Agricultural tire footprint shape correlation to treads penetration in different soils

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Abstract

Aim of this work is looking for a correlation between footprint and soil penetration volume of treads in agricultural tires.
Three tyres of different dimensions, fitted on the same tractor with different pressures and loads (N=not ballasted; Z=ballasted) were tested for defining the area of the single footprint shape (SF and SaF), of the multiple footprint shape (MF) and the volume of tyre in soil (V).
Footprints were obtained on rigid surface (SF and MF) and on soils (SaF: sand) with different penetration resistance (soil cone penetrometer value).
Contact area and void area (SF BW) were determined by a software that reads the footprint as an array of pixels in which black pixels and white pixels were distinguished. Volume of treads was measured from plaster mould.
The correlation between tires' footprint surface and volume of penetrated treads has been studied. Soil properties have effects on values but don't have influence on trend in test conditions. Volume of penetration is due mainly to the surface in which treads lean. In the same surface results are influenced by ballast and by inflation pressure. Like in previous study, the use of the ellipse method on image from sand doesn't allow to obtain high correlation with rigid surface, so this application, that with the volume could give the effective interaction between tire and soil, need more studies. The high correlation between data by volume on soil and data by multi-footprints give the possibility to read the interaction tire-surface by two different way.

Keywords: contact area, compaction, sand.

Introduction

In the manufacture of agricultural tires, tread design has particular significance on soil compaction, road behaviour and soil penetration. The problems of stressed soil after tire passages have been studied and pointed out. This effect depends by soil characteristics, vertical load on tyres and by the total pressure on the soil. Heavy vehicles running on soft, moist soils cause huge deflections of soil surface, which are irreversible and immediate after the first pass of a vehicle (Pytka *et al.*, 2005).

The measure of the tyre contact area on rigid surface has always been a reference for properties on soil and on road even if not faithfully representative of its real behaviour (Placckett, 1984). A procedure for defining the total area, the contact area and the void area has been pointed out from CRA-ING of Treviglio. Beside, footprint on rigid surface is not always sufficient to define the real behaviour on field. Aim of this work is looking for a correlation between footprint and penetration volume of treads in the soil.

Materials and methods

Tests have been conducted in Treviglio (BG) at the CRA – ING Research Laboratory during the last year. Three tyres of different dimensions (T1= 420/85R28, T2= 540/65R28, T3=420/70R30) were fitted on the same tractor to tested in four different conditions. The experimental plan considered two inflation pressures (p1= 100 kPa and p2= 160 kPa) and two configuration of the tractor (CZ= with and NZ= without loads).

The tyres were fitted, in succession, on the rear axle of a 4WD agricultural tractor (tab.1).

Table 1. Tractor setting used in the tests

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

To obtain results about the four kind of contact area and the two kind of volume, the method consisted in placing the tyre on the rear axle of the tractor and applying static loads to obtain a deflection "footprint" on different surfaces. To prepare the tire to the single or multiple footprint on paper, treads were painted and placed on a contrasting surface such that a high contrast image of the deflected tread pattern was produced. To print the contact area on a sheet of paper set on the rigid surface the part of contact of the treads was covered with ink.

The footprint image (figure 1) was generated by statically loading the tyre on an appropriate surface, but for the multiple imprint (figure 2) the tyre was rotated in 5 different position in order to fill all the potential area that the tyre would cover. The footprint on the sand (figure 3), was obtained by means of single imprints.

Figure 1. Single footprint shape

Figure 2. Multiple footprint shape

Figure 3. Footprint shape on sand

After this step to generate the tyre footprint upon sheet or sand, a second step was applied for acquiring the image in digital size in which black regions correspond to tyre tread elements and void regions correspond to the space between the tread elements.

The elaboration of the digital image allowed determining the area of contact within footprint and the total area comprising an array of pixels of footprint.

In order to find the total area of the footprint image, a process of geometric construction was undertaken (Romano *et al.,* 2007).

Were defined the area of the single footprint shape on paper and on sand (SF and SaF), the treads area by black pixels (SF BW), the multiple footprint shape (MF) and the volume of footprint on sand and on soil (VOL SA and VOL TE). In this case before obtain each footprint was calculated the texture of the surface observing the penetration resistance by a soil cone penetrometer.

After obtained the footprint both on sand and on soil was prepared a plaster mould to keep the footprint and to extract the volume value.

Volume of treads were obtained from plaster mould shedding sand and by difference from a known volume (figure 4 and 5). In this case, volume sampler made by tread-shaped wood boxes with a known volume were placed on trends of plaster mould and were filled with sand.

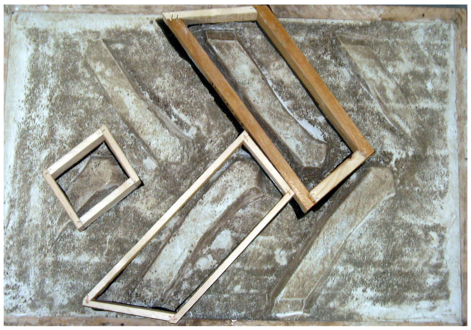

Figure 4. Volume samplers placed on treads

Figure 5. A volume sampler is filling with sand

Results

At the light of all we said, four kind of data were obtained about area and two about volume.

But all collected data represent the same entity that is the interaction between the tire and the soil. So collected data were treated in a statistic model that considers these group of data (SF EL, SF BW, MF, SAF, VOL SA and VOL TE) like repetitions of the same test. In this way the elaboration could show the repeatability of results and the replaceability of a method on an other.

To this aim, was elaborated the table of correlations among all group of data that showed an high correlation (> 95%) between all group of data by paper (SF EL, SF BW and MF) and between data by volume on soil and on sand. Very interesting is the high correlation (R=0,9022) between data by volume on soil and data by multi-footprints that we understand like the possibility to replace a method on an other.

Values of contact area and of volume obtained in test are showed in figure 6 in which are indicated all conditions test and in which we can see trends of all group of data. All methods show different values but the same trend.

All values collected by paper show a low dispersion and the interpolation line in single and in multiple footprint have an $R^2 > 0,90$ (figure 7). Results on sand and in particular areas obtained from sand by the geometric method have too high dispersion ($R^2 = 0,33$) so the method doesn't show a good repeatability.

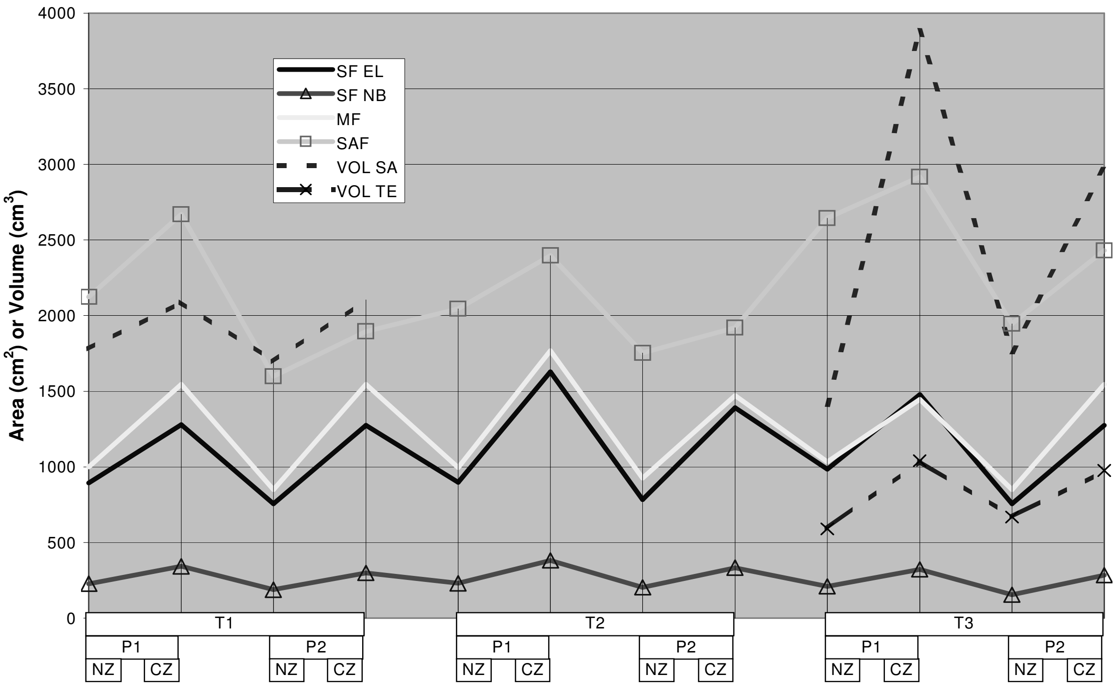

Figure 6. Values of contact area and of volume obtained in test

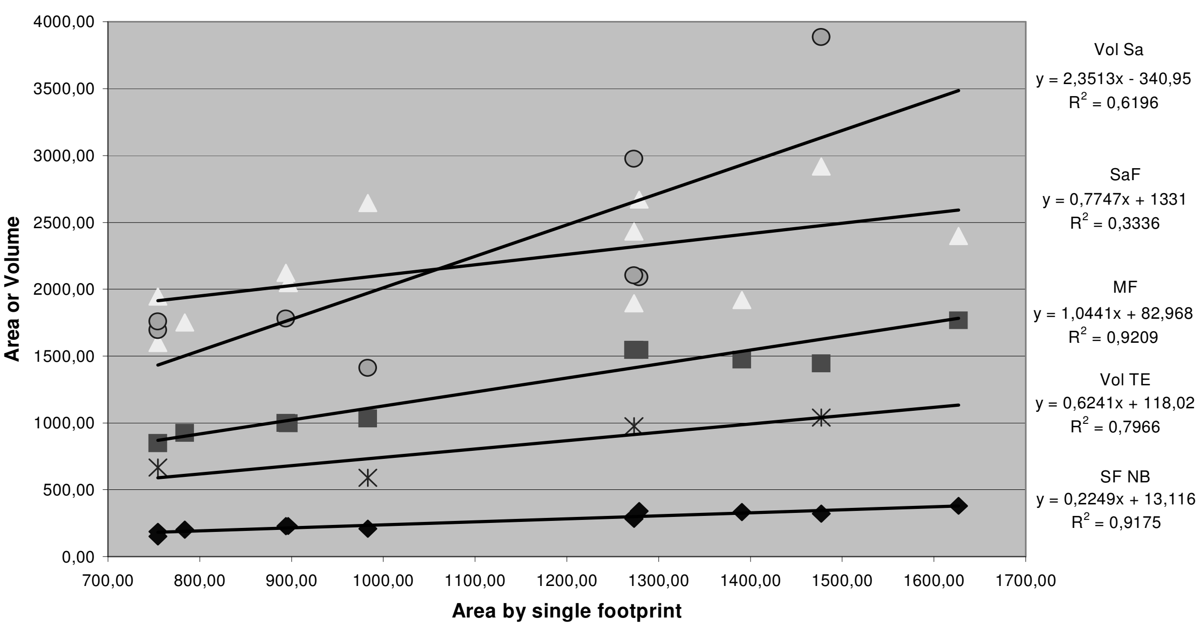

Figure 7. Dispersion of results obtained in all method applied in function of single-footprint ellipse method analysis

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

So, with the support of the statistical significance, we can expose values of volume on soil and on sand instead of all results.

We can see how load and inflation pressure influences the penetration of treads on sand more than soil, but the trend in different condition is the same (figure 8).

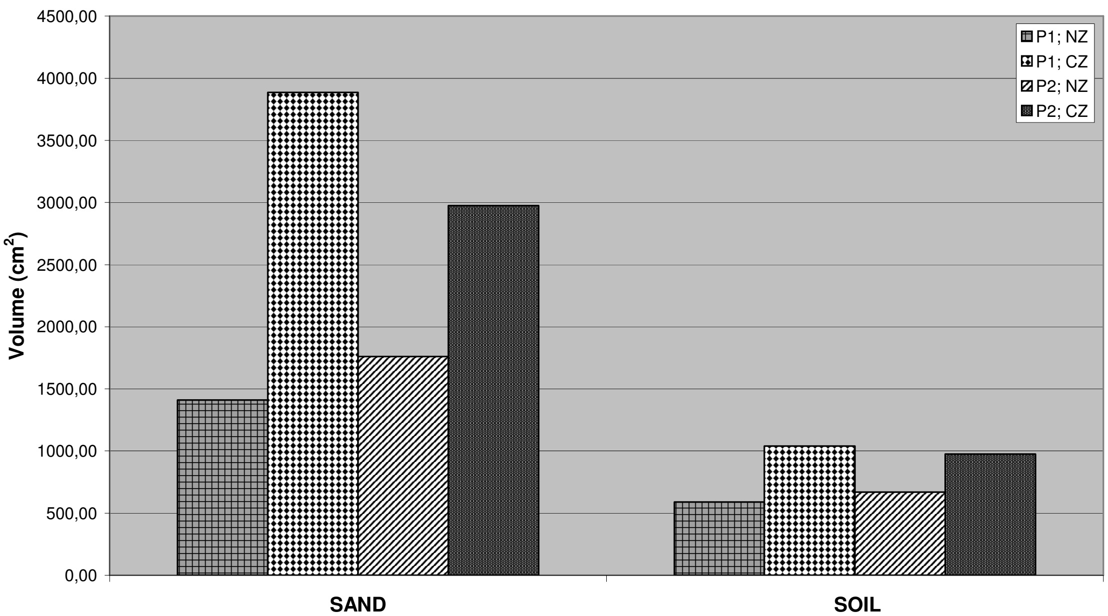

Figure 8. Volumes on sand and on soil

Conclusions

The correlation between tires' footprint surface and volume of penetrated treads has been studied. Soil properties have effects on values but don't have influence on trend in test conditions. Volume of penetration is due mainly to the surface in which treads lean. In the same surface results are influenced by ballast and by inflation pressure. Like in previous study, the use of the ellipse method on image from sand doesn't allow to obtain high correlation with rigid surface, so this application, that with the volume could give the effective interaction between tire and soil, need more studies. The high correlation between data by volume on soil and data by multi-footprints give the possibility to read the interaction tire-surface by two different way.

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