Comparison of Two and Four Track Machines to Rubber Tire Tractors in Prairie Soil Conditions

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ABSTRACT

Traction performance tests were run by Alberta Farm Machinery Research Centre personnel on four-wheel drive tractors with single, dual and triple rubber tires and on track tractors with two and four rubber belt tracks. Traction power delivery efficiency was compared in various tilled and untilled soil conditions representative of the Northern Great Plains. Various ballast set-ups and tire inflation pressures were tested. Power hop problems, steering performance, ease of set-up and overall system costs were also evaluated.

INTRODUCTION

Tractors offer many ways to deliver traction power to the ground. In the past, the only choices were track tractors using steel tracks, or two-wheel drive or four-wheel drive tractors using single or dual bias-ply rubber tires. Today, rubber belt tracks as two parallel tracks or four articulated tracks, radial-ply tires, triple tires and high flotation tires have been added to the selection list. Market conditions and the need for increased efficiency in agriculture have increased the demand for information about traction options. Changes in recommended inflation pressures for radial tires have further complicated the traction selection and optimization process.

During a four year period, engineers at the Alberta Farm Machinery Research Centre (AFMRC) tested various traction systems. Tests were run on single, dual and triple rubber tires on four-wheel drive tractors. Different tractor weight set-ups and different tire inflation pressures were used and included both previous and current weight and tire inflation recommendations. Tests were also run on the dual rubber belt track system used on Caterpillar Challenger (TM) tractors and on the four rubber belt track system demonstrated on the Case-IH Quadtrac (TM) prototypes. Tests were conducted in several soil conditions representative of the Northern Great Plains.

The tests were a joint effort of AFMRC in Lethbridge, Alberta and the Northern Tractor Resource Center (NTRC) in Havre, Montana to provide information about the power delivery characteristics of each of the traction systems. Case-IH, Caterpillar, Firestone, Flexi-coil, Ford New Holland, Gilbert and Riplo, Goodyear, John Deere, Leon Manufacturing, Morris Industries, and numerous farmers cooperated in the tests.

LITERATURE REVIEW AND DISCUSSION

Several researchers have reported the differences in traction performance between single and dual tires, between single tires and tracks, and between dual tires and tracks.

Domier et al., 1970 (1), 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.

Taylor and Burt, 1975 (2), compared a single bias 12.4-28 tire at an inflation pressure of 98 kPa (14 psi) and loads of 500 kg (1,100 lb) and 1,000 kg (2,200 lb) to a steel track. They found tractive efficiencies for the track to be 20 percent higher than for the tire.

Esch et al., 1986 (3), compared rubber belt tracks to a four-wheel drive equipped with dual 20.8-38 bias-ply tires. They reported a 7 to 12 percent increase in tractive efficiency for the tracks.

Evans and Gove, 1986 (4), 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.

Bashford et al., 1987 (5), 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 there was no difference in performance between the singles and duals in the field.
Tires provide better tractive performance as their inflation pressure is decreased. The performance advantages of radial tires compared to bias tires and the importance of setting radial tires to the correct and minimum inflation pressure has been documented in several references. Burt and Bailey, 1981 (6) measured 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. Charles, 1984 (7) measured 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 2,700 kg (5,940 lb) per tire. Wulfsohn et al., 1988 (8) compared the performance of a number of radial and bias tires and found an average increase in tractive efficiency of 6 to 8 percent for radial tires across the 0 to 30 percent slip range. Bashford et al., 1992 (9), compared performance of three different radial tires at three inflation pressures and reported lower tractive efficiencies at the higher pressures.

The minimum allowable inflation pressure for a tire is a function of the weight the tire carries. Tire manufacturers publish load-inflation tables that list the correct inflation pressure for various loads. In late 1991 to early 1992, the load-inflation tables for radial tires were revised to allow lower inflation pressures than what had been recommended in the past. Tire manufacturers suggest that following these new guidelines will result in improved tractive performance with radial tires, Goodyear, 1992 (10). Many of the existing traction performance tests were run with bias tires, often operated at pressures that exceeded even the levels recommended at the time. While the reported data is probably correct, the overpressures and limited use of radial tires reduce the current value of such tests. Considering the five above-mentioned tire and track comparisons, the following can be observed.

For Domier et al., 1970 (1), the four-wheel drive tires were inflated to 110 kPa (16 psi) inner and 96 kPa (14 psi) outer with a load of 1,480 kg (3,260 lb) front and 1,160 kg (2,550 lb) rear per tire. The correct inflation pressure for these tire loads would have been 82 kPa (12 psi) for all the tires. This means the tests were run at a nominal 20 kPa (3 psi) overpressure. Had the tires been radials, the 1992 correct inflation pressure would have been 62 kPa (9 psi) front and 41 kPa (6 psi) rear.

For Taylor and Burt, 1975 (2), the correct inflation pressure for the tire loads would have been 82 kPa (12 psi) at an 850 kg (1,870 lb) load and 110 kPa (16 psi) at the 1,000 kg (2,200 lb) load. At the 500 kg (1,100 lb) load the tire was significantly over inflated. The data shows that the 1000 kg (2,200 lb) load had higher tractive efficiency than the 500 kg (1,100 lb) load.

For Esch et al. (3), the tractor tires were inflated to 95 kPa (14 psi) inner and 85 kPa (12 psi) outer with a load of 1,900 kg (4,180 lb) front and 1,370 kg (3,010 lb) rear per tire. The correct inflation pressures for the tire loads would have been 82 kPa (12 psi) for all the tires. While 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.

For Evans and Gove, 1986 (4), used four-wheel drive tires that were inflated to 83 kPa (12 psi) inner and outer at a load of 1,800 kg (3,960 lb) front and 1,500 kg (3,300 lb) rear per tire. These were 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 from what was tested.

For Bashford et al., 1987 (5), the tires were inflated to a pressure of 124 kPa (18 psi) at a load of 2,300 kg (5,060 lb) for each single and 1,150 kg (2,530 lb) for each dual. The correct inflation pressure for the singles at the 2,300 kg (5,060 lb) load would be 110 kPa (16 psi), and for the duals at the 1,150 kg (2,530 lb) load, 82 kPa (12 psi). For this tractor, the duals were significantly more over inflated, 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 2,300 kg (5,060 lb) load would have been the same 110 kPa (16 psi), while for the duals at the 1,150 kg (2,530 lb) load the pressure would have been 48 kPa (6 psi).

In each of these cases, using correct inflation pressures would have changed the results. Using radial tires with correct inflation pressures by the 1992 standards would have changed the results even more.

**SCOPE OF THE TESTS**

These tests were to provide information to help farmers in the selection and optimization of appropriate traction systems. Tests were run from 1991 to 1994 in conditions representative of the Northern Great Plains. All the tractors that were used were instrumented and data was taken over a range of loads and speeds.

Engineers at AFMRC previously developed a performance measurement system and procedure to simplify traction performance measurements (11). This set-up was used throughout the tests and included an on-board data acquisition system that was portable between vehicles (12). The test equipment was powered by the vehicle and operated by the vehicle driver. Additional information about the measurements, the test procedures and the specific test sites is in the Appendix.

In southern Alberta in the summer of 1991, a Case-IH 9260, a Case-IH 9250 and a Caterpillar Challenger 65 with 610 mm (24 in) wide rubber belt tracks were tested in primary and secondary tillage in a clay-loam, a sandy loam and a heavy clay soil. Both rubber tire 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 using both liquid and cast ballast.

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 loam soil. The rubber tire tractor was tested with single, dual and triple radial tires at various inflation pressures. One ballast weight and ratio was maintained using cast ballast.

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 clay-loam 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 radicals 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 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 liquid and cast ballast.

In southern Alberta in the fall of 1994, a Case-IH 9250 equipped with four positive-drive rubber belt tracks was tested in primary and secondary tillage in a clay-loam soil. One ballast weight and ratio was maintained. Since this tractor was unique, a detailed description is included in the appendix.

The test tractors were at manufacturers' rated engine power levels that ranged from 201 to 276 kw (270 to 370 hp). Measured engine power levels were typically 5 to 15 percent above the advertised values. To remove the effects of engine rating differences, overpowering and engine power variability, and because traction performance is ultimately determined by the amount of available power that can be transferred to the ground, traction performance results were compared using power delivery efficiency. Power delivery efficiency is defined as the ratio of the power entering a traction system compared to the power delivered to the ground. This basis for comparison kept the capabilities of the traction power delivery systems independent of the associated engine systems. Testing also determined the settings and conditions where power delivery was maximized and evaluated how the various traction systems functioned. Factors such as power hop, steering, ease of set-up and system cost were considered.

The tests were intended to determine the effect of the traction systems on farm operations from a practical point of view. Data from a test was evaluated without post processing and with minimum refinement, and as much as possible, from the viewpoint of a farmer. After a run, 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. Figure 1, A, B, C and D, is a set of these plots. Maximum values, their location and the general shape of the curves were recorded. Additional notes were recorded about ride roughness, power hop if it occurred, and travel speed required to obtain maximum drawbar power.

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Figure 1, A and B  Test Plots from a Typical Test.
A = Pull/Weight versus Slip
B = Drawbar Power versus Slip
RESULTS AND CONCLUSIONS

The following results and conclusions deal with the power delivery efficiency of the traction systems. On some rubber tire tractor configurations, power hop, a resonant instability producing a fore/aft bouncing or "porpoising" of a tractor under load, affected performance. It was usually possible to find a set-up and condition where a rubber tire tractor configuration showed this problem. While some information is presented on power hop because of its influence on the test results, a full discussion of the causes and cures of power hop is beyond the scope of this paper.

POWER DELIVERY EFFICIENCY - Tractors with two rubber belt tracks and those with correctly inflated dual radial tires showed the highest power delivery efficiency. For these set-ups, the peak efficiencies were not significantly different in the conditions tested, although the peak occurred at a lower slip level for tracks than for tires, Figure 2.

The effect the number of tires had 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 tractor ballast range, 73 kg/engine kw (120 lb/engine hp), correctly inflated dual radial tires were more efficient than correctly inflated single radial tires. For tire loads near the lower end of allowable ballast ranges, 50 kg/engine kw (83 lb/engine hp), correctly inflated single radial tires showed the same efficiency as duals. Figure 2 shows data for 20.8R42 tires for a tractor weight of 16,400 kg (36,000 lbs). This was 4,100 kg (9,000 lb) per tire for the singles and was just beyond the maximum allowable for these tires.
Figure 3 shows data for the same tires as Figure 2 with a tractor weight of 12,300 kg (27,000 lb), or 3,075 kg (6,750 lb) per tire for singles. The triple tire efficiency ranged from 83 percent of the dual tire efficiency, Figure 2, to 94 percent, Figure 3, but other tests suggested that while triples were always less efficient than duals, there was no clear trend with increasing tire loading.

Bias-ply tires at their correct inflation pressure had lower power delivery efficiency than radial tires at their correct inflation pressures. For 20.8-42 bias-ply dual tires at a load of 10,100 kg (4,600 lb) and an inflation pressure of 82 kPa (12 psi), the power delivery efficiency was 92 percent of that for 20.8 R42 radial dual tires with the same load and an inflation pressure of 69 kPa (10 psi), Figure 4.

The four-track tractor showed lower power delivery efficiency than the two-track tractors or the rubber tire tractors. Figure 5 shows a plot of power delivery efficiency for a 223 kw (300 hp) four-track tractor, a 208 kw (270 hp) 2-track tractor and a 223 kw (300 hp) four-wheel drive tractor, all in the Lethbridge clay-loam soil. In this particular test, the power delivery efficiency of the two-track tractor peaked at 78 percent, 1 percent higher than the 77 percent peak of the four-wheel drive tractor. The four-track tractor had a peak power delivery efficiency of 72 percent, 5 percent lower than the four-wheel drive tractor.

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 6, or drawbar power delivered versus ground speed as shown in Figure 7.
PULL AND TRACTION - Rubber belt tracks developed higher pull for a given tractor weight and slip level than any rubber tire combinations. The peak pull produced by the rubber belts was less affected by soil type or tillage condition than it was for 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 ballasted to the upper end of allowable ballast ranges, dual tires increased the pull/weight ratio at a given slip level when compared to singles, Figure 8. Moving to triples had no further effect on pull/weight ratio. At a ballast weight near the lower end of allowable ballast ranges, moving from singles to duals to triples had little effect on the pull/weight ratio, Figure 9.

As engine power increased on the two-track rubber belt tractors, their ability to deliver full drawbar power at low speeds and slip was reduced and they responded more like rubber tire tractors. The Caterpillar Challenger 65, 65B and 75 had rated engine power levels of 201, 212 and 242 kw (270, 285 and 325 hp), respectively. Since they all weighed about 14,500 kg (31,900 lb), the weight-to-power ratios were respectively 72, 68 and 60 kw/kg (118, 112 and 98 lb/hp). Figure 11 is a graph of drawbar power developed in a 6.3 km/h (4 mph) gear for each of these tractors and shows a 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 had a gradual slip curve, and in a 10 km/h gear (6 mph) all the tractors had a steep curve like the 65 shown in Figure 11.

On the four-track rubber belt tractor, the weight was 16,700 kg (36,850 lb) and the power was 223 kw (300 hp). These were not varied, but the shape of the drawbar power versus slip curve was similar to one for the 208 kw (270 hp) two-track Challenger 65, Figure 12. Both these tractors had a weight-to-power ratio around 73 kg/kw (120 lb/hp).

The two-track and four-track rubber belt systems tested had adequate traction to deliver 150 kw (200 hp) at the drawbar at field speeds of 5km/h (3.1 mph) and above in 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.

BALLAST EFFECTS - Adding ballast to a tractor increased pull at a given slip and 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 affected power hop. Heavier tractors experienced less problems with power hop than lighter tractors of the same power level. Heavy tractors were less likely to hop, and when they did, the hop was less severe than it was for lighter tractors. This could have been because of the additional mass or because the heavier tractors operated at lower slip levels for the same load.

BALLAST RATIO EFFECTS (rubber tire tractors only)
- Changing the front/rear static ballasted weight ratio from 60/40 to 55/45 to 50/50 had no effect on overall power delivery efficiency or on peak pull. It did affect the power delivered by the front axle and the rear axle. As shown in Figure 13, for radial duals at a pull/weight ratio of 0.35, the 60/40, 55/45 and 50/50 ratio tractors had front-to-total power ratios of 0.52, 0.46 and 0.40. Single and triple tires showed similar ratios. These front-to-rear power ratios were measured while pulling a floating hitch cultivator and would be further reduced when pulling an implement with a downward hitch load.

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

TYPE OF BALLAST EFFECTS (rubber tire tractors only) - The type of ballast, whether cast mounted on the axle or on 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 somewhat less prone to experience hop than those with fluid ballast at the rear. Other
combinations with fluid at the rear were much less prone to hop than the same combinations with cast at the rear. When hop did occur, it was easier to control on tractors with fluid ballast than on tractors with cast ballast. The fluid was typically concentrated at the rear of the tractor, where it increased the stiffness of the tires on the rear. Different stiffness front to rear was important in controlling power hop.

TIRE INFLATION PRESSURE EFFECTS (rubber tire 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 tire pressures set at the 1992 manufacturers' published minimum inflation pressures for a given tire load. As shown in Figure 14, for dual tires, increasing the inflation pressures from the correct 55 kPa (8 psi) for the load to 96 kPa (14 psi) reduced the power delivery efficiency by 7 percent at peak efficiency. Similar reductions occurred with single and triple radial tires. Bias-ply tires showed a similar trend but a lower magnitude of effect.

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 achieving maximum 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 the tires on that end was decreased. Raising pressures on one end decreased the total efficiency for a tractor by about one third of the amount that the efficiency would have been decreased by raising pressures in the tires on both ends. Figure 15 is a graph showing how the power delivery efficiency was reduced across the range of pull/weight as the tractor tires were over inflated, first on one end, then on the other, and then on both. For the front tires the rated pressure was 62 kPa (9 psi) and the over inflation or high pressure was 124 kPa (18 psi). For the rear, the rated pressure was 48 kPa (7 psi) and the high pressure was 96 kPa (14 psi). In this particular test the tractor experienced power hop at both the rated front/rated rear pressures and the high front/high rear pressures. The hop was removed with both the high front/rated rear and the rated front/high rear pressures.

Figure 15. 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 pressure 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. To optimize a rubber tire tractor, both had to 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 problem with two-track rubber belt tractors than with rubber tire tractors or four-track rubber belt tractors. With a light draft load, all the tractors steered well. Under a heavy draft load the different traction systems steered differently. The four-track rubber belt tractor continued to steer just as well as under a light load. The rubber tire tractors continued to steer, but showed a tendency to pull or slip sideways while cornering. The rubber belt tractors with two tracks steered poorly. Near
their maximum draft they would not steer at all, but would continue in a straight line when the steering wheel was turned. Steering returned when the draft was reduced. The steering response was somewhat improved on a rubber belt tractor with 890 mm (35 in) wide rubber belts, but was still inadequate under heavy draft.

Steering the rubber belt tractors with two tracks used more power than steering the rubber tired tractors or the rubber belt tractor with four tracks. On the two-track tractor, the long rubber belt track had a sliding or scrubbing action as it turned, which used more power than the rolling action of a tire. Since the rubber belt differential steering mechanism sped up one track, this also used additional power.

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

COMPACATION - Although soil compaction was not directly measured in the 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, four-wheel drive rubber tire tractors ballasted to over 77,000 kg (35,000 lb) require triple tires to reduce their average ground pressure to the nominal 41 kPa (6 psi) ground pressure of the two-track rubber belt tractors. As discussed previously, there is a performance penalty in using triples to achieve low average ground pressure. The rubber belt tractor with four tracks had an average ground pressure of 28 kPa (4 psi). Since tire inflation pressures are currently limited at the low end to 41 kPa (6 psi), it would be impossible for rubber tire tractors to equal this ground pressure.

The theoretical average ground pressure may not be representative of actual ground pressure for a rubber belt track under load. 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 the weight they carry increases. This increases the contact area and the 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.

In traction overload or a loss of flotation situations, the rubber tire tractors dug 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.

COSTS - Rubber belt traction power costs more than comparable rubber tire traction power. Using dealer-supplied retail prices from Alberta in the fall of 1992, a rubber belt tractor with two tracks 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. Based on 1994 figures, the cost of the rubber belt tractor with four tracks was estimated to be about 35 percent higher than a comparable rubber tire tractor.

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, and were 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 for these tests. 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 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, measured as described in the Appendix, was a good substitute for tractive efficiency when comparing tractor performance.

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

Engine speed was an adequate in-the-field 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 in-the-field 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 data set from the tests represents a significant resource
about power hop causes and controls. Analysis related to 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 quickly measured. Work is continuing to define a simple ground compaction parameter or procedure that can be used effectively at the farm level.

EXTENSION - Work is continuing to put the information from these tests into an accessible, understandable and easily-used format to help farmers in traction decisions, both those associated with buying new systems and those associated with optimizing existing traction set-ups.

SUMMARY

Traction power is an important part of an overall farm efficiency and cost control strategy. While there is a great deal of information available about traction systems, some of the information is of less value today because it no longer reflects current understanding and standards. The Alberta Farm Machinery Research Centre has developed a current package of efficiency and performance information about traction systems. This information can be used to assist farmers in making the best use of their existing tractors and can help them to select the most appropriate traction delivery systems for their operation.

REFERENCES


APPENDIX

DETAILED TEST INFORMATION

Test Instrumentation and Computations - The terminology used conforms wherever possible to ASAE's standard traction and tractor terminology (13). The values measured and the methods of measuring them were as follows:

Draft - the horizontal pull a tractor developed was measured by a horizontal load cell between the tractor and the towed implement. Vertical forces were ignored.

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
The test procedure for a traction test was completed in the low track. A radar unit placed on the tractor and aimed at the wheel or track. Vertical Acceleration - the acceleration or shaking of a tractor along the up-down axis 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 and speed pick-up placed between the engine and 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 (11).

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 using a PTO load and a 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 (14).
- Drawbar Power - the amount of power produced at the rear of the tractor and delivered to an implement was computed from the pull and the vehicle speed.
- Percent Power Delivery - 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 the 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 (11), 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 for a traction test system was the AFMRC simplified procedure (11) 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 variable 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 data 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.

A surface moisture sample and a subsoil moisture sample were taken at most sites. 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 by the next 100 mm (4 in).

SITE SPECIFIC TEST NOTES

Alberta 1991 - Tests were completed in the low organic clay-loam, sandy and heavy clay soil during July and August. The Case-IH 9250 and 926.0 four-wheel drive tractors were equipped with dual 20.8 R38 radial tires. The Caterpillar Challenger 65 was equipped with two 610 mm (24 in) wide rubber belt tracks. Prior to the field tests, the 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 a pivot steer and a fixed frame four-wheel steer design. A 13 m (43 ft) Leon Manufacturing chisel plow was used for the draft load at each site. 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. When compared 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 low organic heavy clay soil, in both primary and secondary tillage, from mid-September to mid-October. Four tractors were used - a John Deere 8760 and 8960 four-wheel-drive, a Caterpillar Challenger 75 with two 700 mm (27.5 in) wide tracks, and a Caterpillar Challenger 75 with two 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 8960 was tested with dual 24.5 R32 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, engine power and fuel consumption measurements were made on both Deere tractors and on the narrow-track Cat 75. Since the wide-track Cat did not have a PTO, no power measurements were made on it. The computer-controlled engine parameters were set by the dealer to be identical on both machines. Both John Deere tractors were equipped with engine torque meters and readings from these were 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 moderate organic loam soil, in August in a high organic clay-loam soil, and in October in a low organic clay-loam soil. A John Deere 8760 four-wheel drive with single, dual and triple 20.8 R42 radial tires and a Challenger 65 with two 610 mm (24 in) wide tracks were tested in the moderate organic loam 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 high organic clay-loam soil with dual 20.8 R42 radials along with a Caterpillar Challenger 65B with 610 mm (24 in) wide tracks. While this condition would normally have been a very wet soil condition where flotation would be a limit, during these tests the soil was unusually dry and firm. The chisel plows used were 43 ft Flexi-coil units. The John Deere 8760 was tested in the low organic 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 repeated on the same strip over and over again. 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 torque meter 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 low organic clay-loam soil. A Ford New Holland 946 four-wheel drive was tested with single, dual and triple 20.8 R42 radial tires and a John Deere 8770 four-wheel drive was tested with dual and triple 20.8 R42 radial tires. Both tractors were equipped with in-line engine dynamometers that measured engine power directly during the field tests. The Ford New Holland was also equipped with a rear driveline dynamometer. This allowed the determination of the power split from the front axle to rear axle. Fuel consumption 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.

Alberta 1994 - Tests were completed in November in both primary and secondary tillage in a low organic clay-loam soil. A Case-IH 9250 four-wheel drive that had been modified to be a four-track machine was tested. The wheel assemblies had been replaced with four separate positive drive rubber belt track assemblies. Prior to the tests, the PTO power produced and the engine speed were measured at the AFMRC lab using a dynamometer. These numbers were used to compute the power level from engine speed during field tests. Field loads were provided by a 13 m (43 ft) Friggstad chisel plow. The tractor was run at only one ballast set-up.

FOUR TRACK MACHINE DESCRIPTION

The four track rubber belt tractor tested by the Alberta Farm Machinery Research Centre was a Case-IH 9250 articulated four-wheel drive tractor modified into a four track machine. The wheel assemblies had been replaced with four separate triangular GripTrac (TM) rubber belt track assemblies manufactured by the Gilbert and Riplo Company of Ravenna, Michigan. The tractor and track combination was custom-built by a local Case-IH dealer to be similar to the QuadTrac (TM) prototypes displayed and demonstrated at farm shows by Case Corporation.

A side view of the tractor is shown in Figure A1 and front view in Figure A2.
The drive roller for each GripTrac (TM) assembly was bolted to the tractor axle hub where the wheel rims had been. Each drive roller was 990 mm (39 in) in diameter and was constructed with a centre section divided with 20 rounded-edge plates that served as gear teeth. A structural member ran across the tractor underneath each axle and provided a pivot point for each track assembly that was directly below the centre line of the drive roller. Each track assembly formed an asymmetrical triangle about the drive roller. The track frame held five lower wheels, a front and rear 500 mm (19.75 in) diameter idler, and three 250 mm (10 in) diameter rollers. Four of the rollers were rigidly mounted in the lower frame bar. Belt tensioning was accomplished with a hydraulic accumulator system that pushed one end idler (either front or rear, depending on how the track was mounted) out along the axis of the frame. The rubber belt tracks were 775 mm (30.25 in) wide belts with a chevron-ground engaging lug pattern on the outside surface and centre drive lugs on the inside surface. Typically seven of the inner lugs were fully engaged in the drive roller teeth. Since the diameter of the drive roller was less than the diameter of the original drive tires, the net gear ratio of the tractor and, hence the speed in each gear, was reduced by some 30 percent.

Figure A3 is a photo of a side view of a single track and Figure A4 is a drawing of a track showing the significant dimensions.

Figure A4. Track Assembly Dimensions.

Figure A5 gives dimensions for the overall tractor configuration. As shown in Figures A1 and A5, on the test tractor the rear track frames were reversed compared to the front tracks. This gave extra clearance in the centre of the tractor for turning, but it also meant that the rear tracks ran with the tensioning idler on the tight side of the rubber belt. The tractor and track assemblies had been operated for some 200 hours and there was no indication that this had been a problem.

Figure A5. Overall Tractor Dimensions.

The tractor was equipped with a PTO and a three-point hitch. Total weight of the tractor with a three-quarter full fuel tank was 16,700 kg (36,850 lb). The static front axle weight was 9,200 kg (20,280 lb) or 55 percent of total weight, and the rear axle weight was 7,500 kg (16,570 lb), 45 percent of total weight. There was no additional ballast on the tractor.