Paper No. 93-1516
AN ASAE/CSAE MEETING PRESENTATION

SINGLE, DUAL AND TRIPLE TIRES AND RUBBER BELT TRACKS IN PRAIRIE SOIL CONDITIONS

by

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SUMMARY:

Traction performance tests were run at the Alberta Farm Machinery Research Centre on four-wheel drive tractors with single, dual and triple rubber tires and on rubber belt track tractors. Comparisons were made in various tilled and untilled prairie soil conditions during a three year period using a simple instrumentation set and test procedure. The results were viewed from a practical standpoint using the efficiency of power delivery as the comparison basis. No power delivery difference was found between single or dual radial tires and rubber belt tracks when the tires were set at inflation pressures that were correct by 1992 standards. Single and dual radial tires were more efficient than triple radial tires. Dual radial tires were more efficient than dual bias tires. The efficiency of all radial tire combinations was reduced when they operated at higher than rated inflation settings. Power hop was a significant concern on certain rubber tire set-ups. Steering under load was a concern on rubber belt tractors.

KEYWORDS:

Belt, Machinery Management, Measurement, Performance, Power Hop, Power Transmission, Rubber, Slip, Tires, Track, Traction, Tractive Efficiency, Tractors

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Introduction

Farmers have a wide range of choices for delivering traction power to the ground. In the past, the options were track type tractors with steel tracks, or two-wheel drive or four-wheel drive rubber tire tractors with single or dual bias ply tires. Now rubber belt tracks and radial ply tires as singles, duals or triples have been added to the selection list. The continuing need to improve efficiency in agriculture brings an increased demand for information about these various traction options. Recent changes in recommended inflation pressures for radial tires have further complicated the selection and optimization process.

During a three year period, engineers at the Alberta Farm Machinery Research Centre (AFMRC) tested the rubber belt track system used on Caterpillar Challenger tractors along with various combinations of single, dual and triple rubber tires on four-wheel drive tractors. Draft and performance tests were run in several soil conditions with various tractor weight set-ups and with tire inflation pressures that reflected both previous and current weight and tire inflation recommendations. The tests developed information about the power delivery characteristics of each of the traction systems.

The tests were a joint effort between AFMRC in Lethbridge, Alberta, and the Northern Tractor Resource Center (NTRC) in Havre, Montana. Farmers and manufacturers including Case-IH, Caterpillar, John Deere, Firestone, Flexi-coil, Ford New Holland, Goodyear, Leon Manufacturing and Morris Industries cooperated in the tests.

Literature Review

Various researchers have evaluated and reported on the differences in traction performance between singles and duals, between single tires and tracks, and between dual tires and tracks.

Domier et al. (1970) compared a dual 18.4-38 bias ply two-wheel drive, a dual 18.4-38 bias ply four-wheel drive, and a steel tracked tractor. They reported an 8 percent increase in tractive efficiency for the tracks over the four-wheel drive. The four-wheel drive tires were inflated to 110 kPa (16 psi) inner and 96 kPa (14 psi) outer at a load of 1480 kg (3260 lb) front and 1160 kg (2550 lb) rear per tire.

Taylor and Burr (1975) compared a single bias 12.4-28 tire at an inflation pressure of 98 kPa (14 psi) and loads of 500 kg (1100 lb) and 1000 kg (2200 lb) to a steel track and found tractive efficiciencies for the track to be 20 percent higher than for the tire.

Esch et al. (1986) compared rubber belt tracks to a four-wheel drive equipped with dual 20.8-38 ply tires. They report a 7 to 12 percent increase in tractive efficiency for the tracks. The tractor tires were inflated to 95 kPa (14 psi) inner and 85 kPa (12 psi) outer at a load of 1900 kg (4180 lb) front and 1370 kg (3010 lb) rear per tire.

Evans and Gove (1986) compared a dual 20.8 R38 radial ply four-wheel drive, and a rubber belt tracked tractor. They reported a 20 percent increase in tractive efficiency for the tracks in loose soil and a 6 percent increase in firm soil. The four-wheel drive tires were inflated to 83 kPa (12 psi) inner and outer at a load of 1800 kg (3960 lb) front and 1500 kg (3300 lb) rear per tire.

Bashford et al. (1987) compared single and dual 18.4-38 bias ply tires at the same total weight and tire pressures. They reported that on concrete the singles had greater tractive efficiency than the duals but that there was no difference in performance between the singles and duals in the field. The tires were inflated to a pressure of 124 kPa (18 psi) at a load of 2300 kg (5060 lb) for each single and 1150 kg (2530 lb) for each dual.

A problem with using much of this previous work today results from the tire inflation pressures used. The traction advantages of radial tires compared to bias tires and the importance of setting radial tires to the correct minimum inflation pressure has been documented in several references. Burt and Bailey (1981) reported the effect of inflation pressure and tire load on the tractive efficiency of 20.8 R38 radial tires. They found a decrease in tractive efficiency as tire inflation pressure increased. Chades (1984) reported the effect of inflation pressure and tire load on the tractive efficiency of single radial 18.4 R38 tires. He found a 7 percent decrease in tractive efficiency with a 55 kPa (8 psi) increase in inflation pressure at a tire load of

2700 kg (5940 Ib) per tire. Wulfsohn et al. (1988) compared the performance of a number of radial and bias ply tires and found an average increase in tractive efficiency of 6.8 percent across the 0 - 30 percent slip range. Bashford et al. (1992) compared performance of three different radial tires at three inflation pressures and reported lower tractive efficiencies at the higher pressures.

From a traction standpoint, tires function best when run at their correct inflation pressure. This pressure is a function of the load on the tire and tire manufacturers publish load-inflation tables that show the correct pressures for the various loads. In late 1991 to early 1992, the major tire manufacturers published revised load-inflation tables for radial tires that contained changes in the recommended inflation pressures. These new tables allowed much lower pressures than those in the past. The tire companies suggest that following the new guidelines will result in improved performance (Goodyear Tire Company, 1992). Many earlier traction performance tests on tire and track configurations used bias tires, often run at pressures that exceeded the recommended levels. While the reported data from such tests are correct, the over pressures and lack of radial tires reduces their value in current comparisons. Considering the five above mentioned tire and track comparisons, the following can be observed.

For Domier et al. (1970), the correct inflation pressure for the tire loads would have been 82 kPa (12 psi) for all the tires, hence the tests were run at a nominal 20 kpa (3 psi) over pressure. Had the tires been radials, the 1992 correct inflation would have been 62 kPa (9 psi) front and 41 kPa (6 psi) rear.

For Taylor and Burt (1975), the correct inflation pressure for the tire loads would have been 82 kPa (12 psi) at the 850 kg (1870 Ib) load and 110 kPa (16 psi) at the 1000 kg (2200 Ib) load. At the 500 kg (1100 Ib) load the tire was significantly overinflated. This is reflected in the data, which shows the 1000 kg (2200 Ib) load to have higher tractive efficiency than the 500 kg (1100 Ib) load.

For Esch et al. (1986), the correct inflation pressure for the tire load would have been 82 kPa (12 psi) for all the tires. This was close to what was actually run. Had the tires been radials the 1992 correct pressures would have been 69 kPa (10 psi) front and 41 kPa (6 psi) rear.

Evans and Gove (1986), ran at correct inflation pressures for the time. The 1992 correct inflation pressures for these tires and loads would have been 62 kPa (9 psi) front and 48 kPa (6 psi) rear, a 20 kPa (3 psi) front and 41 kPa (6 psi) rear reduction in pressure.

For Bashford et al. (1987), the correct inflation pressure for the singles at the 2300 kg (5060 Ib) load would be 110 kPa (16 psi), and for the duals at the 1150 kg (2530 Ib) load, 82 kPa (12 psi). For this tractor, the duals were significantly more overinflated, 41 kPa (6 psi), than the singles, 13 kPa (2 psi). Had the tires been radials, the 1992 correct inflation pressure for the singles at the 2300 kg (5060 Ib) load would have been the same 110 kPa (16 psi), while for the duals at the 1150 kg (2530 Ib) load the pressure would have been 48 kPa (6 psi).

In each of these cases, using correct inflation pressures would have changed the values and could have influenced the comparisons. Using radial tires with 1992 correct inflation pressures would have influenced the results even more.

Test Description

Purpose of the Tests

These tests were to develop information about traction systems to assist farmers in the selection of an appropriate system and the optimization of that system. The tests showed the impact of the traction systems on farm operation from a practical point of view. Because a traction system's performance is ultimately determined by the amount of available power that can be transferred to the ground as useful work, the tests concentrated on measuring power delivery efficiency, the ratio of the power put into a traction system that is delivered to the ground. The tests also determined the settings and conditions where power delivery was maximized. Finally the tests evaluated how the various traction systems functioned as they delivered power, considering factors such as power hop, steering, ease of set-up and cost.

Scope of the Tests

Tests were done during 1991, 1992 and 1993, in soil conditions typical of the Northern Great Plains. All the tractors used were instrumented and data was taken over a wide range of drafts and speeds.

In southern Alberta in the summer of 1991, a Case-IH 9260, a Case-IH 9250 and a Caterpillar Challenger 65 were tested in primary and secondary tillage in a clay loam, a sandy loam and a heavy clay soil. Both wheel tractors were tested with dual radial tires. A single inflation pressure, ballast weight and ballast ratio was maintained using fluid ballast.

In northern Montana in the fall of 1991, a John Deere 8760, a John Deere 8960, a Caterpillar Challenger 75 with 700 mm (27.5 in) wide tracks and a Caterpillar Challenger 75 with 890 mm (35 in) wide tracks were tested in primary and secondary tillage in a heavy clay soil. Various combinations of radial and bias single, dual and triple tires at various tire inflation pressures were tested. Ballast weights and ratios were varied and both liquid and cast ballast were used.

In central Alberta in the early summer of 1992, a John Deere 8760 and a Caterpillar Challenger 65 were tested in primary and secondary tillage in a dark brown soil. The wheel tractor was tested with single, dual, and triple radial tires at various inflation pressures. One ballast weight and ratio was maintained and only cast ballast was used.

In northern Alberta in the late summer of 1992, a John Deere 8760 with dual radial tires and a Caterpillar Challenger 65B were tested in primary and secondary tillage in a black soil. Only one tire inflation pressure and ballast set-up was used.

In southern Alberta in the fall of 1992, a John Deere 8760 was tested with dual and triple radials in primary and secondary tillage in a clay loam soil. Various tire inflation pressures were tested. One ballast weight was maintained but several ballast ratios were tested using both liquid and cast ballast.

In southern Alberta in the summer of 1993, a Ford New Holland 946 with single, dual and triple radials and a John Deere 8770 with dual and triple radials were tested in secondary tillage in a clay loam soil. Various tire inflation pressures and ballast weights and ratios were tested using both liquid and cast ballast.

The test tractors were at manufacturers' rated engine power levels ranging from 201 kw (270 hp) to 276 kw (370 hp). The measured engine power levels were 5 to 15 percent above the advertised values. To remove any effects of engine rating differences, overpowering or engine power variability, results were compared using power delivery efficiency, the ratio of power at the drawbar divided by the power produced by the engine. This kept the comparisons of the capabilities of the traction power delivery systems independent of the engine systems they were associated with.

Test Instrumentation and Computations

Engineers at AFMRC previously developed a performance measurement system and technique to simplify traction performance measurements (Turner, 1993b). This system was used throughout these tests and included an on-board data acquisition system that was portable between vehicles (Turner, 1992). All the equipment was powered by the vehicle and operated by the vehicle operator. The values measured and the methods of measuring them were as follows:

DRAFT, the horizontal pull a tractor developed, was measured by a load cell between the tractor and the towed implement.

GROUND SPEED, the speed that a tractor was moving, was measured by a radar unit placed on the tractor and aimed forward.

WHEEL or TRACK SPEED, the speed the surface of a power delivery system was moving, was measured by a radar unit placed on the tractor and aimed at the wheel or track.

VERTICAL ACCELERATION, the acceleration or shaking of a tractor in the up-down direction, was measured by an accelerometer placed near the centerline of the front axle.

ENGINE POWER LEVEL, the power produced by an engine, was measured in several ways. On some tractors, power levels were measured directly with a torque meter placed between the engine and the transmission. On others, power level substitutes such as engine speed, turbo boost pressure, or fuel rail pressure were measured. When a substitute signal was used, the signal was first calibrated to the actual power level using the PTO substitute method discussed by Turner (1993b).

ENGINE FUEL CONSUMPTION, the amount of fuel an engine burned at a given power level, was measured during the 1991 tests only. On one tractor this was measured directly with a fuel flow metering system. On the others, fuel consumption substitutes such as engine speed, turbo boost pressure or fuel rail pressure were measured. When a substitute signal was used, the signal was first calibrated to the actual fuel consumption with a PTO load and timed interval test.

The values that were calculated included the following:

SLIP, the amount of lost motion between the track or wheel and the ground, was computed from the signals of the two radar guns (Turner, 1993a).

DRAWBAR POWER, the amount of power produced at the rear of the tractor and delivered to an implement, was computed from the product of the pull and the vehicle speed.

PERCENT POWER DELIVERED, the percentage of the power produced by the engine that was available at the rear of the tractor and delivered to an implement, was computed by dividing the power produced at the rear by power produced at the PTO. This is a substitute or analog for tractive efficiency that can be used in the same manner as tractive efficiency (Turner, 1993b), and was the main performance comparison used in the tests.

SPECIFIC FUEL CONSUMPTION, the amount of fuel burned to produce a unit of drawbar power, was computed by dividing the fuel used by the drawbar power produced.

Test Procedure

The test procedure used was the AFMRC simplified procedure (Turner, 1993b), that determined the entire range of performance for a tractor. A tractor was set to a specific tire, ballast and tire inflation combination and the instrumentation was calibrated. The tractor was operated in the field using 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 percent). 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 percent) 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 individual readings on each channel. Once a maximum for a gear was reached, whether slip or engine load, additional data was taken around the 10 percent slip level and around the engine rated speed, when either or both points could be reached.

Test notes specific to each of the sites are as follows:

Alberta 1991

Tests were completed in clay-loam, sandy, and heavy clay soil during July and August. The Case-IH 9250 and 9260 tractors were equipped with dual 20.8 R38 radial tires and the Caterpillar Challenger 65 with 610 mm (24 in) wide rubber belt tracks. Prior to the field tests, the engine PTO power produced, engine speed and fuel consumed versus engine load were measured at the AFMRC lab using a dynamometer and an AFMRC developed fuel mass flow system. These numbers were used to compute the power and fuel consumption levels from engine speed during field tests. The Case-IH 9250 pivot steer tractor did not have a PTO but was included in the draft tests to observe any differences between the pivot steer and the fixed frame four-wheel steer design. A 13 m (4.3 ft) Leon Manufacturing chisel plow was used for the draft load

at each of the sites. All the tests were run with tire inflation pressures of 83 kPa (12 psi), the correct and recommended pressure for the tire load by tire manufacturers in 1991. Comparing to the revised tire inflation guidelines released in 1992, the tires in these tests were overinflated. The pressures could have been reduced to 76 kPa (11 psi) front and 55 kPa (8 psi) rear.

Montana 1991

Tests were conducted at one site, a heavy clay soil, in both primary and secondary tillage, from mid-September to mid-October. Four tractors were used - a John Deere 8760, a John Deere 8.960, a Caterpillar Challenger 75 with 700 mm (27.5 in) wide tracks, and a Caterpillar Challenger 75 with 890 mm (35 in) wide tracks. The John Deere 8760 was tested with single 24.5 R32 radial tires, dual 20.8 R42 radial tires and dual 20.8-42 bias ply tires. The John Deere 8.960 was tested with dual 20.8 R42 radial tires, triple 20.8 R42 radial tires, dual 710/70 R38 radial tires, and single 710/70 R38 radial tires.
As with previous tractors, fuel and engine power measurements were made on both Deere tractors and on the narrow track Cat 75. The wide track Cat did not have a PTO so no power measurements were made but the Caterpillar dealer did set the computer controlled engine parameters to be identical on both machines. Both John Deere tractors were equipped with engine dynamometers and the readings from these were also correlated with the calculated values obtained from the PTO tests. Field loads were provided by a 18 m (59 ft) farmer modified John Deere Chisel Plow. The tractors were run with various inflation pressure and ballast set-up combinations.

Alberta 1992

Tests were completed in June in a dark brown soil, in August in a black soil, and in October in a clay-loam soil. A John Deere 8760 with single, dual and triple 20.8 R42 radial tires and a Challenger 65 with 610 mm (24 in) wide tracks were tested in the dark brown soil. This condition was selected as a condition where the flotation of the vehicles would be a limit. The John Deere 8760 was tested in the black soil with dual 20.8 R42 radials along with a Caterpillar Challenger 65B with 610 mm (24 in) wide tracks. This condition would normally have been a very wet soil condition where flotation would be a limit but during the tests was unusually dry and firm. The chisel plows used were 43 foot Flexi-coil units. The John Deere 8760 was tested in the clay-loam soil with dual and triple 20.8 R42 radials. In this test sequence, all the tests were run in the same strip of the field. The strip was initially worked repeatedly to produce a well tilled loose soil condition and tests were then run using that strip repeatedly. The chisel plow used was a 14 m (45 ft) Morris. On the Challenger 65 and the 65B, the PTO power was initially measured with a PTO dynamometer and was then calculated from engine speed during the field tests. The John Deere 8760 was equipped with an engine dynamometer and engine power was measured directly during the field tests and correlated with PTO and engine readings from the tractor used in 1991. Fuel measurements and calculations were not made in 1992. The tractors were run with various inflation pressure and ballast set-up combinations.

Alberta 1993

Tests were completed in September in a clay-loam soil. A Ford New Holland 946 was tested with single, dual and triple 20.8 R42 radial tires and a John Deere 8770 was tested with dual and triple 20.8 R42 radial tires. Both the tractors were equipped with in-line engine dynamometers and engine power was measured directly during the field tests. The Ford New Holland was also equipped with a rear drive line dynamometer that enabled the determination of power split, front axle to rear axle. Fuel measurements and calculations were not made in 1993. As in the final test sequence of 1992, all these tests were run in one well worked strip of the field. The chisel plow used was a 14 m (45 ft) Flexi-coil. Various inflation pressure and ballast set-up combinations were tested.

A surface moisture sample and a subsoil moisture sample were taken at most of the sites before each test. The surface moisture was determined as the dry basis average of the top 100 mm (4 in), or the tilled area of the soil, and the subsoil sample as the next 100 mm (4 in).

Data Analysis Method

Data from a test was evaluated without post processing or refinement and, as much as possible, from the viewpoint of a farmer. Plots were made of pull-to-weight ratio versus slip, drawbar power versus slip, percent power delivered versus slip, and percent power delivered versus pull-to-weight ratio. Maximum values, where they occurred, and the general shape of the curves were recorded. Additional notes were recorded about the performance of the set-up as far as ride roughness, power hop if it occurred, and travel speed required to obtain maximum drawbar power.

Results and Discussion

The presented results deal with the power delivery efficiency and the operation characteristics of the traction systems. Power hop had a significant effect on rubber tire tractor performance during some runs. Power hop is a resonant instability resulting in a fore/aft bounding or "porpoising" of the tractor under load and it was usually possible to find some set-up and condition where a rubber tire tractor configuration had this problem. While some information is presented on power hop and its influence on the test results, a full discussion of the causes and cures of power hop is beyond the scope of this paper. Analysis of the data is continuing and a presentation about power hop in prairie soils is being prepared.

Pull and Traction

The rubber belt tracks developed higher pull for a given tractor weight than any of the rubber tire combinations. Considering peak pull produced, the rubber belts were less affected by soil type or condition than the rubber tires. The average pull of the tracks at 10 percent slip for all the conditions tested was 140 percent of the average pull of the tires in the same conditions.

For four-wheel drive tractors weighing 73 kg/engine kw (120 Ibs/engine hp), dual tires increased the pull/weight ratio at a given slip level when compared to singles, Figure 1. Moving to triples had no further effect on pull/weight ratio. This weight was at the upper end of the allowed ballast range.

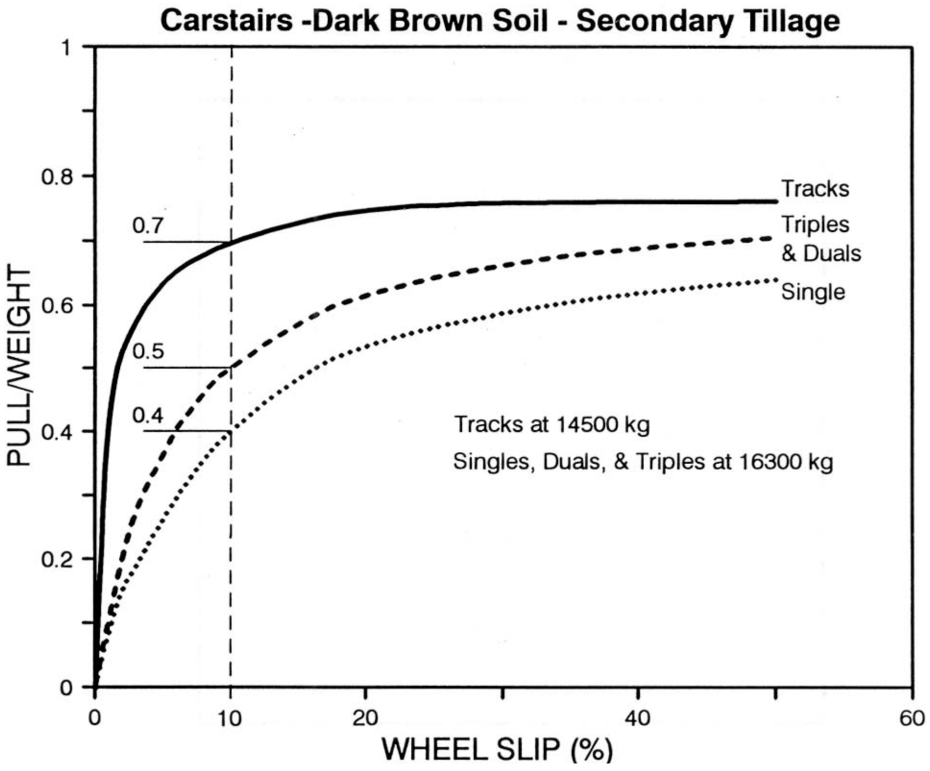

Figure 1. Effect of number of tires on pull at high ballast weight.

At a weight of 50 kg/engine kw (83 lbs/engine hp), which is at the low end of the ballast range, moving from singles to duals to triples had little effect on the pull/weight ratio, Figure 2.

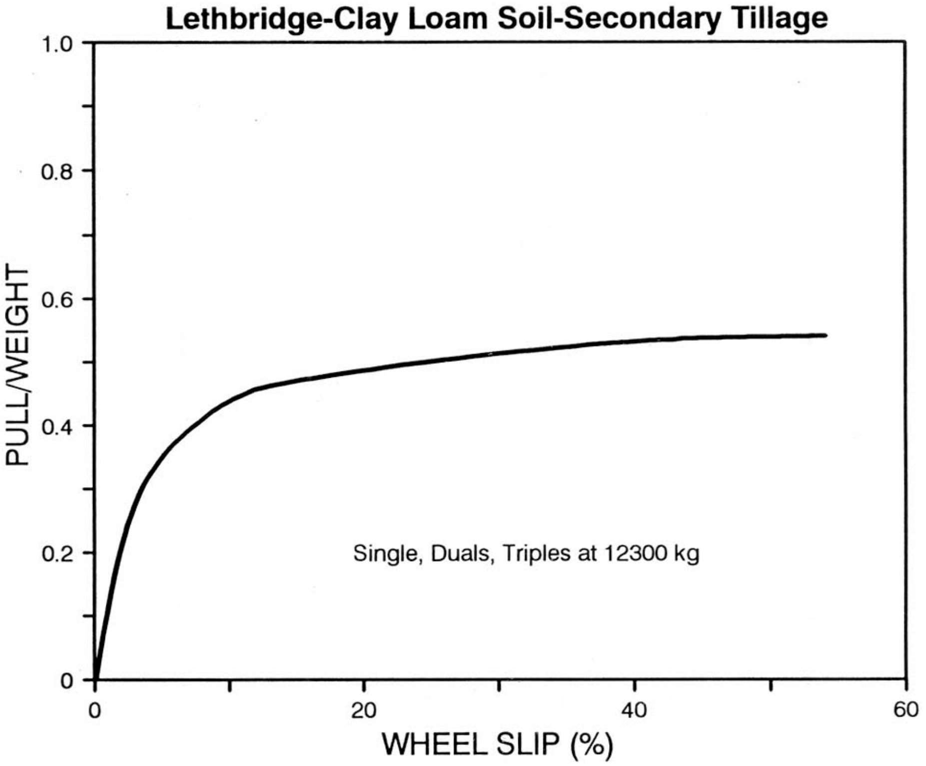

Figure 2. Effect of number of tires on pull at low ballast weight.

The 210 kw (270 hp) rubber belt tractors developed maximum drawbar power around 1 to 3 percent slip while the wheel tractors developed maximum drawbar power around 8 to 12 percent slip. Figure 3 is a graph showing drawbar power developed in an 8 km/h (5 mph) gear for singles, duals, triples and tracks in secondary tillage in the Carstairs Dark Brown soil. The shape is typical for all the soil conditions.

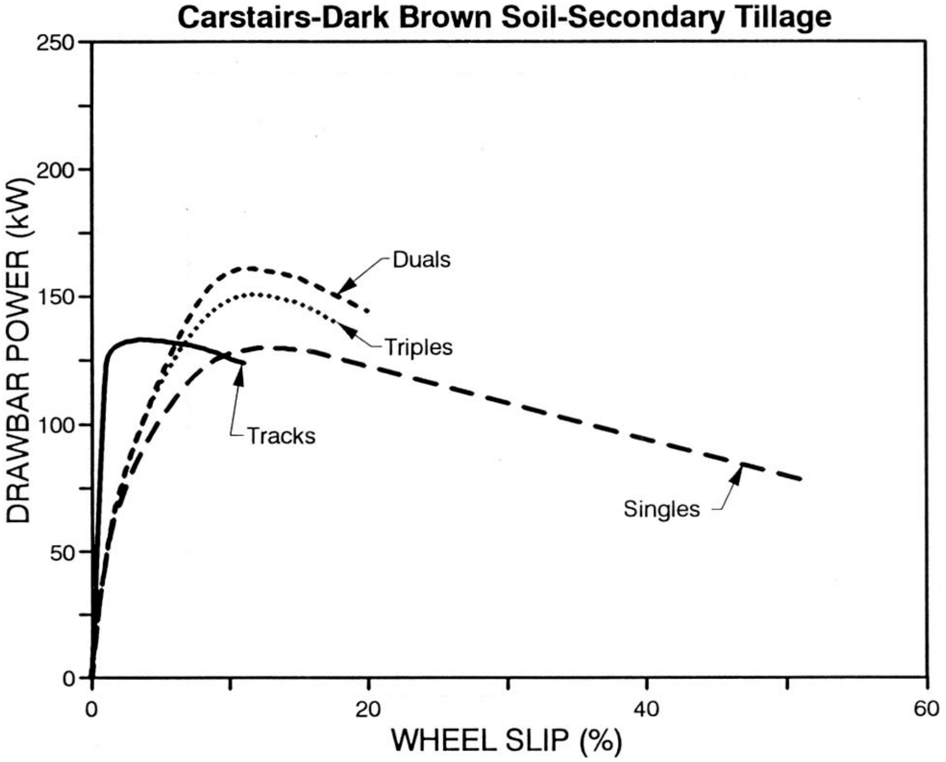

Figure 3. Drawbar Power developed versus slip for tires and tracks.

As the power was increased on rubber belt tractors, their ability to deliver full drawbar power at low speeds and low slips was reduced and they responded more like the wheel tractors. The Caterpillar 65, 65B and 75, had rated engine power levels of 201 kw (270 hp), 212 kw (285 hp) and 242 kw (325 hp), respectively. Since they all weighed around 14,500 kg (31,900 Ibs), the power-to-weight ratio decreased as the engine power was increased. Figure 4 is a graph of drawbar power developed in the 6.3 km/h (4 mph) gear for each of these tractors and shows the more gradual slip curve for the 65B and the 75 at maximum drawbar power. In an 8 km/h (5 mph) gear, only the 75 showed the gradual slip curve, and in a 10 km/h gear (6 mph) all the tractors had a steep curve like the 65 in Figure 4.

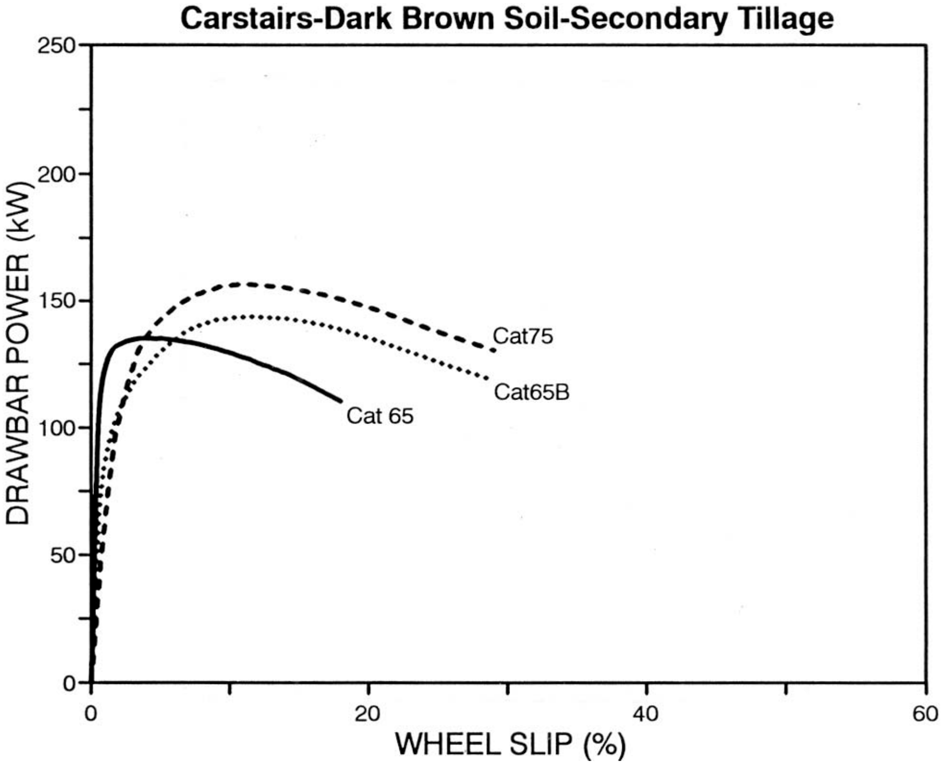

Figure 4. Drawbar Power Developed vs slip for Cat 65, 65B and 75.

All the rubber belt systems tested had adequate traction to deliver 150 kw (200 hp) at field speeds of 5 km/h (3.1 mph) and above in all the soil conditions tested. All the rubber tire power delivery systems tested had adequate traction to deliver 150 kw (200 hp) at field speeds of 8 km/h (5 mph) and above.

Efficiency of Power Delivery

Rubber belt tracks and correctly inflated dual radial tires showed the highest power delivery efficiencies. The peak efficiencies were not significantly different in the conditions tested although they occurred at a lower slip level for tracks than for tires, as shown in Figure 5.

The effect of the number of tires on power delivery efficiency depended on the tire loads. Triple radial tires were lower in efficiency than duals or singles at all tire loads. For tire loads near the maximum of the allowable range, correctly inflated dual radial tires were more efficient than correctly inflated single radial tires. For tire loads near the mid-point of the allowable range, correctly inflated single radial tires showed the same efficiency as duals.

Figure 5 shows data for 20.8 R42 tires for a tractor weight of 16400 kg (36000 lb), or 4100 kg (9000 lb) per tire for singles. Figure 6 shows similar data for the same tires and a tractor weight of 12300 kg (27000 lb), or 3050 kg (6750 lb) per tire for singles. The triple tire efficiency ranged from 83 percent of the dual tire efficiency as shown in Figure 5 to 94 percent as shown in Figure 6, but other tests showed there was no clear trend with increasing tire loading.

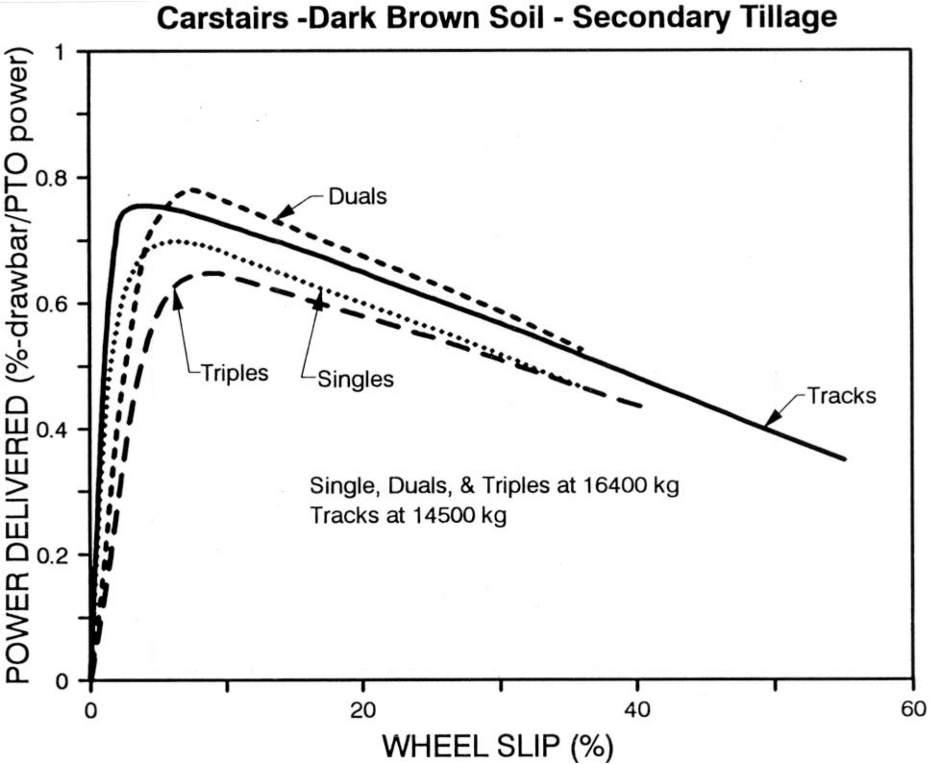

Figure 5. Power Delivery Efficiency at 16,000 kg total tractor weight.

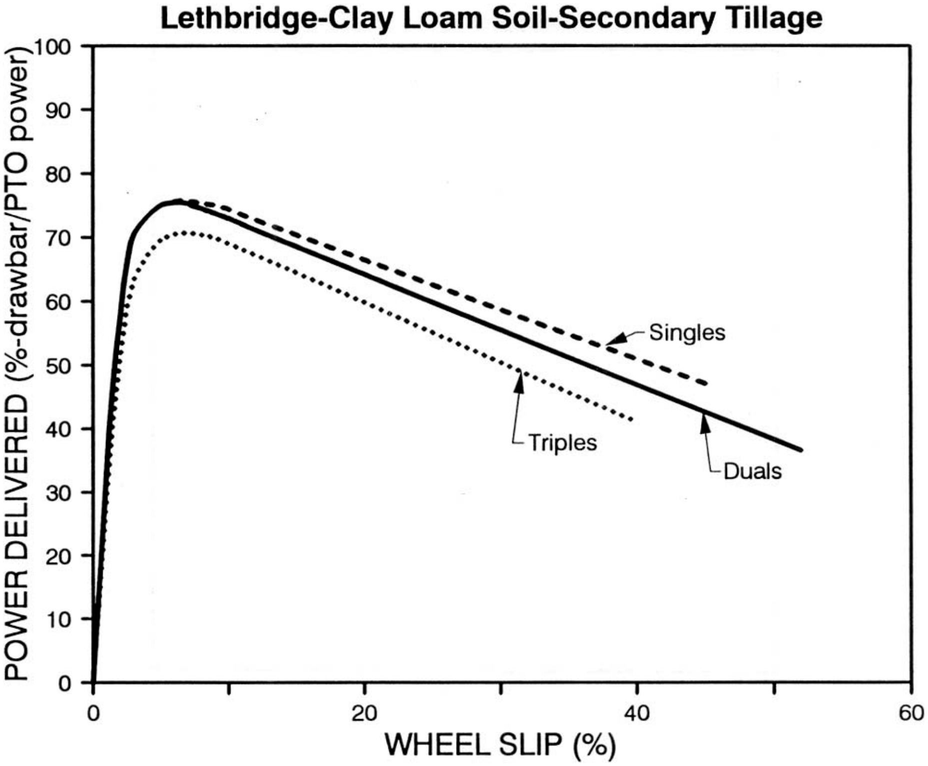

Figure 6. Power Delivery Efficiency for 12,300 kg total tractor weight.

Bias ply tires at their correct inflation pressure had lower power delivery efficiencies than radial tires at their correct inflation pressures. For bias ply duals the power delivery efficiency was 92 percent of that for radial duals of the same size at the same load, Figure 7.

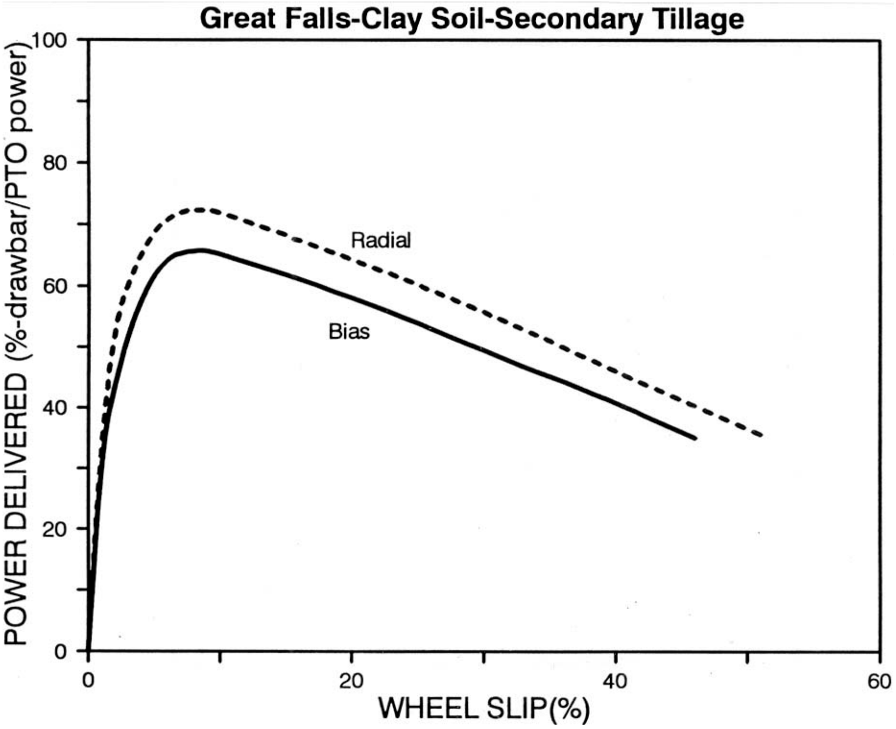

Figure 7. Power Delivery Efficiency for Bias Duals and Radial Duals.

The rubber belt tracks had a wider range of efficient operation than even the best rubber tire combinations. This was true whether considering percent power delivered versus pull/weight ratio as shown in Figure 8, or drawbar power delivered versus ground speed as shown in Figure 9.

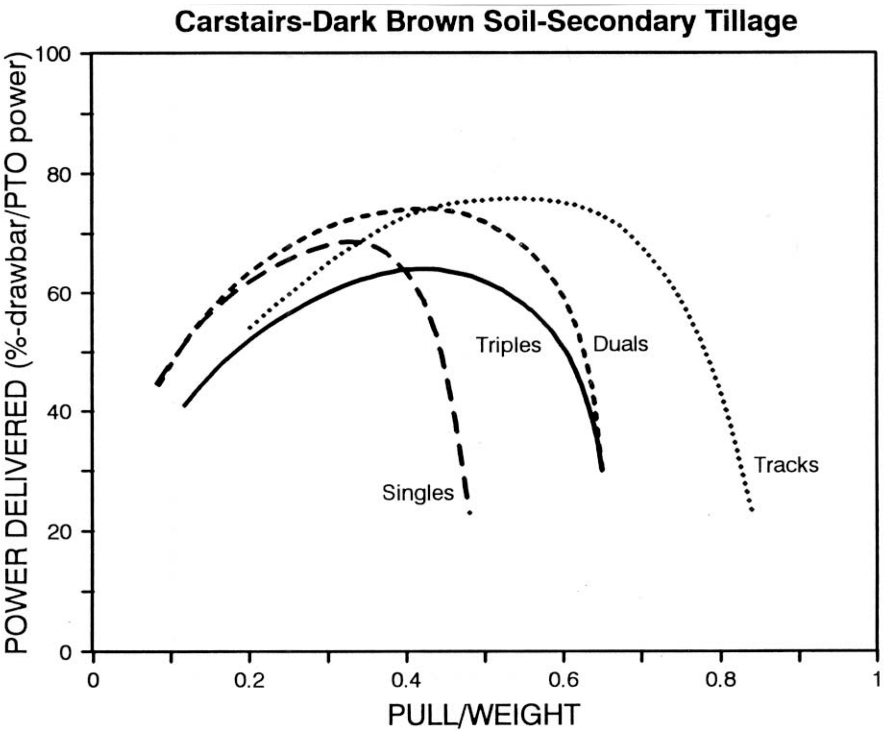

Figure 8. Power Delivery Efficiency versus Pull to Weight at 16400 kg total tractor weight.

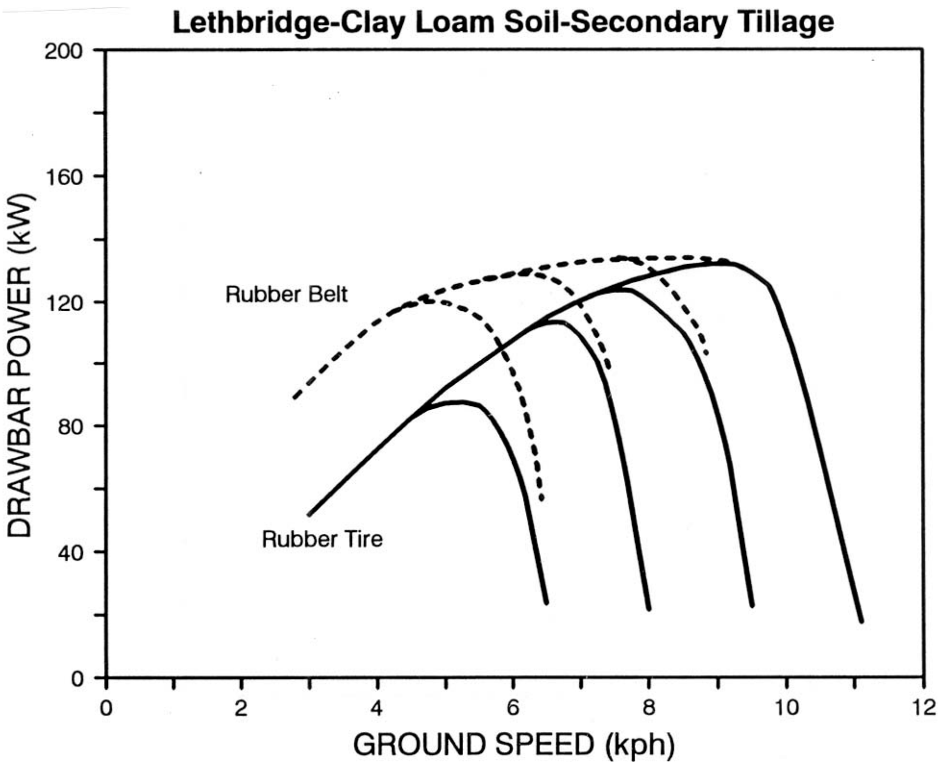

Figure 9. Drawbar Power Developed versus Ground Speed for a rubber belt tractor and a dual radial tire tractor.

Ballast Effects

Adding ballast to a tractor increased the pull at a given slip level and the total pull in direct proportion to the weight added. There was no effect on power delivery efficiency or pull-to-weight ratio. At the time of these tests, there were no ballast options for the rubber belt tractors so their weight was not changed. The effect of reducing the weight-to-power ratio by increasing the power was discussed previously.

The weight-to-power ratio of rubber tire tractors had an effect on power hop. Heavier tractors experienced less problems with power hop than lighter tractors of the same power level. They were less likely to hop, and when they did, the hop was less severe than it was for lighter tractors. This may have been because of the mass itself or because the heavier tractor operated at a lower slip level for the same load.

Ballast Ratio Effects- Wheel Tractors Only

Changing the static ballasted weight ratio from 60/40 to 55/45 to 50/50 front-to-rear had no effect on power delivery efficiency or on peak pull. Changing the weight ratio did have an effect on the power delivered by the front axle and the rear axle. As shown in Figure 10, for radial duals at a pull/weight ratio of .35, the 60/40, 55/45 and 50/50 ratio tractors had, respectively, 52 percent, 46 percent and 40 percent of the total power coming through the front axle. The values were the same for single tires and triple tires. These front-to-rear power ratios were measured while using a floating hitch cultivator and would be further reduced by an implement with a downward hitch load, whether static or dynamic.

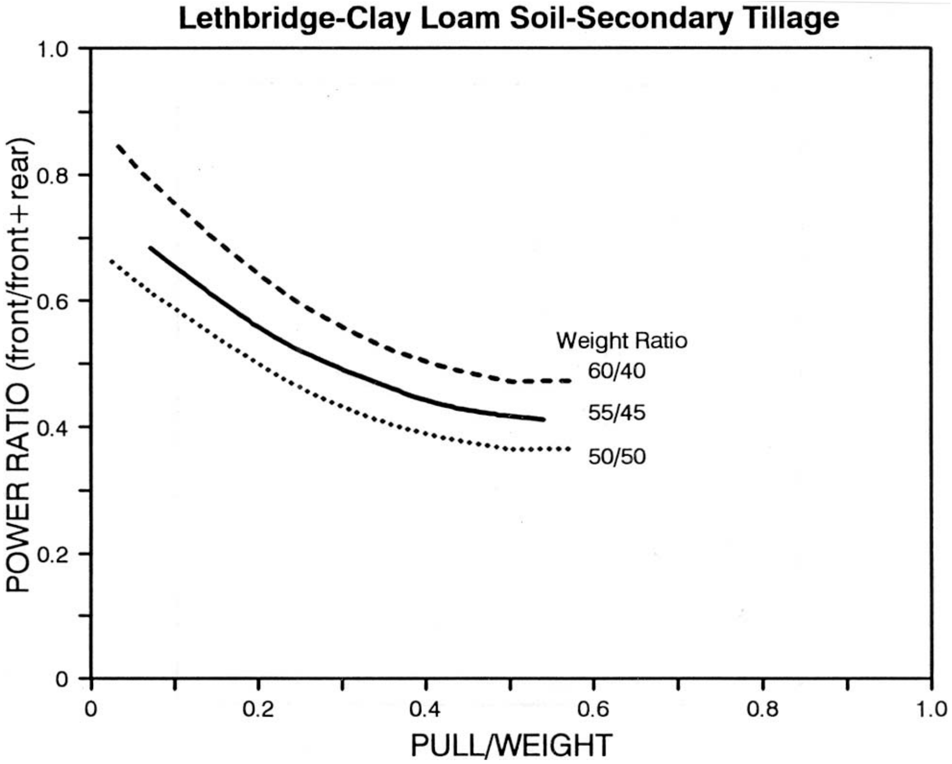

Figure 10. Effect of front/rear weight ratio on front/rear power ratio.

Power hop occurred more frequently and was more difficult to control on tractors at the 50/50 ballast ratio than on tractors at the 55/45 ratio. This may have been because both ends of the tractor had equivalent stiffness or spring rates at the 50/50 split.

Type of Ballast Effects - Wheel Tractors Only

The type of ballast, whether cast on the axle or the frame, or fluid in the tires, had no effect on power delivery efficiency or peak pull.

Some tractor and tire combinations with cast ballast at the rear were slightly less prone to experience hop than those with fluid ballast at the rear. When hop did occur, it was easier to control on tractors with fluid ballast than it was on tractors with cast ballast.

Tire Inflation Pressure Effects - Wheel Tractors Only

Tire inflation pressure had a significant effect on the performance of radial tire equipped tractors. The best power delivery efficiency was obtained with the tire pressures at the 1992 manufacturers' published minimum inflation pressures for a given tire load. As shown in Figure 11, for dual tires, increasing the inflation pressures from the correct 55 kPa (8 psi) to 96 kPa (14 psi) reduced the power delivery efficiency by 7 percent. Similar reductions occurred with single and triple radial tires. Bias ply tires were affected less but the same trend existed.

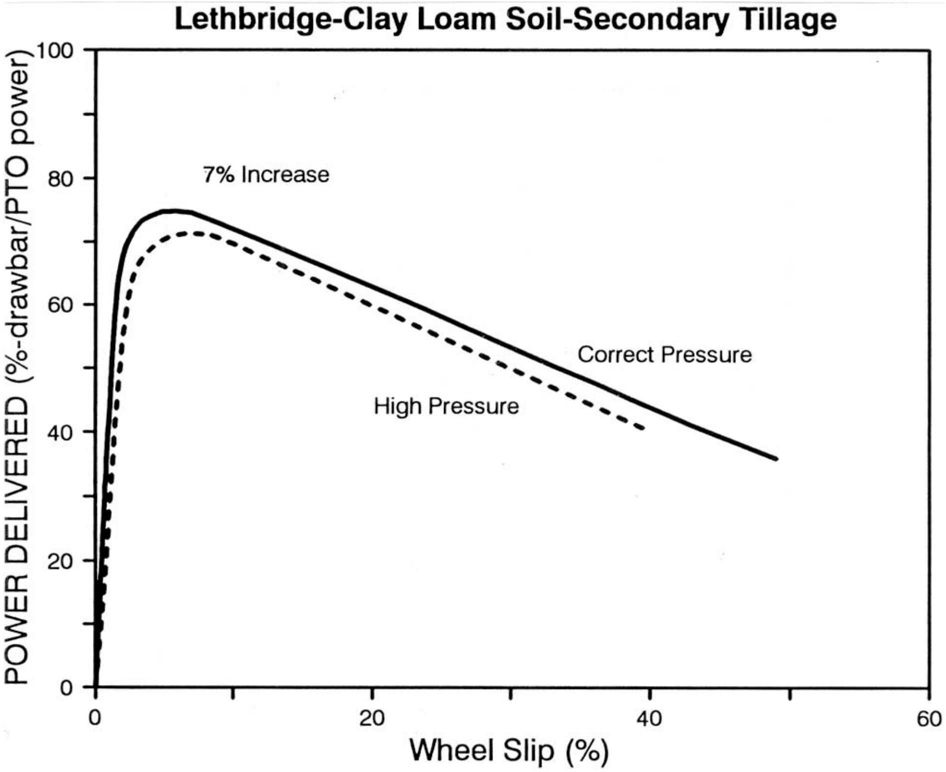

Figure 11. Effect of tire pressure on power delivery effectiveness.

Tire inflation pressure had a significant effect on power hop. If hop occurred it was always possible to control and/or remove it within the working range of the tractor by changing tire inflation pressure. The basic approach to control hop was to soften the tires on one end of the tractor by reducing their pressure to the minimum allowable and to stiffen the tires on the other end of the tractor by increasing their inflation pressure until the hop disappeared. It was important to increase the stiffness of the tires on whichever end was already the stiffer. Typically this was the front tires on a tractor with cast ballast and the rear tires on a tractor with fluid ballast. There was a trade off between tractive efficiency and controlling hop with inflation pressure. As the inflation pressure was increased on one end of a tractor, the power delivery efficiency of those tires was decreased. Raising pressures on one end decreased the total efficiency for a tractor by about 1/3 of the amount that the efficiency would have been decreased by raising pressures in the tires on both ends.

Figure 12 is a graph that shows how the power delivery efficiency was reduced across the range of pull/weight as the tractor tires were overinflated, first on one end, then on the other, and then on both. In this particular test the tractor experienced power hop at both the rated front/rated rear pressures and the high front/high rear pressures. There was no hop at the high front/rated rear or the rated front/high rear pressures in this test.

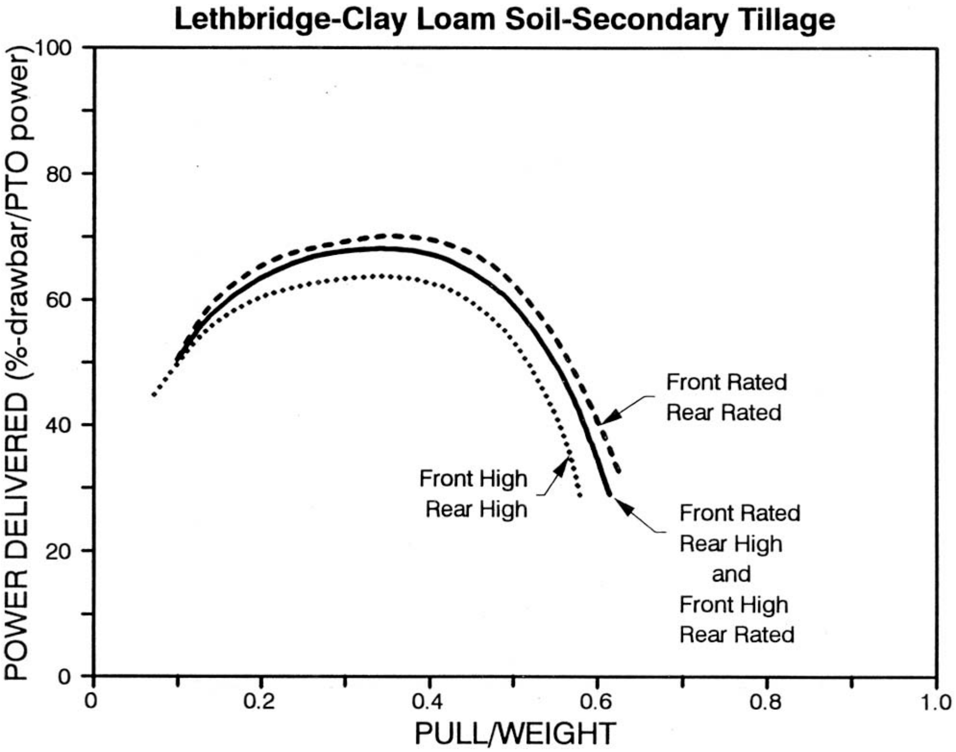

Figure 12. Power Delivered versus Pull to Weight for various inflation pressures.

Tractor Optimization

Optimizing a rubber tire tractor for a given ground condition, draft load, and speed was more difficult than it was for a rubber belt tractor. The rubber belt tractors had no ballast or pressure adjustments but still functioned at an optimum over a wide range of soil conditions and loads. The optimum range of operation with ballast and inflation pressures set for a given soil condition and load was more narrow for a wheel tractor. As discussed previously, both ballast and tire inflation pressures affected rubber tire tractor performance and to optimize a tractor, both had be considered and adjusted. It was possible to optimize single, dual or triple tires for a given ground condition, draft and speed, but the optimum settings and the optimum performance were not the same for each configuration.

Steering

Steering was more of a concern with the rubber belt track tractors than with the rubber tire tractors.

With light draft loads, both types of tractor steered well. Under heavy draft the rubber tire tractors continued to steer but with a tendency to pull sideways when cornering. Under normal to heavy draft the rubber belt tractors steered poorly and near maximum draft, not at all. The tractor would continue in a straight line when the steering wheel was turned and this would continue until the draft was reduced. The steering response was somewhat improved with the 890 mm (35 in) wide rubber belts but was still inadequate under heavy draft.

Steering the rubber belt tracked tractors used more power than steering the rubber tired tractors. The rubber belt track had a sliding action as it turned which used more power than the rolling action of a tire. As well, the rubber belt steering mechanism sped up one track and this required additional power.

The rubber tired tractors steered with little soil disturbance. What soil disturbance there was, was proportional to the load and resultant slip of the tires. The rubber belt tractors disturbed the soil surface proportional to the load and resultant slip of the tires. The rubber belt tractors disturbed the soil surface significantly when they turned, whether under load or not. The sliding tracks pushed soil sideways and produced significant ridges and depressions.

Compaction

Although soil compaction was not measured in these tests, the following compaction concerns and observations about tires and tracks were noted.

A common assumption for wheel tractors has been that average ground pressure can be approximated by the tire inflation pressure. Given this assumption, most four-wheel drive rubber tire tractors require triple tires to reduce their average ground pressure to be equal to the rubber belt tractors. As discussed previously, there is a performance penalty in using triples to achieve low average ground pressure.

Under average to heavy draft load, weight shifts to the rear of a tractor. On a rubber tire tractor, the rear tires tend to flatten out as their load is increased. This increases their contact area and their average ground pressure remains about the same. On a rubber belt tractor, there can be no flattening or area increase, and as weight shifts, the ground pressure at the rear of the tractor must increase. Because of this, theoretical average ground pressure may not be representative of actual compaction for a rubber belt track under load.

In traction overload or a loss of flotation situations, the rubber tire tractors dug down into the ground more rapidly than rubber belt track tractors, even when both were at similar average ground pressures. This may have been due to differences in the shape of the area where the ground pressure was applied.

Cost/Benefit

Rubber belt tractors cost more than comparable rubber tire tractors. Using dealer supplied retail prices from Alberta in the fall of 1992, a rubber belt tractor cost 15 percent more than an equivalent drawbar horsepower rubber tire tractor equipped with dual radial tires. Comparing actual prices paid by farmers in Alberta during the same time the difference was even greater, with rubber belt tractors about 30 percent more than rubber tire tractors. The cost for a wheel tractor was about the same whether equipped with single radials or dual radials, and about 5 percent higher when equipped with triples.

Tractor costs are situation and location dependent, and can change quickly. The dealer retail prices used for comparison were the December 1992 retail prices in Alberta, in Canadian dollars. They included freight, ballast and delivery to a farm in Alberta, but did not include any taxes. The actual prices paid by customers were determined from interviews with customers who dealt on tractors in Alberta during the November to December 1992 period, in Canadian dollars, again including freight, ballast and delivery, but not taxes.

Test Procedure Issues

A chisel plow or field cultivator worked well as an in-the-field dynamometer for tractor tests and provided satisfactory draft adjustment resolution. Best results were obtained with a unit that was oversized for the tractor being tested. An offset disk was marginal as a field dynamometer and a deep ripper was not acceptable. This was because of the difficulty in varying the draft of these implements.

Percent power delivered, the ratio of drawbar power to some known engine power level measurement, was a good substitute for tractive efficiency when comparing tractor performance.

Percent slip could be measured accurately from one specific wheel or track, provided that the readings were averaged for 2 to 4 seconds.

Engine speed was an adequate substitute for engine power level and fuel consumption, if the actual power level and fuel consumption had been measured and related to engine speed before tests began.

Turbo boost pressure was not an adequate substitute for engine power level with the measurement equipment used but might have been acceptable with more stable pressure gauges.

Fuel rail pressure was not an adequate substitute for engine power because it remained at an unchanging peak along the variable speed part of the engine curve.

FUTURE WORK

Power Hop

As previously noted, power hop had a significant effect on tractor performance when it occurred. It was usually possible to make a given tractor configuration hop with some combination of settings. The test data represents a significant resource about power hop causes and controls. Analysis about power hop is continuing and will be reported when complete.

Compaction

No direct measurements were taken on compaction during these tests because of the lack of wide agreement on a useful compaction parameter that can be measured at the farm level. Work is continuing to define a simple ground compaction parameter or procedure that can be used effectively on the farm.

Extension

Work is continuing to put the traction information from these tests into an accessible, understandable and easily used format for farmers to help in traction decisions, whether buying new systems or optimizing existing ones.

SUMMARY AND CONCLUSION

The Alberta Farm Machinery Research Centre has developed a significant package of efficiency and performance information about currently available traction systems. This information can be used to assist farmers in making the best use of the tractors on their farms and to help select the most appropriate traction delivery systems for their operation.

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