7-1981

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RR No. 81-13

July, 1981

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Department of
Agricultural Engineering

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by F. D. Tompkins and L. R. Wilhelm[1]

Introduction and Previous Work

Radial-ply tractor drive tires were first introduced in Europe about 1957 by the Pirelli Company (Worthington, 1962). Forrest et al. (1962) compared the tractive capabilities of these early radial-ply designs with conventional bias-ply tires on three soils and on concrete. Tires were inflated to 12 psi. Their tests showed that the radial tires produced eight percent more drawbar pull in sand, 23 percent more in loam, 21 percent more in clay, and a maximum of 33 percent more on concrete when compared to conventional tires. Results of tests repeated at inflation presures of 14 and 16 psi were substantially the same.

Thaden (1962) reported that radial-ply tires developed up to 29 percent more drawbar pull than bias-ply tires when both were operated at 16 percent slip in certain soil conditions. He noted, however, that the pull advantage of radials tended to drop off as slip increased above this level.

Worthington (1962) indicated that, for operation on alfalfa sod and on a hard dirt track, radial tires consistently produced higher coefficients of traction than bias-ply tires when the slip was less than 15 to 20 percent. However, in tests on concrete, radials produced higher coefficients of traction for all values of slip considered.

VandenBerg and Reed (1962) compared tractive performance of radial and bias-ply tires on concrete and on four soils with textures ranging from sand to clay. They concluded that radial-ply carcass construction did not affect maximum traction but did improve tractive performance in the 0 to 30 percent slip range.

B. F. Goodrich Tire Company introduced radial-ply tractor tires in the United States in 1973 (Buckingham, 1975). Bohnert and Kenady (1975) presented a B. F. Goodrich comparative analysis of radial and bias R1 tractor tires. They noted that the ground contact area, or tire footprint, of the 18.4R34 radial tire was approximately 22 percent greater than that of the comparably sized bias tire. Using tires with identical molded features over a slip range of 0 to 30 percent, they found that the radial tire developed 17.6 percent more traction in a tilled soil condition than the tire with bias-ply construction. In tests on tilled soil to compare the radial design to five commercial bias tires in the 0 to 30 percent travel reduction range (slip range), the radial tire averaged 14.6 percent more traction. Over the same slip range in the tilled soil, the tractive efficiency of the radial design was 6.7 percent more than the average efficiency of the commercial bias designs. Other U. S. manufacturers have begun marketing radial-ply tractor tires since 1973 (Buckingham, 1975).

Taylor et al. (1976) measured the coefficient of net traction and the tractive efficiency of a radial and a bias tire constructed in the same mold to assure identical dimensions. At 15 percent slip, the coefficients of net traction for the radial tire exceeded those for the bias tire by six to 18 percent in five of seven soil conditions. The tractive efficiency of the radial was slightly higher across the full range of travel reductions in five of seven soil conditions. They concluded that radial tires have the greatest advantage on firm surfaces and that the advantage would be gradually lost as the soil surface becomes softer. For maximum advantage, they noted that most of the soil-tire deformation should occur on the tire, not on the soil.

Gee-Clough et al. (1977) compared the tractive performance of two radial tires and one bias-ply design in a wide variety of field conditions over a three-year period. Results indicated that at 20 percent slip the coefficients of traction for the radials averaged five to eight percent above those for the bias tires when inflation pressures were low. However, maximum tractive efficiencies did not dif-

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Acknowledgement: **The authors acknowledge the contribution of M. W. Cantrell, President of Unique Software Development, Knoxville, Tennessee, in data handling and analysis. Also acknowledged are W. E. Hart, J. B. Wilkerson, and R. S. Freeland, Graduate Research Assistants, Department of Agricultural Engineering, University of Tennessee.**

fer. As the inflation pressure was increased to the maximum permissible value, radial and bias tires were similar in tractive performance.

Study Objectives

The objective of this study was to compare the tractive performance of three sets of R1 tractor drive tires (two radial-ply models and one bias-ply design) operated in a tilled medium clay soil. Additionally, fuel requirement of the tractor equipped with the test tires was to be monitored over the range of operating conditions.

Test Site Description

The test site, located on a University of Tennessee Agricultural Experiment Station Field Laboratory about five miles south of Knoxville, Tennessee, contained approximately 1.5 acres. Eighteen soil samples were collected from sites situated in a uniform grid pattern over the test plot. Analyses of the soil particle size distribution in the individual samples were performed using the pipette method (Day, 1965). Mean percentages of sand, silt, and clay were 37, 36, and 27, respectively. Thus, the soil textural class was clay loam based upon the U. S. Department of Agriculture classification chart (USDA, 1951).

Average slope of the test area was 1.1 percent in the direction of machine travel. Average cross slope (transverse to the path of machine operation) was 5.6 percent.

Several weeks prior to initiating the tire field tests, the plot was disked several times with a heavy tandem disk harrow to thoroughly chop and incorporate a crimson clover cover crop. The soil was pulverized to a depth of eight inches or more. The soil was maintained in this thoroughly pulverized condition throughout the test program. A hand-operated commercial model soil cone penetrometer equipped with a cone having a base area of 0.5 inch^2 was used to measure the mechanical condition of the soil periodically during the test period (Davidson, 1965; ASAE, 1980a). The soil mass was fragmented and fluffed to the extent that measurable penetrometer readings were not obtained in the top six-inch layer. Readings below the six-inch depth were presumed insignificant in describing the medium encountered by the tires during machine operation.

Drawbar Loading

A heavy-duty wing-type tandem disk harrow was used to provide variable drawbar loading. The harrow, a Model 200303 manufactured by Taylor Implement Division of Pittsburgh Forgings Company, had a cutting width of 13.6 feet with the wings folded. In this folded position, the disk weight was approximately 580 pounds per foot of cut width. Disk blades were 22 inches in diameter and spaced nine inches apart. Drawbar pull was varied by varying the operating depth of the harrow.

The No-Slip Condition

Zero, or no-slip, conditions may be those of zero net traction or zero input torque to the traction device as well as zero drawbar pull for the vehicle (ASAE, 1980c). The surface condition used to define the zero condition must also be considered. According to Bailey and Burt (1977), zero conditions include (a) net traction equals zero when the tire is operating on the test surface, (b) input torque equals zero when the tire is operating on the test surface, and (c) input torque equals zero when the tire is operating on a nondeformable surface. Collins et al. (1980) obtained slip measurements from a 97-ptohp tractor equipped with 18.4-38 tires operated on loamy sand and sandy loam soils. Using an asphaltic concrete surface to establish the zero condition, they determined that the tire slip which resulted from overcoming just the vehicle rolling resistance in the untilled soil with cornstalks in the surface was as high as 7.5 percent. Thus, they concluded that slip, the relative motion at the mutual contact surface of the traction device and the supporting medium, should be based upon a zero condition established on a nondeformable surface. Subsequent slip measurements in the test medium should then be referenced to this zero condition.

Obtaining the zero input drive torque condition is not generally practical in most field test schemes. Collins et al. (1980) determined the apparent tire rolling radii on a tractor first driven and then towed over a measured distance on a nondeformable surface. Although the wheel revolutions were greater when the tractor was driven, the difference was one percent or less. Therefore, driving the tractor over a measured course with a nondeformable surface instead of operating at the zero input torque condition should represent a zero condition with an error in absolute slip of less than one percent.

The effective rolling circumference of each set of tires used in this study was determined by driving the ballasted tractor through a 200-foot distance on an asphaltic concrete surface and counting wheel revolutions. The tractor was operated slowly (less than one mph), and tests were repeated four times. Operation on this nondeformable surface was considered to be the zero slip condition.

Data Acquisition Instrumentation

The instrumentation system described by Tompkins and Wilhelm (1981) was used to collect the tire test data. However, the system was modified slightly for improved operation and convenience. A schematic of the modified system is shown in Figure 1.

The heart of the instrumentation system was a Digital Equipment Corporation (DEC) PDP11/03-LK microcomputer. This unit was equipped with 32K words of memory, a four-port serial interface, a sixteen-channel A/D board, and a specially designed digital input counter board. The counter board replaced a separate microprocessor counter box described by Tompkins and Wilhelm (1981).

A DEC TU58 cassette tape system was used for data storage. Two tape drives were used. One tape contained system software while the other was used for recording data.

Operation of the system was controlled and monitored using a DEC M7142 serial video module and a small video monitor. These permitted continuous operator interaction throughout the tests.

Input to the microcomputer system included fuel consumption, ground speed, right and left axle rotational speeds, and drawbar pull. All inputs except drawbar pull were in the form of digital (TTL) pulses. Fuel consumption was measured by a Fluidyne Model 1240D fuel meter. The number of pulses from the meter in a given period was proportional to the fuel used during that period. Forward speed was measured by a fifth wheel with a 72-tooth gear mounted on the wheel axle. A magnetic sensor (DI-MAG Model 58426) provided a TTL pulse each time a gear tooth passed the sensor. Rear axle rotation was measured using similar magnetic sensors and 120-tooth gears. All digital inputs were counted for each one-second interval during testing. This procedure permitted rate calculations during each test plus cumulative measurements for the entire test.

Draft measurements were obtained using a drawbar dynamometer based upon the design of Johnson and Voorhees (1979). Strain gage measurements from this unit were transmitted to the A/D board in the computer backplane and recorded at one-second intervals.

A software package developed specifically for the above instrumentation system permitted considerable flexibility in operation. The software included routines for system calibration, data acquisition, and display/review of recorded data. Once data acquisition was begun, the system was capable of operating continuously until tests for a given set of tires were completed.

Test Procedure

Tire and Test Vehicle Preparation

Three sets of R1 tractor drive tires, identified in Table 1, were mounted on W16L-38 rims compatible with the Massey-Ferguson MF 2675 test vehicle. Prior to mounting the tires, the rims were weighed and measured (see Table 1). Bead seat widths and bead seat diameters shown are means of several measurements at various locations on the rims. Maximum variations represent the differences in greatest and smallest values obtained for a given rim.

Each tire was weighed prior to mounting (see Table 1). The weight of each tube was between 23 and 23.5 pounds. Tires were mounted with tubes and inflated to 20 psi air pressure. No liquid ballast was injected. Tires and rims were marked to detect rim slip.

Measurements of tire section width, tread chord width, and tread outside diameter were obtained for each tire immediately after mounting and inflation; and the measurements were repeated approximately 24 hours later. These values are presented in Table 1. Tread radius measurements were attempted using a stiff metal rod bent to conform to the tread radius. Tread radius values thus obtained varied substantially for a given tire. The values were generally considered to be too inconsistent to be useful in describing the tire shape and were not included in the tabulated data. However, average values for Radial A, Bias and Radial B were estimated to be 27, 18 and 18 inches, respectively.

Racks to accommodate suitcase-type tractor weights were fabricated and attached to the rear axle housing on each side of the test tractor. Portable truck scales were placed under the rear tires, and ballast was added until static load was 5980 pounds per tire. Static rear axle weight varied somewhat during the field test, however, as fuel was consumed by the engine. The 87-gallon fuel capacity tank was located above and behind the rear axle. At one point during the field work, approximately 50 gallons of diesel fuel were required to refill the tank. Assuming a fuel density of 7.08 pounds per gallon (Hunt, 1977), the maximum variation in total rear axle static force should have been less than 350 pounds (three percent).

Field Operation

A 200-foot measured test course was marked in the test plot. At least 100 feet of tilled runway was maintained at each end so that the test vehicle could be stabilized at the selected operating speed before entering the measured course.

The test vehicle was operated at three no-slip travel speeds, namely three, five and seven miles per

Table 1. Test tire and rim specifications.

Tire Designation	Radial A		Bias		Radial B	
Size	18.4R38		W16L-38		18.4R 8	
Ply Rating	8		8		8	
Inflation Pressure (psi)	20		20		20	
Rim	W16L-38		W16L-38		W16L-38	
Static Load Per Tire (lb)	5980		5980		5980	
Effective Rolling Diameter on Asphaltic Concrete at Specified Ballast (in.)	65.5		64.9		67.0	
Assigned Tire No.	1	2	3	4	5	6
Tire Weight (lb)	292	286	205	214	355	356
Section Width (in)						
At Mounting	19.53	19.63	19.23	19.18	18.23	18.25
24 Hours After Mounting	19.66	19.75	19.39	19.32	18.22	18.26
Tread Chord Width (in)						
At Mounting	17.20	17.05	16.56	16.42	17.28	17.34
24 Hours After Mounting	17.28	17.32	16.73	16.59	17.38	17.34
Tread Outside Diameter (in)						
At Mounting	67.5	67.7	67.7	67.6	69.7	69.3
24 Hours After Mounting	68.0	68.3	68.9	68.8	70.3	69.8
Rim Weight (lb)	165	160	163	157	159	161
Rim Bead Seat Width (in)	15.94	15.92	15.90	16.00	15.90	15.90
Maximum Variation (in)	0.04	0.02	0.04	0.04	0.02	0.06
Rim Bed Seat Diameter (in)	38.17	38.11	38.09	38.10	38.12	38.09
Maximum Variation (in)	0.08	0.12	0.04	.0.08	0.20	0.04

hour, approximately. Engine speed was maintained constant at 2500 rpm for all tests. Gear settings of the 24-speed transmission corresponding to the three, five, and seven-mph no-slip velocities were 2H, 4I, and 5H, respectively.

Approximately 40 passes were made through the test course for each pair of tires and each transmission setting. Drawbar load, or draft, for any given run was arbitrary and depended upon the selected operating depth of the disk harrow for that particular pass. Loading was varied for a given tire-transmission setting combination to insure that slip values across the desired 0 to 20 percent range were obtained. For a given set of tires, loading and transmission setting combinations were randomly ordered. For example, a three-mph run with heavy drawbar loading may have been followed by seven-mph run with a light drawbar load.

Data recording was initiated for a given run as the test vehicle entered the 200-foot test course. Recording for that run was terminated when the tractor passed the 200-foot mark. Data for 120 runs (three speeds times 40 passes for each speed) were stored on a single cassette magnetic tape. When tests for a given tire were completed, the data on the cassette tape were transferred to an on-line computer disk file for analysis using the Statistical Analysis System (Helwig and Council, 1979).

Tires were field tested according to the schedule listed in Table 2. Air temperature was measured using a mercury thermometer placed in the shade approximately one foot above ground level. Air temperature values in Table 2 represent the range of air temperatures over the test period for a given tire. Soil moisture values in Table 2 represent the range of values observed during tests with a given tire. Soil moisture samples were taken at randomly selected locations over the field at two to four-hour intervals while the tests were in progress. Gravimetric determination of moisture content involved the oven drying method (Gardner, 1965).

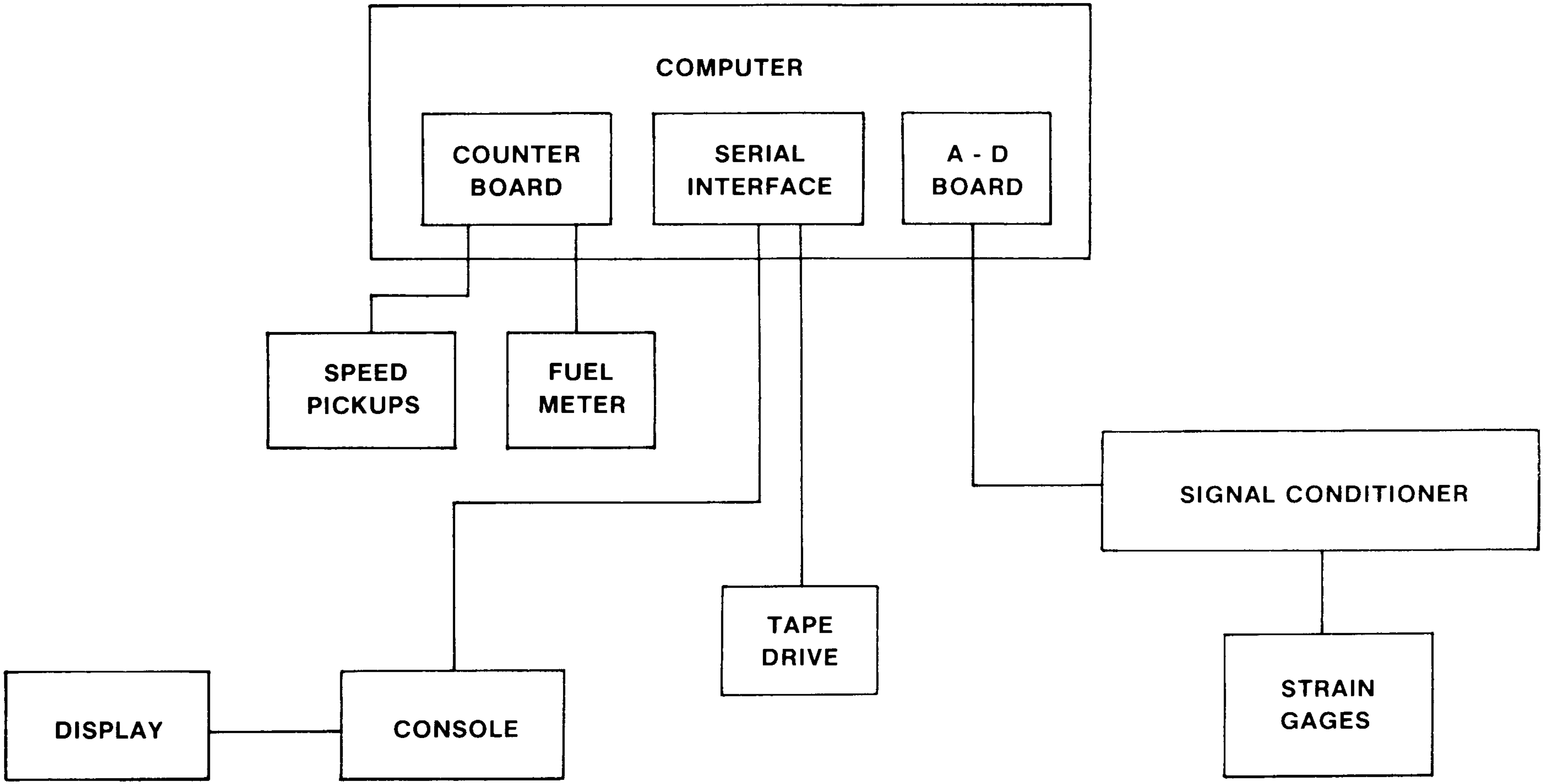

Figure 1. Schematic of microcomputer-based instrumentation system used for data acquisition.

Table 2. Air Temperatures and soil moisture levels during tire testing

Tire	Date of Testing	Air Temperature (°F)	Soil Moisture Content (%)
Radial A	May 14, 1981	69-79	11.5-13.4
Bias	May 23, 1981	79-80	11.9-14.6
Radial B	May 24, 1981	80-81	11.7-12.8

Results and Discussion

Measurable rim slip was observed on only one tire. The outside bead of the radial identified in Table 1 as tire number 2 continued to creep slightly throughout the field tests under implement load. Total slip of this bead after 120 passes through the test plot was approximately 0.6 inch.

Values of wheel slip, ground speed, implement draft, and fuel consumption used for data analysis were averaged for a given 200-foot run. Since the sampling interval during machine operation was one second, an average of approximately 30 samples of each parameter contributed to mean values characterizing a given run. Consequently, about 40 mean values (40 run averages) of a given parameter were used in the analysis of a particular tire-speed combination.

Best-fit curves were fitted to the data using a non-linear regression procedure (Helwig and Council, 1979). Drive wheel slip as a function of implement draft was fitted with an exponential growth curve of the form

$$S = Ae^{Bd}$$

where

S = drive wheel slip, percent
A and B = constants determined by regression
e = the numerical quantity having a natural logarithm equal to one, numerically 2.71828 . . . (Thomas, 1960)
d = implement draft, pounds.

These best-fit equations for the three sets of tires are plotted in Figures 2, 3, and 4 for no-slip speeds of 3, 5, and 7 mph, respectively. The actual regression equations defining the individual curves are listed in Table 3.

Figures 5 through 13 show plots of the regression equations for drive wheel slip as a function of implement draft for each of the nine tire-speed combinations. The actual data points are shown with each curve to give an indication of variability in the data. One indication of goodness of fit is the standard error of the mean estimates (Snedecor and Cochran, 1967). The standard error associated with each regression equation (each tire-speed combination) is shown in Table 3. The smaller the standard error, the better the goodness of fit.

Note that at the 7-mph no-slip speed, slip values were generally less than ten percent. No values near 20 percent were obtained because the test vehicle was not capable of delivering the necessary power to achieve slips of that magnitude at high field speeds. The regression equations were used to plot to a slip level of 20 percent for illustration purposes. However, one should be wary of extrapolating the data beyond their own range, as such extrapolation may be incompetent to furnish reliable evidence of trend (Snedecor and Cochran, 1967). An argument to support extrapolation in this case, nonetheless, is the similarity of this curve to those observed at three and five miles per hour which do have points over the entire 0 to 20 percent slip range.

Data for both sets of radial-ply tires at all speeds were pooled and compared to the bias-ply tire composite data over all speeds. Drive wheel slip as a function of implement draft for the two tire types is shown in Figure 14. Note that at every load level, slip of the bias tires exceeded that of the radial tires. Regression equations and estimates of error associated with the two curves are shown in Table 4.

The time rate of fuel consumption as a function of implement draft for the three sets of tires is shown for operation at 3, 5, and 7 mph in Figures 15, 16, and 17, respectively. Curves defined by the regression equations are plotted and actual data points are indicated for each tire-speed combination in Figures 18 through 26. The actual exponential growth curve equations and estimates of error are given in Table 5.

The time rate of fuel consumption as a function of drawbar horsepower for the three sets of tires is

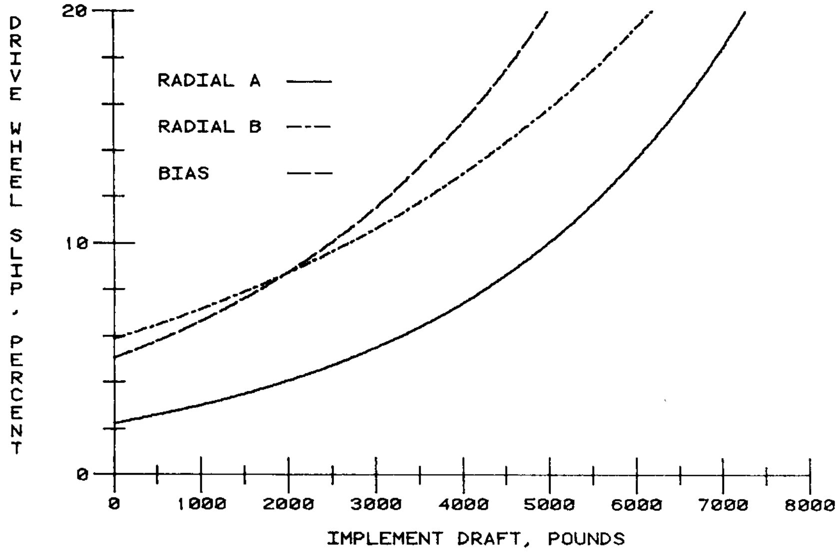

Figure 2. Drive wheel slip as a function of implement draft at a no-slip operating speed of 3 mph.

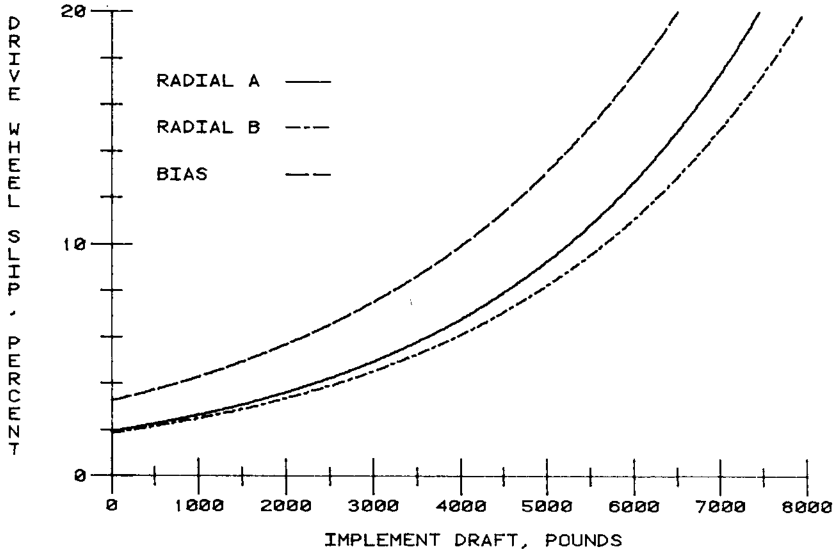

Figure 3. Drive wheel slip as a function of implement draft at a no-slip operating speed of 5 mph.

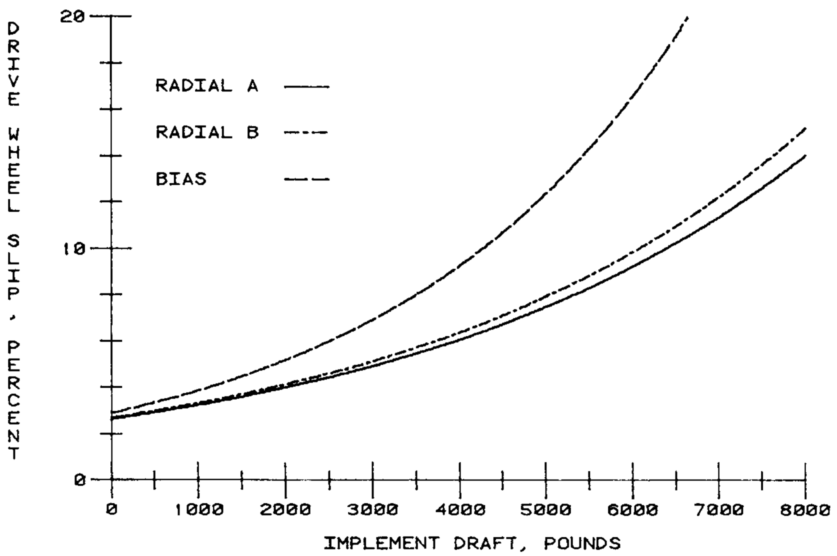

Figure 4. Drive wheel slip as a function of implement draft at a no-slip operating speed of 7 mph.

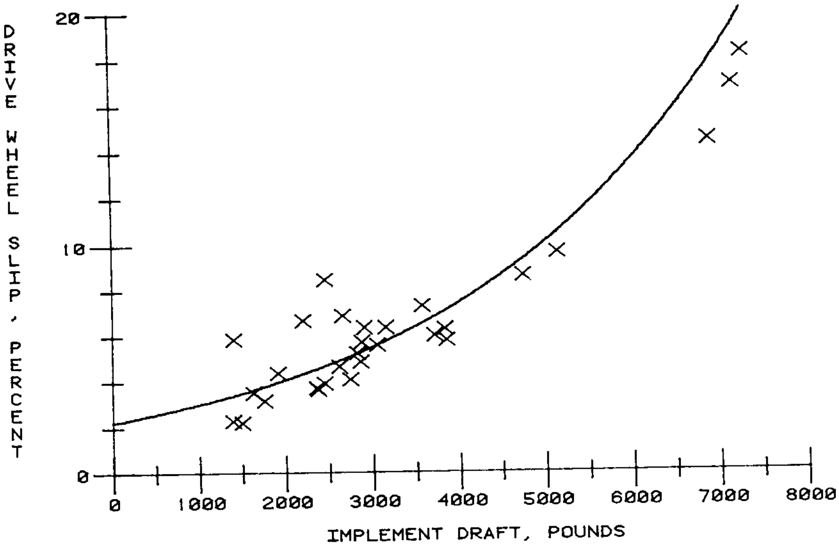

Figure 5. Drive wheel slip of Radial A as a function of implement draft at a no-slip operating speed of 3 mph.

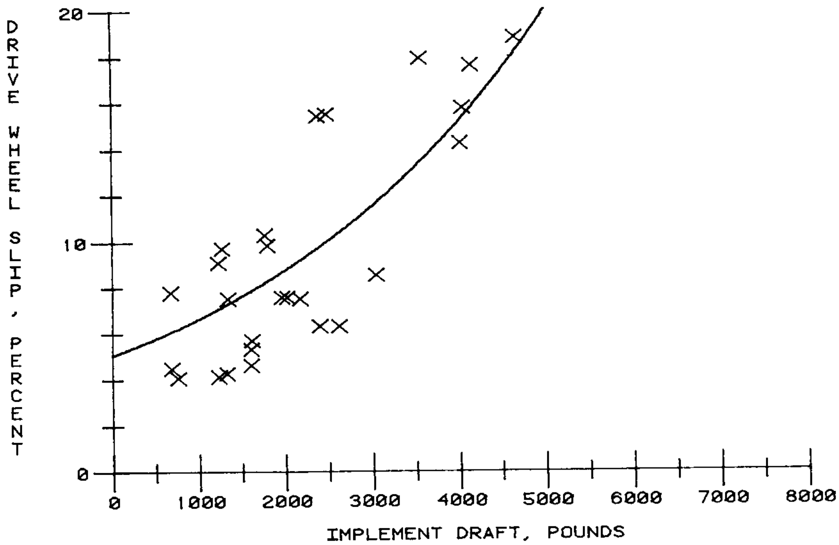

Figure 6. Drive wheel slip of Bias tires as a function of implement draft at a no-slip operating speed of 3 mph.

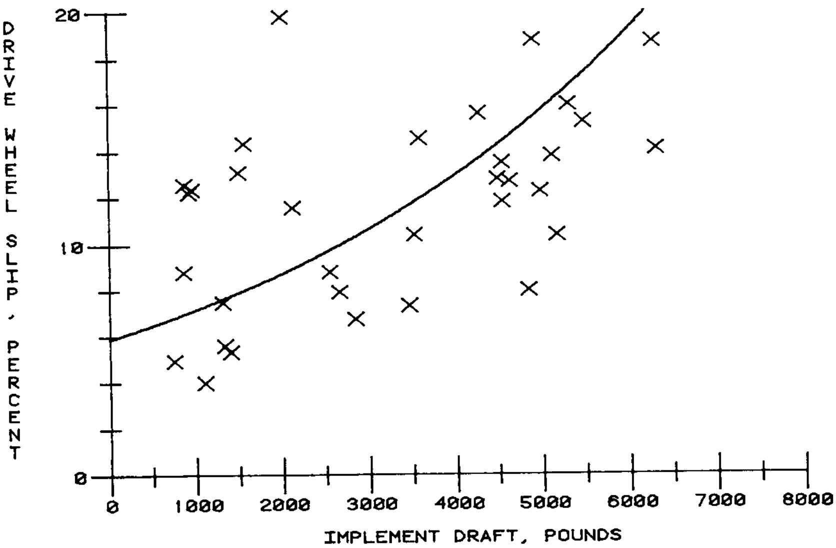

Figure 7. Drive wheel slip of Radial B as a function of implement draft at a no-slip operating speed of 3 mph.

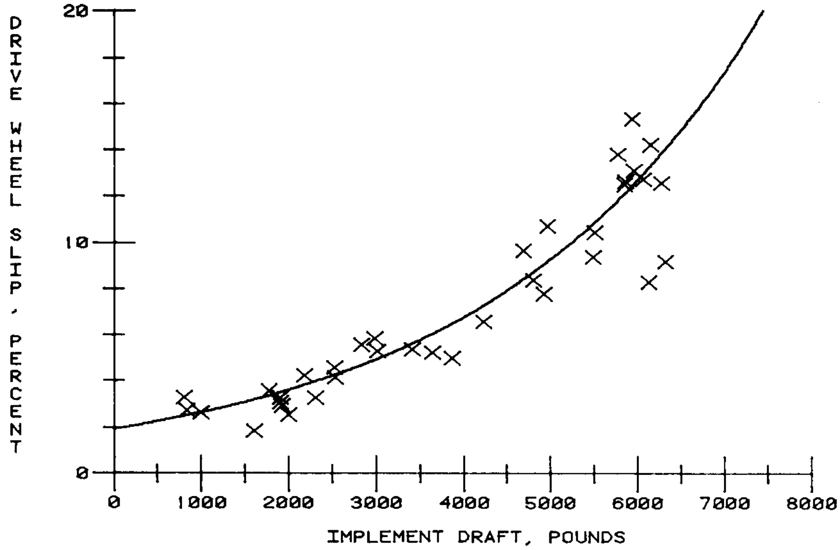

Figure 8. Drive wheel slip of Radial A as a function of implement draft at a no-slip operating speed of 5 mph.

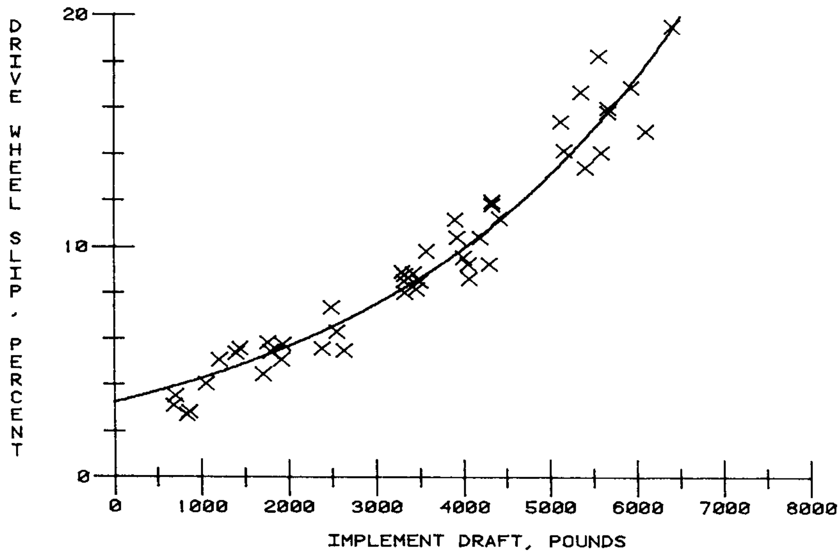

Figure 9. Drive wheel slip of Bias tires as a function of implement draft at a no-slip operating speed of 5 mph.

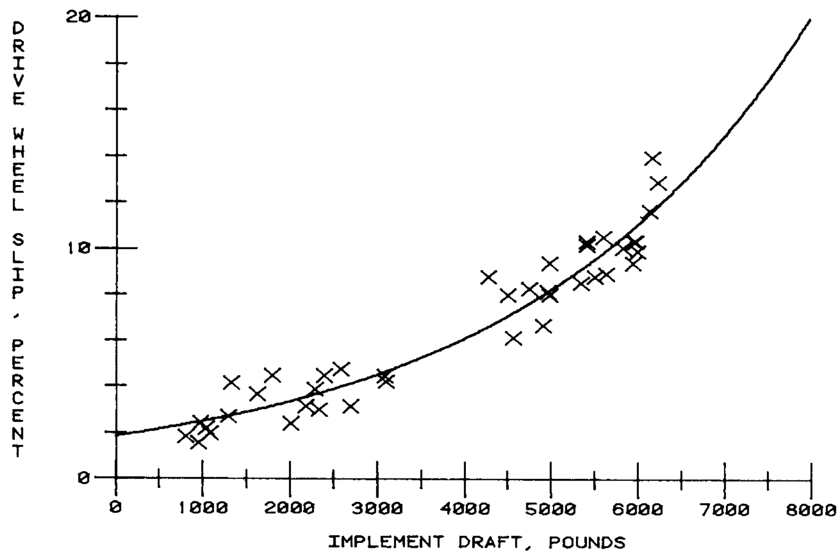

Figure 10. Drive wheel slip of Radial B as a function of implement draft at a no-slip operating speed of 5 mph.

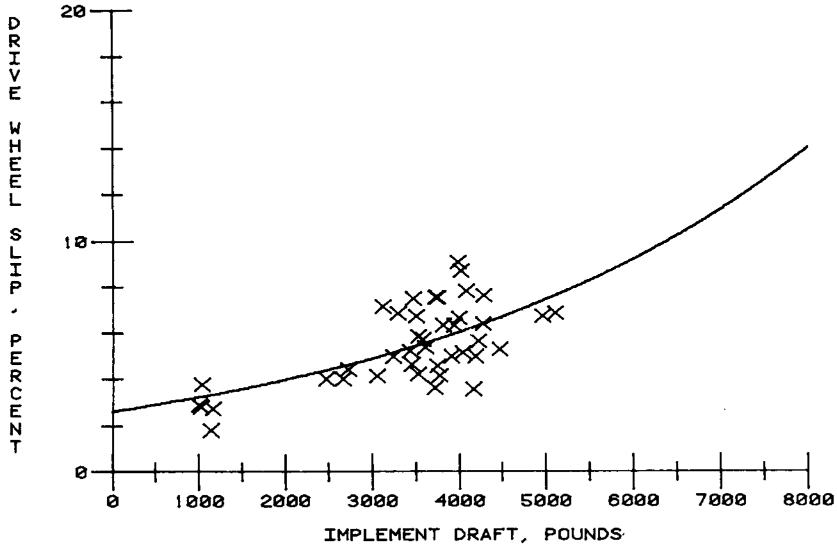

Figure 11. Drive wheel slip of Radial A as a function of implement draft at a no-slip operating speed of 7 mph.

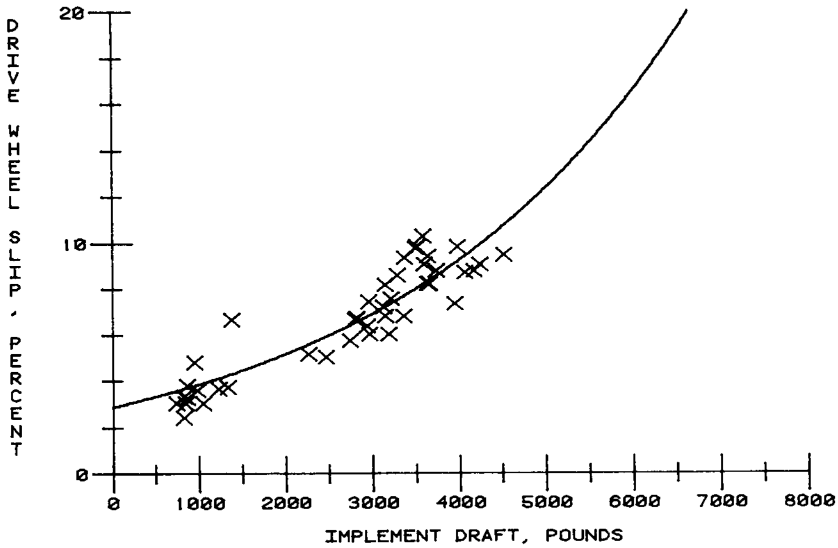

Figure 12. Drive wheel slip of Bias tires as a function of implement draft at a no-slip operating speed of 7 mph.

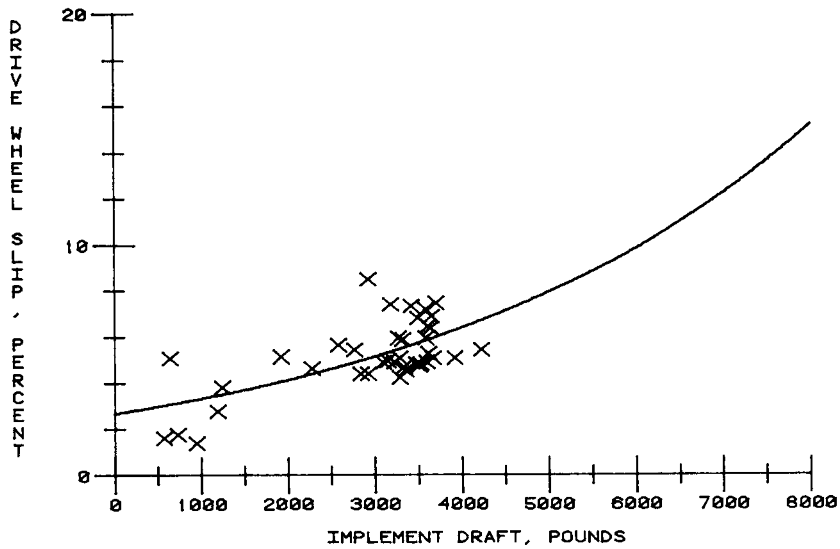

Figure 13. Drive wheel slip of Radial B as a function of implement draft at a no-slip operating speed of 7 mph.

Table 3. Regression equations and estimates of error for drive wheel slip (S) as a function of implement draft (d).

Tire	Speed (mph)	Regression Equation	Standard Error of the Estimate	Figure
Radial A	3	$S = 2.2310e^{0.00030131d}$	1.70	2, 5
	5	$S = 1.9388e^{0.00031335d}$	2.06	3, 8
	7	$S = 2.6286e^{0.00020924d}$	1.35	4, 11
Bias	3	$S = 5.0479e^{0.00027577d}$	3.07	2, 6
	5	$S = 3.2522e^{0.00027947d}$	1.07	3, 9
	7	$S = 2.8877e^{0.00029136d}$	0.99	4, 12
Radial B	3	$S = 5.8872e^{0.00019762d}$	4.38	2, 7
	5	$S = 1.8580e^{0.00029814d}$	0.97	3, 10
	7	$S = 2.6822e^{0.00021684d}$	1.19	4, 13

Table 4. Regression equations and estimates of error for drive wheel slip (S) as a function of implement draft (d).

Tire	Regression Equation	Standard Error of the Estimate
Radial	$S = 2.1105e^{0.00031656d}$	3.13
Bias	$S = 2.9417e^{0.00033269d}$	3.08

Table 5. Regression equations and estimates of error for time rate of fuel consumption (F) as a function of implement draft (d).

Tire	Speed (mph)	Regression Equation	Standard Error of the Estimate	Figure
Radial A	3	$F = 2.8306e^{0.00008660d}$	0.1429	15, 18
	5	$F = 3.0146e^{0.00014018d}$	0.3886	16, 21
	7	$F = 4.1331e^{0.00013833d}$	0.4738	17, 24
Bias	3	$F = 2.8827e^{0.00009131d}$	0.1542	15, 19
	5	$F = 3.2123e^{0.00013218d}$	0.3087	16, 22
	7	$F = 3.7611e^{0.00016856d}$	0.4041	17, 25
Radial B	3	$F = 2.9243e^{0.00008780d}$	0.1765	15, 20
	5	$F = 3.2019e^{0.00013639d}$	0.3945	16, 23
	7	$F = 3.8615e^{0.00016357d}$	0.3908	17, 26

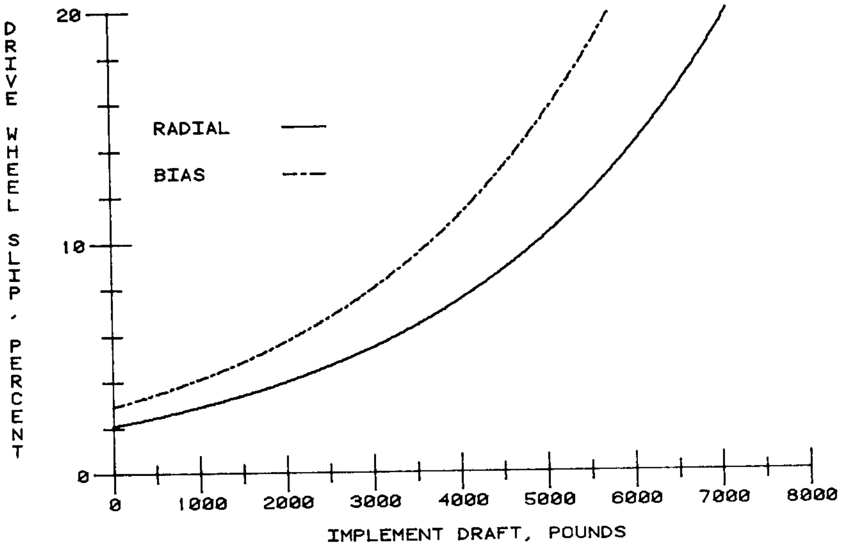

Figure 14. Drive wheel slip of radial-ply and bias ply tires as a function of implement draft. The radial curve represents combined data for two radial-ply designs. Operating speeds were 3, 5, and 7 mph.

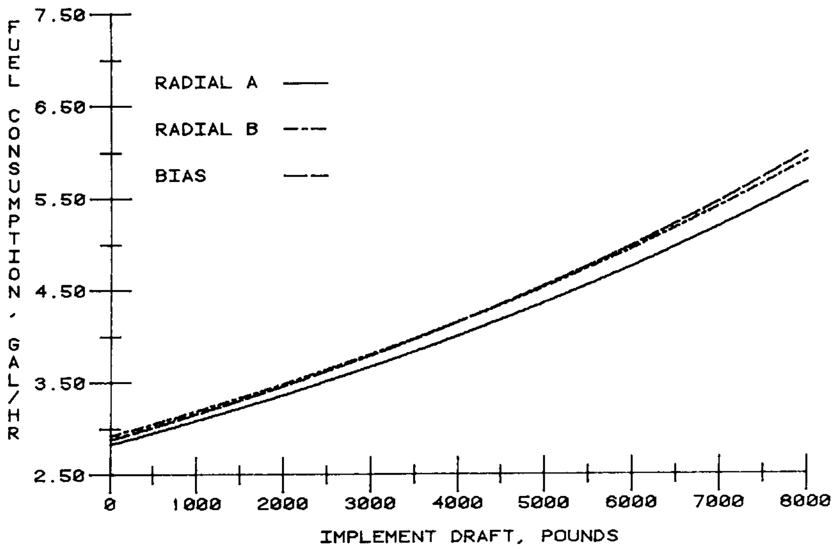

Figure 15. Time rate of fuel consumption as a function of implement draft at a no-slip operating speed of 3 mph.

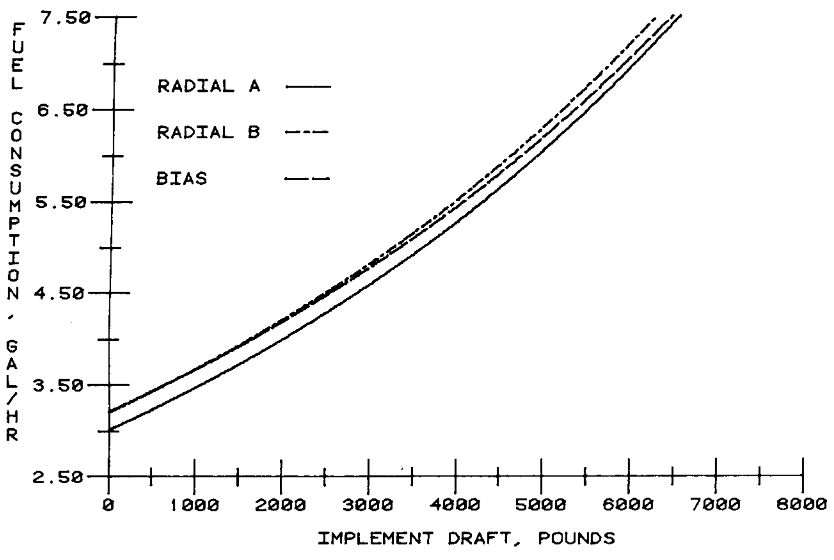

Figure 16. Time rate of fuel consumption as a function of implement draft at a no-slip operating speed of 5 mph.

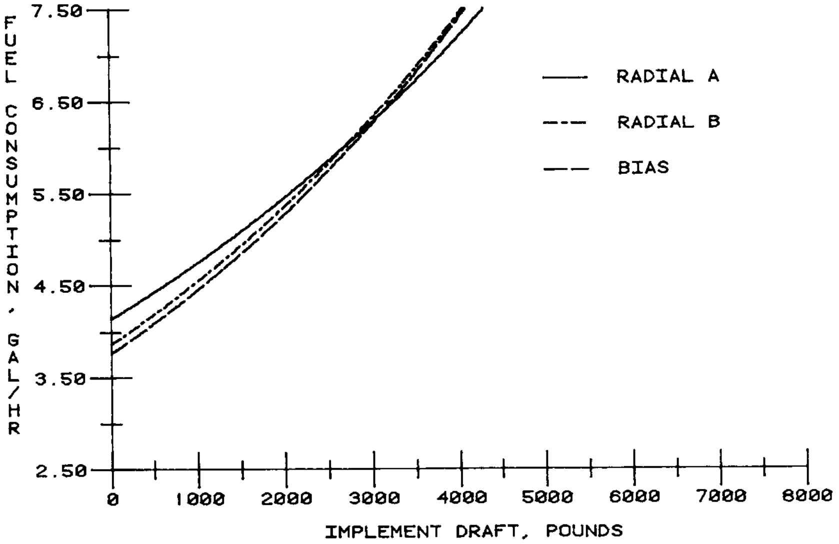

Figure 17. Time rate of fuel consumption as a function of implement draft at a no-slip operating speed of 7 mph.

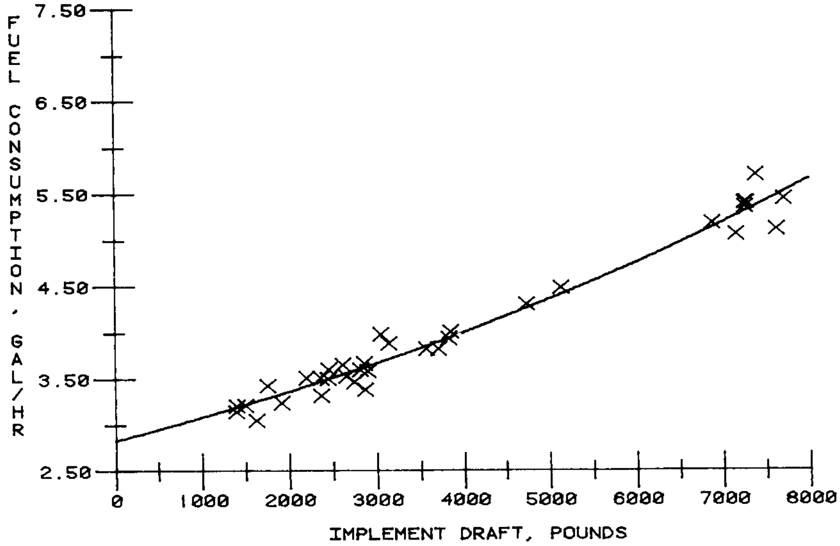

Figure 18. Time rate of fuel consumption with Radial A as a function of implement draft at a no-slip operating speed of 3 mph.

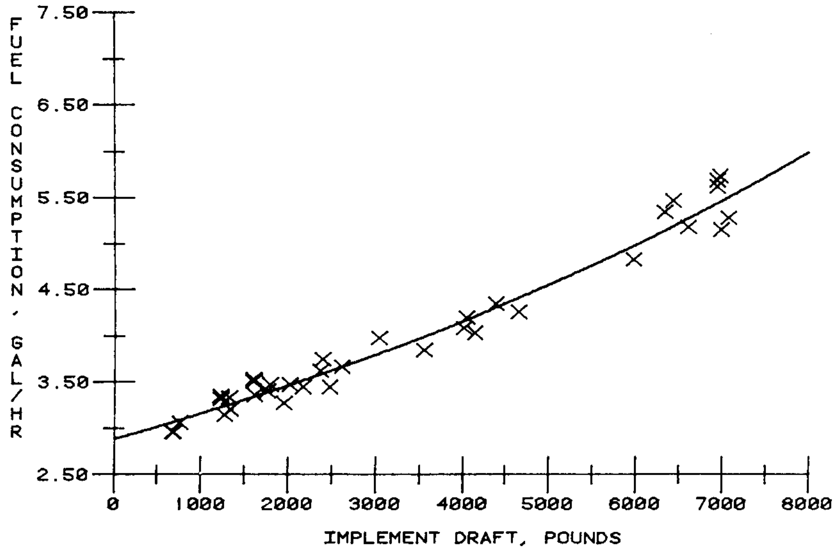

Figure 19. Time rate of fuel consumption with Bias tires as a function of implement draft at a no-slip operating speed of 3 mph.

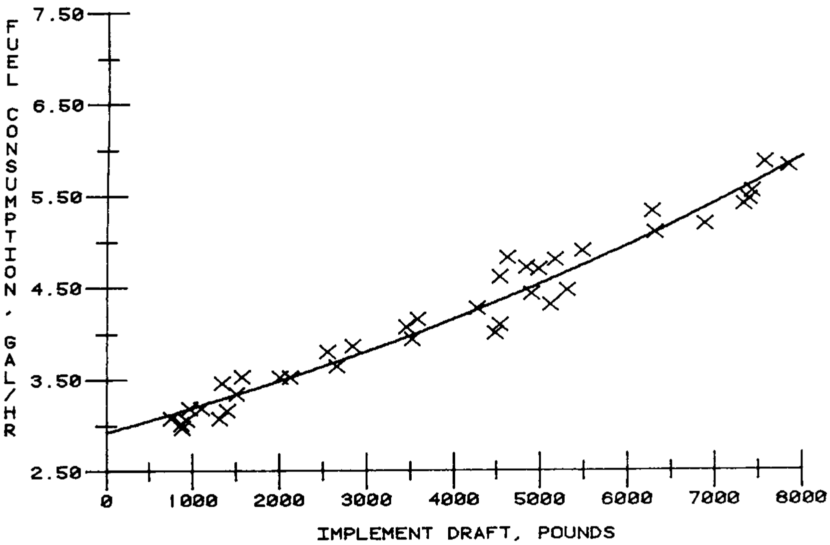

Figure 20. Time rate of fuel consumption with Radial B as a function of implement draft at a no-slip operating speed of 3 mph.

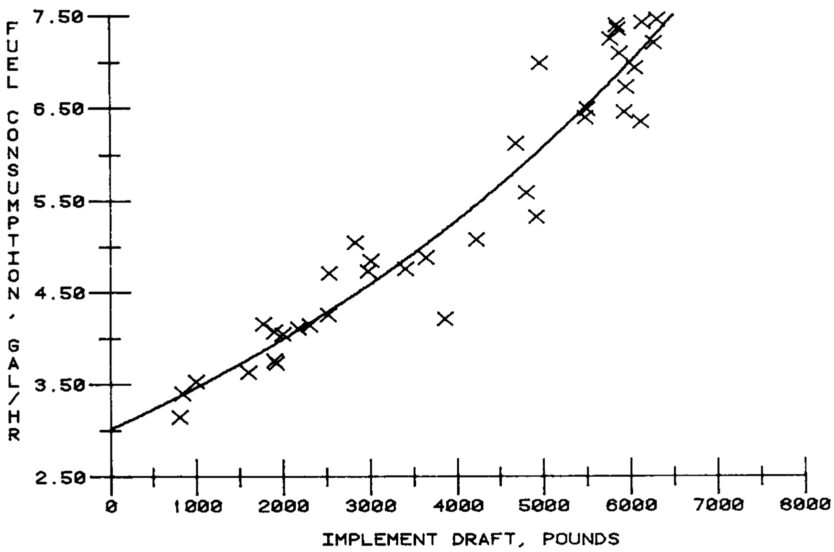

Figure 21. Time rate of fuel consumption with Radial A as a function of implement draft at a no-slip operating speed of 5 mph.

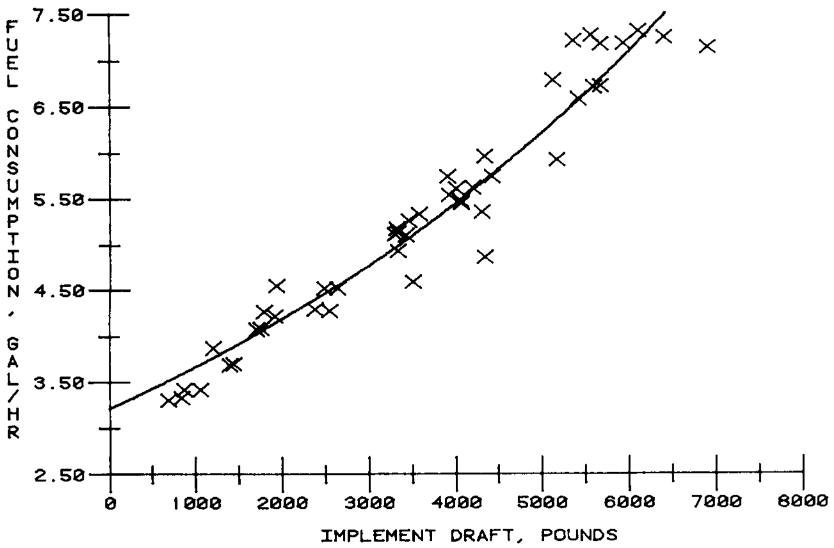

Figure 22. Time rate of fuel consumption with Bias tires as a function of implement draft at a no-slip operating speed of 5 mph.

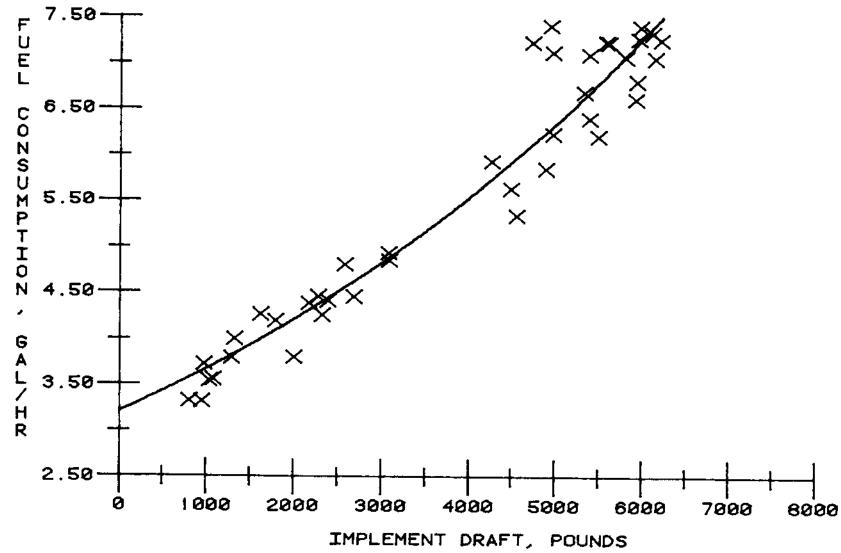

Figure 23. Time rate of fule consumption with Radial B as a function of implement draft at a no-slip operating speed of 5 mph.

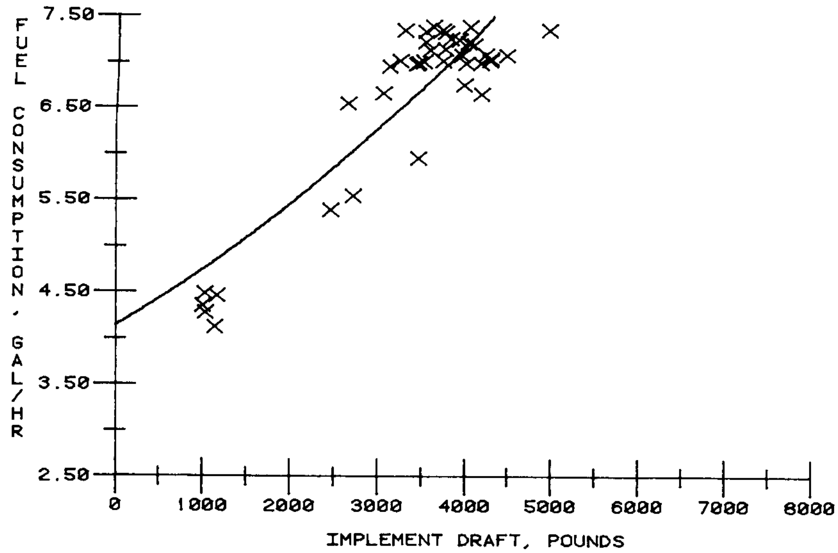

Figure 24. Time rate of fuel consumption with Radial A as a function of implement draft at a no-slip operating speed of 7 mph.

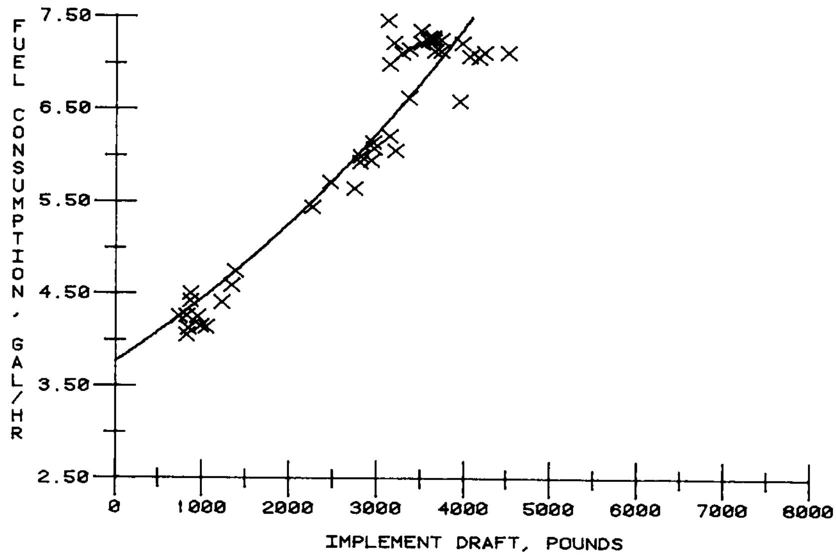

Figure 25. Time rate of fule consumption with Bias tires as a function of implement draft at a no-slip operating speed of 7 mph.

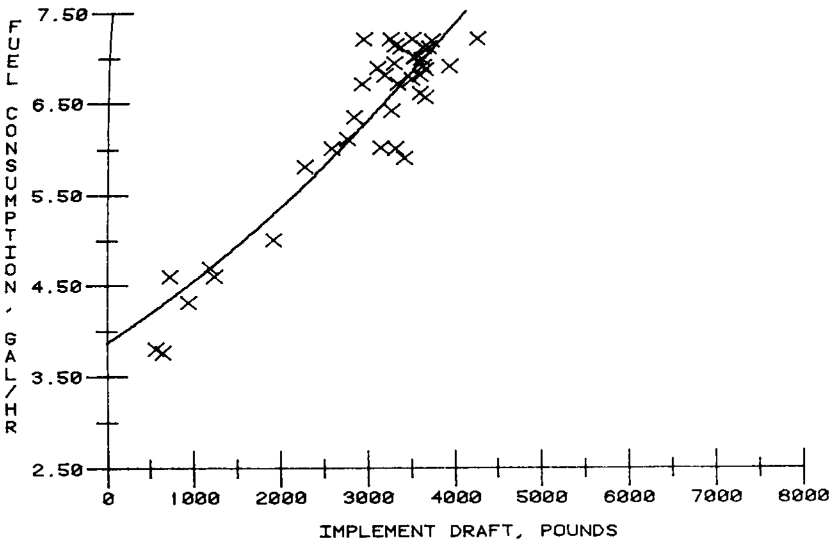

Figure 26. Time rate of fuel consumption with Radial B as a function of implement draft at a no-slip operating speed of 7 mph.

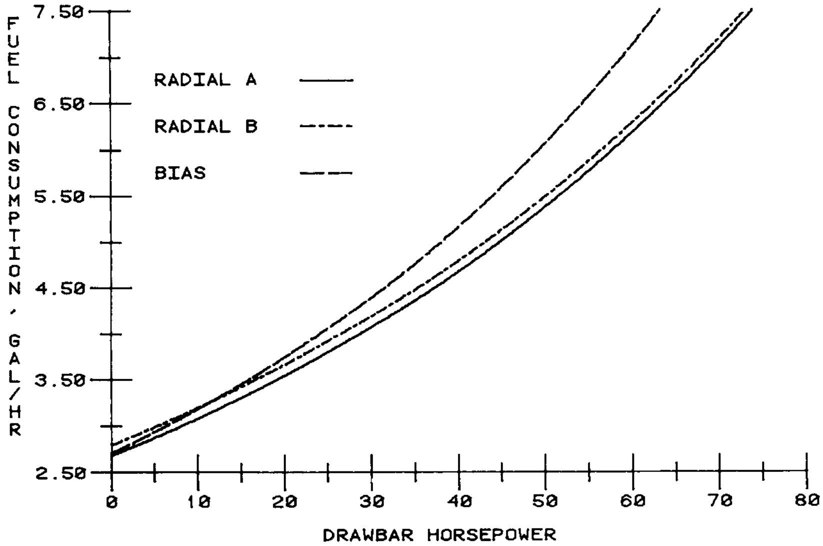

Figure 27. Time rate of fuel consumption as a function of drawbar horsepower at a no-slip operating speed of 3 mph.

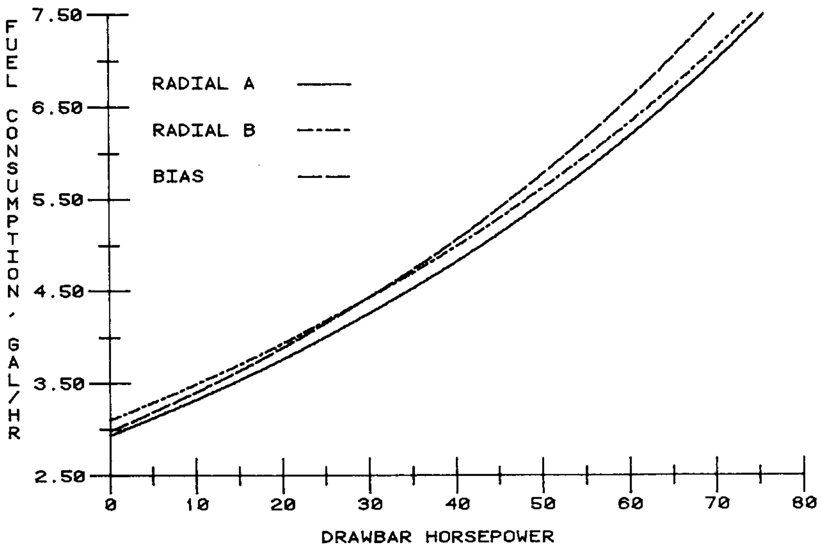

Figure 28. Time rate of fuel consumption as a function of drawbar horsepower at a no-slip operating speed of 5 mph.

shown for operation at 3, 5, and 7 mph in Figures 27, 28, and 29, respectively. Corresponding regression equations and estimates of error are presented in Tabel 6.

The fuel consumption per unit area of land tilled as a function of implement draft for the three sets of tires operated at no-slip speeds of 3, 5, and 7 mph is shown in Figures 30, 31, and 32, respectively. Corresponding regression equations and estimates of error are shown in Table 7. A field efficiency of 100 percent was assumed (ASAE, 1980b).

Predicted drawbar pull as a function of drawbar horsepower for the three sets of tires at the three no-slip operating speeds is shown in Figures 33, 34, and 35. Regression equations and corresponding estimates of error for each curve are listed in Table 8. The exponential curve fitted to the data was of the form

$$d = A\,(e^{BP} - 1)$$

where

d = implement draft or drawbar pull, pounds
A and B = constants determined by regression
e = the numerical quantity having a natural logarithm equal to one
P = drawbar horsepower.

Theoretical field capacity (ASAE, 1980b) as a function of implement draft for the three sets of test tires at the three travel speeds is shown in Figures 36, 37, and 38. Regression equations defining each curve and estimates of error corresponding to each equation are listed in Table 9. Theoretical field capacity values were determined from implement width and actual ground speed as follows:

Table 6. Regression equations and estimates of error for time rate of fuel consumption (F) as a function of drawbar horsepower (P).

Tire	Speed (mph)	Regression Equation	Standard Error of the Estimate	Figure
Radial A	3	$F = 2.6818e^{0.01390429P}$	0.1379	27
	5	$F = 2.9337e^{0.01242359P}$	0.4414	28
	7	$F = 3.8390e^{0.00901538P}$	0.3909	29
Bias	3	$F = 2.7106e^{0.01607175P}$	0.2132	27
	5	$F = 2.9807e^{0.01321616P}$	0.2905	28
	7	$F = 3.6212e^{0.01043452P}$	0.3844	29
Radial B	3	$F = 2.7936e^{0.01348962P}$	0.1821	27
	5	$F = 3.0976e^{0.01191185P}$	0.4151	28
	7	$F = 3.7540e^{0.00978006P}$	0.3536	29

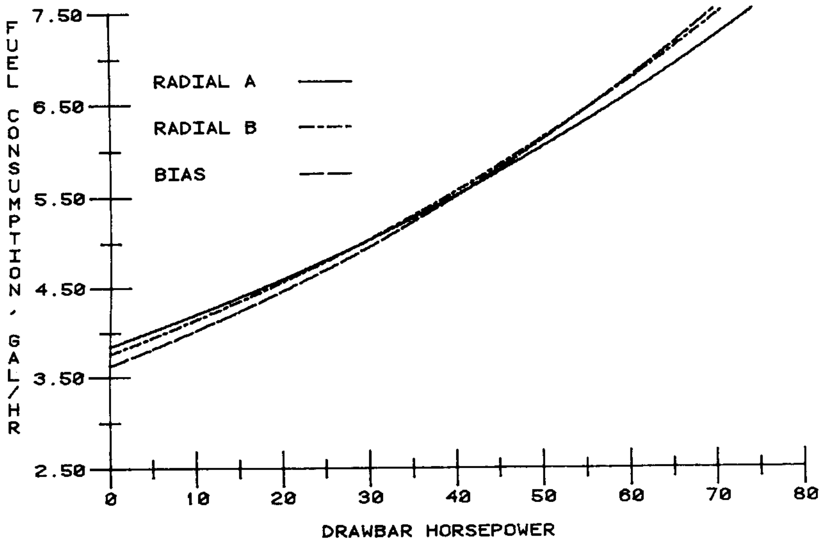

Figure 29. Time rate of fuel consumption as a function of drawbar horsepower at a no-slip operating speed of 7 mph.

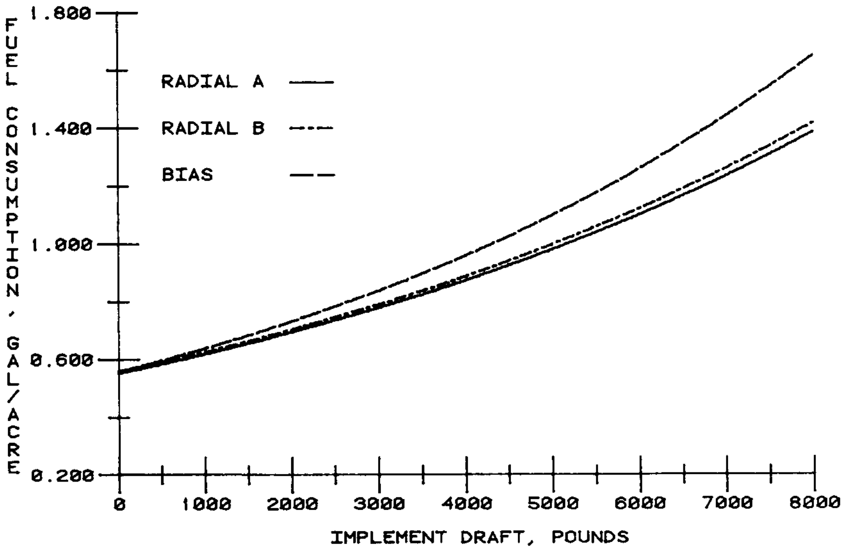

Figure 30. Fuel consumption per acre tilled as a function of implement draft at a no-slip operating speed of 3 mph. A field efficiency of 100 percent is assumed.

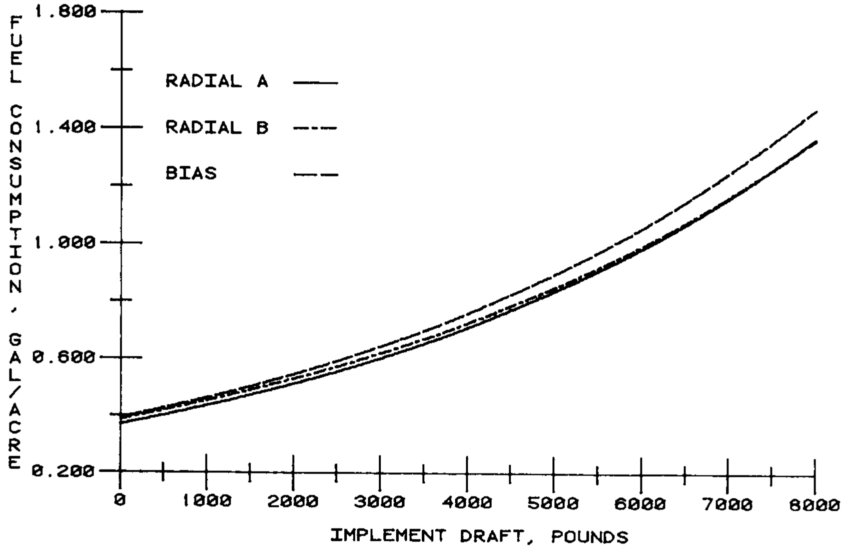

Figure 31. Fuel consumption per acre tilled as a function of implement draft at a no-slip operating speed of 5 mph. A field efficiency of 100 percent is assumed.

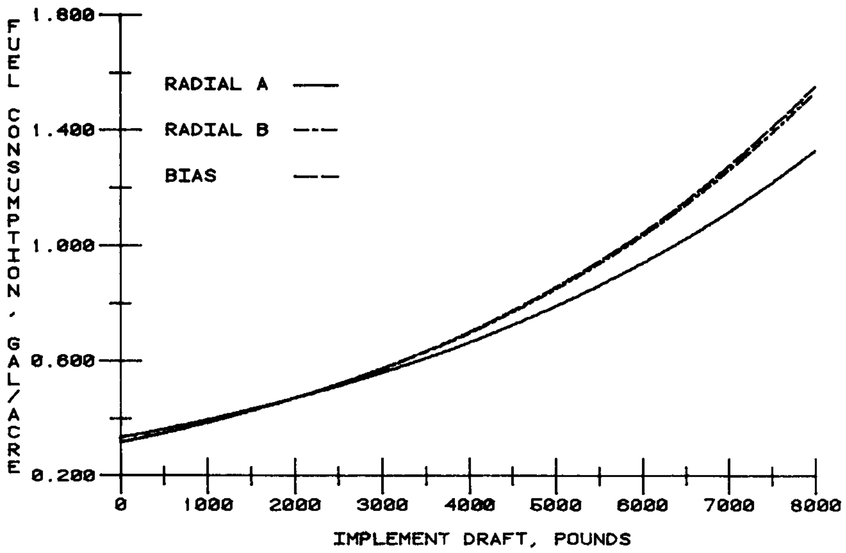

Figure 32. Fuel consumption per acre tilled as a function of implement draft at a no-slip operating speed of 7 mph. A field efficiency of 100 percent is assumed.

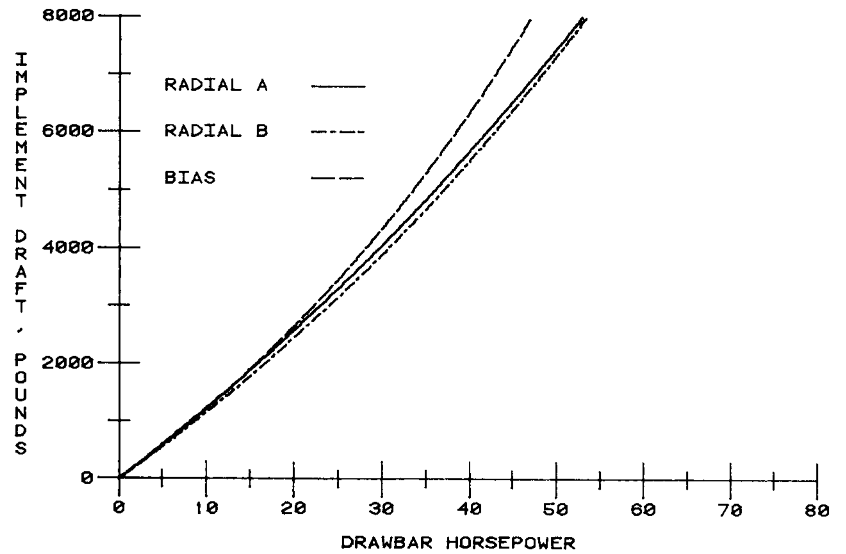

Figure 33. Implement draft as a function of drawbar horsepower at a no-slip operating speed of 3 mph.

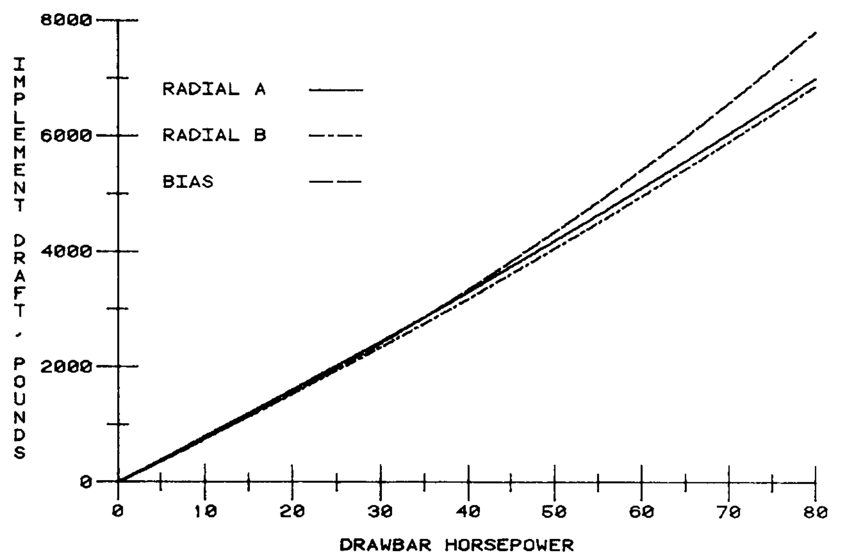

Figure 34. Implement draft as a function of drawbar horsepower at a no-slip operating speed of 5 mph.

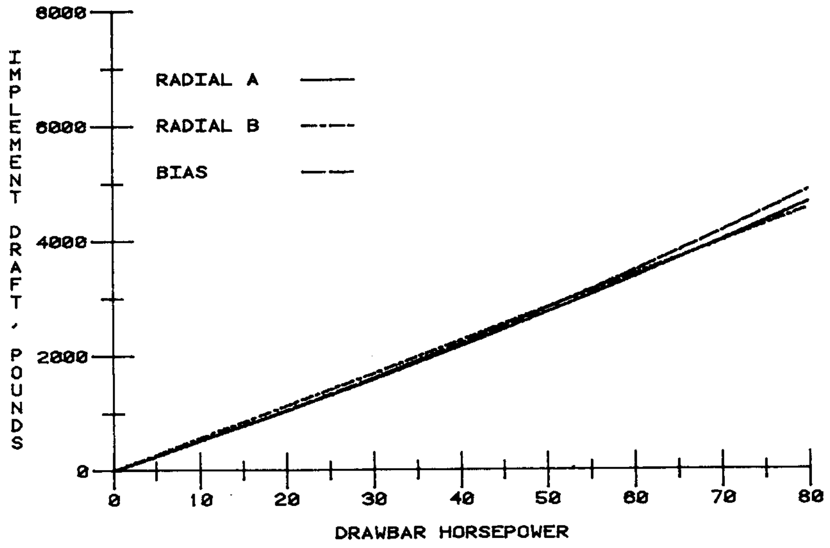

Figure 35. Implement draft as a function of drawbar horsepower at a no-slip operating speed of 7 mph.

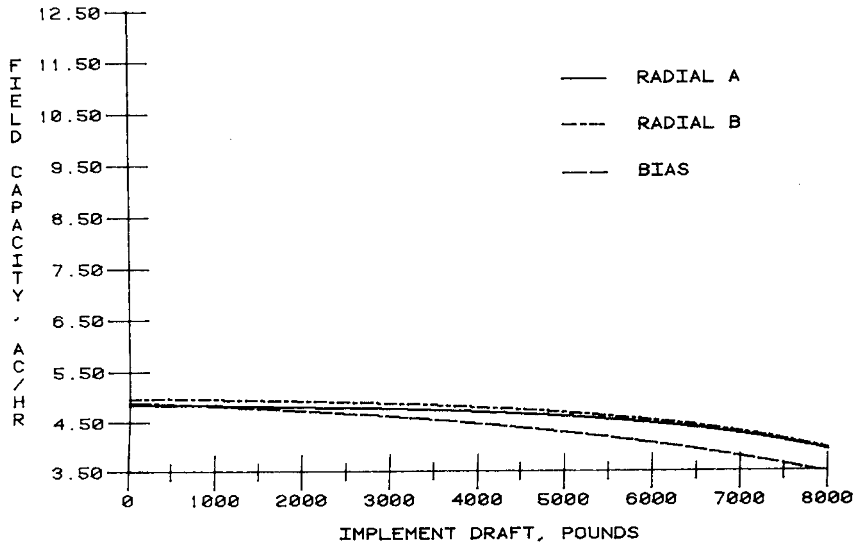

Figure 36. Theoretical field capacity as a function of implement draft at a no-slip operating speed of 3 mph.

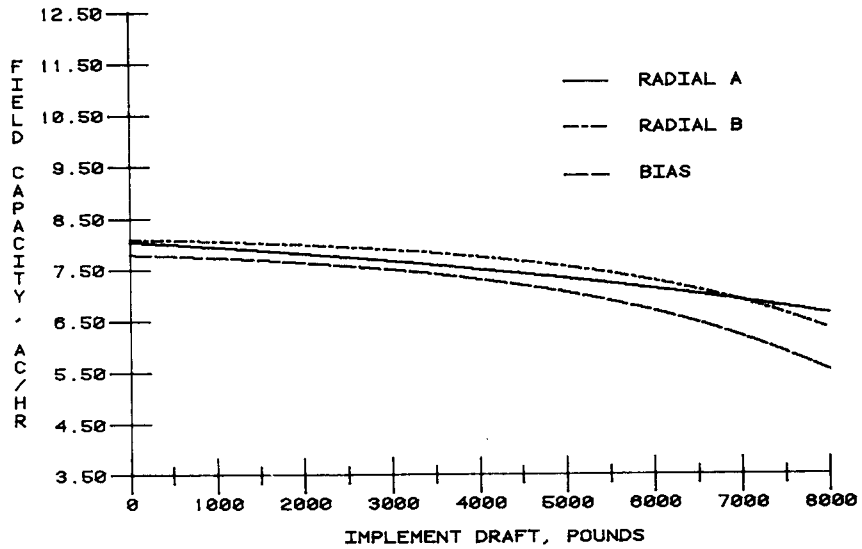

Figure 37. Theoretical field capacity as a function of implement draft at a no-slip operating speed of 5 mph.

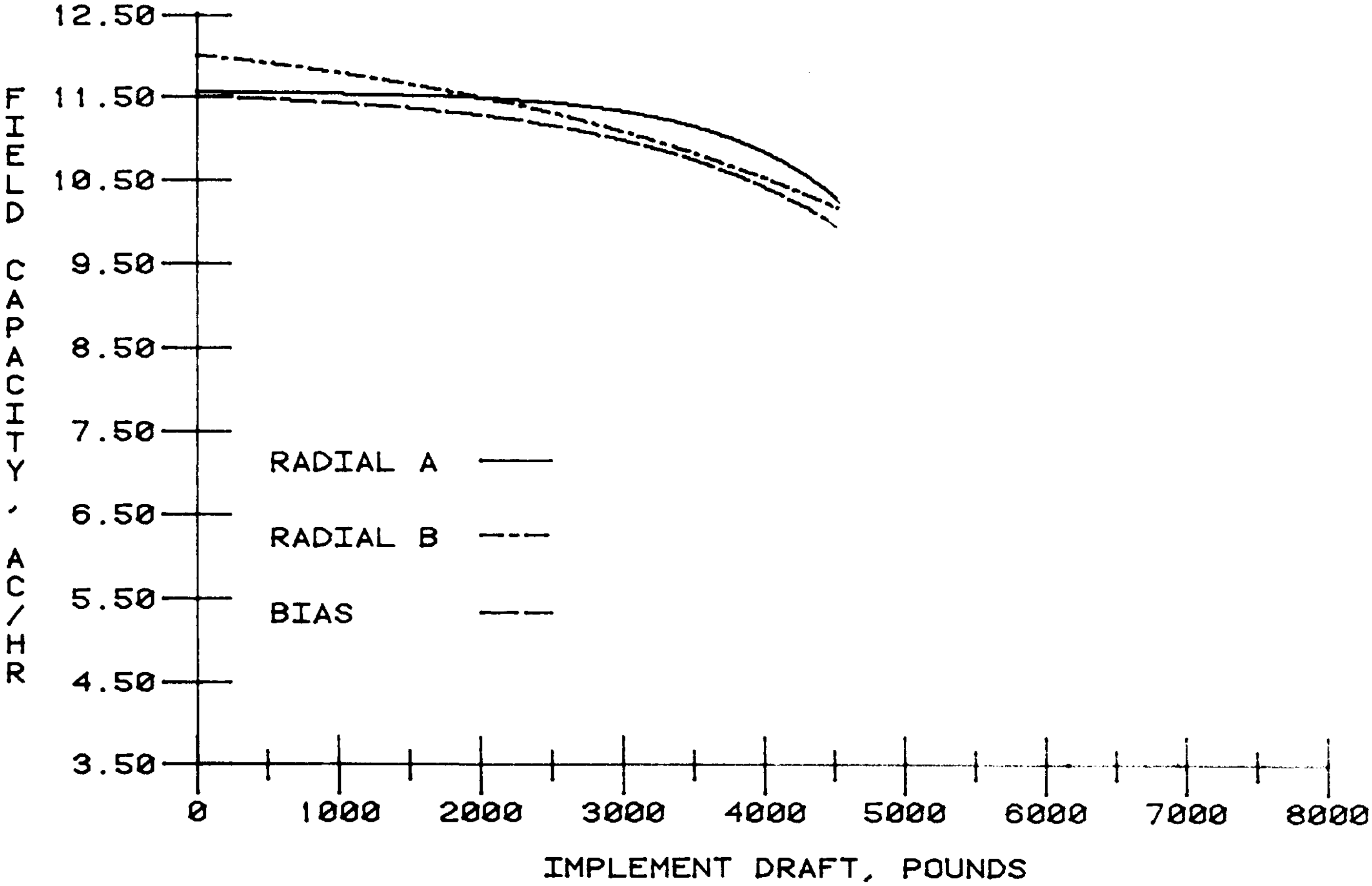

Figure 38. Theoretical field capacity as a function of implement draft at a no-slip operating speed of 7 mph.

Table 7. Regression equations and estimates of error for fuel consumption per acre of land tilled (G) as a function of implement draft (d).*

Tire	Speed (mph)	Regression Equation	Standard Error of the Estimate	Figure
Radial A	3	$G = 0.5504e^{0.00011547d}$	0.0316	30
	5	$G = 0.3676e^{0.00016414d}$	0.0627	31
	7	$G = 0.331e^{0.00017290d}$	0.0360	32
Bias	3	$G = 0.5570e^{0.00013582d}$	0.0539	30
	5	$G = 0.3906e^{0.00016570d}$	0.0429	31
	7	$G = 0.3163e^{0.00019912d}$	0.0380	32
Radial B	3	$G = 0.5560e^{0.00011701d}$	0.0409	30
	5	$G = 0.3852e^{0.00015784d}$	0.0578	31
	7	$G = 0.3173e^{0.00019701d}$	0.0350	32

*A field efficiency of 100 percent is assumed.

Table 8. Regression equations and estimates of error for drawbar pull (d) as a function of drawbar horsepower (P).

Tire	Speed (mph)	Regression Equation	Standard Error of the Estimate	Figure
Radial A	3	$d = 12653\ (e^{0.00925337P}-1)$	146.3	33
	5	$d = 26692\ (e^{0.00291295P}-1)$	199.3	34
	7	$d = 13051\ (e^{0.00381094P}-1)$	186.8	35
Bias	3	$d = 6569\ (e^{0.01688624P}-1)$	172.5	33
	5	$d = 9806\ (e^{0.00732553P}-1)$	135.1	34
	7	$d = 10200\ (e^{0.00487517P}-1)$	80.9	35
Radial B	3	$d = 9518\ (e^{0.01140879P}-1)$	163.0	33
	5	$d = 19717\ (e^{0.00373799P}-1)$	122.4	34
	7	$d = 135212\ (e^{0.00041377P}-1)$	169.9	35

Table 9. Regression equations and estimates of error for theoretical field capacity (T) as a function of implement draft (d).

Tire	Speed (mph)	Regression Equation	Standard Error of the Estimate	Figure
Radial A	3	$T = 4.8726 - 0.037612e^{0.00040367d}$	0.0891	36
	5	$T = 8.9420 - 0.902941e^{0.00011806d}$	0.2618	37
	7	$T = 11.5709 - 0.008021e^{0.00112378d}$	0.4148	38
Bias	3	$T = 5.2398 - 0.354263e^{0.00020108d}$	0.0840	36
	5	$T = 7.9821 - 0.189620e^{0.00032127d}$	0.1601	37
	7	$T = 11.5981 - 0.084654e^{0.00065585d}$	0.2264	38
Radial B	3	$T = 5.0265 - 0.058266e^{0.00036514d}$	0.0658	36
	5	$T = 8.2015 - 0.1177666e^{0.00034708d}$	0.1499	37
	7	$T = 12.5969 - 0.583419e^{0.00031480d}$	0.5076	38

$$T = \frac{S \times W}{8.25}$$

where

T = theoretical field capacity, acres per hour
S = actual travel speed, mph
W = effective width of the implement, feet.

Regression equations showing field capacity as a function of implement draft were of the form

$$T = A + Be^{Cd}$$

where

T = theoretical field capacity, acres per our
A, B, and C = constants determined by non-linear regression procedure
e = the numerical quantity having a natural logarithm equal to one
d = implement draft, pounds

CONCLUSIONS

Radial and bias-ply tires were operated in loose clay loam soil with drawbar loading to produce drive wheel slips in the 0 to 20 percent range. Test results indicated the following:

1. Average travel reduction (slip) associated with the radial tires was less than with the bias-ply tires for a given level of drawbar loading. The magnitude of the slip difference tended to increase as drawbar load increased.
2. The time rate of fuel consumption associated with a given drawbar horsepower output tended to be less with the radials than with the bias tires. This trend was most pronounced at low operating speed and heavy drawbar loading.
3. The fuel requirement per acre tilled tended to be less for the radial tires, especially when implement draft was high.
4. For a given level of implement draft, the drawbar horsepower output of the tractor tended to be greater with the radial tires because of increased travel speed resulting from less wheel slippage.
5. The theoretical field capacity of the tractor equipped with radial-ply tires was greater than when bias tires were used. This trend was most pronounced at high drawbar loading where radials slipped less than bias tires.

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