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Corn seeding process fault cause analysis based on a theoretical and experimental approach

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ABSTRACT

Contemporary trends have set the need for high precision systems in agricultural operations, but it is the seeding technology in the first place that must satisfy the toughest demands to achieve the highest possible profit. The improvement of seeding precision is impossible without knowledge of the working principles of all parts of a singulation mechanism and all factors which influence the seeding errors. The evolution of a seeder depended crucially on the improvement of the testing methodology and techniques. This paper presents a photo-electronic device which monitors the seed flow at free fall after leaving the seeding mechanism. An air blowing seeding mechanism was used to simulate the seeding. Its performances were tested with seven varieties of corn seed, two seeding plates, two different air flow rates, and four different speeds of revolution of the seeding plate. A full factorial design was used to determine the significance of influence of four input factors and interactions of two of them. Data validation was done by comparing the values calculated according to visual analysis of high-speed camera recordings and photo-electronic system data where a strong relationship was achieved ($R^2 > 0.99$). It was determined that the speed of revolution of the seeding plate had the greatest influence on the varying distance between the consecutive seeds, while the seed variety exerted the least influence. The pressure of air flow and the variety of the seeds had the most significant influence on the variation of quality of feed index, although, the type and speed of revolution of the seeding plate were also statistically significant parameters. The occurrence of miss and multiple seed were caused by air flow pressure, variety of the seeds, type of the seeding plate, i.e., speed of revolution of the seeding plate. The applied optimization method can be a useful tool for finding the best possible combination of input parameters observed in the test in order to fulfill the criteria which vary depending on the user's needs.

1. Introduction

In modern crop farming production systems, soil treatment is changing in the direction of decreasing the intensity of soil tillage (Kostić et al., 2016, Biddoccu et al., 2016). Hence, field conditions have become more difficult (soil is less homogenous, more compacted with greater presence of plant residue), and high accuracy of seed dosage and field germination is far more complex to achieve (Farooq and Siddique, 2015; Kassam et al., 2014). A large number of agricultural experts agree that seeding quality plays an important role in field crop production (Cay et al., 2018; Karayel and Ozmerzi, 2002). If plants are given equal access to all field resources, favorable preconditions can be created to maximize the genetic potential of the variety-hybrid. Equal spatial distribution of plants provides optimal conditions for each plant, thus reducing the competition between them (Heege, 1993; Griepentrog, 1998; Karayel and Ozmerzi, 2002). The importance of plant arrangement in the field with respect to the quality and yield size depends on the plant species. In general, increased inter-row and inner-row seed distance implies greater importance of uniform distribution of plants, and vice versa. Jaggard (1990) emphasizes the importance of precision seeding in the production of sugar beet because uneven distance of the seeds affects the unequal growth and formation of the roots, thus reducing the effectiveness of a harvester. Seeding quality affects effectiveness of weed control during the vegetation period, as the possibility of weed spreading increases with more empty spaces which is the result of a seeding error. Lan et al. (1999) state that seeding affects directly the final yield and indirectly the financial effects of production. Mechanical herbicide-free control of sugar beet by

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longitudinal and lateral tractor drive requires the formation of a rectangular plant arrangement (Schölderle et al., 2008). Robinson et al. (1982) found that sunflower yield in Minnesota decreased up to 30% due to an uneven distribution of seeds.

Regarding the seed dosage process and all the relevant factors, Kostić et al. (2011) recognize “external” and “internal” factors which affect the quality of seeding. The external factors are variables that are not related to the design of the seeding mechanism but still influence the seeding errors. Those are the seeder ground speed, physical properties of the seed, soil roughness, terrain inclination, etc. Most of these variables are erratic and the degree of their influence is impossible to predict. Internal factors relate to technical characteristics of the seeding apparatus, such as kinematics of the seeding device, efficiency of seed ejector and excess seed remover, transmission drive system, the type of seed feeding device, the mode of transporting the seeds to the furrows, seeding mechanism clearance to the ground, etc. Fornstrom and Miller (1989) state that the operating speed and the way the seed is ejected to open furrows are essential elements of the precision seeding.

The quality of seeder operations is evaluated by standard statistical indicators that are calculated based on the data from which extreme values were excluded (less than 0.5 seed spacing and bigger than 1.5 seed spacing) in accordance with the general rules defined by the standard ISO 7256/1. The most widely used parameter is CV (*coefficient of variation*) as average relative deviation of the measured distance from the mean value. Kachman and Smith (1995) claim that precision seeding involves variability less than 30%, while Griepentrog (1998) and Celik et al. (2007) claim that this variability is below 20%. Irla and Heusser (1991) state that an acceptable quality of feed index (the percentage of spacings that are greater than half but not greater than 1.5 times than the set seeding distance in mm) for precision seeding should be over 90%. This phenomenon depends more on the average seed distance than on the absolute spacing error and could be inadequate for the estimation of seeding quality, which was also observed and explained in detail by Müller et al. (2006). Smith et al. (1991) and Kachman and Smith (1995) define a Coefficient of Precision-CP3 (percentage of the spacings that are within ± 15 mm of the set seeding distance) parameter to estimate the seeding quality. This parameter is combined with other statistical indicators (arithmetic mean and standard deviation).

The precision of seeders can be tested in real in-field conditions, where all objective factors are involved, or in controlled conditions in the laboratory, where seeding is simulated using the appropriate devices and omitting the “external” factors (McLean, 1974; Hollewell, 1982; Thomson, 1986; Brooks and Church, 1987; Hofman, 1988; Kachman and Smith, 1995; Bracy et al., 1998; Özmerzi and Karayel, 1999; Özmerzi et al., 2002). In-field quality control is a method typically used by agricultural practitioners but it has some disadvantages. Determination of the seeding quality in the field can be carried out after the plant seeding or germination. If it is carried out after the germination, then there is a probability of occurrence of certain measurement errors due to the factors which are not related to the seeder operation. These factors are germination and sprouting strength of the seed, as well as the inhomogeneity of moisture distribution in the zone of the seed layer, the influence of pests, quality of soil preparation, etc. If the measurement is performed immediately after the seeding, it is necessary to dig out a few seeds from particular field zones with a certain number of repetitions. The required number of examination sections depends on the number of row units of the seeder. This technique reduces the relevance of the measured data due to the disturbance of the actual seed position during digging. Additionally, it is impossible to obtain a sufficient amount of data since the technique is time consuming. Contrary to the in-field method, a laboratory technique is more often used in simulating the seeding conditions, since it allows a detailed analysis of the seeding mechanism efficiency irrespectively of the influence of other factors (rolling of the seed in a furrow, influence of the fall height, vibrations) which present real conditions. The relative movement of the seeder on the surface is simulated while the revolution of the seeding plate is controlled by electronic regulation of the drive motor as well as the power of the air flow. Simulation of seeding along the adhesive endless tape is the first laboratory technique characterized by a small number of valid samples in one measurement session and other defects that are explained in detail by Kocher et al. (1998). Laboratory evaluation of the seeding mechanism quality uses advanced systems such as optical sensors (Kocher et al., 1998; Lan et al., 1999). The system consists of a control unit connected to a PC and a software interface to read the records from a sensor that measures the pass time intervals of two consecutive seeds and the location of the seed passing through the sensor. Another innovative approach was presented by Karimi et al. (2009) which involves conversion of acoustic effects of seeds hitting the membrane into an electric signal with spectral characteristics. Post-processing analysis uses these characteristics to obtain the seeding distances from simulated seeding. Laboratory evaluation of the seeding mechanism was done by Navid et al. (2011) using the method of image processing from a camera. A comparative analysis of the measured distances with image processing techniques and adhesive tape measurement gave calibration characteristics that indicated high reliability of image processing. Authors point out that in relation to the optoelectronic system, image processing is more favorable because it is not sensitive to the size of the seed, or to the detection of multiple seeds. Karayel et al. (2006) applied high-speed image detection in laboratory measurements of seed spacing. The system was tested under conditions of high-frequency flow of small and large seeds in order to confirm the system's operation in the most complex circumstances. The recording was performed at 700 Hz sampling rates using video processing software. It was concluded that no seed was missed and that a high coefficient of data accuracy was established by comparing the data obtained by a standard measurement method with adhesive tape. A disadvantage of the method is a complicated procedure of extraction and processing images in the software.

The primary goal of this research is to validate the possibilities of photosensor evaluation method using data and image analysis in simulated conditions. Also we would like to reveal the strength of influence of observed variables on the seeding distribution accuracy.

2. Material and method

2.1. Theoretical analysis of real influences on the seed free fall trajectory

This analysis takes into account all variables that affect the motion of the seed immediately before and after leaving the seeding mechanism, except the influence of the air resistance and the aerodynamics of the seed during its fall. When leaving the seeding device, seed path is most often approximated by a projectile motion with a horizontal and vertical component of the velocity, which further defines the range of the starting point of ejection. Kocher et al. (1998) explained the irrelevance of determination of the seeded seeds distances based on the measured seed drop intervals only because of the variable path of the seed fall. Hypothetically, the falling time interval of two consecutive seeds can differ, although seed ejection time intervals are identical, which introduces an additional variable. In that sense, the resulting component of seed fall velocity had a dominant influence on the location of the seed drop. The analysis was carried out in order to define the components that influence seed kinematics.

Depending on the design of the seeding mechanism (diameter of seeding plate and number of holes) and the desired seeding rate, the ground speed of the seeder is usually different from the peripheral speed of the seeding plate, so the resulting horizontal component of the seed velocity most often has direction towards the movement of the seeder. The intensity of the seed rolling into the open furrow is proportional to the ratio between the horizontal component of seed velocity and ground velocity. A higher operating speed causes the speed difference between the ejected seed and seeder to increase as well. Thus

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