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Modelling in FEM the soil pressures distribution caused by a tyre on a Rhodic Ferralsol soil

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Abstract

Tyre traffic over soil causes non-uniform ground pressures across the tyre width and along the soil–tyre contact area. The objective of this paper was to obtain in the topsoil the shape, magnitudes, distribution and transmission in depth of the ground pressures from a finite element model of soil compaction. The influence of tyre inflation pressure, tyre load and soil water content over the pressures propagation in the soil was analysed. The model shows how to low inflation pressure the tyre carcass supports most of the total load and the biggest peak pressures are distributed in the tyre axes when it traffics over firm soil. For high inflation pressure the incremented stiff causes that pressure is distributed with parabolic shape. In wet soil the inflation pressure does not influence on the ground pressure distribution, this depends only on the tyre load. The inflation pressure and tyre load changed the shape of the vertical pressures distribution on the surface of a hard dry soil, but these variables did not affect the distribution of vertical stresses in a soft wet soil or below a depth of 0.15 m.
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1. Introduction

Total land area cultivated on a global scale is 1.6 billion hectares of which 25% are degraded. Parts of this land are degrading through farming practices that result in water and wind erosion, nutrient mining, soil compaction, salinization and soil pollution (FAO, 2011). Soil compaction is a physical form of soil degradation that alters soil structure, limits water and air infiltration, and reduces root penetration into the soil (Nawaz et al., 2013). Soil compaction in cropping systems is caused by machinery traffic applying stresses larger than the soil bearing capacity (Hamza and Anderson, 2005).

Several researchers have suggested that stresses distribution, axle load, number of passes, speed forward and travel reduction induce the soil compaction associated to machinery traffic (Nawaz et al., 2013; Hamza and Anderson, 2005; Alakukku and et al., 2003; González et al., 2009). Botta et al. (2002) found that subsoil compaction depends only on axle total weight independently of ground pressure, tyre pressure or single or dual tyre. These authors also found a

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direct relationship between ground pressure and soil compaction in the topsoil independent of axle load.

Alakukku et al. (2003) have defined that surface soil compaction takes place until a depth of 0.3 m or in the soil tillage layer (topsoil) and subsoil compaction takes place to depth under soil tillage layer. The soil compaction in cropping systems affects mostly the upper layer of soil (topsoil compaction) but it is also observed at certain depth (subsoil compaction) (Nawaz et al., 2013).

Tyre traffic over soil causes non-uniform stresses distributions across the tyre width and along the soil–tyre contact area (Gysi et al., 1999; Keller et al., 2007; Mohsenimanesh and Ward, 2010; Schjønning et al., 2008), generally ground pressures are higher than the tyre inflation pressure (Lozano et al., 2013). Some factors determining stresses distribution are influenced by factor as tyre inflation pressure, axle load, tyre–soil contact area, lug, tyre stiffness (bias or ply) and single or dual tyre (Hamza and Anderson, 2005; González et al., 2009; Schjønning et al., 2008; Goering et al., 2006; Gysi et al., 2001) and other factors are determined by soil conditions. Many researchers have shown different stresses distribution for several soil conditions depending on soil type, soil texture and soil strength (Keller et al., 2007; Schjønning et al., 2008; Keller and Arvidsson, 2006; Lamandé and Schjønning, 2008; Söhne, 1958). Schjønning et al. (2008) refer that knowledge about the shape and area of the tyre footprint and the magnitude and distribution of stresses distributions have practical implications on the topsoil compaction. These factors are also decisive for the pressures reaching the subsoil, as well as the potential of improving our understanding of ground pressures propagation to the soil.

Most of the ground pressures researches were done in experimental conditions (Keller and Arvidsson, 2006; Farhadi et al., 2013; Sandu et al., 2010; Senatore and Iagnemma, 2014), this method produces results that are valid only for the particular soil testing conditions, and to be extended to other conditions new experimental work is needed. One disadvantage of the procedure is that it is laborious, time consuming, and expensive (Rashidi et al., 2005). In field conditions, it is difficult to measure and maintain the experimental parameters during testing; it is not possible to evaluate all values range of the different variables influencing soil response to machinery traffic. The few studies on stresses distribution have reported their results in a very empirical way, which makes it difficult to draw general conclusions on the effects of wheel load, inflation pressure, tyre characteristics and soil conditions (Lamandé and Schjønning, 2008). The modelling allows making recommendations to the farmers and advisors concerning the technologies and agricultural equipment to use in order to reduce the risk of soil compaction. Furthermore, the depth until which the compaction takes place or the depth of the hardpan layer and the stresses distribution transmitted to soil in depth can be established (González and et al., 2013). An important aspect in the development of models for traffic effect over soil is the prediction of the actual stresses distribution created in the soil by the machines used in crop production (Abu-Hamdeh, 2003).

Two main methods have been used for modelling stresses distribution in the tyre–soil interface and its transmission in soil depth, a pseudo analytical model (Keller et al., 2007; Schjønning et al., 2008; Lozano et al., 2013; Lamandé and Schjønning, 2008; Keller, 2005; Trautner et al., 2003; Van den Akker, 2004) and the finite element model (Mohsenimanesh and Ward, 2010; González and et al., 2013; Berli and et al., 2004; Biris et al., 2009; Cui et al., 2007; Gysi, 2001; Mohsenimanesh et al., 2009; Poodt et al., 2003). The Finite Element Method (FEM) is actually the most advanced mathematical tool, which can be used to study tyre–soil interaction (Rashidi et al., 2005; Biris et al., 2009). Many of these models have the limitation that the tyre is not represented (Rashidi et al., 2005; Abu-Hamdeh, 2003; Berli and et al., 2004; Biris et al., 2009; Cui et al., 2007; Gysi, 2001; Poodt et al., 2003). Only the effect of a uniform stresses distribution is simulated on a soil area with a preset shape. It constitutes an oversimplification of the problem and it would yield erroneous contact conditions, because the tyre–soil stresses distribution is the result of simultaneous tyre and soil deformation (González et al., 2011). The first method has been used successfully, but it has the same limitation of presetting the shape and dimensions of contact area and the ground pressure in the tyre–soil interface (González and et al., 2013). Most models developed by this method are based on knowledge of tyre parameters and mechanical soil properties.

The stresses and their distribution in tyre–soil contact area are calculated from known equations. Based on analytical equations for stress propagation in soil the effect of tyre load over soil is calculated.

Cui et al. (2007) developed a model in finite element method obtaining the shape and magnitude of vertical stresses transmitted to soil for a stresses distribution caused by a beam with a contact area, flexural rigidity and an applied uniform vertical stress above it to describe the tyre–soil interface. Although this model solves the problem of the uniform pressure of stresses distribution, it has the disadvantage mentioned above.

Mohsenimanesh et al. (2009) developed a non-linear multi-laminated FE tractor tyre model, which considers the nearly incompressible property of the tread rubber block of the tyre on a multi-layered soft soil representing a significant step forward in the prediction of tyre–soil interface pressures. Although the soil response was simplified when an elastic linear model was used to represent the soil material properties.

Developing a FE model that includes the tyre model and its interaction with a model representing plastics properties of the soil will allow obtaining more precise predictions of the transmissions and pressures distribution caused in the soil by an agricultural tyre. From these elements, this research was carried out with the objective of obtaining

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