9-1999

Wide Tires, Narrow Tires

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SAE TECHNICAL PAPER SERIES

1999-01-2784

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Reprinted From: Agricultural Machinery, Tires, Tracks, and Traction (SP-1474)

The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL

International Off-Highway & Powerplant Congress & Exposition
Indianapolis, Indiana
September 13-15, 1999

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (724) 776-4841 Fax: (724) 776-5760

ISSN 0148-7191

Printed in USA

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ABSTRACT

Tractive performance comparisons among five different size tires were made on two different surface conditions, a wheat stubble field and a tilled wheat stubble field. Radial 18.4R46, 20.8R42 and 710/70R38 radial tires; and bias 750/65-38 and 850/55-42 tires were used.

Instrumentation to evaluate tractive performance was installed on a two-wheel drive and a mechanical front wheel drive agricultural tractor. Axle torques, drawbar pull, travel speed, and engine rpm were recorded for a series of drawbar pulls on the two soil surfaces.

Tractive performance evaluations among the tires were made by comparing the relationships of dynamic traction ratio to slip, tractive efficiency to slip, and tractive efficiency to dynamic traction ratio.

In general, narrower tires exhibited performance advantages over wider tires.

INTRODUCTION

Wider agricultural drive tires are now available and manufactured by a number of domestic and foreign manufacturers. Advertisements for these tires promote better tractive performance and reduced soil compaction. Literature specifically addressing these issues, for these new wider tires, is sparse.

LITERATURE REVIEW

Dwyer and Heigho (1984) used a single wheel tester to compare tractive performance of 18.4-38, 20.8-38, 23.1-30, 23.4-38, and 25.5-38 single drive tires. They found that the tractive performances of the 23.1-30, 23.4-38, and 25.5-38 tires were lower than the 18.4-38 and 20.8-38 size tires. These results were observed with all tires having the same dynamic loads. The authors felt the benefits of the wide tires may have been seen at higher dynamic loads. Differences in dynamic traction ratios for the tires were minor.

Mueller and Treanor (1985) tested the merits of radial and bias-ply tractor tires as well as those of single and dual tires. The tests were conducted with the same size tires: 20.8-38 10PR bias and 20.8R38 10PR radials. The weight to power ratio was 120 lb/hp for singles and 151 lb/hp for duals. As singles, the radials were significantly better than the bias tires for field productivity and drawbar power. Field productivity, wheel slip, and drawbar power improved when bias duals were replaced with radial duals. At equal drawbar loads, the radials had greater reduction in wheel slip at higher speeds.

Dwyer (1987) used a single wheel test vehicle to compare the tractive performance of a 67-34.0-25 bias tire at 5.0 psi, a 20.8-38 radial tire at 9 psi, and a similar 18.4-34 tire at 12 psi. All tires had similar tread patterns and were tested with the same vertical load of 4,950 lb. The best performance was achieved by the 20.8-38 tire, with little difference in performance between the other two tires. When using empirical predictions of performance, the narrower tires performed as predicted, but the performance of the wide low-pressure tire was considerably lower than predicted. This was thought to be due to bulldozing because of the greater width and increased wheel slip caused by deformation of the soft side-walls. The low-pressure tire had relatively soft side walls and short ground contact area. It was concluded that wide, low-pressure tires were suitable for vehicles requiring small drawbar loads.

Upadhyaya et al. (1989) evaluated three radial tires (16.9R38, 18.4R38, and 24.5R32) on five different soil conditions with different axle loads and inflation pressures (83 kPa and 124 kPa). The results indicated that changes in a given soil condition influence tire performance more than changes in tire loading or dimensions. In a given soil condition, the 24.5R32 tire appeared to perform better than the other two tires. The 18.4R38 tire performed slightly better than the 16.9R38 tire. Changes in soil conditions influenced tire performance much more than changes in tire loading and dimensions.

Bashford and Kocher (1998) studied traction characteristics of 710/70R38 and 18.4R46 tires. The tractive performance differences between the two different tire sizes favored the narrower tire. On a non-tilled surface, the differences in dynamic traction ratio and tractive efficiency were distinct, favoring the 18.4R46 tire. On a tilled surface at slips exceeding 25%, the dynamic traction ratio favored the 710/70R38. On a firm surface, the wider tire had a slight advantage in tractive efficiency at low dynamic traction ratio values while on the soft tilled surface, the wider tire had a slight advantage in tractive efficiency at high dynamic traction ratio values.

OBJECTIVE

Very few published articles were found in which tractive performance of different width tires included the determination of axle power. Therefore, the primary objective of this research effort was to compare the field tractive performance of five different size tires. A 2-wheel drive tractor and a mechanical front wheel drive tractor were used for testing the tires.

TRACTIVE PERFORMANCE

Tractive performance of a tractor can be represented using relationships of dynamic traction ratio (DTR) and tractive efficiency (TE) versus slip. The terminology used in the tractive performance analysis is defined in ASAE (1998) Standard S296.4 General Terminologyfor Traction of Agricultural Tractors, Self-Propelled Implements, and other Traction andTransport Devices.

PROCEDURES

TRACTOR PREPARATION – A Case IH 8920 two-wheel drive tractor (2WD) and a John Deere 8400 mechanical front wheel drive tractor (MFWD) were instrumented to measure axle torque, engine speed, drawbar pull, and ground speed. Calibration procedures and transducers described by Esch (1987), Bashford and Kocher (1998), and Tibbetts (1998) were used in this study.

The tires evaluated on the 2WD tractor were Goodyear 20.8R-42 radial tires, Firestone 710/70R-38 radial tires, Trelleborg 750/65-38 bias tires, and Trelleborg 850/55-42 bias tires. The same size front tires, Goodyear Dyna Rib 14L-16.1, were used for all rear tire combinations. Tire evaluations using this tractor were completed in the summer of 1998.

Tires evaluated on the MFWD tractor were dual 18.4R46 on the rear and single16.9R30 on the front and were Goodyear Dyna Torque radials, and dual 710/70R38 on the rear and single 600/65R28 on the front and were Goodyear DT820 radials. Tire evaluations using this tractor were completed in the summer of 1997. Specific details of the testing of the tires on the mechanical front wheel drive tractor were discussed in Bashford and Kocher (1998). Specifications for the two tractors are illustrated in Tables 1 and 2. The specifications for the MFWD tractor are included for easy comparison to the 2WD tractor.

Table 1. Specifications for the MFWD tractor.

	Row-Crop	**Field**
Tires:	Front: 16.9 R30 Rear: 18.4 R46 duals	Front: 600/65 R28 Rear: 710/70 R38 duals
Inflation Pressure (kPa):	Front: 207 Rear: 83	Front: 124 Rear: 41
Tractor Weight (kg):	Front: 4941 Rear: 7987 Total: 12,928	Front: 5017 Rear: 8233 Total: 14,250
Drawbar Height (cm):	47.2	41.1

Table 2. Specifications for the 2WD tractor.

Rear Tires:	20.8 R42	710/70 R38	750/65-38	850/55-42
Inflation Pressure (kPa):	100	83	69	69
Tractor Weight (kg):				
Front:	2070	2050	2070	2050
Rear:	5486	5864	5680	5905
Total:	7556	7914	7750	7955
Drawbar Height (cm):	46.3	50	52	54

FIELD PREPARATION – Tractive performance tests were conducted on two different surfaces during the two summer tests. The soil type was a silty clay loam. The original surface was a wheat stubble field with the straw baled and removed from the field. The remaining stubble was approximately 160 mm tall. The second surface was the wheat stubble field tilled to a depth of approximately 23 cm with a Noble blade. The tillage was completed with two tillage passes in diagonal directions to better break up the soil.

The average soil conditions for the top three inches for the surfaces on which each tractor operated in are defined inTable 3.

Table 3. Test soil conditions and properties.

Tractor	**Surface**	**Cone Index kPa**	**Bulk Density Mg/m^3**	**Water Content % db**
2WD	Non-Tilled	N/A	N/A	23
2WD	Tilled	----	N/A	23
MFWD	Non-Tilled	135	1.20	21
MFWD	Tilled	----	1.03	21

TESTING PROCEDURE

Drawbar loads were obtained by towing one or more load-unit tractors in series behind the test tractor.

The 2WD tractor was equipped with an 18-speed power-shift transmission. The MFWD tractor was equipped with a 16-speed powershift transmission. A series of gears with forward speeds of approximately 4.0, 5.6, 6.7, and 9.3 km/h were selected. The tractors were operated, in each selected gear, straight ahead through the field at full throttle with the load unit tractor providing the drawbar load. In each gear, data were recorded at different drawbar loads from minimum to maximum where the tractor slippage was in excess of 50%.

Once high slip was reached, a different gear was selected and the procedure was repeated. The tractors were operated in each gear in both directions in the field. This procedure was used to minimize or eliminate the possible effects of any minor grade changes or soil differences on the evaluation parameters.

After the required series of gear runs were completed, the tractor was moved to the second surface and the tests repeated. After the series of tests were completed on the second surface, tires were changed on the test tractor and the tests repeated. Tires were evaluated in parallel adjacent passes through the field to minimize possible changes in soil or grade. A minimum of three sets of 25 observations were recorded at each drawbar load in each gear. Data were later downloaded to a computer and the average of each set of 25 observations calculated to obtain one data point.

RESULTS

STATISTICAL ANALYSIS – A non-linear regression program was used to statistically analyze the tractive performance data. The NLIN program was used to select the best-fit relationship between the original data and the corresponding traction models.

Upadhyaya (1989) used non-linear regression to obtain a best fit of tractive performance data. Bashford and Kocher (1998) used non-linear regression to obtain the best-fit parameters and the 95% confidence intervals for the parameters for traction prediction equations.

The DTR model proposed by Wismer and Luth (1974) was used and is in the form:

$$DTR = BO(1-e^{B1*S}) + B2 \qquad (1)$$

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

A TE model can be expressed in the form:

$$TE = (1-S)[1-(B3/(1-e^{B4*S}))] \qquad (2)$$

with the regression coefficients B3 and B4, and slip , (S), in decimal form.

Model parameter estimates, 95% confidence intervals, and the correlation coefficient values for the non-linear regression analyses on the TE and DTR for each tire by soil surface condition treatment combination are given in Tables 4 and 5.

TRACTIVE PERFORMANCE COMPARISONS – Best fit TE and DTR curves were drawn from regression parameters defined inTables 4 and 5 for the tires tested on each of the two soil surface conditions.

Figures 1 to 6 illustrate the tractive performance comparisons of the radial and bias ply tires on the two surfaces evaluated on the 2WD tractor. Illustrated in Figure 1 are the comparisons of TE as a function of slip for the tires on the non-tilled wheat stubble. At a given slip, the radials had higher TE than the bias tires. The 20.8R42 indicated a small advantage over the 710/70R38 tires for slips less than 15 percent. The radial tires had maximum TE at slips of about six and eight percent, while the bias-ply tires had maximum TE at slips of ten percent. However, the TE of the two sizes of bias ply tires were essentially the same.

Figure 2 illustrates the differences between the tires on the tilled wheat stubble surface. The TE comparison illustrates that the radial tires had higher TE than the bias ply tires up to approximately 20 percent slip. The 20.8R42 tires had higher TE than did the 710/70R38 tires for slips greater than approximately ten percent. The 750/65-38 tires had a small TE advantage over the 850/55-42 tires for slips less than about 25 percent. The radial tires had maximum TE at about 17 percent slip, while the bias-ply tires had maximum TE at about 20 percent slip.

In general, TE increased rapidly from low values to a peak at about eight percent slip on the non-tilled stubble, and about 19 percent slip on the tilled stubble. After reaching peak TE at these slip values, TE decreased at a steady rate as slip continued increasing. The tires evaluated maintained TE near the peak over a wider range of slips for the tilled surface condition than for the non-tilled surface condition. The peak TE on the non-tilled surface were noticeably higher than on the tilled surface condition. On each of the two surface conditions radial tires had higher maximum TE than did the bias-ply tires. Also on each of the two surface conditions, the radial tires reached maximum TE at lower slips than did the bias-ply tires.

Table 4. Dynamic traction ratio and tractive efficiency model parameter estimates and their 95% confidence intervals and associated Pearson=s correlation coefficient for the tests of the tires with the MFWD tractor in 1997.

Tire	Surface	Dynamic Traction Ratio				Tractive Efficiency		
		B0 (95% CI)	B1 (95% CI)	B2 (95% CI)	r	B3 (95% CI)	B4 (95% CI)	r
18.4	Non-Tille	0.75 (0.73, 0.76)	-6.87 (-7.38, -6.36)	0.03 (0.02, 0.05	0.99	0.11 (0.10, 0.12)	-21.42 (-23.97, -18.87)	0.91
	Tilled	0.72 (0.70, 0.74)	-8.13 (-8.75, -7.52)	-0.08 (-0.10, -0.05)	0.99	0.13 (0.12, 0.14)	-12.00 (-13.84, -10.16)	0.80
710/70	Non-Tille	0.67 (0.64, 0.70)	-6.49 (-7.64, -5.34)	0.04 (0.01, 0.08	0.98	0.17 (0.15, 0.19)	-46.58 (-58.34, -34.82)	0.83
	Tilled	0.76 (0.72, 0.79)	-5.11 (-5.84, -4.38)	0.02 (0.00, 0.04	0.98	0.19 (0.17, 0.21)	-18.39 (-21.66, -15.11)	0.70

Table 5. Dynamic traction ratio and tractive efficiency model parameter estimates and their 95% confidence intervals and associated Pearson=s correlation coefficient for the tests of the tires with the 2WD tractor in 1998.

Tire	Surface	Dynamic Traction Ratio				Tractive Efficiency		
		B0 (95%CI)	B1 (95%CI)	B2 (95%CI)	r	B3 (95%CI)	B4 (95%CI)	r
20.8R42	Non-Tilled	0.82 (0.79,0.85)	-6.20 (-6.99,-5.39)	0.07 (0.04,0.11	0.97	0.11 (0.10,0.12)	-28.03 (-32.70,-23.30)	0.91
	Tilled	0.94 (0.89,0.98)	-6.40 (-6.80,-5.90)	-0.16 (-0.21,-0.12)	0.98	0.14 (0.13,0.15)	-5.30 (-6.02,-4.60)	0.98
710/70R38	Non-Tilled	0.71 (0.68,0.78)	-5.00 (-6.81,-4.35)	0.19 (0.15,0.23	0.97	0.12 (0.10,0.13)	-21.20 (-23.40,-19.50)	0.98
	Tilled	0.93 (0.89,0.97)	-5.89 (-6.42,-5.36)	-0.14 (-0.18,-0.09)	0.97	0.19 (0.18,0.20)	-7.62 (-8.23,-6.90)	0.95
750/65-38	Non-Tilled	0.82 (0.79,0.86)	-4.38 (-4.93,-3.82)	0.04 (0.01,0.07	0.97	0.16 (0.13,0.17)	-14.40 (-17.90,-11.00)	0.82
	Tilled	1.00 (0.96,1.00)	-6.13 (-6.55,-5.70)	-0.24 (-0.29,-0.19)	0.98	0.15 (0.13,0.17)	-4.11 (-4.90,-3.30)	0.94
850/55-42	Non-Tilled	0.72 (0.69,0.75)	-6.01 (-6.58,-5.45)	0.04 (0.01,0.07	0.97	0.16 (0.15,0.17)	-15.28 (-17.60,-12.90)	0.94
	Tilled	1.06 (1.00,1.11)	-6.09 (-6.66,-5.53)	-0.28 (-0.34,-0.23)	0.95	0.15 (0.13,0.17)	-3.89 (-4.54,-3.22)	0.98

Figure 3 illustrates DTR as a function of slip on the non-tilled wheat stubble surface. At a given slip the radial tires had a higher DTR than did the bias tires. At slips less than approximately 10 percent, the 710/70R38 had a small advantage over the 20.8R42. But at slips greater than approximately 20 percent, the 20.8R42 had an advantage over the 710/70R38 tires. The 850/55-42 had a DTR advantage over the 750/65-42 at slips between approximately five and 25 percent. This reversed at slips over approximately 30 percent where the 750/65-38 had a DTR advantage over the 850/55-42 tires. The DTR for the radial tires was greater than the DTR of the bias tires over the entire slip range.

Illustrated in Figure 4 are the comparisons of DTR verses slip for the tires tested with the 2WD tractor in 1998 on the tilled wheat stubble surface. The DTR for the two sizes of radial tires was almost identical for slips less than approximately 35 percent slip. At slips above approximately 35 percent the 710/70R38 tires had a small advantage over the 20.8R-42 tires. The 750/65-38 had a small DTR advantage over the 850/55-42 tires at slips less than approximately 15 percent. Between approximately 10 and 30 percent slip, there were no differences between the DTR of the two sizes of bias ply tires.

In all cases observed, the radial tires had a higher DTR than the bias ply tires. However, on the softer surface (tilled wheat stubble), the differences between the radial and bias ply tires were less.

Figure 5 illustrates the comparisons of TE as a function of DTR for a non-tilled wheat stubble surface condition among the four tires tested with the 2WD tractor in 1997. A maximum TE of approximately 0.81 occurred at a DTR from approximately 0.3 to 0.4 for the 20.8R42 tires. The maximum TE for the 710/70R38 tires was approximately 0.77 and occurred approximately between a DTR of 0.35

and 0.45. The bias tires both had an approximate maximum TE of 0.72 at a DTR range between approximately 0.3 and 0.4. The general shape of the performance curves indicated that the radial tires had a higher TE than the bias tires over DTR from 0.25 to 0.7. The 20.8R42 tires had the highest TE of all the tires over the DTR range from 0.13 to 7.0. This meant that the radial tires were more efficient over a wider range of drawbar pulls than the bias ply tires.

TE and DTR comparisons for the tilled surface condition are illustrated in Figure 6. The maximum TE for the 20.8R42 radial tire of approximately 0.64 occurred over a DTR range of 0.4 to 0.50. The maximum TE of 0.61 for the 710/70R38 tires occurred over the same approximate range as the peak for the 20.8R42 radial tire. The performance of the bias ply tires was similar over the DTR range from 0.1 to 0.7, with a maximum of approximately 0.59 for the 750/65-38 and 0.58 for the 850/55-42 tires. Note that all tires reached maximum TE at lower DTRs on the non-tilled surface than on the tilled surface.

The following paragraph and Tables 1 and 4 and Figures 7 through 10 were copied from Bashford and Kocher (1998). Permission was granted by the American Society of Agricultural Engineers. This information was obtained using a mechanical front wheel drive tractor. All performance tests were completed with dual tires on the rear axle of the tractor.

Figures 7 and 8 illustrate the performance comparisons between the 18.4 and 710/70 tires. On the non-tilled surface, the differences in DTR and TE were 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 9 and 10 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.

CONCLUSIONS

1. The TE and DTR differences between the different tire sizes favored the narrower tires.
2. The radial ply tires developed tractive performance advantages over the bias ply tires on both the non-tilled and tilled wheat stubble.

ACKNOWLEDGMENTS

Published as Paper Number 12585, Journal Series, Nebraska Agricultural Research Division.

The authors acknowledge grant support and the loan of a tractor from Caterpillar, Inc., grant support and the loan of tires from Trelleborg, Inc., and the loan of a tractor from Case IH for this research effort.

Trade and company names are included in this article for the benefit of the reader and do not infer endorsement or preferential treatment of the product named by the University of Nebraska.

REFERENCE

1. ASAE Standard S296.4. 1998. General terminology for traction of agricultural tractors, self-propelled implements, and other traction and transport devices. ASAE, St. Joseph, MI 49085.
2. Bashford, L. L. and M.F. Kocher. 1998. Belts v. tires, belts v. belts, tires v. tires. ASAE Paper No. 98-1073. ASAE, St. Joseph, MI 49085.
3. Dwyer, M. J. 1987. The Tractive Performance of a Wide, Low-Pressure Tire Compared with Conventional Tractor Drive Tires. *Journal of Terramechanics*. 24(3):227-234.
4. Dwyer, M. J. and D. P. Heigho. 1984. The Tractive Performance of Some Large Tractor Drive Wheel Tires Compared to Duals. *Journal of Ag. Engng Res*. 29:43-50.
5. Esch, J. H. (1987). Tractive Performance of Rubber Belt Track and Four-Wheel Drive Agricultural Tractors. Unpublished Master=s Thesis. University of Nebraska. Lincoln, NE 68583.
6. Mueller, J. P. and R. R. Treanor. 1985. Tractor Tires Compared Radials, Bias ply, Singles, Duals B Which is Best? ASAE Paper No. 85-1048. ASAE, St. Joseph, MI 49085.
7. Tibbetts, T. S. (1998). Field evaluation of radial and bias tires on two surfaces. Unpublished Master=s Thesis, University of Nebraska. Lincoln, NE 68583.
8. Upadhyaya, S. K., D. Wulfsohn, and G. Jubbal. 1989. Traction prediction equations for radial ply tires. *Journal of Terramechanics*. 26(2):149-175
9. Wismer, R. D. and H. J. Luth. 1974. Off-Road Traction Prediction for Wheeled Vehicles. TRANSACTIONS of the ASAE 17(1):8-10.

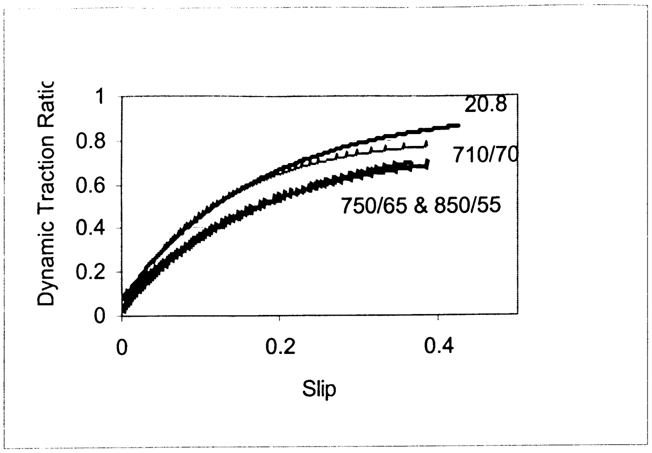

Figure 1. Dynamic traction ratio vs. slip for the designated tires on a non-tilled wheat stubble field.

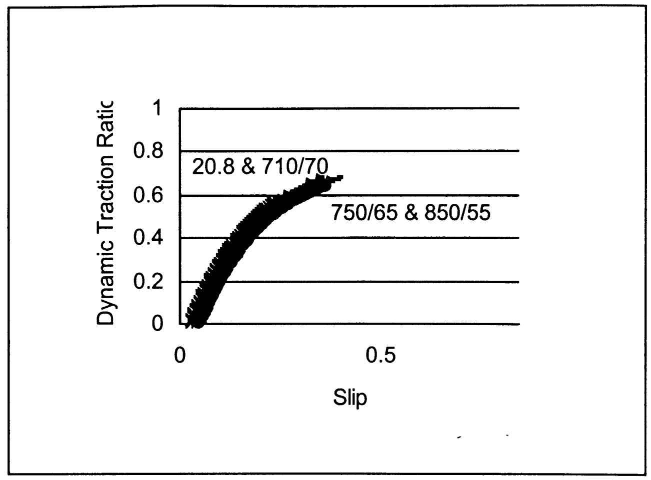

Figure 2. Dynamic traction ratio vs. slip for the designated tires on a tilled wheat stubble field.

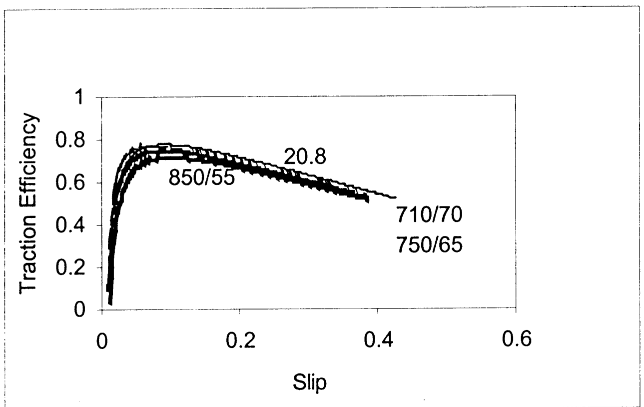

Figure 3. Tractive efficiency vs. slip for the designated tires on a non-tilled wheat stubble field.

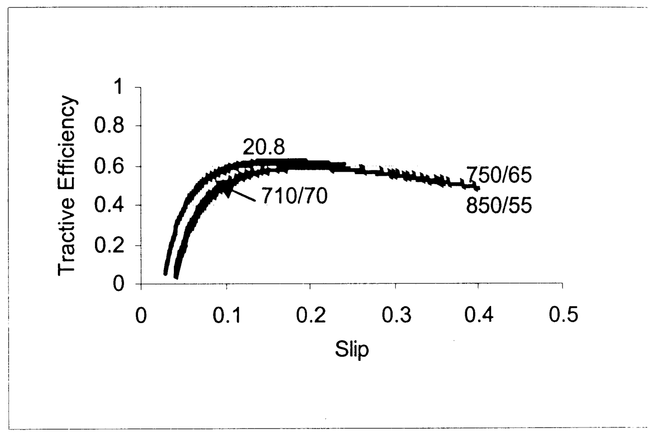

Figure 4. Tractive efficiency vs. slip for the designated tires on a tilled wheat stubble field.

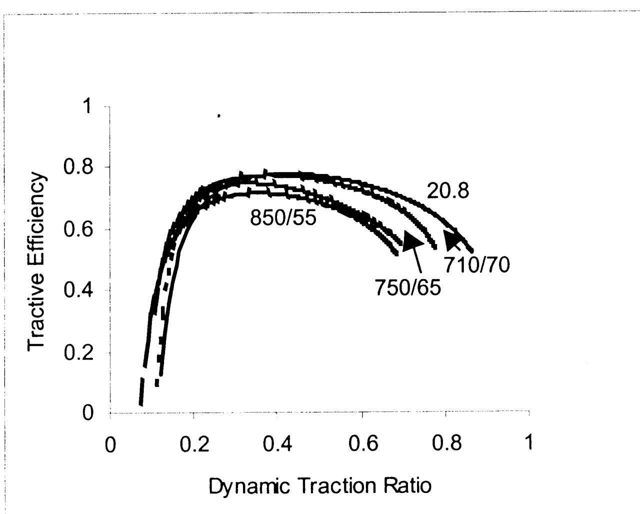

Figure 5. Tractive efficiency vs. dynamic traction ratio for the designated tires on a non-tilled wheat stubble field.

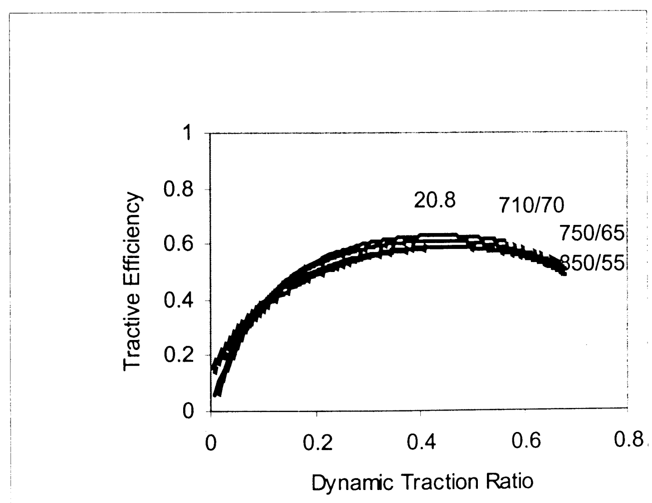

Figure 6. Tractive efficiency vs. dynamic traction ratio for the designated tires on a tilled wheat stubble field.

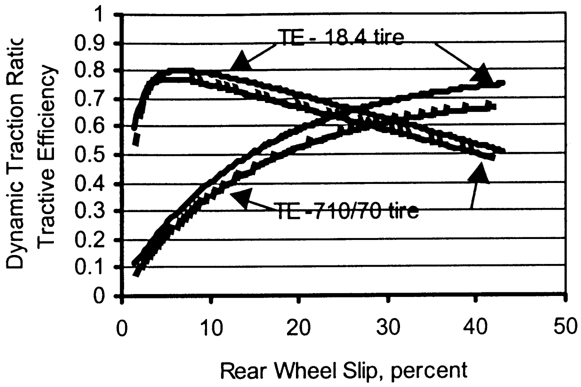

Figure 7. Tractive efficiency and dynamic traction ratio for the designated tires on a non-tilled w heat stubble field.

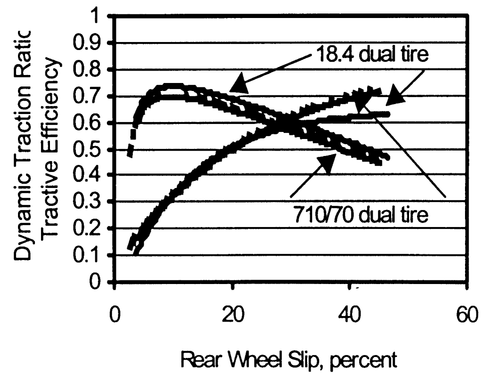

Figure 8. Tractive efficiency and dynamic traction ratio for the designated tires on a tilled w heat stubble field.

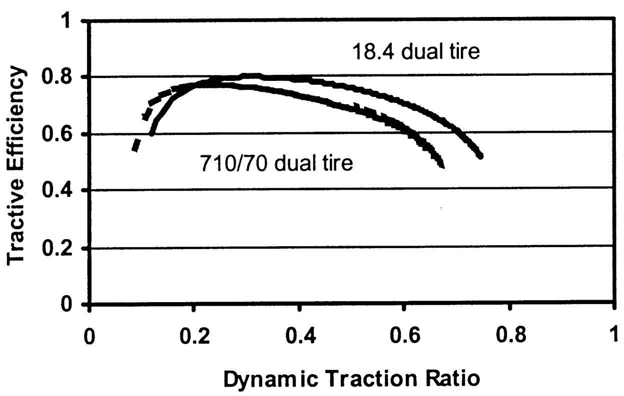

Figure 9. Tractive efficiency vs. dynamic traction ratio for the designated tires on a non-tilled w heat stubble field.

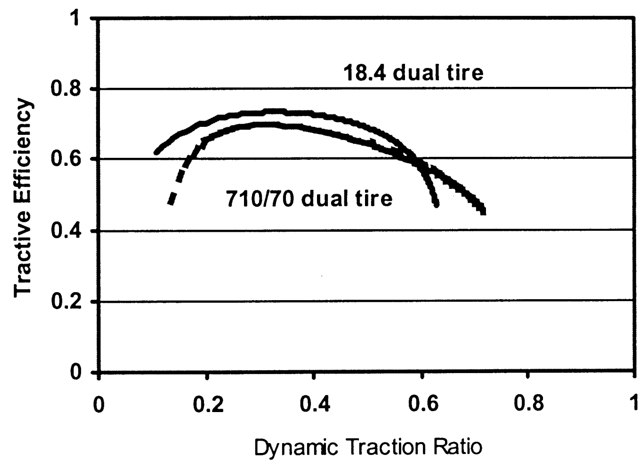

Figure 10. Tractive efficiency vs. dynamic traction ratio for the designated tires on a tilled w heat stubble field.