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Effects of profiling elastic press roller on seedbed properties and soybean emergence under double row ridge cultivation

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ABSTRACT

According to the characteristics of double row ridge cultivation technique, the profiling elastic press roller (PEPR) was designed. In order to further understand the performance of the PEPR, field experiments were conducted to investigate the effects of press roller types and forward velocity levels on seedbed properties and soybean emergence. The three kinds of press rollers were: conventional press roller (CPR), a 300-mm-diameter PEPR (PEPR1) and a 450-mm-diameter PEPR (PEPR2). The three forward velocity levels were: 2 km/h (V1), 4 km/h (V2) and 6 km/h (V3). We measured soil bulk density (SBD), soil moisture content (SMC), temperature, soil cone index (SCI), mean emergence time (MET), percentage of emergence (PE), and consistency of seedling height (CSH). Roller types but not forward velocity levels revealed significant effects on both seedbed properties and soybean emergence. The three press rollers all achieved proper soil bulk density for soybean seeds. Under the same experimental conditions, PEPR1 and PEPR2 helped to conserve more moisture compared with CPR. The soil cone index increased with the increasing soil depth and changed with the roller type as PEPR2 > PEPR1 > CPR. The mean emergence times in PEPR1 and PEPR2 treatments were 0.88 and 1.44 days shorter, respectively, compared with the CPR treatment. Roller types significantly affected percentage of emergence as follows: PEPR2 > PEPR1 > CPR. PEPR1 and PEPR2 outperformed CPR in terms of consistency of seedling height. In addition, the seedling height values in PEPR1 and PEPR2 treatments were 5.8% and 6.5% higher than CPR.

1. Introduction

More than 40% of total annual soybean output in China is provided by the spring soybean-sowing areas in Northeast China, which is the largest and most productive area of soybean cultivation (Xue, 2013). One way of planting soybean widely used in Northeast China is the double row ridge cultivation technique (Lin et al., 2009). This technique, where two rows are sowed in one 60–65 cm wide ridge, matches with advanced cultivation techniques. This technique can make soybean plants uniform on the ridge, ensure the balanced absorption of water and fertilizer, good air ventilation and high light transmission, and create a high-yield soybean population structure. Under the same conditions, this technique improves the soybean yield and fertilizer utilization rate by 15–20% and 10% compared with cultivation technique of single row ridge (Liu et al., 2010; Ma et al., 2007).

Soil compaction after sowing is the last procedure during seeding operation, and its main functions are moisture conservation and wind erosion prevention (Wilkes and Hobgood, 1969). Soil compaction has not yet received enough attention. Very few researches on the press roller are available world-wide (Wu and Feng, 2005). However, some reports relevant to cylindrical press roller, rubber press roller and V type press roller have been published recently, such as one kind of press roller with bionic ridges which could reduce soil adhesion and traction resistance (Tong et al., 2014, 2015). Another novel seeding strip press roller is used in a precision planter, whose unique character is to adjust pressure automatically by using a hydraulic system (Wang et al., 2009). Luo and Gao (2008) designed a combined press roller which

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has been used in no-tillage planters. This press roller can compact ridge edge and seeding strip at the same time (Luo and Gao, 2008). Although these press rollers mentioned above have their own advantages, uneven soil compaction will still occur when they work on a bumpy soil surface. Uneven soil compaction can cause uneven soil physical properties and thereby adversely affect crop emergence and yields (Sang, 1988).

The soil compaction after sowing has significant effects on soil physical properties (Altikat et al., 2006), such as soil bulk density (SBD), soil moisture content (SMC) and soil cone index (SCI) (Altikat and Celik, 2011). SBD is one major indicator of the compaction effect, and in cultivated soils, it generally ranges from 0.9 to 1.8 g cm^{-3} (Erbach, 1987). In many areas, SMC is the most restrictive factor on crop yields. Soil compaction can increase SMC (Berti et al., 2008). SCI comprehensively reflects the mechanical and soil physical properties and is widely used to evaluate the effects of agricultural implements on soil compaction and loosening (Tessier et al., 1997). SCI is also commonly used to assess the growth and the resistance to penetration of crop roots (Atwell, 1993). Pure live seed emergence, plant stand, and seed yields in packed soils are larger compared with non-packed soils for the surface seeded treatment (Berti et al., 2008).

Proper soil compaction is necessary to promote seed emergence and soil moisture content through capillary water supply. As reported, sugar beet is more sensitive to compaction than loosening, and emergence time is shortened significantly at moderate compaction and high initial soil water content (Gemtos and Lellis, 1997). Appropriate soil compaction can increase crop yields (Nasr and Selles, 1995), because it is conducive to complete seed-soil contact and soil moisture conservation, which create a beneficial environment for seed emergence (Wilkes and Hobgood, 1969; Gan et al., 1992). Moreover, corn yield is more responsive to variability in plant emergence than variability in plant spacing (Liu et al., 2004). Uneven seedling emergence almost always inhibits plant growth and reduces grain yield, as early-emerging plants are unable to compensate for the lower yield of late-emerging plants. In comparison, variation in within-row spacing does not affect yields, and interactions between the two factors are not significant (Liu et al., 2004).

To solve the problem of uneven compaction faced by the conventional press roller (CPR), we designed the profiling elastic press roller (PEPR) according to the characteristics of double row ridge cultivation technique (Jia et al., 2015a). The purpose of this study was to determine the effects of PEPR on seedbed properties and soybean emergence under double row ridge cultivation technique.

2. Materials and methods

2.1. Design of the PEPR

In the working process, the PEPR can achieve vertical and horizontal profiles through the stretching deformation of elastic spokes. Fig. 1 illustrates the structure of the PEPR. In the vertical profile, when the working PEPR encounters a bulge on the ground, the contact force between roller surface and ground will increase and the bottom elastic spokes will be compressed, which causes an upward move of the roller surface. When the roller encounters a pit on the ground, the contact force will decrease and the compressed elastic spokes will recover partially, which causes a downward move of the roller surface. In the horizontal profile, when the working roller passes the ridge with inclinable top surface, the elastic spokes at one side of the roller are compressed and the ones on the other side are stretched, which ensures a uniform pressure distribution (Jia et al., 2015a).

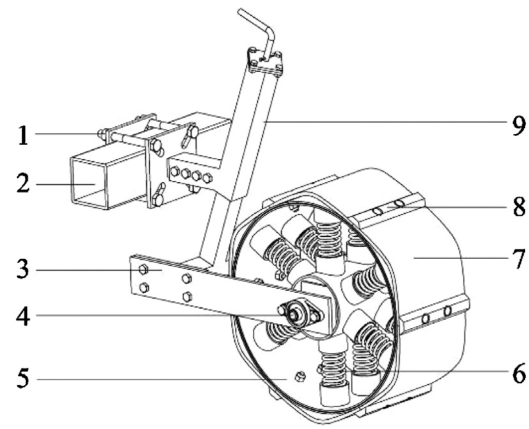

Fig. 1. Structural diagram of PEPR. (1) Grip plate, (2) rack, (3) roller frame, (4) centre axis, (5) cylinder shell, (6) elastic spoke, (7) rubber bulge, (8) rib, (9) adjustable height device.

The soil adhesion-reducing and anti-slip structure (rubber bulge + rib) was inspired by the movements of an earthworm body surface structure. The moving rubber bulges produce distortion, relative displacement and some vibrations. The distortion and relative displacement can produce a desorption force on the contact surface between soil and the roller, thereby reducing the soil adhesion on the roller surface. The vibrations can enhance the soil compaction. Meanwhile, the rib structure of the roller surface can press into the soil under the load action, reducing the slip ratio of the roller in the working process (Jia et al., 2015b).

One conventional press roller (CPR) with 300 mm diameter and 2.6 kg weight was used in this experiment. The CPR will generate pressure as soon as it is in contact with the soil surface and the pressure from CPR can achieve the purpose of soil compaction in the working process. In order to meet the agronomical requirement on pressure, initial pressure would be set by adjusting its height device.

To compare between CPR and PEPR, and between PEPR with different diameters, we designed two PEPRs with 300 mm diameter and 4.2 kg weight (PEPR1) and with 450 mm diameter and 5.1 kg weight (PEPR2). The PEPR1 was equipped with six spokes whose amplitude was 76 mm and the PEPR2 was equipped with nine spokes whose amplitude was 31 mm. The width of all press rollers mentioned above was 210 mm.

2.2. Study site

The experiments were conducted at Bonong Industrial Park (45.78°N; 130.59°E; elevation 197 m) in Qitaihe city, China. The site is located in the cool temperature zone and belongs to the continental monsoon climate of the north temperate zone with strong winds in the spring and autumn. Average annual rainfall is 450–550 mm, total sunshine time is 2350–2450 h, and active accumulated temperature is 2300–2700 °C in the duration when the daily average temperature is over 10 °C. The average temperature of June and August is 20.9–22.8 °C. The total precipitation from June to August ranges from 300 to 350 mm, accounting for over 60% of annual rainfall. The region is dry and cold in winter, and the average annual rainfall in winter is less than 30 mm, accounting for only 5% of annual rainfall. These climate data are summarized over the past 30 years. The field plot was largely flat with fertile soils, and the soil type is typical northeast black clay. The average daily temperature was 19.8–22.1 °C and there was almost no rain during