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ABSTRACT

The objective of field tests was to analyze and compare the performances of an MFWD wheel tractor and an equal sized rubber track (belted) tractor over a wide range of conditions on Texas soils. When comparing the wheel tractor to the belted tractor across three vehicle traction ratios, two soil types and two soil conditions there was very little difference in fuel efficiency or power delivery efficiency. Both MFWD and belted tractors showed their best performance in the range of 0.4 to 0.5 Vehicle Traction Ratio (VTR). The belted tractor showed its greatest benefit when operated at high VTRs and in soft or loose soil conditions.

INTRODUCTION

With the recent introduction of the belted (rubber track) tractor, questions have arisen as to its field performance when compared to a wheel tractor. In the past, studies have been conducted comparing steel tracked tractors to four wheel drive tractors, Domier et al., 1971 (1), Taylor and Butt, 1973 (2), Bdxius and Zoz, 1976 (3). Due to the weight and size of the steel track tractor the comparison tractor was a four wheel drive, 4WD. These studies were conducted prior to the development of the rubber track (belted) tractor. With the introduction of the larger belted tractors, more recent studies have been conducted comparing them to 4WD tractors, Esch et al., 1986 (4), and both two and four rubber track to 4WD tractors, Turner, 1995 (5).

The introduction of the smaller belted tractors with variable gauge and belt widths that are suitable for cultivation in addition to primary tillage has brought about the need to compare them to wheel tractors with approximately the same power and weight and specifically with the MFWD. Zoz, 1997 (6) analyzed and reported on the general characteristics of the tractive mechanism of rubber belt and rubber tire tractors. He concluded that wider belts and larger tires would provide the greatest tractive performance improvement under the most adverse tractive conditions.

Full vehicle performance comparison tests involving two makes of belted tractors and two makes of MFWD tractors were conducted in Alberta, Canada in the late summer of 1996, Turner et al., 1997 (7). Three different series of test sequences were conducted. One series of tests referred to as the SWTS, Southwest Texas State, series were very similar to those described in this research paper and involved two belted and one MFWD tractor. A second series of tests referred to as the AFMRC, (Alberta Farm Machinery Research Center), series were similar to the SWTS series except the methodology and design were different and a different instrumentation package was used to collect the data. Also, an additional MFWD tractor was added to the AFMRC tests.

In addition to these short run series of tests, the tractors were compared in full field tests. In power delivery efficiency, pull and traction, and fuel efficiency, the results between belted and wheel tractors were similar to those found in this study. In general, the results showed only small differences between the belted and wheel tractors on the performance criteria. Differences that were identified occurred at different pulls and soil conditions. When comparing the belted tractors to the wheel tractors in power delivery and fuel efficiency on primary tillage (fallow) and secondary tillage, results showed little difference on good traction conditions when the wheel tractors were optimized (correct tire pressure and ballast). Approximately the same results between tire and belt on different traction conditions were shown in the Zoz, 1997 (6) study.

OBJECTIVE

The objective of this research was to compare the performances of a Mechanical Front Wheel Drive (MFWD) wheel, and a Rubber Track Belted Tractor in representative Texas soils over many conditions. In this article the rubber track tractor will be referred to as belted. The criteria for performance comparisons were:

- Fuel Efficiency- kW•h/L
- Power Delivery Efficiency - DB/PTO power ratio.

Power Delivery Efficiency is differentiated from tractive efficiency in that tractive efficiency is defined in ANSI/ASAE S296.4, (8) as the ratio of output power to input power and axle power is normally the input power. Axle power was not measured in this study.

MATERIALS AND METHODS

Both tractors were tested on a PTO dynamometer in the lab prior to field tests. In addition to PTO power and torque, fuel consumption and efficiency were measured using a positive displacement fuel flow transducer. These data were regressed with engine rpm and diesel injector pump rack position measured in voltage to predict fuel flow and engine torque in the field. (The fuel flow transducer was not used as part of the instrumentation package in the field.) Regression formulas were derived from data collected with engine under 100%, 85% and ¾ of 85% (64%) PTO torque loads at full throttle, rated engine speed and at 1800 rpm (reduced engine speed, no load). The coefficients derived from these regressions were excellent predictors. The MFWD tractor's regression equations yielded an $R^2 = 0.987$ for fuel and an $R^2 = 0.996$ for torque. The belted tractor's regression equations showed fuel $R^2 = 0.978$ and torque, $R^2 = 0.995$.

The MFWD exhibited 3.65% better PTO fuel efficiencies than the belted tractor when averaging fuel consumption under three PTO loads, 100%, 85% and 64%. The MFWD showed a 1.3% fuel advantage at the same 170 kW power. There was no attempt to level this variable. There was a 2.5% difference in PTO power at the rated 2200 erpm, MFWD, 170.24 kW and belted, 174.5 kW. This PTO power difference is a part of differences shown in DB power (DBkW) illustrated in Table 3. Tractor mass and physical dimensions of the MFWD and belted tractor are shown in Table 1.

Table 1. Tractor Descriptions

Specification		Belted	MFWD
PTO Power (kW) @ RES*		175	170
RES (rpm)		2200	2200
Weight, (kg)	Front		4261
	Rear		8395
	Total	12614	12656
Tire size	Front		16.9 R30
	Rear (Duals)		20.8 R42
Belt width(cm)		41	
Tire pressure(kPa)	Front		165
	Rear		75

* Rated Engine Speed

The MFWD was a production model and the belted a prototype. The MFWD tractor was equipped with radial tires. The belted tractor was equipped with 41 cm width rubber tracks. Only total static weights were recorded for the belted tractor while both were operated at the same field weight.

INSTRUMENTATION - Wiring harness and sensors were installed on both tractors to accommodate a multiprocessor based instrumentation and telemetry system, MICRO MAX, developed by Fox et al., 1990 (9), and Shell and Fox, 1993 (10) to collect and analyze tractor and other off-road vehicle data in the field. MICRO-MAX was interfaced with traditional tractor transducers, engine speed (rpm), transmission speed (counts), field speed (km/h) from radar gun, and injector pump rack position (Voltage). The transmission speed sensor was used to record gear and to determine travel reduction.

Both tractors had electronically controlled diesel fuel injection pumps. Additional sensors installed on the tractors included a drawbar equipped with strain gages to measure horizontal force, kN. Radio modems in the tractors and at a base station located near the field allowed data collected and displayed in the tractor to be transmitted to the base computer for monitoring and analyzing.

FIELD TESTS METHODOLOGY - Not only was the objective of the study to compare the performance of the two tractors, but to use a design that would allow statistical analysis of the effects of field and operating conditions on each tractor. To accomplish this, the study was designed to compare the two tractors over six categorical variables, 2 tractor types (TRAC), 2 soil types (ST), 2 soil conditions (SC), 2 engine speeds, 3 engine torques, and 3 vehicle traction ratios (VTR). The two dependent variables were fuel efficiency, kW•h/L, and power delivery efficiency, ratio. Vehicle traction ratio was considered in this study to be the ratio of drawbar pull to static load on the tractor, pull/weight. In other words, a tractor exhibiting a 0.4 VTR is pulling 40% of its weight.

Analysis of variance was used as the statistical procedure in this study because it is designed to compare the combined effects of a group of independent variables on a dependent variable. If the analysis is statistically significant, then there is a very high likelihood (with probability 1 - the significance level) that the means of the independent variables are not all equal. The factorial design allows the simultaneous comparison of the effects of selected levels of the factors (independent variables) on the dependent variables. For example, if the factor "tractor type" is significant when "fuel efficiency" is the dependent variable, then at least some of the tractor types have a different mean fuel efficiency. But if this factor is not significant according to the analysis of variance, then the average fuel efficiency for each tractor type is the same. For factors that are found to be significant, then a main effects analysis is conducted to determine which of the means in the group are different. The analysis may show that all are different or just one is different from the rest which are all equal, etc. The significance level used in the study was 5 percent. This means that there is only one chance in twenty that when the means of the factor are equal, the results of the statistical test will state (falsely) that they are different.

The 2x2x2x2x3x3 factorial design required 144 test conditions. Data were replicated five times in each test condition (matrix) for a total of 720 tests or data files. The means of these replications were used to represent each test matrix. An example matrix collected on the MFVVD and belted tractors on tilled sandy loam soil with full throttle at 90 to 100% torque and 0.4 VTR is depicted in Table 2. The mean fuel efficiency and power delivery efficiency for the MFWD was 2.53 kW•h/L and 0.71 DB/PTO. As a comparison, the belted tractor's performance was 2.91 kW•h/L and 0.84 DB/PTO. In the analysis below, the belted tractor did not consistently show significant fuel advantage in all test conditions. Thus care must be taken in interpreting this example since it represents values obtained when the belted tractor was at its advantage, sandy tilled soil at a 0.4 VTR.

Table 2. Example Data- Sandy Tilled Soil, 90 to 100% Torque and 0.4 VTR

MFWD

Files	Engine RPM	Speed km/h	Power kW	Torq %	Fuel L/h	Pull kN	Effic kW.h/L	Wh\ Slip %	DB/Pto Ratio
	2159	**7.81**	**112.35**	**95.0**	**44.08**	**52**	**2.53**	**8.0**	**0.71**
D041717	2146	8.29	104.32	91.1	42.05	46	2.40	8.5	0.68
D041739	2134	8.15	119.67	99.9	45.37	53	2.64	8.4	0.73
D200856	2169	7.16	102.71	91.9	43.15	52	2.38	7.3	0.67
D201453	2190	7.20	114.77	93.7	44.50	58	2.58	7.3	0.73
D201513	2154	8.25	120.27	98.3	45.33	53	2.65	8.4	0.74

BELTED

Files	Engine RPM	Speed km/h	Power kW	Torq %	Fuel L/h	Pull kN	Effic kW.h/L	Tk Slip %	DB/Pto Ratio
	2170	**9.91**	**134.77**	**96.0**	**46.35**	**49**	**2.91**	**1.2**	**0.84**
D111048	2197	9.94	133.46	90.4	45.01	48	2.97	1.2	0.87
D110141	2130	10.36	135.13	98.7	46.18	47	2.92	1.2	0.84
D110202	2149	9.71	137.64	96.9	46.14	51	2.98	1.2	0.86
D101050	2190	9.78	132.86	95.9	46.86	49	2.84	1.2	0.82
D101052	2186	9.74	134.78	98.1	47.58	50	2.84	1.2	0.81

Travel reduction (slip), pull, speed, fuel consumption and drawbar power were measured and recorded since they are reflected in a tractor's performance. As alluded to previously, the drawbar powers should be normalized to allow for the belted tractor's higher PTO power.

SOIL TYPES AND CONDITIONS - Using the factorial design, tests were conducted in two Texas soils, (ST), a clay loam and a sandy loam, and two soil conditions, (SC) tilled and untilled. The untilled condition was considered ground that had not been tilled or disturbed since the last crop had been harvested, with fields having a crop residue - wheat or maize stubble and some weeds such as Johnson Grass. Tilled soils had been chisel plowed to a depth of approximately 15 cm since the crop had been harvested. Tilled tests in most cases were conducted on soils that had been chisel plowed within two months of the tests. Tests were conducted in the spring and summer of 1996 in Hays, Caldwell, and Guadalupe counties near San Marcos, Texas. Most of the tests were conducted when soil moisture was low and with ambient temperatures in the mid to high 30's °C. An attempt was made to conduct each field test with both tractors within one day of the other while temperatures and soil moisture were the same. When the temperatures or soil conditions changed before test could be replicated with the other tractor for example, if it rained, tests were not used and were repeated.

TEST DURATIONS - Tests were conducted in strips of approximately 122 m or for a duration of approximately 50 seconds with little steering. Tests in each matrix were initiated and data collected after the tillage tool (chisel plow) was lowered and torques and field speeds were consistent. Draft loads and transmission gears were manipulated to put the tractor in the proper VTR and torque ranges for each test matrix.

TORQUE, VTR & ENGINE RPM - Tractors were loaded to three PTO torque intervals, 70 to 80%, 80 to 90%, and 90 to 100% of torque at rated PTO power. 100% torque was considered to be torque exhibited by the tractor when at rated power. Both tractors have torque reserves well beyond 100%. In the Canada study, Turner et al. 1997 (7) tractors were tested at torques above 100%. Pulls were bracketed to 0.3, 0.4 and 0.5 vehicle traction ratios (VTR). Only a few tests were run with 0.6 pull to tractor weight ratios and these tests were not included in the analysis. In the Canada study where the AFMRC and the SWTS test sequences were used, tractors were tested at VTRs including 0.6 and higher. The tractors' torque was manipulated by changing draft (net traction, NT) through lowering or raising the tillage implement, or by changing the tractor gear. Tests in this study were initiated with the throttle set at one of two engine rpm ranges (erpm) prior to loading the tractor. The two ranges were full throttle and throttle adjusted to 1800 erpm. Tests were aborted and data not used if the run could not be completed in a safe manner.

Full field tests were also conducted to compare the two tractors by chiseling a given sized field with each tractor using a typical farming procedure. Data developed using this test procedure are not reported in this paper. This procedure was refined for tests conducted in Canada and the data are presented in that paper, Turner et al. 1997(7).

RESULTS

Field Performances as characterized by fuel efficiency (kW•h/L) and DB/PTO power ratios were used to compare the two tractors. The statistical package *SPSS For Windows* ™ was used to analyze the data to identify statistically significant differences and interactions. Table 3 identifies the mean and standard deviation (SD) for the two dependent variables. The mean and SD of two additional variables, travel reduction (slip %) and power (kW measured at the drawbar) are also shown.

The MFWD was better than the belted tractor in fuel efficiency by 2.21%, 2.77 vs. 2.71 kW•h/L (p<.0001). Some of this may be due to an initial advantage which was discovered on static dynamometer testing explained above and may not be attributable to the traction devices of the tractor. There was no attempt to level this variable. The SD of the MFWD fuel efficiency was higher suggesting that it was more affected by soil and test conditions. Analyzing the data below validated this. The means of the belted tractor reflect better performance in power delivery efficiency and drawbar power across all categorical variables.

Table 3. Descriptive Statistics

TRACTOR		DB/Pto	kW.h/L	DBkW	slip%
Belt	Mean	.7767	2.7060	102.5604	2.5292
	N	72	72	72	72
	Std. Deviation	4.4E-02	.1877	15.1687	1.8519
Wheel	Mean	.7610	2.7720	98.0384	8.4572
	N	72	72	72	72
	Std. Deviation	5.4E-02	.2184	17.1526	3.4627
Total	Mean	.7688	2.7390	100.2994	5.4932
	N	144	144	144	144
	Std. Deviation	5.0E-02	2056	16.2931	4.0624

In analyzing the data it was apparent that two of the six categorical variables, engine torque and engine speed, had very little influence on the dependent variables; therefore, the data were collapsed to a 2x2x2x3 factorial design. The marginal impact of engine torque and speed on tractor performance may be attributed to the electronic governors. In other studies where tractors had mechanical governors engine speed and torque were significant, Shell (11).

MULTIVARIATE TESTS - The levels of significance and their interactions are shown in multivariate tests, Table 4, where both dependent variables, fuel and power delivery efficiencies are considered. Analysis of data in Table 4 shows that the four categorical variables, tractor (TRAC), vehicle traction ratio (VTR), soil condition (SC) and soil type (ST) were significant at the (p<.0001)level. In other words, these four variables exhibited significant influence on the combined dependent variables, fuel efficiency (kW•h/L) and power delivery ratio. Two of the interactions involving soil condition, (TRAC*SC) and (VTR*SC) were significant (p<.0001), with (SC*ST) significant at (p<.003). Of the three-way interactions, TRAC*V'I'R*SC was significant at (p<.001) and TRAC*SC*ST significant at (p<.004). The four-way interaction was not significant.

Table 4. Multivariate Tests

Source	Hotelling's T	STAT F	Num df	Err df	Sig of F
TRAC	4.22	123.4 1	4	117	.0001
VTR(vehicle traction ratio)	.732	10.61	8	232	.0001
SC(soil condition)	1.057	30.91	4	117	.0001
ST(soil type)	1.175	34.38	4	117	.0001
TRAC*VTR	.113	1.64	8	232	.113
TRAC*SC	.910	26.63	4	117	.0001
TRAC*ST	.080	2.35	4	117	.058
VTR*SC	.327	4.75	8	232	.0001
VTR*ST	.065	.941	8	232	.484
SC*ST	.144	4.20	4	117	.003
TRAC*VTR*SC	.239	3.47	8	232	.001
TRAC*VTR*ST	.143	2.07	8	232	.040
TRAC*SC* ST	.137	4.00	4	117	.004
VTR*SC*ST	.109	1.59	8	232	.130
TRAC*VTR*SC*ST	.090	1.31	8	232	239

UNIVARIATE - FUEL EFFICIENCY - After looking at the influence of the four categories TRAC, VTR, SC, and ST on both dependent (performance criteria) variables, univariate tests were conducted to analyze their effects on each of the performance criteria separately. The effects of the categorical variables on the fuel efficiency variable, are illustrated in Table 5. The main effects, SC and ST are significant at (p<.0001), TRAC at (p.005). The descriptive statistics, Table 3 illustrated the TRAC main effect on fuel with a 2.2% MFWD fuel advantage across all field conditions. Again the MFWD showed a 3.65% fuel advantage on the PTO power tests. For the main effect of soil condition tilled vs. untilled, SC has a significant impact on fuel efficiency, 2.822 untilled vs. 2.656 for tilled, a 6.25% difference which was also reflected on the univariate test for power delivery. The main effect of ST, sandy vs. clay is also significant, with the combined tractors exhibiting 2.828 kW•h/L for sand and 2.650 for day with a 6.72% better fuel efficiency on sand. It is important to understand when considering the performance data of both tractors is combined. For example when considering soil type, sandy vs day, the combined fuel efficiency data of both tractors is best on sandy soils as opposed to the combined data for both tractors on clay soils.

VTR does not have a significant main effect on fuel efficiency when both tractors are considered. (VTR was significant in the multivariate tests because of its effect on power efficiency as will be shown in table 6.) Only if VTR is considered in its interaction with soil condition, VTR*SC does it become significant ($p<.0001$). VTR's interaction with soil type (VTR*ST) is not significant ($p<.930$). VTR in a three- way interaction TRAC*VTR*ST is significant ($p<.027$) where in the three-way interaction with SC, TRAC*V'I'R*SC, it is not significant ($p<.667$). The TRAC*SC interaction is significant ($p<.0001$) where TRAC*ST is not ($p<0.083$). The graphs shown below help to explain the significance of the interactions shown in the univariate tests.

Table 5. Analysis of Variance -Fuel Efficiency

Source	SS	df	ms	F	sig
TRAC	.157	1	.157	8.013	.005
VTR(vehicle traction ratio)	7.2 E-02	2	3.6E-02	1.850	.162
SC(soii condition)	.993	1	.993	50.689	.0001
ST(soil type	1.143	1	1.143	58.377	.0001
TRAC*VTR	7.4E-02	2	3.7E-02	1.902	.154
TRAC*SC	.745	1	.745	38.033	.0001
TRAC*ST	6.0E-02	1	6.2E-02	3.059	.083
VTR*SC	1.2E-02	2	6.0E-03	8.912	.0001
VTR*ST	2.8E-03	2	1.4E-03	.072	.930
ST*SC	2.4E-03	1	2.4E-03	.123	.726
TRAC*VTR*SC	1.6E-02	2	8.0E-03	.407	.667
TRAC*VTR*ST	.145	2	7.3E-02	3.711	.027
TRAC*SC*ST	4.7E-02	1	4.7E-02	2.394	.124
VTR*SC*ST	2.4E-02	2	1.2E-02	.619	.540
TRAC*VTR *SC*ST	6.7E-02	2	3.3E-02	1.710	.185
Error	2.350	120	2.0E-02		
TOTAL	1086.338	144			

With regard to the interaction, TRAC*SC ($p<.0001$) illustrated in Figure 1, the wheel tractors fuel efficiency was more impacted by soil conditions than the belted tractor. The tractors when considered together exhibited 6% higher fuel efficiencies on untilled surfaces as compared to tilled, 2.82 vs. 2.66 kW•h/L ($p<.0001$).

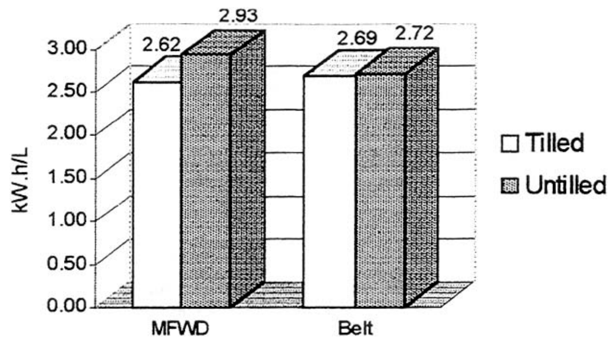

Figure 1. Fuel Efficiency- TRAC*SC ($p<.0001$)

The tractors experienced their highest fuel efficiency at 0.4 VTR, on untilled soil (2.85 kW•h/L). This is shown in an interaction ($p<.0001$) of VTR and SC, Figure 2. Fuel efficiency falls off on tilled soil as VTR increases but remains constant on untilled soil.

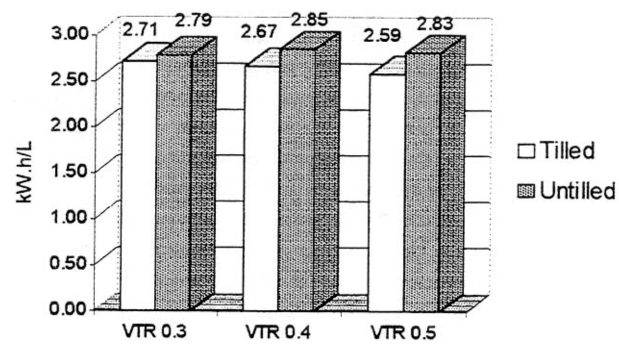

Figure 2. Fuel Efficiency (Both Tractors) VTR*SC ($p<.0001$)

Figure 3, three-way interaction, TRAC*VTR*ST, shows the belted tractor with higher fuel efficiency ($p<.027$) in sand over clay, as does the wheel tractor. The belted tractor performs best with 0.4 VTR on sand where the wheel shows higher fuel advantage at a 0.3 VTR on sand. On clay soil the wheel tractor shows an advantage at the 0.4 VTR over the belted but this advantage disappears when the pull to weight ratio increases to 0.5 VTR.

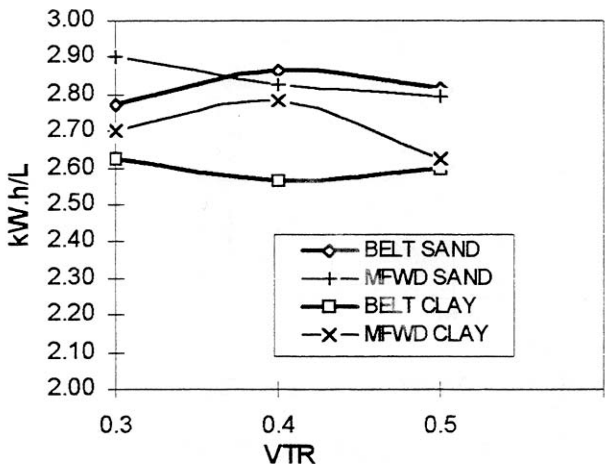

Figure 3. Fuel Efficiency - TRAC*VTR*ST (p<.027)

UNIVARIATE- POWER DELIVERY- The same four categories were tested to determine their effect on the other performance criterion, power delivery ratio. The analysis for power delivery is shown in Table 6. Note that all four main effects are significant for power efficiency (DB/PTO ratio). When looking at the TRAC main effect, the belted tractor showed 0.777 DB/PTO ratio compared to 0.761 for the wheel tractor, in other words transferring the PTO power to the drawbar, (p<.0001). The VTR is also a significant main effect, (p<.006), with the 0.4 VTR the best, 0.798 as compared to 0.793 for 0.3 V'I'R and 0.785 for 0.5 VTR. On the SC main effect untilled surfaces results in 6.2% higher power delivery ratios than tilled surfaces, .792 vs .746 (p<.0001). The main effect of soil condition is due largely to variation on the wheel tractor.

Soil type was also a significant main effect, (p<.0001), on the power delivery of both tractors just as it was for fuel efficiency. Both tractors exhibited higher power delivery ratios for sand than clay (0.792 vs 0.746). The three categorical variables, TRAC, SC, and ST affect both performance criteria. The only issues that could confound the comparison are the initial difference in engine fuel efficiency exhibited by the MFVVD and the higher PTO power exhibited by the belted tractor.

Table 6. Analysis of Variance - Power Delivery Ratio

Source	SS	df	ms	F	Sig
TRAC	8.8E-03	1	8.9E-03	13.167	.0001
VTR (vehicle traction ratio)	7.2E-03	2	3.6E-03	5.322	006
SC (soil condition)	7.7E-02	1	7.7E-02	114.342	.0001
ST(soil type)	7.5E-02	1	7.5E-02	111.612	.0001
TRAC*VTR	5.6E-03	2	2.8E-03	4.165	.018
TRAC*SC	5.5E-02	1	5.5E-02	81.420	.0001
TRAC*ST	6.3E-03	1	6.3E-03	9.306	.003
VTR*SC	1.2E-02	2	6.0E-03	8.912	.001
VTR*ST	5.0E-04	2	2.5E-04	.372	.690
ST*SC	2.0E-04	1	2.0E-04	.298	.586
TRAC*VTR*SC	1.2E-03	2	6.1E-04	.904	.408
TRAC*VTR*ST	8.2E-03	2	4.1E-03	6.070	.003
TRAC*SC*ST	5.0E-03	1	5.0E-03	7.450	.007
VTR*SC*ST	2.9E-03	2	1.5E-03	2.173	.118
TRAC*VTR *SC*ST	6.5E-03	2	3.3E-03	4.839	.010
Error	8.1 E-02	120	6.7E-04		
TOTAL	65.468	144			

When looking at the TRAC*VTR interaction, Figure 4, it is evident that the MFWD exhibits its best DB/PTO ratio at the 0.4 VTR, (p<.018) with a 0.78. The belted tractor also shows 0.78 at two VTRs, 0.4 and 0.5. Both tractors are equal, (0.77 DB/PTO), at the 0.3 V'I'R.

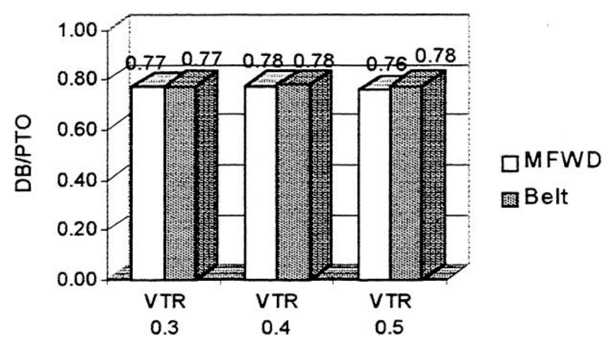

Figure 4. Power Efficiency (All Soils) - TRAC*VTR (p<.018)

The influence of soil condition on the performance of both tractors is depicted in Figure 5. When the belted tractor is operated on tilled soils as compared to untilled, less than 1% deterioration (0.93%) in DB/PTO power delivery ratio occurred, two-way TRAC*SC interaction, (p<.0001). This is similar to the impact SC had on fuel efficiency explained above.

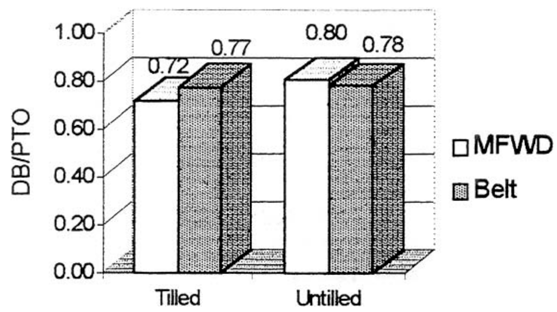

Figure. 5 Power Efficiency-TRAC*SC (p<.0001)

Both tractors do better on sand than clay, as illustrated in Figure 6, when using power delivery as the performance criterion, two-way TRAC*ST (P<.003) interaction. The belted tractor exhibited 0.81 on sand and 0.75 on clay and the wheel tractor 0.78 on sand and 0.74 power efficiency on clay.

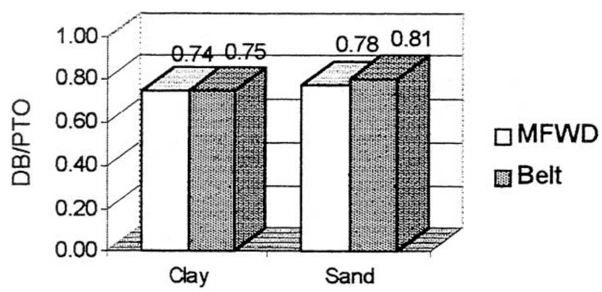

Figure 6. Power Efficiency - TRAC*ST (p.<.003)

The bar graph, Figure 7 illustrates the interaction of VTR*SC, (p<.001), when considering power delivery. The results are similar to fuel efficiency figures. When the data of both tractors were combined they exhibited better performance, higher fuel efficiencies, 2.85 kW•h/L and power delivery 0.80 at the 0.4 VTR on untilled soils

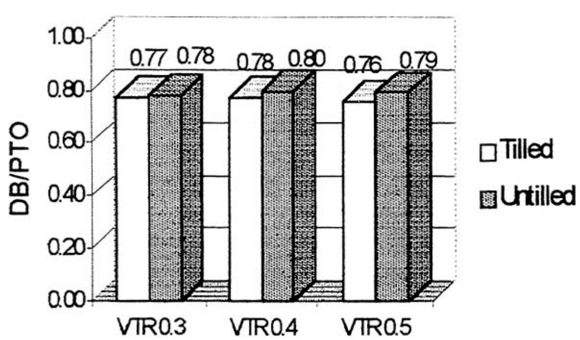

Figure 7. Power Efficiency (Both Tractors) - VTR*SC (p<.001)

The three-way interaction TRAC*VTR*ST, (p<.003), is shown in Figure 8. The VTR is on the horizontal axis with each line representing tractor and soil type. The lines representing the belted tractor on both soil types is almost parallel, with the sand on top. The belted tractor is slightly better at the 0.5 over 0.4.VTR on sand This graph illustrates that the belted tractor is rather stable over all VTRs. The MFVVD decreases in DB/PTO at VTRs greater than 0.4.

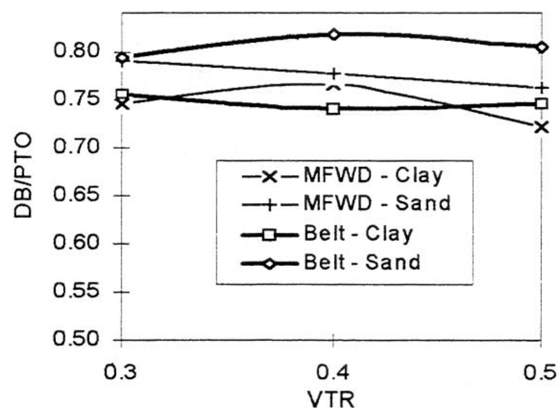

Figure 8. Power Efficiency - TRAC*VTR*ST (p<.003)

Figure 9 also illustrates a three-way interaction, TRAC*SC*ST, (p<.007). The lines representing the belted tractor on sand and clay are almost parallel to the

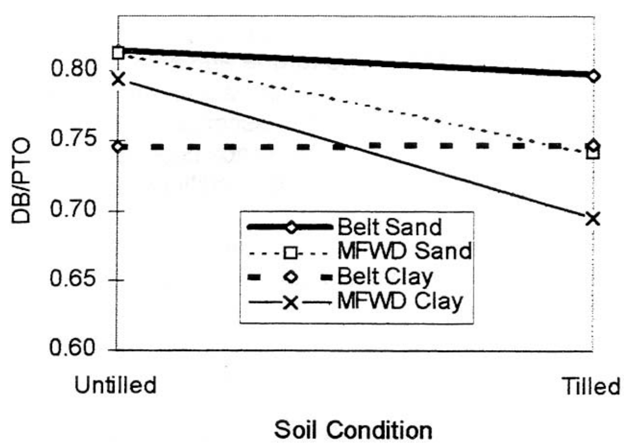

Figure 9. Power Efficiency - TRAC*VTR*ST (p<.007)

horizontal axis where the lines representing the MFWD show a decline on both soil types when moving from an untilled field to a tilled one.

The four way interaction, TRAC*VTR*SC*ST (p<0.010), is shown in Figure 10. There was not a great deal of difference between the two tractors on untilled sand. The wheel tractor exhibited higher efficiency on untilled clay where the belt shows better power efficiency on tilled clay and tilled sand at all VTRs.

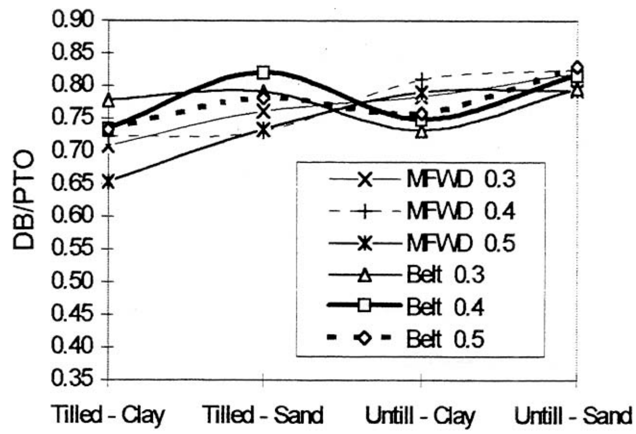

Figure 10. Power Delivery - TRAC*VTR*SC*ST (p <.010).

CONCLUSIONS

Two equal sized tractors, an MFWD and a belted tractor were compared in 720 field performance tests and 144 test conditions as measured by power delivery efficiency (DB/PTO ratio) and fuel efficiency (kW•IVL) in three Texas counties. Six categorica variables were considered in the comparison, tractor type (MFWD vs. belt), soil condition (tilled vs untilled), soil type, (sandy vs clay) vehicle traction ratio (three ratios 0.3, 0.4 and 0.5), three engine torques and two no-load engine speeds. The torque and engine speeds were found to have little impact on the results. Analysis of variance was used to ascertain the statistical significance of the difference between the tractors operating in different field conditions.

When all test conditions are combined, the belted tractor's power delivery efficiency exceeded the MFVVD's by 2.1%.

- The belted tractor exhibited an average 2.5% travel reduction (slip in %) where the wheel tractor experienced 8.5 % across all tests.
- The wheel tractor exhibited 2.2% better fuel efficiencies, but this difference may not be attributed to the traction elements, it was found in PTO dynamometer tests that the MFWD wheel tractor exhibited better fuel efficiencies when compared to the belted tractor at the same PTO loads.
- The two performance criteria, fuel and power efficiency were found to be related and in most cases, the effect of the four categorical variables on each performance criteria were approximately the same. VTR was the exception.
- When considered together the tractors exhibited 6% better fuel efficiencies and 6.2% power delivery efficiencies on untilled surfaces as compared to tilled. They showed a 6.8% fuel advantage and a 6.1% power delivery advantage in sandy over clay soils.
- When considered together the tractors showed the highest fuel efficiency at a 0.4 vehicle traction ratio (VTR), 2.85 kW•h/L. This is shown in an interaction of VTR and soil condition. They averaged 2.79 kW•h/L at 0.3 VTR and 2.83 at 0.5 VTR.
- The power efficiency and fuel efficiency of the MFVVD tractor deteriorated in tilled soils. The belted tractor showed it's greatest benefit in poor traction conditions or high pulls.
- When comparing the belted tractor to the wheel tractor across all three V'I'Rs, two soil types, and two soil conditions there is very little difference in fuel efficiency or power delivery.

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DEFINITIONS

Power Delivery Efficiency - the ratio of drawbar power to PTO power (DB/PTO) at a given operating point.
Vehicle Traction Ratio or Traction Ratio (VTR) - the ratio of drawbar pull to total static weight.
Travel Reduction - wheel slip in %.
Tilled Soil - has been tilled since a crop has been harvested. No or little residue or vegetation on surface.
Untilled Soil - has not been tilled or disturbed since harvesting a crop. May have some vegetation, stubble and weeds on the surface.