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MODELLING TRACTIVE PERFORMANCE FOR DRIVE WHEEL

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Abstract - A model was developed by regression analysis to predict the tractive performance of 7.00-18 radial ply tire for agricultural tractors. Different parameters that affect the cone index of soil and wheel slip were considered for the analysis. To obtain experiments values belonging to tractive performance of tire, a study was conducted in the soil bin by using a single wheel agricultural tire test machine. Performance of this model was compared with model developed by Wismer and Luth (1974) to predicted tractive performance. Mathematical and statistical methods were used to fitting and analysing of models. Results showed that M_1 model outputs were closer to experimental values than M_2 model outputs for prediction of traction performance
Keywords - Tire, Traction performance, Prediction of traction

1. INTRODUCTION

As energy from fossil fuel sources dwindles and subsequently becomes more expensive, the efficient utilisation of energy resources becomes a major concern to agricultural production systems. The farm tractor consumes approximately 20 % of the total on farm energy requirements. The results shown that from 20 to 55 % of the energy delivered to the drive wheels of tractors are wasted in the traction elements.

Macnab et al., (1977) developed a computer program for tractor tractive performance and energy requirements. The computer model required a tractor's physical and geometric characteristics as exogenous parameters for the tractive performance model. They obtained the maximum tractive efficiency at lower slips than the maximum fuel economy.

Wong (1978) and Turner (1984) have made all present similar analysis of tractive effort and slip of track device. The maximum gross traction of a track is limited by the shear strength of the soil and the contact area of the track. Esch (1987) has shown that the dynamic traction ratio (DTR) can be predicted by:

$$DTR = A\frac{\tau_{mx}}{W}\left[1-\frac{k}{S.l}\left(1-e^{\frac{-S.l}{k}}\right)\right]-\frac{MR}{W} \qquad (1)$$

Where

A : Contact area of track,
τ_{max} : Shear strength of the soil,
W : Vehicle load,
k : Horizontal shear deformation modulus of the soil,
s : Slip,
l : length of the track,
MR : motion resistance.

and the tractive efficiency (TE) can be predicted by:

$$TE = (1-S)\left\{1 - \frac{MR}{A\tau_{max}\left[1 - \frac{k}{S.l}\left(1 - e^{\frac{-S.l}{k}}\right)\right]}\right\} \quad (2)$$

where the terms are as previously described.
Esch et al., (1990) used the non-linear regression to fit experimental data to modified forms of the Wismer and Luth (1974) traction prediction equations. Upadhyaya (1988) used non linear regression to obtain best fit curves from tractive performance data from six different types of tires.
The choice of an appropriate model is important and not always straightforward. The model should be as simple as conveniently possible, valid over an appropriate range of conditions, and consistent with the data. Any model is usually to some extent tentative and subject to revision. A provisional model might be based upon empirical evidence, past experience or upon assumed theory. Consistency of the provisional model with the data needs to be checked, for example, by the use of residuals (Hinkley et al., 1991).
The objective of this study was to develop the prediction equations best fit for dynamic traction ratio and tractive efficiency from tractive performance data of tire.

2. MATERIAL AND METHODS

All tests were conducted in the soil bin at the Department of Agricultural Machinery, Selçuk University, Turkey by using a single-wheel agricultural tire test machine as described by Çarman (2001). Soil bins containing clay loam were for the study. The average cone index of soil was approximately 1500 kPa for a depth of 20 cm.
Tire used in this study was a 7.00-18 radial ply. In experiments, tire was operated at dynamic loads of 4, 5 and 6 kN and at constant inflation pressure of 150 kPa.
Dynamic traction ratio and tractive efficiency were used in evaluating of the traction performance of tire. These data were calculated for drawbar pulls and axle powers varying as a depending on dynamic load.
In order to predict dynamic traction ratio (DTR) and tractive efficiency (TE), Minitab statistical programme was used. Cone index of soil, tire dimensions and slip were used as a variable to obtain of predicted equations. Developed non linear regression models (M_1) are given in below.

$$DTR = S^{0.5112} Cn^{-0.61} e^{2.371 - 0.5761S + 0.00364Cn} \quad (3)$$

$$TE = S^{-0.1436} Cn^{-2.142} e^{5.559 - 2.763S + 0.04567Cn} \quad (4)$$

Where
S: Slip,
Cn: Wheel numeric,

$$Cn = \frac{CI.b.d}{W} \quad (5)$$

Where
CI: Cone index of soil (kPa)

b: Unloaded tire section width (m)
d: Unloaded overall tire diameter (m),
W: Dynamic wheel load (kN)

In order to compare developed models, the models (M_2) proposed by Wismer and Luth (1974) were used. These equations are:

$$DTR = 0.75\left(1-e^{-0.3Cn.S}\right)-\left(\frac{1.2}{Cn}+0.04\right) \quad (6)$$

$$TE = (1-S)\left[1-\frac{\frac{1.2}{Cn}+0.04}{0.75\left(1-e^{-0.3Cn.S}\right)}\right] \quad (7)$$

where the terms are as previously describe.

The developed models were tested according to mathematical and statistical methods. In order to determine the relative error (ε) of models, the following equation was used.

$$\varepsilon = \frac{100\%}{15}\sum_{i=1}^{15}\left|\frac{y-\tilde{y}}{y}\right| \quad (8)$$

Where
$\tilde{y}$: Predicted value,
y : Measured value

In addition, goodness of fit (η) of predicted models were calculated by following equation.

$$\eta = \sqrt{1-\frac{\sum_{i=1}^{15}(y-\tilde{y})^2}{\sum_{i=1}^{15}(y-\bar{y})^2}} \quad (9)$$

Where
$\bar{y}$: Mean of measured values

3. RESULTS AND DISCUSSION

The measured and predicted values according to two different models of dynamic traction ratio and tractive efficiency are given in Table 1, and Figures 1 and 2. As increasing slip values, the tractive efficiency decreased while dynamic traction ratio increased. When increasing wheel numeric values, dynamic traction ratio and tractive efficiency decreased.

The relationships between predicted values according to two models and measured of tractive performance (DTR and TE) in different working conditions are given in Figures 3 and 4.

The relationship between predicted values according to two different models and measured of dynamic traction ratio was significant (Fig. 3). The correlation coefficients of relationships were found 0.977 for M_1 and 0.810 for M_2. For dynamic traction ratio, the mean of measured values and predicted values obtained from M_1 and M_2 models were 0.503, 0.502 and 0.597 respectively. The mean relative error of M_1 and M_2

prediction models were found 4.45% and 25.42% respectively. The goodness of fit (η) models were 0.977 for M_1 and 0.22 for M_2.

Table 1. Measured and predicted values, and relative error of predicted values

		Dynamic traction ratio					Tractive efficiency				
S	Cn	M*	M_1	ε	M_2	ε	M*	M_1	ε	M_2	ε
0,0660	54,67	0,300	0,2730	0,0900	0,4340	0,4466	0,715	0,7356	0,0288	0,8173	0,1431
0,1820	54,67	0,430	0,4289	0,0026	0,6501	0,5120	0,470	0,4615	0,0181	0,7468	0,5890
0,2620	54,67	0,480	0,4934	0,0279	0,6778	0,4122	0,350	0,3511	0,0032	0,6762	0,9320
0,3450	54,67	0,520	0,5414	0,0412	0,6854	0,3181	0,265	0,2684	0,0127	0,6007	1,2668
0,4050	54,67	0,548	0,5677	0,0359	0,6871	0,2538	0,230	0,2222	0,0340	0,5458	1,3730
0,0650	43,74	0,310	0,2984	0,0374	0,3629	0,1708	0,725	0,7236	0,0019	0,7885	0,0876
0,1710	43,74	0,450	0,4603	0,0229	0,6030	0,3401	0,490	0,4699	0,0411	0,7456	0,5217
0,2610	43,74	0,550	0,5425	0,0136	0,6581	0,1966	0,360	0,3448	0,0421	0,6703	0,8620
0,3120	43,74	0,570	0,5771	0,0125	0,6701	0,1755	0,270	0,2919	0,0812	0,6251	1,3152
0,3800	43,74	0,600	0,6138	0,0230	0,6774	0,1291	0,235	0,2352	0,0007	0,5639	1,3994
0,0780	36,45	0,302	0,3539	0,1717	0,3575	0,1836	0,740	0,7203	0,0266	0,7658	0,0348
0,1680	36,45	0,487	0,4973	0,0212	0,5576	0,1450	0,495	0,5032	0,0165	0,7358	0,4864
0,2420	36,45	0,637	0,5743	0,0984	0,6239	0,0206	0,380	0,3892	0,0241	0,6787	0,7860
0,3320	36,45	0,662	0,6410	0,0318	0,6572	0,0073	0,290	0,2900	0,0001	0,6013	1,0734
0,3920	36,45	0,700	0,6741	0,0370	0,6668	0,0475	0,245	0,2399	0,0207	0,5481	1,2370

M*: Measured values

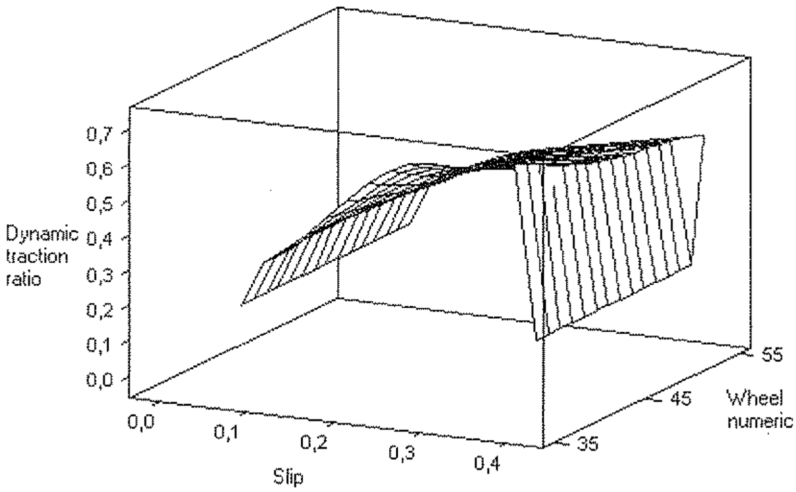

Figure 1. Dynamic traction ratio relation to slip and wheel numeric

The relationship between predicted values according to two different models and measured of tractive efficiency was significant (Fig. 4). The correlation coefficients of relationships were found 0.997 for M_1 and 0.927 for M_2. For tractive efficiency, the mean of measured values and predicted values obtained from M_1 and M_2 models were 0.417, 0.416 and 0.674 respectively. The mean relative error of M_1 and M_2 prediction models were found 2.35% and 80.72% respectively. The goodness of fit (η) models were 0.997 for M_1 and negative for M_2.

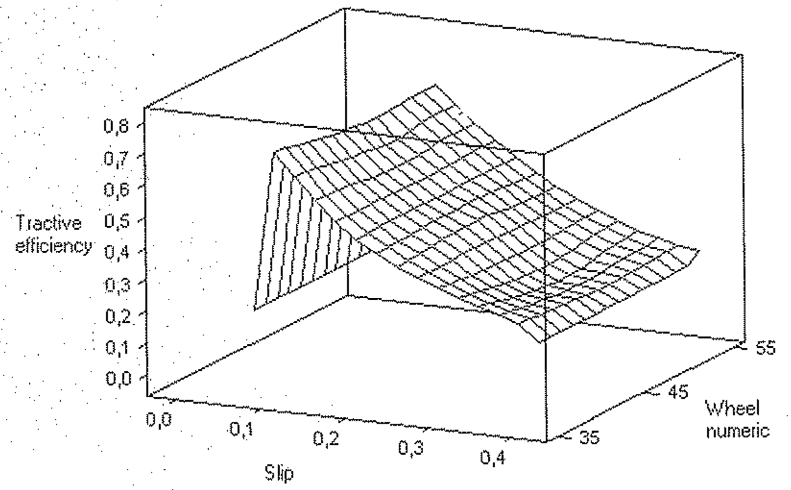

Figure 2. Tractive efficiency relation to slip and wheel numeric

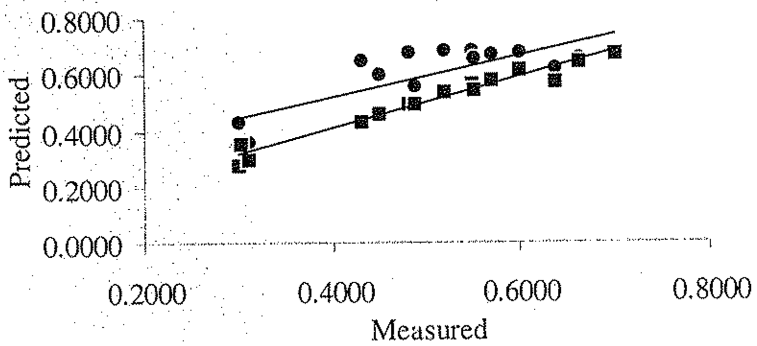

Figure 3. Correlation between measured and predicted values of dynamic traction ratio (□: M_1, •: M_2)

It was seen that when compare models, the smallest predicted error and the biggest relationship between measured and predicted values according to M_1 model of tractive efficiency were found. The highest goodness of fit was obtained in M_1 model developed for tractive efficiency. The prediction values according to M_2 model did not represent the measured values due to be negative the goodness of fit of M_2 model for tractive efficiency. Results shown that, M_1 model outputs were closer to experimental values than M_2 model outputs for prediction of traction performance.

The models developed in prediction of the dynamic traction ratio and tractive efficiency as criteria of tractive performance in an acceptable range can be used as a reference for further traction studies.

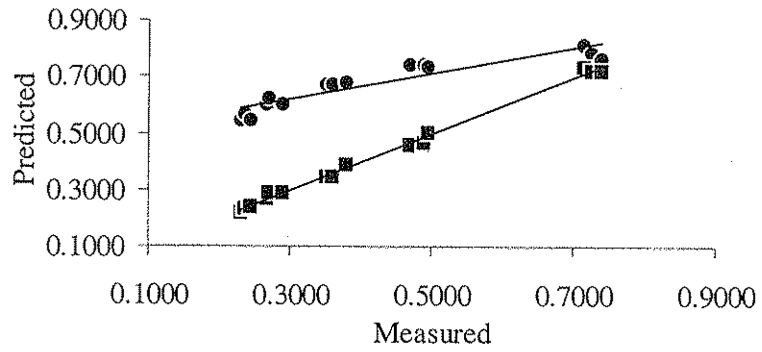

Figure 4. Correlation between measured and predicted values of tractive efficiency (□: M_1, •: M_2)

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