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Real time laboratory and field monitoring of the effect of the operational parameters on seed falling speed and trajectory of pneumatic planter

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ABSTRACT

Laboratory tests are usually carried out with different technologies and under quite different conditions to field tests. In this study, a laboratory test was proposed to assess seed spacing uniformity which is applicable in a field situation. In this method, a high-speed camera system was used to detect seed falling trajectory, which is an effective factor on uniformity of seed spacing in both conditions of laboratory and field. Experiments were performed with four pressures (30, 40, 50 & 60 kPa) two forward speed ranges (3 to 4.5 km/h and 6 to 8.5 km/h) and two types of seed (maize and castor) under two conditions of laboratory and field. Results revealed that the highest value of quality of feed for the seed of castor with mean of 98.31% (at forward speed of 3.0 to 4.5 km/h and 4.0 kPa vacuum pressures), and for maize seed with mean of 80% (at 3.0–4.5 km/h and 4.0 kPa) were obtained under laboratory and field conditional, respectively. To determine the locations of seed in the different frames, equations of seed trajectories were first obtained for every treatment and then a general equation was extracted from the entire data set of treatments. This equation is: $y = 3.523e^{-0.077x}$ with value for coefficient of determination, $R^2 = 0.902$. The results show that under operating speed range of 3 to 4.5 km/h, seed spacing uniformity for different treatments of both seeds is statistically the same at 95% confidence level both in the laboratory and in the field. At a forward speed of 6 to 8.5 km/h and 4 levels of vacuum pressure, the difference among calculated mean and actual mean of speeds of fall is statistically significant at 5% probability level.

1. Introduction

When planting row crops it is most important to place the seeds at a specified spacing and depth within the seedbed. Pneumatic planters meter seed by using a vacuum to draw individual seeds into small holes drilled in a rotating plate. The plate rotates into an area without vacuum and the seed drops into and travels down the seeding tube for final placement in the soil. The seed metering mechanism in pneumatic planters obtains their propulsion from the ground wheel of the planter so that seed disk rotation speed increases with increasing groundspeed to maintain the same seed spacing. Advantages of this type of planter includes more precise control of seed spacing with lower rate of seed damage, and compatibility for a wide range of seeds with only slight changes in the seed metering mechanism (Shafii and Holmes, 1990; Guarella et al., 1996). Thus 'pneumatic' planters are more popular among farmers.

A number of factors affect spacing of seeds and these include vacuum pressure (which is related to the size and weight of the seeds), forward speed, seed quality, soil conditions and the skill of the operator Higher ground speeds, which are preferred by farmers to increase planting rate, necessitate an increase in the rate that seed is delivered into and seeding tube. This higher rate of seed delivery results in an inconsistent seeds spacing. Karayel and Ozmerzi (2001) stated that variability in the seed spacing by a precision vacuum seeder increased with increasing forward speed. They found that a forward speed of 1 m/s uniformly produced better seed pattern than 1.5 and 2 m/s for precision sowing of melon and cucumber seeds. The physical properties of the seeds are the most important factors in determining the optimum vacuum pressure of the precision vacuum seeder. Choosing vacuum pressures either higher or lower than optimum reduces seed spacing uniformity. Karayel et al. (2004) showed that, for various seeds, increasing vacuum pressure increases multiple seed drop and decreases miss index. Therefore, seed spacing uniformity is affected by the forward speed as well as the vacuum pressure.

The aim of this study was to understand possible reasons of non-uniformity in seed spacing under different vacuum pressures and

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forward speeds by investigating how seed falling trajectories are affected by the forward speeds and vacuum pressures from two different viewing angles under laboratory and field condition. The obtained results can be used for machine design, machine performance evaluation as well as optimization of vacuum pressures and forward speeds of pneumatic planter to get higher seed spacing uniformity.

2. Literature review

Because seed spacing uniformity is an important criterion in evaluating precision seeder performance, many studies have been conducted to evaluate this under both in the field and in the laboratory conditions. Seed spacing uniformity can be easily be monitored in laboratory tests by using the instrumentation and a grease belt. Field evaluations are carried out under real condition. Studies such as Kachman and Smith (1995), Panning (1997) and Smith et al. (1991) evaluated the distance between plants in the field, on a grease belt test stand, and in a furrow.

Kocher et al. (1998) and Lan et al. (1999) both developed an opto-electronic sensor for laboratory evaluation of seed spacing evaluation. In their methods, the time interval between seed drops and front to back location where each seed passed through the sensor was measured to determine seed spacing. In the opto-electronic sensor system developed by Kocher et al. (1998), seed size with a diameter less than about 3 mm did not consistently block enough of the light beam to reliably trigger the 5 mm diameter phototransistors. The LED and phototransistor size was a limiting factor and a light barrier with a light barrier with smaller diameter light-emitting diodes and phototransistors might work with smaller seeds. Another limitation of both systems developed by Kocher et al. (1998) and Lan et al. (1999) was that multiple seeds passing simultaneously at higher frequencies could not be detected which reduce overall measurement accuracy. Karayel et al. (2006) used a high-speed camera system and a sticky belt for laboratory evaluation of seed drill seed spacing uniformity and velocity of falling of seeds. They showed that seed spacing could be determined by a high speed camera system, and it did not miss any seed. Alchanatis et al. (2002) developed a high-resolution optical system to evaluate performance parameters of pneumatic planters in the laboratory. This system utilized a line scan camera connected to a computer-based frame grabber. The camera recorded any desired seed fall rate and displayed it on-line on a computer screen. Liao et al. (2009) used a camera system to define the optimum performance parameters of the pneumatic precision metering device for rapeseed. They stated that no seed damage was observed with the pneumatic seeder and the quality of seed spacing uniformity was substantially affected by rotational speed of the metering disk and air vacuum pressure. In a laboratory study, Yang et. al. (2010) investigated the precision metering performance of magnetic-type seeders based on machine vision using a high-speed camera system. The results showed high accuracy of seed spacing when used in real-time detection with the coefficient of variation and standard deviation both less than 5%. Navid et al. (2011) evaluated a seed metering device and found that image processing method from a digital camera (Nikon, D70) was well correlated with grease belt seed placement. Zhan et al. (2010) studied seed spacing uniformity of rapeseeds in a pneumatic planter. They used a high-speed camera system mounted on a laboratory seeder test-rig to record the motion of seeds. The horizontal displacement and the seed falling time were predicted by the numerical analysis and compared with the high-speed camera system measurements. The relative errors of horizontal displacement and falling time were less than 5.5% and 6.5%, respectively, indicating good agreement. Ding et al. (2013) assessed the effect of positive pressure of pneumatic precision metering device on initial velocity V_0 (V_{0x} and V_{0y}) and the angle α between the V_0 and V_{0x} for the seeding process of rapeseed using 152.4 m.s^{-1} high speed camera and image processing technology. Statistical analysis indicated that the angle between V_0 and V_{0x} decreases with increasing positive pressure which indicates the impact on V_{0x} is larger than that on V_{0y} as positive pressure increases.

3. Materials and methods

To optimize the most important operational parameters of planter (vacuum pressure and ground speed) the pneumatic planter was operated at a constant speed directly over the soil bin and in field condition. Therefore, experiments were conducted with: two ground speed range [(low speed) 3.0–4 km/h; and (high speed) 6.0–8.5 km/h]; and four levels of vacuum pressure [3.0, 4.0, 5.0, and 6.0 kPa] and two crop types (maize and castor). A three-factor factorial (2 speeds × 4 pressures × 2 crops) experiment was designed using randomized complete block with three replications for each treatment. Seed spacing was measured over a distance of 18 m. The pneumatic planter was adjusted to achieve a seed spacing of 200 (mm) for both maize and castor. The data were statistically analyzed to determine the effect of vacuum pressure and ground speed on four performance indices, namely, quality of seed index, multiple index, miss index and precision in spacing that define the pattern of seed distribution of a planter according to Kachman and smith (1995) (Refer to Appendix A).

In previous studies on seed spacing uniformity, a grease belt test stand in a laboratory condition was used to determine sowing uniformity of each seed at the different operational parameters. In the present study, tests were carried out in the laboratory as well as in the field conditions. In this research a metal bin was fabricated and placed over a concrete surface to work as a soil bin and to run the laboratory test A pneumatic planter (Unissem) was mounted on a tractor (MF399) and passed over the soil bin. Thus, the acquired data would be more reliable and practical. The tractor was instrumented to measure: forward speed, wheel sleep, drawbar pull, motor RPM, and fuel consumption. The wheel drive of the seed metering mechanism was equipped with Rotary Encoder (model S48-8-0360ZT (TK1)) to determine the seed disk rotation. Vacuum pressure was monitored using a 0 mbar to −1000 mbar pressure transmitter (BT 10-210). Seed falling trajectories was monitored using a CCD (charge-coupled device) camera (Fuji F660EXR) capable of capturing images with a sustained speed of 320 frames per second and a spatial resolution of 320 × 240 pixels. All data was transmitted to a data logger and displayed in real time on computer screen.

The seeder was a general-purpose seeder fabricated for row crops such as maize, castor and soya beans. The vacuum plate diameter was 230 mm and is mounted vertically. The holes of the vacuum plate were 50 mm in diameter for both maize and castor and these holes were equally drilled along a 200 mm diameter pitch circle. Because the planter had no seed tube so the height of the seeder was kept low in order to decrease the chance of non-uniform spacing that due to the seed bouncing if dropped from height. The same seeder was operated in the field as well as under laboratory conditions.

3.1. Computerized data acquisition system

A processing unit with a wide range of instructions for scanning and sampling signals, was used to scan and record the output signals from the sensors according to algorithm presented in Fig. 1. This unit consisted of: processing board, sensor boards, power board, data reception and software. The acquired data were processed by a special software written in C Sharp programing language. Processed data were transmitted wirelessly to the user.

An ARM family microcontroller was placed on the processing board for data processing. Generally technical specifications and capabilities of processing unit are: