Effect of "Correct" Pressure on Tractive Efficiency of Radial Ply Tires

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Summary:
Radial ply tractor tires were introduced on farm tractors nearly 20 years ago and their merits in terms of tractive performance have been well documented. Recent changes to the tire load-inflation tables allowing radial tire pressures to go as low as 6 psi have placed increased focus on performance differences and on actual pressures being used by our farmer customers. A series of traction tests were conducted on two tire sizes where the performance at "correct" pressure was compared to the performance at elevated pressures typical of that found on customer tractors. Results show 4-7% improvement in peak efficiency by using the correct pressure, roughly equal to the difference between bias and radial ply tires. These results are supported by a number of tests conducted by The Alberta Farm Machinery Research Center on 4WD tractors with singles, duals, and triple tires at correct and high pressures. Even greater differences in tractor performance can result depending upon how a tractor is ballasted, that is, where it is operating on the pull-slip curve.

Keywords:
Tires, Traction, Tractive Efficiency, Performance, Tire Inflation Pressure, Tractors, Tires, Slip

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INTRODUCTION:
Radial ply tractor tires were introduced on farm tractors nearly 20 years ago. Their merits in terms of tractive performance have been well documented. Recent changes to the tire load-inflation tables allowing radial tire pressures to go as low as 6 psi have placed increased focus on performance differences and on actual pressures being used by our farmer customers.

PURPOSE:
Traction test results were used to evaluate the effect of tire pressures on performance. Two separate sets of data were used. The first involved complete traction tests on specific tires (Zoz) compared using tractive efficiency. The second was from field tests of tractors with several different tire combinations (Turner) compared using percent power delivered.

CONCLUSIONS:
1. A consistent 4 to 7% improvement in peak tractive efficiency (Zoz) and power delivery (Turner) was obtained with tires correctly inflated when compared to those that were overinflated in the range of 8 to 10 psi.

2. Even greater differences in tractor performance can result depending upon how tractors are ballasted, that is, where they may be operating on the pull-slip curve.

3. The greatest improvement in performance from using correct inflation pressures is obtained on softer and looser soils; as the soil strength increases the differences become smaller with little or no difference being obtained on a concrete surface.

4. Little performance difference was noted between tires operating at rated (correct) pressure with two different weights. The weights were selected to provide about a 10 psi rated pressure difference.

5. The increase in performance that can be obtained by use of proper tire pressure is significantly greater than that to be expected from engine, hydraulic, and drive train improvements. Unfortunately, it can not be demonstrated on the concrete test track.

TEST PROCEDURE (Zoz):
Two tire sizes were available for test. These were 18.4R42 and the new 710/70R38. Both were tested in the single tire configuration with the following weights, soils, and pressures.

<table>
<thead>
<tr>
<th>Tire</th>
<th>Tire Load Rating, psi</th>
<th>Tire Pressure, psi</th>
<th>Soils/</th>
<th>Graph Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Firm Untilled</td>
<td>Loose Tilled</td>
</tr>
<tr>
<td>710/70R38 S</td>
<td>14</td>
<td>24</td>
<td>101</td>
<td>103</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>14</td>
<td>105</td>
<td>107</td>
</tr>
<tr>
<td></td>
<td>6 (minimum)</td>
<td>14</td>
<td>109</td>
<td>111</td>
</tr>
<tr>
<td></td>
<td>6 (minimum)</td>
<td>6</td>
<td>117</td>
<td>119</td>
</tr>
<tr>
<td>18.4R42 S</td>
<td>24</td>
<td>24</td>
<td>121</td>
<td>123</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>24</td>
<td>125</td>
<td>127</td>
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<td></td>
<td>14</td>
<td>14</td>
<td>129</td>
<td>131</td>
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</tbody>
</table>
Tests were conducted using a John Deere 4450 two wheel drive tractor equipped with strain gaged axles. Tractor rear weight was set for the tire load rating and pressure and the front weight was adjusted so that approximately 20% of the static weight was on the front. (Note: During these tests no attempt was made to compensate for the front wheel motion resistance, only to keep the front weight at the same percent of total for all the test combinations. During later tests the front motion resistance was compensated for by making front motion resistance ratio equal to that of the rear using circular references in the spreadsheet and calculated front weight to adjust the drawbar pull.)

Data recorded were drawbar pull, tractor travel speed, axle torque, and axle speed. Drawbar pull was varied using a load tractor and load unit to obtain pulls from nearly zero to that which gave approximately 30-40% slip. Tire free rolls were taken on a relatively hard surface. Dynamic weight on the tires was calculated using drawbar pull, drawbar height, and tractor wheelbase.

Tests were conducted in Arizona in undisturbed (firm untilled) soil and that which had been tilled and disked to a depth of approximately 10 inches (loose tilled). Soil cone penetrometer readings were taken with 8 replications using a hand held cone penetrometer.

**TEST PROCEDURE (Turner):**

Data was extracted from a series of tests run using a simplified instrumentation system and traction test procedure. The instrumentation system was designed to measure performance parameters on tractors quickly without requiring modification to the tractor and has been described by Turner, (1992). Real time infield measurements of horizontal pull, ground speed, wheel surface speed, and engine speed were made on all tractors. On some tractors, the engine output torque was measured and used to calculate engine output power. On other tractors the engine output power was calculated using the PTO Substitute Method or the Approximate Engine Power Method (Turner, 1993a).

The simplified test procedure was used to determine the entire range of performance for a given tractor, tire, ballast, and tire inflation pressure combination. Initial measurements were made of tractor weight, weight distribution, and tire pressures. The tractors were operated in the field with a chisel plow as a load and tested in at least three different gears. One was a gear low enough to allow overloading the traction system to produce excessive slip (40 to 50%). A second gear was in
the normal operating range. A third was a gear high enough to overload the engine at low (5 to 10%) slip levels. In each of these gears, the test was started with the implement out of the ground. The draft was then increased from zero up to the maximum in a series of small increments. Once the tractor reached equilibrium after a draft increment, a 10 to 30 second data snapshot was recorded, representing some 100 to 300 readings. Once a maximum for a gear was reached, whether slip or engine load, additional data was taken around the 10% slip level and around the engine rated speed, when either or both points could be reached.

After a run, the groups of raw data values for each snapshot were averaged to produce individual points. For each point, percent slip was calculated from the ground speed and wheel surface speed. Power delivery efficiency was calculated from the power developed at the drawbar compared to the calculated engine output power. The averaged data file for a run typically contained from 8 to 15 discrete test points and could be used to produce various performance comparison plots. This test data analysis procedure has been used to report traction performance comparisons previously (Turner, 1993b).

**DATA ANALYSIS (Zoz):**
Data for the mean values from the test runs were entered into a spreadsheet for calculation of the tire performance parameters and for plotting. Three plots were made using slip, gross traction ratio, and net traction ratio as the independent variable. However, since any comparisons of tire pressures on customer tractors is likely to be done without implement change (constant pull?) use of Net Traction Ratio (P/W) as the independent variable seems most meaningful for this presentation and easiest to understand. The following is an example of the data showing the three logical ways to plot traction data:

![Example of test data plotted against slip.](image1)

![Example of data plotted against Net Traction Ratio.](image2)

![Example of data plotted against Gross Traction Ratio.](image3)
Spread of the data points is typical of the data. For visual clarity the data points have been removed on the graphs where performance comparisons are being made.

**DATA ANALYSIS (Turner):**
The original tests were run to evaluate the power hop characteristics of the tractors. Tractors were tested with various combinations of gears, weights and weight distributions with various tire combinations and tire pressures. Tests were run in sandy clay loam, and heavy clay soils, in firm untilled soil (primary tillage condition) and tilled (secondary tillage condition), and in some cases in a third very much over tilled condition. By selecting only certain tests from the entire group, a group of tests could be obtained with the same combinations of tractor, gears, weights, weight distributions and tire sizes but with tire pressures correct in one set and overinflated in the other. For each such set of tests, all the individual test data points were combined into one file. To reduce the point scatter and better show the curve shapes, the data in each file was sorted in ascending order based on the pull to weight ratio. A moving average was then applied with the averaging interval around 5% of the total number of points.

The plots used for comparisons were Percent Power Delivered and Percent Wheel Slip plotted against the Pull to Weight Ratio (P/W). P/W is the same as Net Traction Ratio, (ASAE, 1983). Percent Wheel Slip and slip ratio are analogous. While Percent Power Delivered is not identical to the more traditional tractive efficiency, it contains similar information and can be used in the same way.

**TEST RESULTS (Zoz):**
Test results are shown by comparisons of the correct and high pressures on a series of graphs for the tires, soil conditions and pressures. These graphs are labeled "Over Pressure Comparisons". Also included are graphs comparing the performance at rated load at two tire pressures. These are labeled "Rated Pressure Comparisons".

Loads for each test condition are not specified directly in terms of weight but are defined as the rated load conditions for a certain tire pressure. For example, the tire load rating for 18.4R42 single tires operating at 14 psi is 10,240 lb (4640 kg) axle load (two tires; 25 mph). For purposes of this paper this is defined as the "14 psi load rating", the "correct" pressure for the tire at that weight.

The following graphs show the Over Pressure Comparisons for the 710/70R38 tires at 6 psi and 14 psi load ratings in "Firm Untilled" and "Loose Tilled" soils.

![Over Pressure Comparison](image-url)
Tractive efficiencies are shown by the upper pair of curves on each plot while the supporting slip, motion resistance, and gross traction ratios are also shown. Peak tractive efficiency was normally highest with the correct pressure and occurs at a net traction ratio of about 0.40. In general, greater differences were obtained in the looser tilled soil.

The following comparisons are for the 18.4R42 tire at 14 psi load rating:

In addition to the tests at over pressure conditions, tests were conducted at the rated load conditions for the two pressures. Following are comparisons for 710/70R38 tire at 6 and 14 psi and for the 18.4R42 tire at 14 and 24 psi rated loads:
The lower rated pressure tire tended to operate more efficiently at high net traction ratios. Use of incorrect pressure had a greater effect than tire load at correct pressure.

Tire load has a major affect upon the operating point and must be correct for the drawbar pull and/or speed of operation. For example, if the tractor is set up correctly for near maximum tractive efficiency (P/W approx. 0.40) for one load condition and the tractor axle load is doubled, the P/W is now 0.20 and the tractive efficiency may be significantly lower than maximum; or, more commonly, the pull may increase and the tractor operates at P/W in the range of 0.5 or higher. In this case not only is the efficiency lower than maximum but the affect of incorrect pressure is even greater.

In addition to the field tests, a series of tests were also conducted on the concrete test track to further extrapolate the effects of "soil" condition on performance with correct and overinflated tires. The following graph shows the results of these tests on 18.4R42 tires with correct inflation pressure of 14 psi and overinflated to 24 psi. The data were plotted as individual
graphs but when overlaid the results were indistinguishable and the curves are shown with all the data points:

![Graph](image)

**18.4R42 S On Concrete; 14 psi load**

**TEST RESULTS (Turner):**
Six separate sets of pressure comparisons are graphed. Each set contains various combinations of gear, weight, and weight distribution for the given tractor and tire setup that is described. The individual points are graphed along with the fitted curves to indicate the quantity of data.

- **Ford New Holland 946 on dual 20.8 R42 tires and overtilled soil - 60 tests, 30 correct and 30 overinflated**
- **John Deere 8770 on dual 20.8 R42 tires and overtilled soil - 24 tests, 12 correct and 12 overinflated**
- **Ford New Holland 946 on single 20.8 R42 tires and overtilled soil - 24 tests, 12 correct and 12 overinflated**
- **John Deere 8760 on dual 20.8 R42 tires and firm untilled soil - 40 tests, 20 correct and 20 overinflated**
John Deere 8760 on dual 20.8 R42 tires and tilled soil - 78 tests, 39 correct and 39 overinflated

John Deere 8960 on dual 20.8 R42 tires and tilled soil - 12 tests, 6 correct and 6 overinflated

Each comparison shows an improvement in power delivered and a reduction in wheel slip for correctly inflated tires across the full range of the pull to weight curve. Peak power delivery efficiencies typically occur at pull to weight values between 0.35 and 0.40.

The data appears to suggest that the John Deere Tractors were more efficient than the Ford New Holland tractors but it is not appropriate to make that conclusion. Percent power delivery on the John Deere tractors was determined using engine power calculated by the PTO Substitute Method. Because the Ford New Holland tractors did not have PTO’s, their engine power was calculated by the Approximate Engine Power Method. The PTO Substitute Method can be used for tractor to tractor comparisons but the Approximate Engine Power Method only allows comparisons between different setups on a given tractor.
SUMMARY:
The following two charts provide a summary of the results from both Turner and Zoz and show graphically the improvement in efficiency that can be expected from using correct radial tire pressures. Tractors correctly ballasted can expect to see an improvement of 4 to 7% in drawbar power when tires are correctly inflated. If the tractor is operating at high pulls and slips greater than the optimum, even greater improvement can be expected. Over the long term, this improvement in efficiency should show up as decreased fuel consumption.
REFERENCES

1. Agricultural Engineers Yearbook of Standards. 1983. ASAE Standard S296.2 - Uniform Terminology for Traction of Agricultural Tractors, Self-Propelled Implements, and other Traction and Transport Devices


