COMPARISON OF PREDICTED AND MEASURED DRAWBAR PERFORMANCE OF TRACTORS ON AGRICULTURAL SOILS

by

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INTRODUCTION

Several methods have been used to predict the drawbar output of tractors on agricultural soils. The parameters of soil strength and characteristics of tire performance are included in these methods. An earlier paper (2) reported on the characteristics of tractive performance of a "standard" tractor with 13.6-28 tires. The parameters used in the analysis were:

Coefficient of net traction (μ)

$$= \frac{\text{Net Pull}}{\text{Dynamic Weight}} \quad \ldots\ldots\ldots\ldots\ldots 1$$

Coefficient of gross traction (μ_T)

$$= \frac{\text{Gross Thrust}}{\text{Dynamic Weight}} \quad \ldots\ldots\ldots\ldots\ldots 2$$

Coefficient of rolling resistance (ρ)

$$= \frac{\text{Rolling Resistance}}{\text{Dynamic Weight}} \quad \ldots\ldots\ldots\ldots\ldots 3$$

Tractive power coefficient (π) = $\mu(1-s)$ where s is travel reduction 4

Tractive efficiency (η_{tr})

$$= \frac{\text{Drawbar Horsepower}}{\text{Input Wheel Horsepower}} = \frac{\mu(1-s)}{\mu_T} \quad \ldots\ldots\ldots\ldots\ldots 5$$

The field results indicated that a decreasing "load factor"* of a tire increased the coefficient of net traction on loose surfaces. One common set of performance parameters represented most load factor ratios on firm surfaces.

This paper compares (a) the traction performance characteristics of tractors with varying tire sizes and weights, and (b) the measured drawbar performance of the tractors and their predicted performance based on the tractive performance characteristics of the "standard" tractor.

*Load factor is defined as the ratio of static rear weight to maximum allowable static weight for the same pressure.

PROCEDURE

Field testing of the seven tractors followed the procedure for the "standard" tractor with 13.6-28 tires (2). The tractors were connected (test tractor—load tractor—standard tractor) to facilitate forward speed and drawbar pull measurements. The fifth wheel or forward speed indicator on the standard tractor recorded the actual forward speed. The pull transducer was mounted on the drawbar of the test tractor. The standard tractor was tested separately under the same conditions.

The drawbar pull and forward speed data together with physical data such as static weight, wheel base, drawbar height, etc., were used in computer programs to obtain the necessary data for comparison (1).

These tests were carried out on only one soil type namely Osborne clay, however, the surface conditions varied from loose cultivated fallow land to firm stubble land. The moisture content of the soil ranged from 43.7% in the fallow to 24.4% in the stubble field.

The MF 150 tractor with 13.6-28 rear tires and 100% load factor (max-

TABLE I. REAR WHEEL WEIGHTS AND TIRE PRESSURES OF TRACTORS TESTED IN THE FIELD.

Tractor	Total Rear Weight (lbs)	Tire Size	Pressure Used (psi)	% of Maximum Allow. Load	Tire Condition
1	2525	12.4 x 28	11	65.8	Good
2	4860	13.6 x 28	14	100.0	New
3	4425, 5010	14.9 x 24	14	82.0, 92.8	Good
4	6015	14.9 x 38	14	90.3	Good
5	3715	16.9 x 30	23,14	51.3	New
6	5690	18.4 x 30	14	66.0	Good
7	7680	23.1 x 26	11	62.1	Worn
8	8900	23.1 x 30	13	67.5	New

TABLE II. TIRE SPECIFICATIONS (TAKEN FROM A TIRE COMPANY HANDBOOK).

Tire Size	Sec. Diam. Inches	Diameter Inches	Loaded Radius Inches	Loaded Sect. Width Inches	Contact Area* Sq. Inches
12.4 x 28	12.7	49.4	22.8	13.4	140
13.6 x 28	14.1	51.5	23.5	14.7	153
14.9 x 24	15.0	50.0	22.4	16.4	181
14.9 x 38	15.0	64.0	29.4	16.4	215
16.9 x 30	16.4	58.2	26.0	17.8	243
18.4 x 30	18.8	61.4	27.5	20.7	290
23.1 x 26	23.2	62.5	27.1	24.7	342
23.1 x 30	23.1	67.2	30.0	24.7	398

*By personal communication with R.W. Ellis, The Goodyear Tire and Rubber Company.

imum allowable static weight of 4860 lbs. at 14 psi) was used as a standard for all tests. The seven tractors had different load factors and inflation pressures as shown in Table 1. The tires were either new or with fairly good lugs except for the 23.1-26 tires on the 10,030 lb. tractor which were worn considerably. Other tire data are shown in Table 2.

The field results are presented in two ways (1) as a comparison of traction parameters and (2) as a comparison of predicted and measured drawbar performance.

Part I

Comparison of Traction Parameters

Figures 1 (a) and 1 (b) show the comparison on Osborne clay stubble. The larger tires (both in diameter and contact area) outperformed the standard tire. The load factor had been shown to have very little influence on this surface (2). The differences must be considered quite significantly an effect of diameter. The worn lugs on the 23.1-26 tires probably prevented penetration to slightly denser soil and consequently the coefficient of net traction started to level off more for this tire at high travel reductions.

Figures 1 (c) and 1 (d) are for Osborne clay fallow that was cultivated and harrowed. In Figure 1 (c) the larger diameter tires generally outperformed the standard tire. The performance however of the 23.1-30 tires compared to the 14.9-38 and 16.9-30 tires indicate that factors other than diameter had an influence. Figure 1 (d) shows the effect of many factors in that a small diameter tire (12.4-28) considerably outperformed the larger diameter tire (23.1-30). The influence of load factor alone cannot explain the differences obtained. The inability of the larger tire to penetrate, along with cleaning problems combined with both the load factor and diameter effect resulted in lower performance. The moisture content of the fallow field in Figure 1 (d) was 43.7% (0-3") as compared to 38.4% (0-3") for the same field in Figure 1 (c).

Part II

A Comparison of Actual and Predicted Field Performance of Tractors

The drawbar performance of seven tractors with varying tire sizes and weights was predicted from the performance parameters of the standard tractor. The field measurements were used to check the prediction.

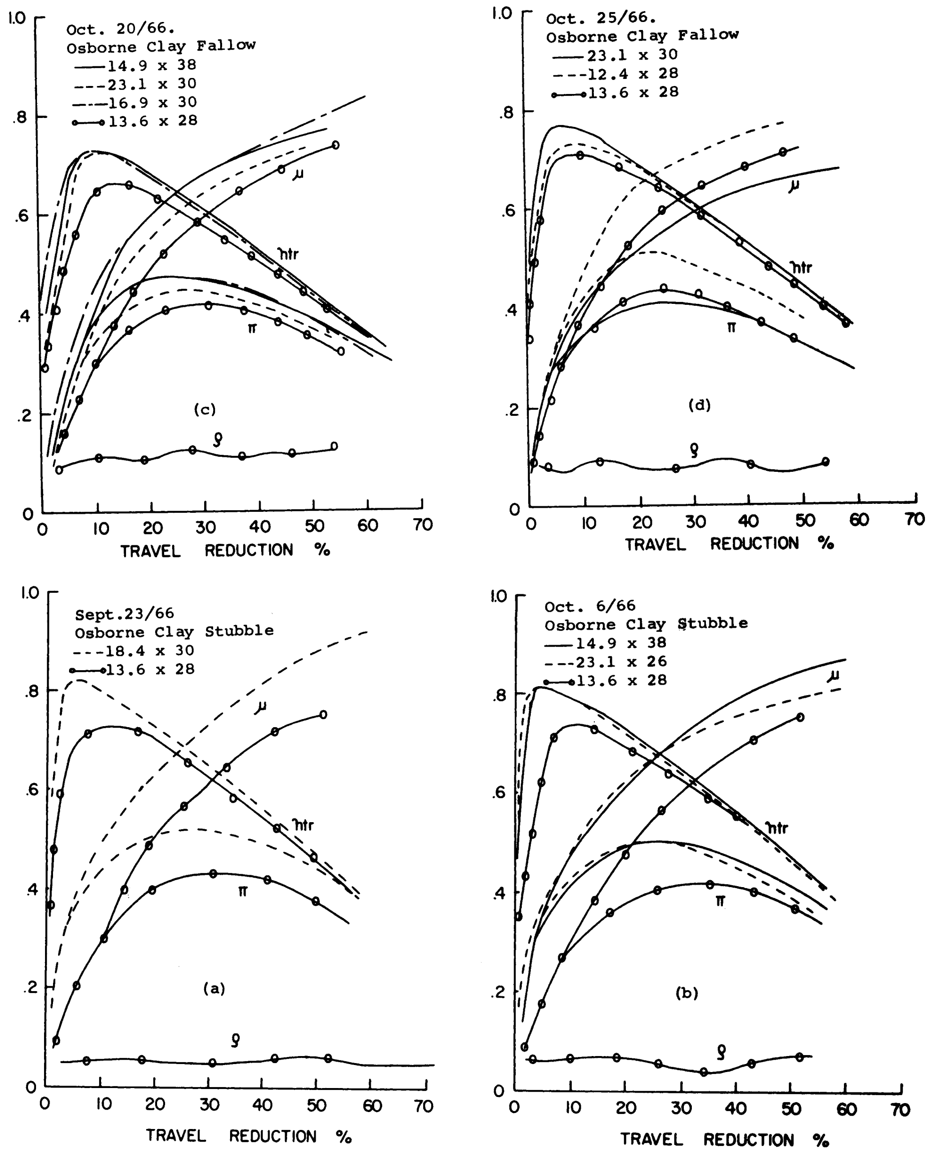

Figure 1. Performance parameters for several tires on Osborne clay: (a) and (b) stubble, (c) and (d) fallow.

In the prediction of drawbar performance the following assumptions concerning the influence of load factor and tire diameter were made: (a) the coefficients of front and rear wheel rolling resistance varied inversely with the diameter, (b) the correction for diameter of the coefficient of net traction from the standard tractor on Osborne clay stubble was one-half the relative difference in diameter multiplied by the coefficient of net traction (μ) at 30% travel reduction. This correction was added uniformly to the μ-curve of the standard tractor to obtain the calculated μ^1 curve for the comparison tractor. Although the method of correction was arbitrarily selected, Kliefoth (3) used a similar approach to correct for the tire diameter. (c) A correction for load factor on Osborne clay fallow was based on the results obtained with different load ratios on the standard tractor (2). This correction was added uniformly to μ to obtain μ^1 for the particular tractor. The performance parameters of the standard tractor on Osborne clay stubble and fallow are shown in Figure 2. The prediction equations used were:

WHTTR(K)=
((RWRRCO*RRR + DBH*U(K))/
(WHLBS—FWRRC*(RRR—FRR)

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—(RWRRCO*RRR)
—DBH*U(K)))*SRWT
DRWT(K)=SRWT+WHTTR(K)
DFWT(K)=SFWT—WHTTR(K)
THRUST(K)=DRWT(K)*U(K)
RRFW(K)=DFWT(K)*FWRRC
PULL(K)=THRUST(K)
—RRFW(K)
DBHP(K)=PULL(K)*FWSPD*(1
—SLIP(K)/100.)/375.
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Where:

SFWT	=	static front wheel weight, lbs.
SRWT	=	static rear wheel weight, lbs.
STOWT	=	total weight of tractor and operator, lbs.
FRR	=	front wheel rolling radius, ft.
RRR	=	rear wheel rolling radius, ft.
DBH	=	drawbar height, ft.
FWRRC	=	front wheel rolling resistance coefficient, dimensionless.
WHLBS	=	wheelbase of tractor, ft.
CGDIST	=	horizontal center of gravity of tractor, ft.
RWRRCO	=	rear wheel rolling resistance coefficient, dimensionless.
FWSPD	=	forward speed at zero pull, mph.
U(K)	=	corrected coefficient of net traction, dimensionless, at a given slip.
SLIP	=	travel reduction (from standard tractor curve), percent.
DRWT	=	dynamic rear wheel weight, lbs.
DFWT	=	dynamic front wheel weight, lbs.
THRUST	=	drawbar pull plus front wheel rolling resistance, lbs.
DBHP	=	drawbar horsepower.

The predicted and measured values for drawbar horsepower and travel reduction are shown versus drawbar pull in Figures 3, 4, 5, and 6. The travel reduction was evaluated on the assumption that the engine speed dropped 6% from no-drawbar-pull to maximum pull.

On Osborne clay stubble the predicted and measured drawbar horsepower agree well up to maximum drawbar horsepower (Figures 3 and 4). In Figure 4 the engine speed of the tractor was pulled down from 1400 RPM at idle to 800 RPM at maximum pull. The measured drop in forward speed and drawbar power was therefore greater than the decrease calculated from travel reduction alone.

For most tractors the measured travel reductions were usually slightly lower than the predicted values.

On Osborne clay fallow both the measured drawbar horsepower and

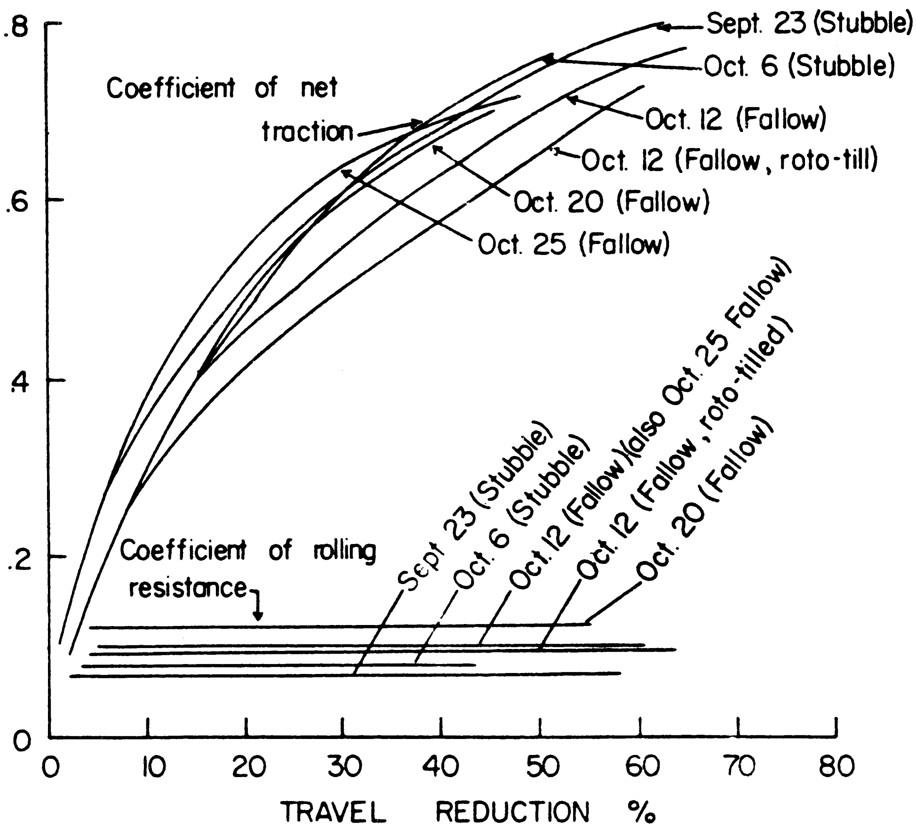

Figure 2. Traction characteristics of the soil as determined by the standard tractor (13.6-28) tires.

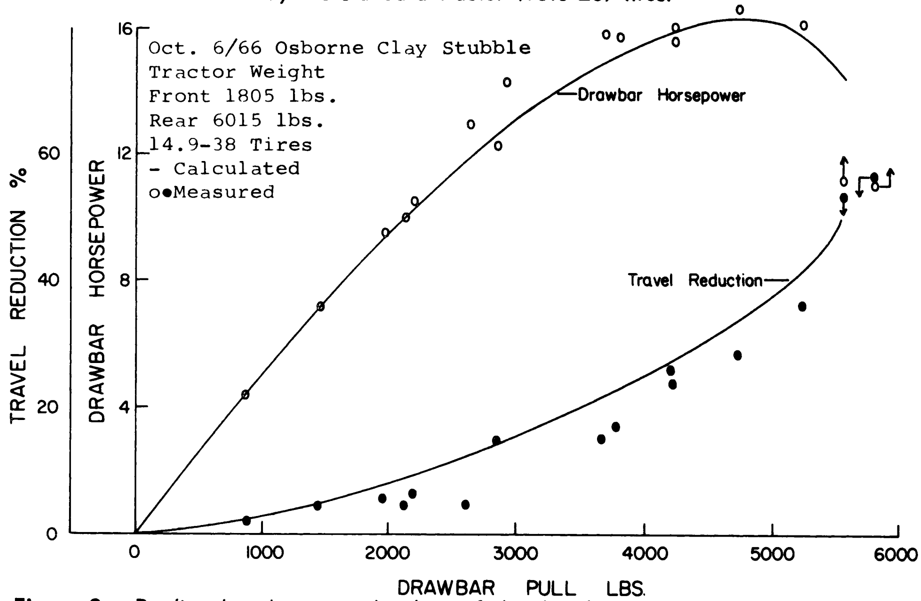

Figure 3. Predicted and measured values of drawbar horsepower and travel reduction on Osborne clay stubble (7820 lb. tractor).

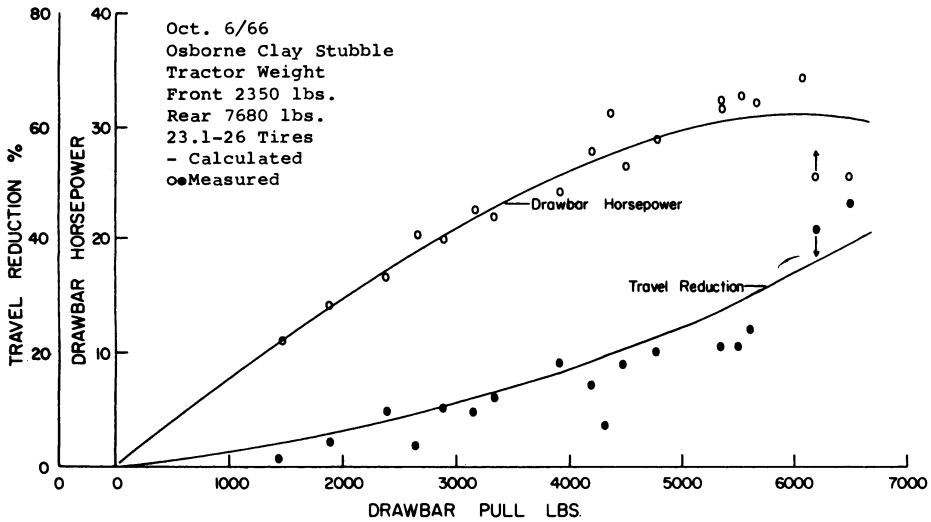

Figure 4. Predicted and measured values of drawbar horsepower and travel reduction on Osborne clay stubble (10,030 lb. tractor).

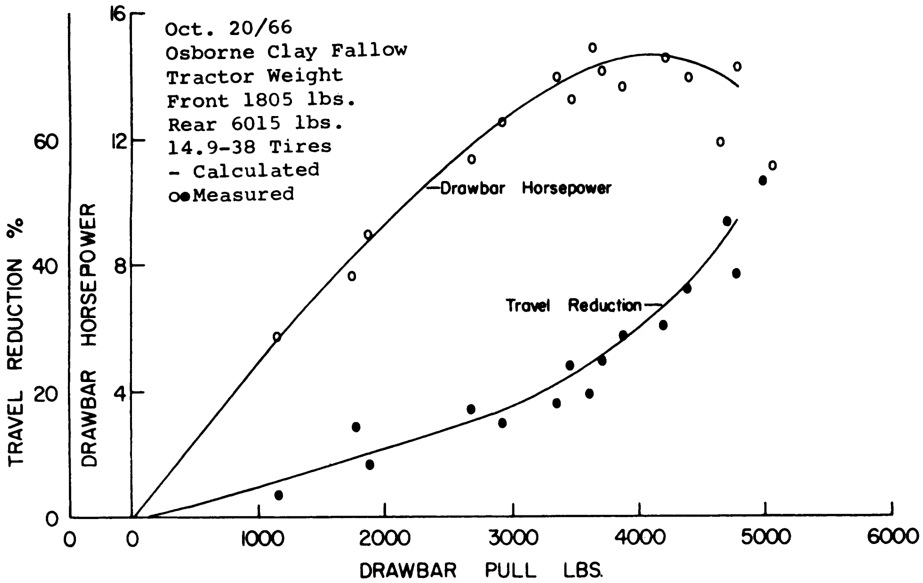

Figure 5. Predicted and measured values of drawbar horsepower and travel reduction on high moisture content Osborne clay fallow (7820 lb. tractor).

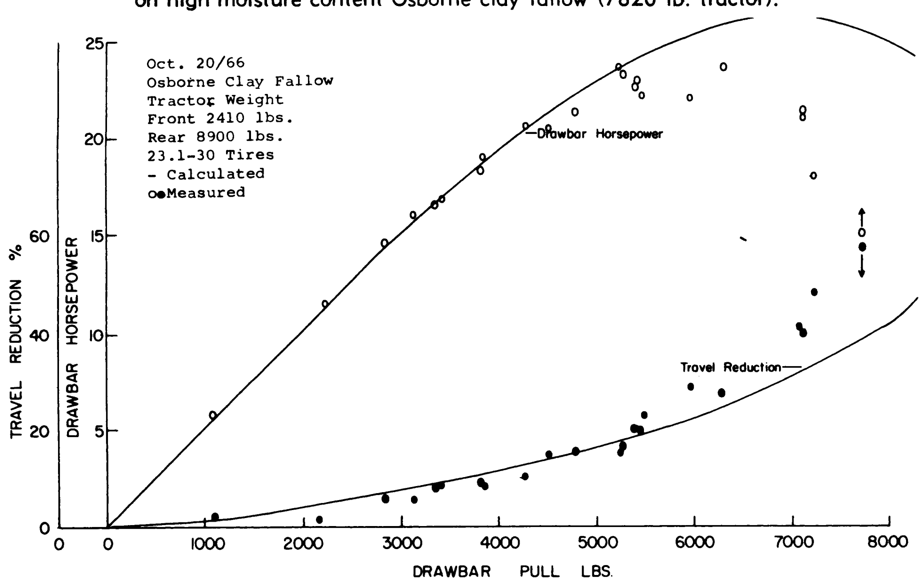

Figure 6. Predicted and measured values of drawbar horsepower and travel reduction on high moisture content Osborne clay fallow (11,310 lb. tractor).

travel reduction are in good agreement with the predicted values except near the maximum drawbar pull (Figures 5 and 6). It should be remembered that the tractor with 23.1-30 tires (Figure 6) had twice the weight of the standard tractor.

Tests were also made with three more tractors with total weight between 3700 and 9480 lbs. and on three other soil conditions. The only observation in addition to what has been mentioned was that on wet sticky soil, tire width may have a negative influence on traction.

SUMMARY

1. Increased tire diameter resulted in increased tire performance except for one case where an interaction between tire pattern and soil moisture was indicated.
2. On a firm soil surface differences in tire performance were due to a "diameter" effect, whereas on loose soil surfaces the increase in performance characteristics could be accounted for by the "load factor" effect.
3. The drawbar horsepower of seven tractors was predicted from basic parameters obtained with a standard tractor. The agreement between predicted and measured output was reasonable taking into consideration natural soil variability and the testing procedure used.

ACKNOWLEDGEMENTS

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3. Kliefoth, F. 1964. Die Ermittlung Der Zugfahigkeit der Ackerluftreifen. KTL Schleppertest, Grundlagen and Berechnug des Berichtes für die Landwirtchaft K.T.L. Ber. 81: 16-25.