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A pressure measurement method based on profiling elastic press roller

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ABSTRACT

A novel method was introduced based on a type of profiling elastic press roller to solve the problem that soil compaction pressure is difficult to monitor in real time. The pressure real-time values were acquired through the measurement of the profiling elastic press roller's eccentricity. In order to evaluate the relationship between the profiling elastic press roller's eccentricity and the pressure, the study was conducted in an indoor soil bin, in July 2015. Three experimental treatments with soil volumetric moisture content 14.9%, 22.7% and 29.7%, were used in clay soils. The relationship between the profiling elastic press roller's eccentricity and soil cone index, and the relationship between the static pressure and soil cone index, were investigated. With the equivalent relationship of the cone index, the data was curve fitted and the model equation was established between eccentricity and pressure, in the topsoil layer in which the depth is 0–0.1 m. The correlation coefficient values (R^2) of the model equation all reached 0.99 at three experimental treatments, indicating the high degree of correlation. In order to evaluate the pressure measurement method, the validation experiments were conducted. The relationship was compared between the cone index predicted from the press roller measurements and the cone index measured from the manual measurements. The results showed that the dots of scatter diagram are all concentrated around the 1:1 ratio line, with high R^2 values, at three volumetric moisture contents. These experiments indicate that the predictions were very consistent with the manual measurements, indicating the pressure measurement method based on the profiling elastic press roller can be used into real-time pressure monitoring.

1. Introduction

Soil compaction is a key procedure in the operation flow of agricultural production. Through soil compaction, the soil clods are appropriately crushed to moderately compact (Lipiec and Hatano, 2003). Soil compaction can promote water storage and water retention and significantly improve the crop emergence rate (Metin et al., 2005; Sefa and Ahmet, 2011).

Soil compaction causes a rearrangement of soil particles which decreases pore spaces resulting in decrease of water permeability and water conductivity and air movement and change of soil thermal properties (Gemtos and Lellis, 1997; Murungu et al., 2003; Jia et al., 2016). Appropriate soil compaction helps to effectively increase seedbed temperature (high specific heat of water) and humidity, before winter, to improve seed emergence rate and seedling survival rate. As reported, soil compaction in winter wheat farmland improved the soil moisture contents before winter and at the starting stage as well as the night soil temperature before winter (Zhang et al., 2014). The compaction strength (or pre-compaction stress = stability threshold of the soil between the elastoplastic and the elastic zone) of 150–200 kPa in cotton and beet fields shortened the emergence time and improved the survival rate of seedlings (Gemtos and Lellis, 1997). The emergence rate of maize was increased under the compaction by a 700 N press roller (Tong et al., 2015). Under the reduced tillage system, the emergence rate of red lentils was improved by the pressure 90 kPa and by seedling compaction (Sefa and Ahmet, 2011). The compaction strengths effective on rice and maize are different (Iijima et al., 1991), indicating that crops require different soil compaction strengths under the same tillage conditions.

Moreover, too low or too high compaction strength may produce very different soil compaction effects (Dilraj and Sjoerd, 2006). After tillage sowing operations (subsoiling, rotary tillage, sowing), no compaction and too low compaction strength are both

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unfavorable for preservation of soil moisture and seedbed temperature (Sefa and Ahmet, 2011). Too high compaction strength makes soil very compacted, which is unfavorable for crop growth (Arvidsson et al., 2001; Ansorge and Godwin, 2008, 2007). As reported, too high compaction strength inhibited the growth of maize roots and thereby reduced maize yield (Tolon-Becerra et al., 2011). Jorajuria et al. (1997) observed a negative effect of compaction due to heavy tractors on the grassland productivity. Thus, keeping appropriate compaction strength, as one of important yield factor, is significant for improvement of sowing quality.

To guarantee the soils after tillage and sowing operations are kept at appropriate compaction strength, farmers usually adopt cone penetrometer to measure cone index. If the compaction strength does not meet the tillage requirement, it can be adjusted by changing the press devices. However, due to the complexity of field environment, the press devices is affected by surface topography and large cultivation unit lateral structure (Jia et al., 2007), which makes it hard to keep pressure stable. Thus, pressure monitoring is necessary and used as the basis to adjust the press machinery and guarantee stable pressure. However, the commonly-used press devices are usually cylindrical-shaped. The traditional pressure calculation methods, due to the uncertainty of affected areas, are unable to accurately calculate pressure or to monitor real-time pressure (Chinese Academy of Agricultural Mechanization Sciences, 2007).

Since soils are the operation target of press devices, analyzing the action mechanism of pressure on soils is very significant. The common way is to analyze the relationship between pressure and soil compaction (Håkansson and Lipiec, 2000). Larson et al. (1980) analyzed the relationship between pressure and soil bulk density and thereby proposed a soil compaction logarithm model (Larson et al., 1980). Based on the relationship between soil density and press stress, Bailey et al. (1986) built a three-parameter soil compaction model. Indoor and outdoor soil compaction tests on the relationship between soil density and vertical stress underlie the appropriate parameter design for press rollers (Zhang et al., 1995). Researchers proposed some mathematical relationship models from the perspectives of cone index, moisture content and bulk density, and described the rules among these three indices (Ayers and Perumpral, 1982; Upadhyaya et al., 1982; Busscher, 1990). Thus, based on the relationship between pressure and soil compaction, we aim to explore an effective method to monitor real-time pressure.

The paper introduced a novel method based on a type of profiling elastic press roller to monitor real-time pressure. This press roller undertakes the profiling function through the use of built-in double symmetry elastic spokes, and eccentricity of its central shaft matches with the pressure. Our hypothesis is that a model equation between the press roller's eccentricity and the pressure can be established for real-time pressure measurement, through investigating the relationship between the press roller's

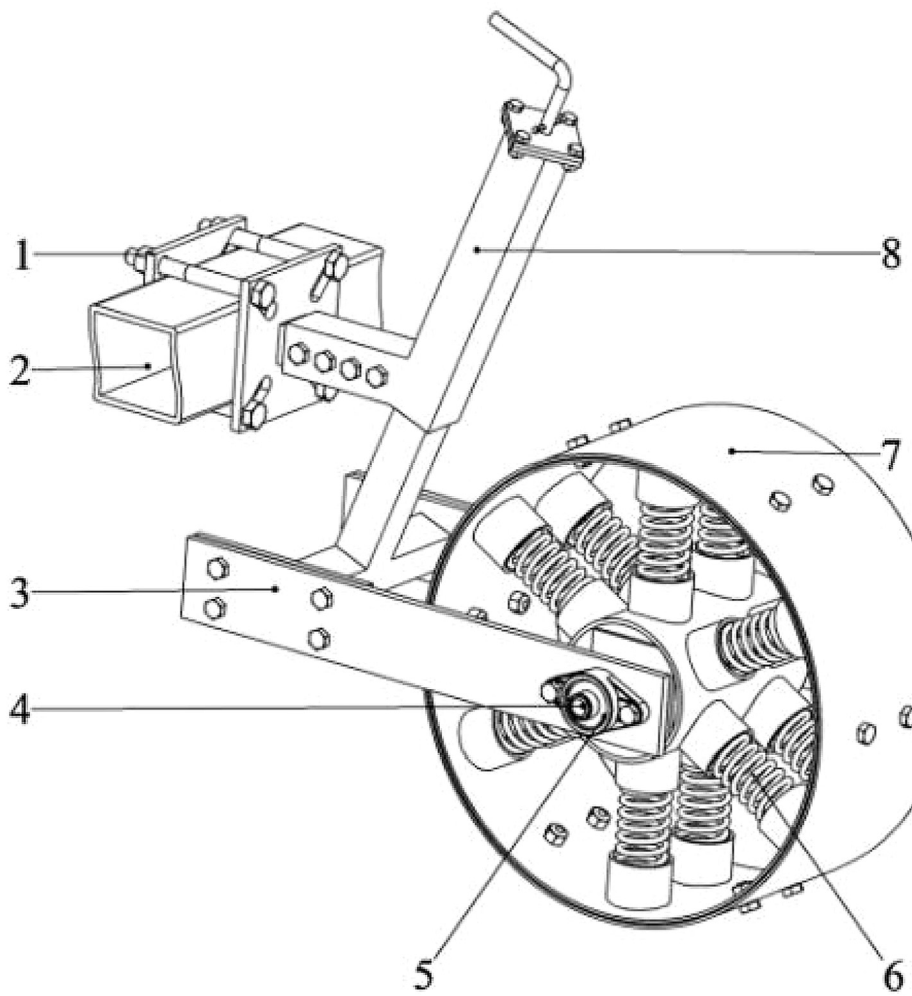

Fig. 1. Structural diagram of profiling elastic press roller. 1. Grip plate, 2. Frame, 3. Roller frame, 4. Cental shaft, 5. Spherical bearing, 6. Elastic spoke, 7. Roller cylinder, 8. Adjustable height device.