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FULL LENGTH ARTICLE

Net traction of a driven wheel as affected by slippage, velocity and wheel load

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Net traction;
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Velocity;
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Soil bin

Abstract The objective was to assess the effect of velocity at three levels (i.e. 0.8, 1 and 1.2 m/s), slippage at three levels (i.e. 10, 12 and 15%) and three levels of wheel load (i.e. 2, 3 and 4 kN) on net traction utilizing a single-wheel tester in the soil bin facility of the Department of Agricultural Machinery of Urmia University. Analysis of variance (ANOVA) was developed to verify the effectiveness of the aforementioned parameters on the objective of the study at 1% significance level. It was found that the increment of wheel load and slippage results in the increment of net traction. However, it was deduced that velocity has no significant effect on net traction.

1. Introduction

Within the realm of Terramechanics terminology, net traction of a driven wheel is defined as the subtraction of gross traction and rolling resistance. Tractive performance parameters of driven wheels account for the most prominent operational task of agricultural tractors. Qualitative and quantitative analysis of traction force in a precise manner is feasibly performed in soil bin environment under the provision of a controlled condition. Furthermore, optimizing the performance of agricultural tractors could, therefore, help to minimize energy dissipation (Tiwari et al., 2009). Correct insight into soil-wheel interactions results in energy retrenching. A sufficient understanding of optimized tractive performance is essential for instrumentation of appropriate machinery and economization. Tire parameters such as wheel load, slippage, velocity, and inflation pressure affect tractive performance of wheels at different degrees of significance. Net traction force is considered as a pertinent measure of tractive performance parameters (Elwaleed et al., 2006).

Comprehensive semi-empirical studies dealt with soil-wheel interactions trace back to Waterways Experiment Station (WES) researches which were extravagantly less than ideal (John, 1981). In the series of experimentations by WES, some of tractive performance parameters were measured and then were correlated to soil mechanical properties characterized by a cone penetrometer device.

A study was planned to evaluate the accuracy of Wismer–Luth and Brixius equations in predicting net traction ratio of a high-lug agricultural tires utilizing single-wheel tester on the basis of tire inflation pressure, wheel load and wheel

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numeric. From statistical standpoint, the mean effects of aforementioned parameters on tire net traction ratio were found to be highly significant, while the interaction of inflation pressure and wheel numeric was not significant (Elwaleed et al., 2006).

In a previous attempt of the authors, a radial ply tire was used in an undriven wheel tester assembly to determine the effects of wheel velocity, tire inflation pressure, and vertical load on rolling resistance of wheel in a clay-loam soil. It was inferred that rolling resistance, of tractive performance parameters, is a polynomial with the order of two functions of wheel load where it has reverse linear relationship with tire inflation pressure. Velocity was found to have insignificant effect on rolling resistance (Taghavifar and Mardani, 2013).

Different single wheel testing equipments were used to investigate tire performance and different mathematical methods were used to process the measured data (Schreiber and Kutzbach, 2007). However, the study lacks the analysis of traction in zero-slip definitions and therefore, fails to provide comprehensive insight into real term condition of terrain-machine interaction with nonzero slippage levels. Since slippage is a production of terrain-vehicle systems, applying a desired value of slippage to the wheel in the experiments is not applicable to consider the slippage as an input variable.

A comprehensive literature review indicates that the literature is poor regarding the analysis of net traction by adjustment of various desired slippages utilizing a single-wheel tester in a soil bin facility. Therefore, the objective to assess the effects of slippage, wheel load and velocity on net traction was developed in this investigation. The hypotheses below were outlined in this study:

(i) Wheel load, velocity and slippage have significant effects on net traction.
(ii) Combined single-wheel tester and soil bin facility could further assist for provision of a controlled condition.

2. Materials and method

The capacious soil bin of the Department of Agricultural Machinery of Urmia University characterizes 24 m length, 2 m width and 1 m depth which brings about removal of boundary effects. Comprised of a single wheel-tester, a general purposed carriage, control panel, and soil processing equipment, the general system is appropriate to cover soil-wheel experiments. The carriage dimension is 1.90 m × 2 m × 0.95 m weighing a total of 485 kg. At two sides of soil bin, a rail road was used to facilitate the motioning of carriage and attached single wheel-tester along the soil channel. An electromotor with the power of 22 kW at nominal rotational speed of 1457 rpm was used to pull the carriage on the sides of rail road through chain system. For rotational speed of the engine, a SV 220IS5-2 N O, 380V model of LG inverter (brand LS) was used with an information display panel that provided speed control for the carriage and with the application of chain system enabled the forward and reverse movement of the carriage.

The single wheel tester consisted of a main hub to accommodate the various sizes of tires, lifting arms, a loading platform and a power transmission system. The U shape frame of wheel tester had the ability to be rotated around its vertical axis to form angled direction for the movement. An L-shape frame connected the wheel-tester and carriage. An induction motor of 5 kW, 3-phase, 1430 sync rev/min was used to generate the driving power for the wheel. The speed of the motor was initially reduced by gear box (7.5:1) then reduced by a gear reduction unit (4.5:1) and the latest reduction ratio was (33.75:1). A general view of soil bin facility and single-wheel tester and a detailed schematic of the system are illustrated in Figs. 1 and 2, respectively. The tire was directly driven by the electromotor. An electric motor and an inverter were used to impose desired rotational speed for wheel. Difference between imposed rotational speed for wheel-tester and carriage speed provided preferred slippage levels. Furthermore, the wheel's forward rate for a non-slip condition was measured. With the determined rotational speed and the rolling tire, linear speed of wheel was calibrated. The carriage traversing speed was also adjustable by the invertor which controls the rotational speed of the electromotor. The subtraction of the carriage speed from wheel velocity, divided by the wheel velocity yielded different levels of slippage. The utilized tire for experimentations was a 220/65R21 driven tire. As appreciated in Figs. 1 and 2, tester hub and the L-shape frame of carriage are connected by means of a four-bar mechanism each of which are horizontally parallel and holds a load cell for quantification of wheel tractive performance. This mechanism provides both sufficient strength of connections in pivots and following ground unevenness for the tester during motioning. The data acquisition system for the test is located in a special place on the carriage, as shown in Fig. 1. Four load cells were located on four parallel arms to measure the horizontal forces to determine traction force and another load cell was located on a bolt power of wheel to measure the vertical load on the wheel. The vertical load cell transmitted data to a separated digital indicator. Load cells sent data to a Bongshin digital indicator BS722 model and from the output digital indicator by RS232 port to a data logger. In addition to synchronization, data were sent by USB port to a computer and then were stored. Soil properties and the general flow of the experiments are given in Tables 1 and 2, respectively.

Figure 1 A general view of the single-wheel tester inside a capacious soil bin facility.

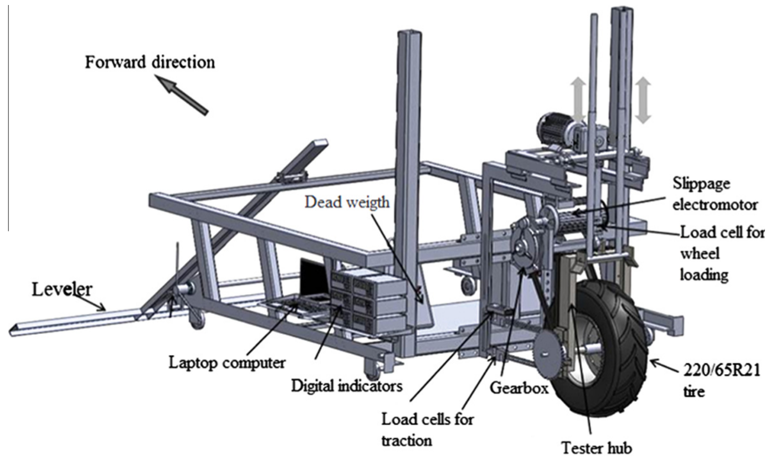

Figure 2 A schematic of the utilized single-wheel tester along with its detailed components.

Table 1 Soil constituents and its measured properties.

Item	Value
Sand (%)	34.3
Silt (%)	22.2
Clay (%)	43.5
Bulk density (kg/m^3)	2360
Frictional angle (°)	32
Cone index (kPa)	700

3. Results and discussion

The obtained data were then analyzed statistically using SAS (Statistical Analysis Software) at 1% significance level. Analysis of variance (ANOVA) was developed for the effects of wheel load, velocity, slippage and their mutual and holistic interactions with net traction (Table 3). As appreciated from Table 3, velocity has no significant effect on net traction where wheel load and slippage have significant effect on net traction ($P < 0.01$). The mutual effects of velocity × wheel load and wheel load × slippage are significant at 1% and 5% levels, respectively. Finally, the triple effect of wheel load × slippage × velocity and mutual effect of velocity × slippage are not significant.

3.1. Effect of wheel load on net traction

As appreciated from Figs. 3–5, net traction force increases by increase of wheel load. The lowest net traction value of 0.46 kN corresponded to the wheel load of 2 kN, velocity of 1 m/s and slippage of 15%. Correspondingly, the greatest value of net traction with 0.96 kN was in concern with wheel load of 4 kN, slippage of 8% and velocity of 8 m/s. Additionally, the greatest increase of net traction with 38% augmentation is in regard with the increment of wheel load from 2 to 4 kN at slippage of 15% and velocity of 0.8 m/s. It is deduced, from Figs. 3–5, that net traction is a nonlinear function of wheel load and may be better expressed by a function of polynomial with the order of two. Similar reports concerned with tractive performance parameters in the literature confirm the discovered trends in this investigation (Taghavifar and Mardani, 2013; Pytka et al., 2006; Degirmencioglu and Way, 2004; Çarman, 2002). The increase of traction force due to increase of wheel load could be attributed to the entrapment of greater soil volume between tire lugs and increase of resistive tangential force of soil volume which bolsters soil-tire interaction and thus results in increase of traction force.

Table 2 Summary of experiment conducted.

Independent parameters			Dependent parameter
Wheel load (kN)	Slippage (%)	Velocity (m/s)	
2	8	0.8	Net traction (kN)
3	12	1	
4	15	1.2	

Table 3 Results of variance analysis of factorial test with variables of velocity (V), Slippage (S) and vertical load (W).

Source	Sum of squares	df	Mean square	F
V	0.088	2	0.044	4.570^{ns}
W	2.356	2	1.178	121.729**
S	0.316	2	0.158	16.304**
V × W	0.270	4	0.067	6.964**
V × S	0.005	4	0.001	0.125^{ns}
W × S	0.004	4	0.001	0.109^{ns}
V × W × S	0.013	8	0.002	0.171^{ns}
Error	0.522	54	0.010	
Total	76.416	81		

df, degree of freedom.
^{ns} not significant.
** $P < 0.01$.

3.2. Effect of velocity and slippage on net traction

The trends of net traction variation due to various slippages at different velocities are plotted in Figs. 6–8. In all of the treatments, increase of slippage brings about increase of net traction. Increase of slippage increases resistive tangential force

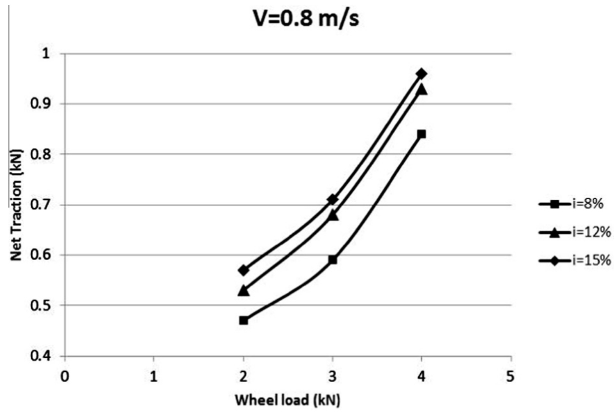

Figure 3 Effect of wheel load on net traction at three slippage levels of 8, 12 and 15% at a velocity of 0.8 m/s.

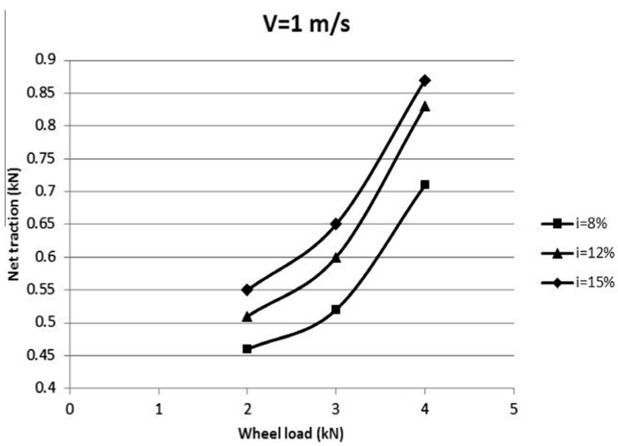

Figure 4 Effect of wheel load on net traction at three slippage levels of 8, 12 and 15% at a velocity of 1 m/s.

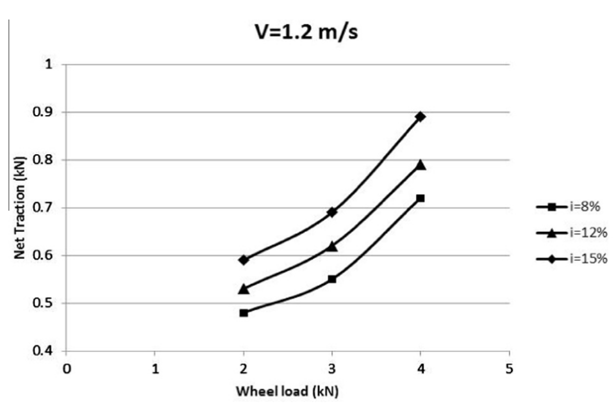

Figure 5 Effect of wheel load on net traction at three slippage levels of 8, 12 and 15% at a velocity of 1.2 m/s.

of soil volume and thus results in increment of net traction force. Similar results have been reported by researchers which confirm the results of the present study (Tiwari et al., 2009; Schreiber and Kutzbach, 2007, 2008; Zoz and Grisso, 2003; Kawase et al., 2006; Çarman and Taner, 2012).

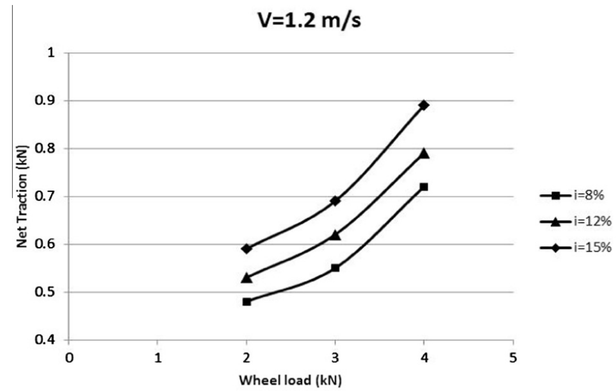

Figure 6 Effect of slippage on net traction at three velocity levels of 0.8, 1, and 1.2 m/s at a wheel load of 2 kN.

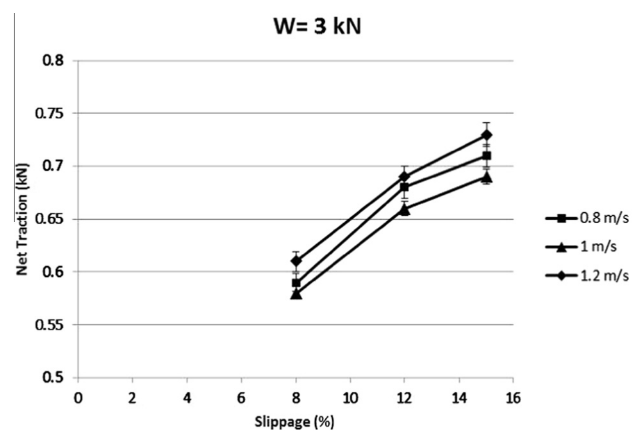

Figure 7 Effect of slippage on net traction at three velocity levels of 0.8, 1, and 1.2 m/s at a wheel load of 3 kN.

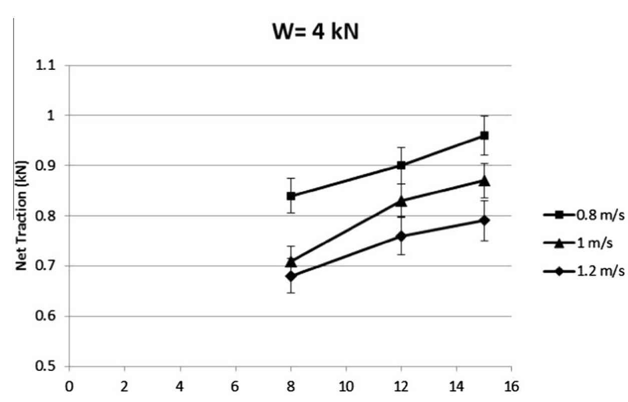

Figure 8 Effect of slippage on net traction at three velocity levels of 0.8, 1, and 1.2 m/s at wheel load of 4 kN.

The error bars in Figs. 6–8 at the significance level of 1% indicate that the velocity has no significant effect on net traction. Similar reported results approve ineffectiveness of velocity on tractive performance parameters (Taghavifar and Mardani, 2013; Zoz and Grisso, 2003; Verschoore and Duquesne, 2001; Shmulevich et al., 1998). This could also be attributed to invariability of contact area due to velocity which is confirmed in (Taghavifar and Mardani, 2013).

4. Concluding remarks

A soil bin facility equipped to a single-wheel tester device featuring a slippage induction system to make various slippage adjustments was utilized to assess the effects of slippage, wheel load, and velocity on net traction force of a driven wheel. Developing analysis of variance (ANOVA) at 1% significance level, it was found that wheel load and slippage are significantly effective on net traction force wherein velocity has no significant effect on net traction force. The conclusions drawn from this investigation were as following:

(i) Net traction increases by increase of slippage more likely by function with a reverse polynomial with order of two.
(ii) It was observed that net traction is a function of wheel load with polynomial of the order two.
(iii) Induction of different levels of slippage to the tester wheel is feasible in utilized single-wheel tester as an advantage of this facility over similar systems.

References

Çarman, K., 2002. Compaction characteristics of towed wheels on clay loam in a soil bin. Soil Tillage Res. 65 (1), 37–43.

Çarman, K., Taner, A., 2012. Prediction of Tire Tractive Performance by Using Artificial Neural Networks. Mathematical and Computational Applications 17 (3), 182.

Degirmencioglu, A., Way, T.R., 2004. Tractive performance comparisons of radial-ply and bias-ply agricultural tractor drive tires. Agric. Eng. 10 (1–4), 1–8.

Elwaleed, A.K., Yahya, A., Zohadie, M., Ahmad, D., Kheiralla, A.F., 2006. Net traction ratio prediction for high-lug agricultural tyre. J. Terramechanics 43 (2), 119–139.

John, C.H., 1981. Traction prediction using physical properties. Trans. ASAE 25 (6), 1420–1425.

Kawase, Y., Nakashima, H., Oida, A., 2006. An indoor traction measurement system for agricultural tires. J. Terramechanics 43 (3), 317–327.

Pytka, J., Dąbrowski, J., Zając, M., Tarkowski, P., 2006. Effects of reduced inflation pressure and vehicle loading on off-road traction and soil stress and deformation state. J. Terramechanics 43 (4), 469–485.

Schreiber, M., Kutzbach, H.D., 2007. Comparison of different zero-slip definitions and a proposal to standardize tire traction performance. J. Terramechanics 44 (1), 75–79.

Schreiber, M., Kutzbach, H.D., 2008. Influence of soil and tire parameters on traction. Res. Agric. Eng. 54, 43–49.

Shmulevich, I., Mussel, U., Wolf, D., 1998. The effect of velocity on wheel performance. J. Terramechanics 35 (3), 189–207.

Taghavifar, H., Mardani, A., 2013. Investigating the effect of velocity, inflation pressure, and vertical load on rolling resistance of a radial ply tire. J. Terramechanics 50 (2), 99–106.

Tiwari, V.K., Pandey, K.P., Sharma, A.K., 2009. Development of a tyre traction testing facility. J. Terramechanics 46 (6), 293–298.

Verschoore, R., Duquesne, F., 2001. Simulation of the influence of differential control on tractor work rate. J. Terramechanics 38 (4), 221–233.

Zoz, F.M., Grisso, R.D., (2003). Traction and Tractor Performance. ASAE distinguished lecture series no. 27, ASAE, St Joseph, MI, 49085-9659, USA.