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FIRST APPROACH TO CORRELATE THE TIRE CONTACT AREA TO TRACTION FORCE IN THE FIELD

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ABSTRACT Tractor working capacity could be restricted by the losses along all the power train including the effect of tires. Since increasing the pulling performance is the key for operational and cost effective practices, tire selection and arrangement have been investigated. The pulling properties of an agriculture tire depend on several factors characterizing the interaction with soil. In order to estimate the possible correlations between geometrical measures of the tires and the force exchanged with soil, the CRA-ING Research Laboratory of Treviglio investigated footprints obtained on paper sheets by inked treads. From these footprints were studied both the total area and only the area from treads, and were correlated with the drawbar force. Two tractors fitted with different tires and in different test conditions were tested. During the 2009 field test season, the performance of several different tires made by different companies in two test campaigns were compared on three different fields, two ballast weight setups, two tire pressure setups (100,160 kPa) and different wheel slippage percentage with two and four wheel drive. Data processing showed a high correlation between the values of the contact area and the drawbar force at certain values of the wheel slippage.

Keywords: contact area, agricultural tires, traction, slippage

INTRODUCTION In the modern agriculture, the tractor has a crucial role that also depends on the efficiency of the other machinery involved thus influencing the quality and the costs of many farm operations. Even if the power of the tractor engine is efficiently converted to traction power, in any case a greater energy is required to accomplish each operation. Indeed, the working capacity of a tractor is limited by the losses along the power train. Approximately 12-18% of the engine power output is lost before it reaches the tractor axle's (Sabanci, 1997). This loss represents the difference between engine and axle power. Another important portion of the losses occurs between the axles and the ground estimated ranging 20 to 40% (Mowitz and Fink, 1987).

Many researchers have studied this topic; in most cases the research has investigated this issue through the traction tests comparing different tractor setups with different types of tires (Kucera et al., 1985; Jurek and Newendrop, 1983; Wulfsohn et al., 1988).

Other studies have tried to find a relationship between the geometric aspect of tires and pressures on soil. This aspect was explored through single or 3D footprint (Grecenko, 1995; Ronai and Shmulevich, 1995; Romano et al., 2009).

In studies on the tread front surface Romano et al. (2009) showed high correlations (R^2=0.977) between the values obtained from volumes on sand and on soil. It seemed indicating the possibility of evaluating the penetration of the treads in each kind of terrain by means of correlation with a standard reference soil (sand). The results outlined that the surface of the front treads showed an higher correlation with volume on terrain (0.915) and on sand (0.864). In such a way the results could suggest the possibility of using data from footprint and from front treads for an indirect measure of the penetration volume on substrate, but it is important to define the typology of terrain on which tests are carried out.

To learn more about the possible indirect measures to be collected on tires, it is therefore necessary to collect and evaluate, in this phase, data from a dynamic observation of the interaction between tire and soil.

For these reasons, the present work has investigated the correlation between the contact area recorded by footprint on hard surface and traction obtained by the same tires mounted on a tractor that moved on three different soil types .

MATERIAL AND METHODS During the year 2009 tests have been conducted at the CRA-ING Reasearch Laboratory, Treviglio (BG), Italy, to observe the performance of three tires (T1= 420/85R28, T2= 540/65R28, T3=420/70R30) made by different companies in two test campaigns and alternatively mounted on an agricultural tractor (Table 1).

Tires were compared on three different soils:

- a soft ground with low skeleton percentage (S1 – Figure 1);
- a compacted soil with low skeleton percentage (S2 – Figure 2);
- a soft ground with high skeleton percentage (S3 – Figure 3).

Figure 1. S1 track

Figure 2. S2 track

Figure 3. S3 track

The test was carried out in , two ballast weight setups (Z= with and N= without ballast), two tire pressure setups (p1= 100 kPa and p2=160 kPa), and six different wheel slippage percentage (15, 20, 25, 30, 35, 40) with two and four wheel drive.

Table 1. Tractor's settings used in the tests.

Tractor setting	Tractor mass (kg)		
	Front	Rear	Total
Not ballasted	1455	1810	3265
Ballasted	795	3440	4235

A dynamometric vehicle of 10 tons was used for breaking the tested tractor (fig.4).

Figure 4. The pull bar test on the S1 track

Optical encoders and a Peiseler wheel allowed to measure the slippage. The forward speed was between 4 and 5 km/h, depending from the slippage, but is not important for the pull bar force.

The test were carried out maintaining constant the slippage by the dynamometric vehicle and obtaining the average value of the force at the pull bar.

The description of the procedure for obtaining tire's footprint was presented in a previous paper (Romano *et al.,* 2007). Essentially, the procedure provides to place the tire on the rear axle of the tractor and to apply static loads to obtain a deflection footprint on different surfaces. Treads were painted and placed on paper sheets on a rigid surface (levelled concrete) for obtaining a contrast image of the deflected treads for the single (SF, figure 5) and multiple footprint (MF).

The multiple imprints were obtained rotating the tyre in 5 different positions in order to fill all the potential area. The footprint on the sandy soil (SaF) was obtained by means of single imprints.

Figure 5. Single footprint shape

The images were acquired in digital format; the digital images allowed determining the area of contact within footprint and the total area comprising an array of pixels of footprint.

The volume of the treads was obtained from plaster mould from footprint both on sand and on soil (VOL SA and VOL TE). The penetration resistance was measured and controlled by a soil cone penetrometer.

Volume of treads were obtained by difference from volume sampler made by tread-shaped wood boxes with a known volume that were placed on the treads of the plaster mould and were filled with sand. Always from the plaster mould was obtained the front surface of the treads reproducing their shape with pieces of paper. These pieces were then acquired as image and their area measured.

RESULTS Data obtained from tests of slippage on different surfaces were compared with data obtained from footprint's analysis. Results were treated in a statistic model that considered all conditions like groups (SF EL, SF BW, MF, SAF, VOL SA, VOL TE, S1, S2, S3). In this way the elaboration could show the repeatability of tests.

Greater correlations (0.75-0.91) were recorded between the areas of single footprint (SF EL) and the data collected by slippage (25, 30 and 40%) on grassy ground. The data from tests of slippage (20, 30 and 35%) on sandy soil are correlated (0.81-0.89) with the area obtained from only trend (SF NB). Slippage on the same grassy ground showed high correlation (0.76-0.82) with the multi footprint (MF), (0.58-0.83) with the area obtained on sand (SAF) and (0.51-0.95) with the volume obtained on sand (VOL SA).

In Table 2) the calculated correlations among all groups of data are shown.

Table 2. Table of correlations among all groups of data.

Thesis	SF NB	MF	SAF	VOL SA	VOL TE	S1	S2	S3
SF EL	0.96	0.96	0.58	0.79	0.89	0.01-0.50	0.34-0.91	0.15-0.54

SF NB	0.95	0.50	0.63	0.89	0.52-0.82	0.06-0.77	0.08-0.86
MF		0.50	0.62	0.90	0.01-0.60	0.35-0.82	0.06-0.61
SAF			0.55	0.48	0.07-0.49	0.06-0.83	0.07-0.34
VOL SA				0.98	0.03-0.84	0.51-0.95	0.04-0.43

These correlations, verified by preliminary statistical tests, indicating a relationship between geometric shape of the tire and his treads and effect of slippage on the pull bar force. In particular, the results obtained from slipping on the grassy ground appear to be related to areas obtained from single or multiple print, from area of treads and from the volume obtained on the ground melted.

Obtained correlations were also observed in the dispersion of data in order to verify the trend. An example of this dispersion is showed in figure 6 in which could be seen data from slipping tests on grassy ground are correlated with the results obtained from single footprint.

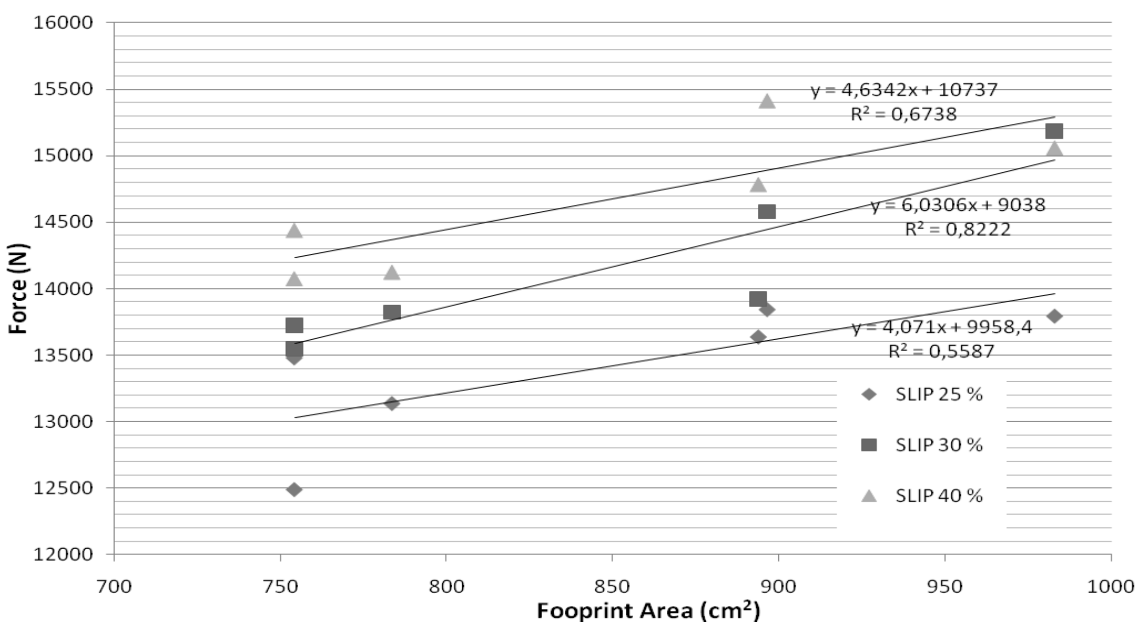

Figure 6: Dispersion between Single footprint (SF EL) and data from slippage test on grassy ground (S2).

The analysis of variance to evaluate main effects and interaction among factors in tests, confirms the high influence on results by inflation pressure (p<0,001) and loads of tractor (p<0,001). However, the overall dimensions and the method didn't have influence on tests. Any interaction between factors didn't appear by this analysis.

CONCLUSIONS Data processed, showed an high correlation between the values of the contact area and the drawbar force at certain values of the wheel slippage. Tests studied, confirming the previous works, indicates a relationship between geometric shape of the tire and his treads and effect of slippage on the ground. It's necessary to improve the test methodology in order to better define the standard terrain characteristics for studying tyre's footprint

Moreover, it could therefore follow this line of study to learn how geometric test could presage the performance of the tire in action and what could be the parameters necessary to refine the interpretation.

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