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Seed drill instrumentation for spatial coulter depth measurements

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ABSTRACT

An even and correct depth placement of seeds is crucial for uniform crop germination and for obtaining the desired agricultural yield. On state-of-the-art seed drills, the coulter down pressure is set manually by static springs or heavy weights, which entails that the coulter's seeding depth reacts to variations in soil resistance. The aim of the study was to develop and test an instrumentation concept installed on a low-cost, lightweight, three meter wide, single-disc seed drill, for on-the-go measurements of spatial depth distributions of individual coulters under real field conditions. A field experiment was carried out to measure individual coulter depths at three different operational speeds. The targeted seeding depth was −30 mm but shallower mean coulter depths were obtained and the depth decreased slightly – although not significantly – with increasing speed, i.e. to −22.1, −20.9 and −19.0 mm for 4, 8, and 12 km h^{-1}, respectively. The coulter depths ranged between −60 mm (below the surface) and even above surface at all speeds, but the variation tended to decrease with decreasing speed. However, soil resistance influenced coulter depth as indicated by a significant block effect. The mean coulter depth varied up to ±5 mm between the blocks. In addition, significant depth variations between the individual coulters were found. The mean depths varied between −14.2 and −25.9 mm for the eleven coulters. The mean shallowest coulter depth (−14.2 mm) was measured for the coulter running in the wheel track of the tractor. The power spectral densities (distribution) of the coulter depth oscillation frequencies showed that the majority of oscillations occurred below 0.5 Hz without any natural vibration frequency. The study concluded that the instrumentation concept was functional for on-the-go spatial coulter depth measurements.

1. Introduction

An even seed depth placement in the desired seedbed are crucial for the germination and even emergence of a crop (Henriksson, 1989; Håkansson et al., 2002). The desired depth of seeding is at the bottom of a shallow loose soil layer and above a more compacted tilled or no-tilled layer (Chang et al., 2004; Håkansson et al., 2002). When preparing seedbeds, the tillage operation is chosen relative to the soil condition. Seedbed structure should be homogeneous, supporting an adequate combination of moisture and heat for optimal seed germination and emergence (Håkansson et al., 2002). An optimal seedbed is also expected to minimise evaporation, erosion and reduce the risk of pesticide leaching (Petersen et al., 2016). However, it has been shown that the risk of poor emergence depends more on the seeding depth than on the aggregate size and distribution in the seedbed (Håkansson et al., 2002). The sensitivity to suboptimal seeding depth differs between crop species. Small seeds with low energy content germinate faster, but tend to be more sensitive to depth variations (Håkansson et al., 2011). For instance, yellow clover yielded 87% germination success at −20 mm seeding depth but only 4% germination at −80 mm seeding depth (Ghaderi-Far et al., 2010). Seeding depth has generally a significant impact on the germination rate and emergence delay (Baskin and Baskin, 1998; Håkansson et al., 2011). Håkansson et al. (2011) showed that the period of delay for 50% barley emergence increased almost linearly with increasing seeding depth, within the range of −10 to −90 mm seeding depth at 20 °C. The final emergence percentages were variable, at approximately 85, 100 and 95% for −10, −39 and −50 mm seeding depths, respectively. Another study showed

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that wheat emergence varied likewise as a parabola with the seeding depth, with an 80% emergence for −55 mm depth, decreasing to 70% when the depth was changed to −35 or −80 mm (Kinsner et al., 1993). Any delay or reduction in emergence can have considerable negative effects on competitiveness against weeds, on plant development and subsequently on the final crop yield. Therefore it is crucial to seed uniformly at the targeted depth (Boiffin et al., 1992; Depenthal, 2009; Håkansson et al., 2002; Kinsner et al., 1993).

Achieving an uniform seed placement at the desired depth can be a challenging task for seed drills, due to variations in soil resistance affecting the coulter depth, which potentially results in considerable seeding depth variations (Brennan and Leap, 2014; Garrido et al., 2011; Kinsner et al., 1993). The coulter down pressure is determined manually at the beginning of the operation by adjusting the coulters spring's tension. The spring adjustment is based on the operator experience (Kinsner et al., 1993) and the producer's recommendations, potentially evaluated according by carrying out random checks during initial test drives in the field. This means that the setting of the working depth depends primarily on the operator, which potentially causes errors. Furthermore, effects of spatial variations of soil resistance and operational speed on the coulters are not taken into account. Variations in soil penetration resistance depend on different factors such as texture, water content, bulk density (Dexter et al., 2007; Elaoud et al., 2014), but the soil resistance acting on the coulter is primary affected by the tillage intensity before seeding and the applied soil compaction from the tractor wheels. Soil-coulter interaction varies with soil resistance composition and the operational speed. Multiple mechanical coulter designs are available to comply with the coulter depth variations. Some of these seeding methods have been compared by Heege (1993) and all tend to vary with respect to depth uniformity. The most common low-cost seed drill constructions are glide shoes, single or double-disc coulters, without pressure wheels. To our knowledge, none of the available seed drills are able to measure individual coulter depths.

Few studies have been published on electronic seeding depth control for arable crops. Weatherly and Bowers (1997) developed a hydraulically actuated seeding depth control system that planted the seeds based on the measured soil moisture conditions. The seeding depth was dynamically controlled based on a soil drying front sensor combined with modelling, as moisture is considered significant for reliable germination. Conventional seedbeds are generated to a fixed depth, with the seed usually placed at the bottom of the seedbed (Håkansson et al., 2002). However, individual coulter depth measurements were not a part of the study. Recently, Suomi and Oksanen (2015) modified a seed drill for depth control. The seed drill was with single disc, where each coulter had a wedge roller attached on the side and a common roller (12 rubber wheels) for compacting and levelling the soil. The system used multiple sensors; the surface was measured with two ultrasonic sensors combined with angle measurements of two installed soil gauge wheels running on the surface. Rotary sensors were used to measure the angle of three coulters. The system was able to maintain the desired depth within a tolerance of ±10 mm at 10 km h^{-1}.

Nielsen et al. (2016) developed a novel coulter depth sensing and control system, which was tested for one coulter in a soil bin. The system measured the coulter position and controlled the coulter pressure with a hydraulic system. However, the sensing system needed additional development to be implemented on a full-scale seed drill operating in a real seedbed, where the seed drill lateral frame height can be unsteady and the entire machine operates dynamically.

The aim of the present study was to evaluate the performance of the novel coulter depth measurement system developed by Nielsen et al. (2016) after further development and implementation on a low-cost, lightweight, three meter, single-disc seed drill operating under real field conditions, determining coulter spatial depth distribution and the effect of operational speed. Our hypothesis was that coulter depths would depend on soil conditions, operational speed and the lateral positioning of the coulter on the seed drill.

2. Materials and methods

2.1. Instrumentation of the seed drill

The experimental setup consisted of a three meter Ecoline Kongskilde single disc seed drill (DK), modified with a sensing system to measure the individual coulter depths (Fig. 1).

For sensing the coulters' positions, linear position sensors were installed on every second coulter with 250 mm lateral distance of the three meter wide seed drill i.e. eleven in total. The essential instrumentation is shown in a computer-aided design (CAD) drawing in Fig. 2 and in a front view picture of the seed drill in Fig. 3. The linear position sensors ("TX2" from Novotechnik, U.S., IP67, resolution at 0.01 mm and linearity up to 0.05%) measured the coulters' positions in relation to the machine traverse frame (Figs. 2 and 3, ❶). Two ultrasonic distance sensors ("P43" from PIL Sensoren, IP65, DE, linearity error < 0.5%) were installed perpendicular to the traverse frame of the seed drill, in front of coulter 4 and 8, to measure the vertical frame height, relative to the soil surface (Figs. 2 and 3, ❷). From these height measurements, the soil surface was dynamically estimated using linear interpolation between the sensors. As the machine was 3 m wide, two ultrasonic sensors were considered sufficient for prediction of the soil surface; however, additional sensors will include additional micro topography. By dynamically combining this height with the coulter position measurements, the system was able to include frame height variations, caused by variation in the wheel penetration of the seed drill. This variation could be caused by a change in soil resistance or a change in machine weight (i.e. seed quantity in the seed drill varies across the field).

For data processing and data logging a "B&RX20" controller was used (B&R Industrial Automation, AT, 12 bit A/D converter) with a flash memory, installed in a control box (Fig. 3, ❸). The system was programmed to measure individually coulter depths and log the measurements with a frequency of 100 Hz. The controller was also connected to a GNSS unit ("BT-Q1000XT", Qstarz, TW) to record the global position and log it with the coulter depth measurements. To study the impact of the wheel tracks from the tractor

Fig. 1. Experimental seed drill from Kongskilde modified with the coulter depth measurement system.