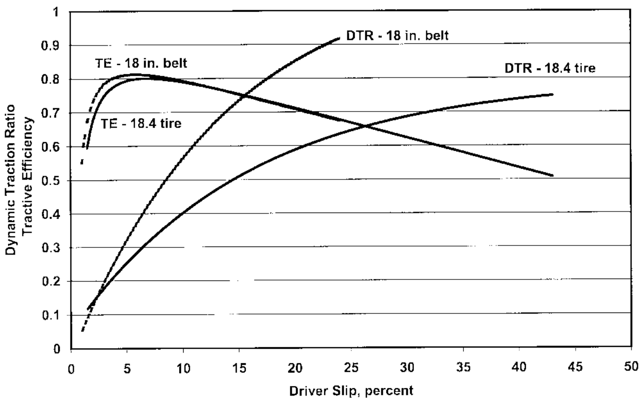

Figure 5–Tractive efficiency and dynamic traction ratio vs slip for the 46-cm (18-in.) belt and 18.4 rear tires on a non-tilled wheat stubble field.

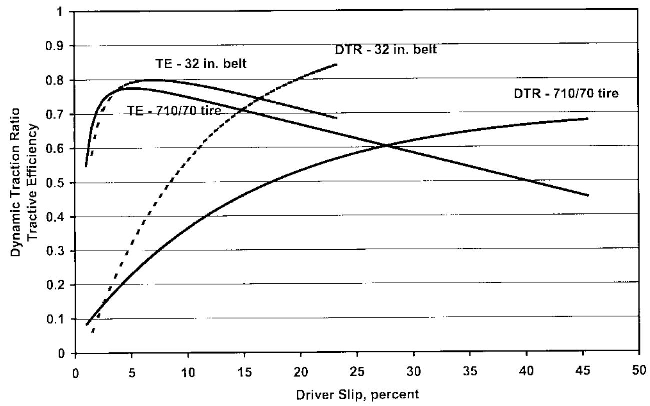

Figure 7–Tractive efficiency and dynamic traction ratio vs slip for the 81-cm (32-in.) belt and 710/70 rear tires on a non-tilled wheat stubble field.

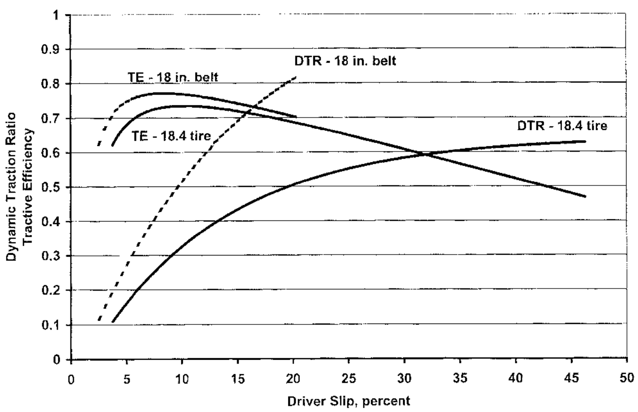

Figure 6–Tractive efficiency and dynamic traction ratio vs slip for the 46-cm (18-in.) belt and 18.4 rear tires on a tilled wheat stubble field.

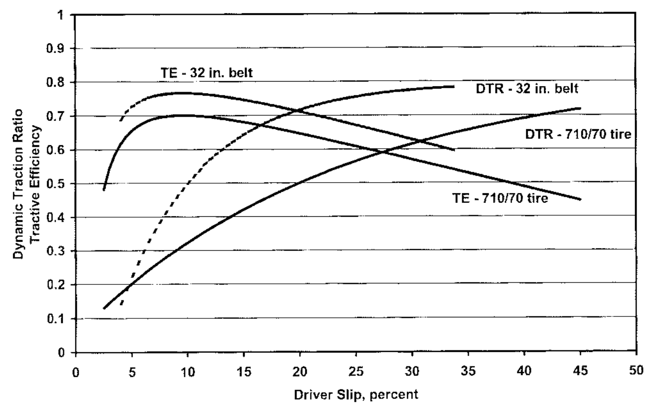

Figure 8–Tractive efficiency and dynamic traction ratio vs slip for the 81-cm (32-in.) belt and 710/70 rear tires on a tilled wheat stubble field.

18.4 rear tires on a non-tilled wheat stubble. At a given slip, the belt had a higher DTR than the tire. However, the TE of the two traction devices on this particular surface was essentially the same. The belt indicated a small advantage for slips less than 10%. Figure 6 illustrates the differences between the 46-cm (18-in.) belts and 18.4 rear tires on a tilled wheat stubble surface. Again, there were large DTR differences between the two traction devices on this tilled surface, with the belt having a much higher DTR than the tire for a given slip. The TE comparison illustrates that the belt had a higher tractive efficiency up to approximately 20% slip. The TE advantage for the belt varies from approximately 10% at 5% slip down to approximately 3% at 10% slip.

Illustrated in figure 7 are the comparisons between the 81-cm (32-in.) belts and the 710/70 rear tires on a non-tilled wheat stubble surface. The DTR for the belt was again higher than for the tire over the slip range from 5% to 25%. The TE difference between the two traction devices was minimal at slips less than 5%, but the difference was more evident at slips greater than 5%. The advantage to the belt was approximately 4% to 5%. Figure 8 makes the same comparisons for the two traction devices on a tilled wheat stubble surface. The difference in the DTR between the two traction devices was again obvious. However, the TE of the belt was approximately 6% greater than the tire over the entire slip range.

In all cases observed, the belt had a higher DTR than the tire. The TE of the tire approached the TE of the belt on the firmer surface (non-tilled stubble). However, on the softer surface (tilled stubble), the belt had a higher TE than the tire.

Belt vs Belt

Figures 9, 10, 11, and 12 illustrate the performance comparisons between the 46-cm (18-in.) belt and the 81-cm (32-in.) belt. Figures 9 and 10 suggest that there was some advantage to the 46-cm (18-in.) belt at specific slips. However, figures 11 and 12 suggest that there were minimal differences in the TE versus DTR curves, with a slight advantage to the 46-cm (18-in.) belt at low DTR on the non-tilled surface. On the tilled surface, there appeared to be an advantage to the 46-cm (18-in.) belt at high DTR.

Tire vs Tire

Figures 13 and 14 illustrate the performance comparisons between the 18.4 and 710/70 tires. On the non-tilled surface, the differences in DTR and TE were

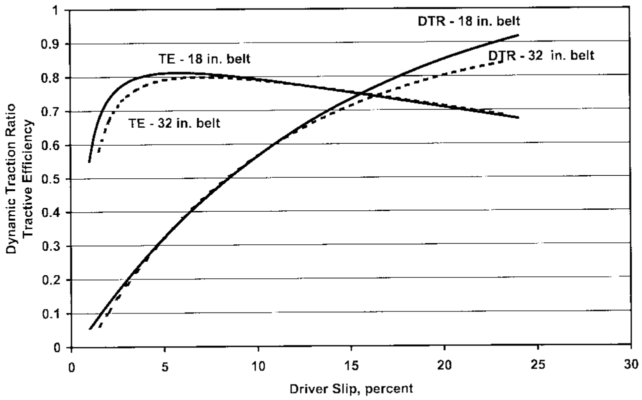

Figure 9–Tractive efficiency and dynamic traction ratio vs slip for the 46-cm (18-in.) and 81-cm (32-in.) belts on a non-tilled wheat stubble field.

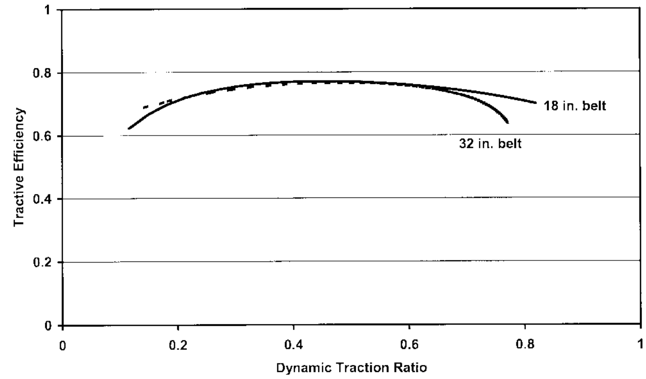

Figure 12–Tractive efficiency vs dynamic traction ratio for the 46-cm (18-in.) and 81-cm (32-in.) belts on a tilled wheat stubble field.

distinct with both measures of performance favoring the 18.4 tire. On the tilled surface, the TE favored the 18.4 tire. The DTR values were similar up to a slip of approximately 25%, then the DTR favored the 710/70. The TE versus DTR curves illustrated in figures 15 and 16 favored the narrower tire over most of the DTR range. On the firmer, non-tilled surface, the wider tire did have a slight advantage at low DTR values, while on the softer tilled surface, the wider tire had a slight advantage at high DTR values.

From Esch et al. (1990), it was anticipated that the belts would show a better tractive performance than the tires, which they did. The performance differences between the two belts were minimal. However, the performance differences between the two tires in favor of the narrower tire were not expected.

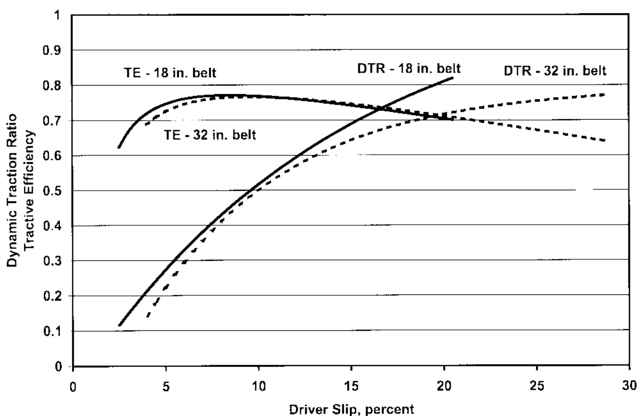

Figure 10–Tractive efficiency and dynamic traction ratio vs slip for the 46-cm (18-in.) and 81-cm (32-in.) belts on a tilled wheat stubble field.

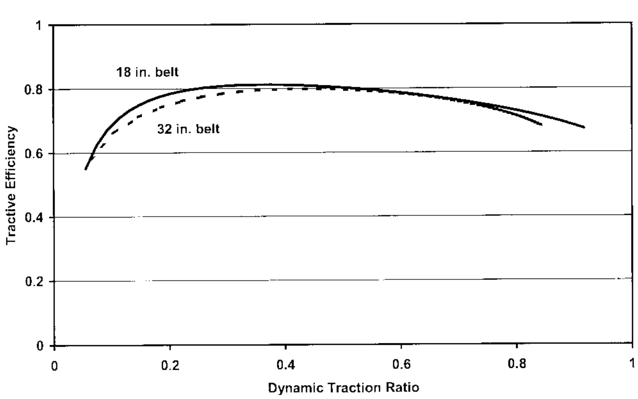

Figure 11–Tractive efficiency vs dynamic traction ratio for the 46-cm (18-in.) and 81-cm (32-in.) belts on a non-tilled wheat stubble field.

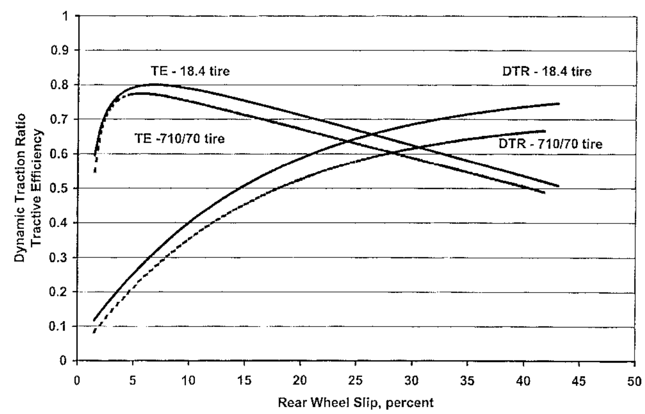

Figure 13–Tractive efficiency and dynamic traction ratio vs slip for the 18.4 and 710/70 rear tires on a non-tilled wheat stubble field.

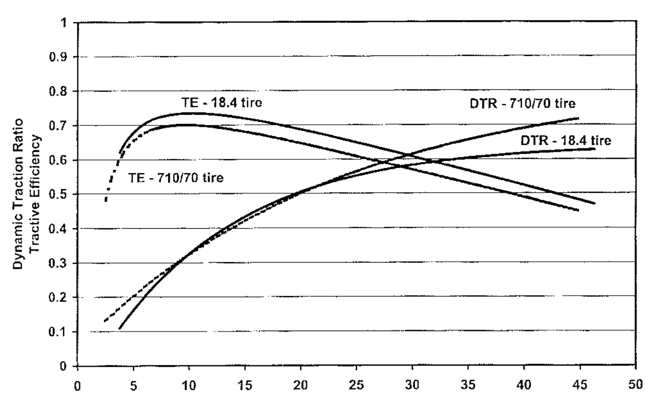

Figure 14–Tractive efficiency and dynamic traction ratio vs slip for the 18.4 and 710/70 rear tires on a tilled wheat stubble field.

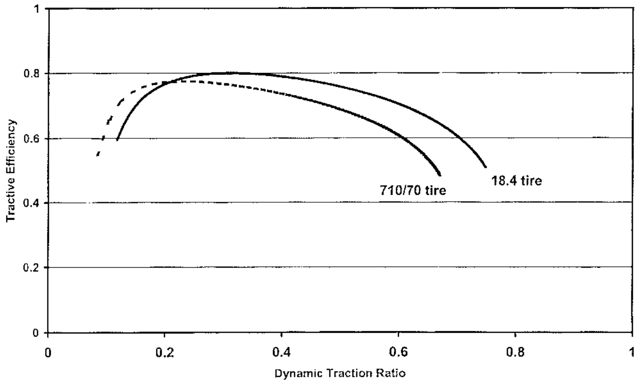

Figure 15–Tractive efficiency vs dynamic traction ratio for the 18.4 and 710/70 rear tires on a non-tilled wheat stubble field.

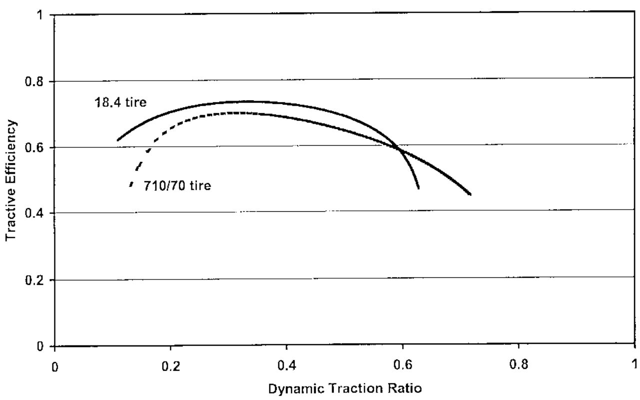

Figure 16–Tractive efficiency vs dynamic traction ratio for the 18.4 and 710/70 rear tires on a tilled wheat stubble field.

Conclusions

The conclusions are:

1. Maximum tractive efficiencies were higher for the rubber belts than the tires and the differences increased at high DTR values, and for the softer tilled soil.
2. Dynamic traction ratios at a given slip were higher for the rubber belts than for the tires.
3. The rubber belts operated at a higher tractive efficiency over a wider range of dynamic traction ratios than the tires.
4. In general, the rubber belts developed small tractive performance advantages over the tires on firm surfaces with more significant tractive performance advantages on softer surface conditions.
5. The tractive performance differences between the two different tire sizes favored the narrower tire.
6. The tractive performance differences between the two different rubber belt widths were minimal.

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