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DEVELOPMENT OF A SOYBEAN SOWING MODEL UNDER LABORATORY CONDITIONS

Jan Turan[1], Vladimir Višacki[1], Patrik Burg[2], Pavol Findura[3], Aleksandar Sedlar[1], Milos Rajkovic[4], Martin Zach[5]

[1]Faculty of Agriculture, University of Novi Sad, Trg D. Obradovića 8, 21000 Novi Sad, Serbia
[2]Faculty of Horticulture, Mendel University in Brno, Valtická 337, 691 44 Lednice, Czech Republic
[3]Slovak University of Agriculture in Nitra, Faculty of Engineering, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic
[4]Institute of Field and Vegetable Crops, Maksima Gorkog 8, 21000 Novi Sad, Serbia
[5]Expert Engineering Department, Institute of Lifelong Learning, Mendel University in Brno, Zemědělská 1/1665, 613 00 Brno, Czech Republic

Abstract

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Sowing is affected by numerous factors, and thus high-quality sowing is a very important task for agricultural engineers and managers of profitable agricultural production. The primary purpose of sowing is placing seeds at proper depths and in-row spacings in well-prepared soil. Plant population particularly gives prominence to sowing as it directly affects the uniformity of plant growth and development. Soybean planting is especially dependent on the quality of planting for yield formation due to the significant vicinity of seeds. Provided all external factors of high-quality sowing are met, i.e. sowing conditions, the quality of sowing depends upon the planting mechanism. The following features of the planting mechanism are the most important: RPM of the seed disc, the travel speed of a seeder, and the values of gauge and vacuum pressure. This paper presents the results of sowing three different fractions of soybean seeds under laboratory conditions. The quality measurement of sowing was performed at different values of vacuum pressure and RPM of the seed disc. On balance, an increase in vacuum pressure results in improved sowing quality due to a stronger adherence of seeds to the seed disc. Lower values of vacuum pressure do not exert significant effects on the quality of sowing, regardless of the seed fraction. However, higher RPM of the seed disc entail an increase in the coefficient of variation. On the basis of the results obtained, a mathematical model for predicting changes in the coefficient of variation of sowing quality was developed using different operating parameters.

Keywords: sowing, quality, coefficient of variation, vacuum pressure, seed disc, seeder, seed

INTRODUCTION

The management of quality sowing is an important task for agricultural experts and managers of profitable agricultural production. The primary purpose of sowing is placing seeds at proper depths and in-row spacings in well-prepared soil. Seeds ought to be planted in such a manner as to facilitate simultaneous germination and seedling emergence. To achieve a uniform plant growth and development, seeds have to be of high quality, free of genetic diseases and without mechanical damage. Moreover, the size of seeds affects not only the quality of sowing but also the potential for germination and seedling emergence. Seeds fairly uniform in size, with few very small or very large kernels, would reduce problems in precision planting. Owing to the seed size and physiology, soybean germination begins with the seed imbibing approximately 50% of its weight in water. The seed also requires to be planted at a depth ranging from 0.02 to 0.04 m. These factors emphasize the importance of planting uniformity to the optimum yield formation.

Sowing has never been a factor of paramount importance in crop production to date. Plant population particularly gives prominence to sowing as it directly affects the uniformity of plant growth and development. Sowing is affected by numerous factors such as the readiness of a plot for growing, micro- and macro-landscape, sowing depth, seedbed quality, seed size, travel speed of a seeder, RPM of the seed disc, values of gauge and vacuum pressure in pneumatic seeders, transmission ratio, planting mechanism, etc. Soybean planting is especially dependent on the quality of planting for yield formation because of the significant vicinity of seeds. Provided all external factors of high-quality sowing are met, i.e. sowing conditions, the quality of sowing depends upon the planting mechanism. The following features of the planting mechanism are the most important: the RPM of the seed disc, the travel speed of a seeder, and the values of gauge and vacuum pressure.

Bracy *et al.* (1998), examining the quality of planting, argue that the quality of planting decreases with an increase in in-row seed spacings. Parish and Bracy (1998) state that vacuum seeders are more efficient with a wide array of seeds. The planting uniformity is high at different parameters and seed sizes in contrast with mechanical seeders. The variability of in-row seed spacings increases with an increase in the sowing speed (Karayel and Ozmerzi, 2001). Karayel *et al.* (2004) display a mathematical model for calculating the vacuum pressure required for the high-quality planting of the 1,000 soybean kernel (1,000 K) weight. They consequently argue that a vacuum pressure of 30 kPa is necessary for the high-quality soybean planting. Singh *et al.* (2005) examined the effects of the seed disc speed, vacuum pressure and seed shape on the quality of planting. They determined the quality of planting according to the miss, multiple and feed indices. Similar findings were stated by Moody *et al.* (2003), accompanied by adequate sowing parameters for each variety regarding the RPM of the seed disc and the diameter of holes in the seed disc. Yazgi and Degirmencioglu (2007) described sowing by means of a CCD model within the RSM design. Zhan *et al.* (2010) conducted a study with the purpose of increasing the quality of planting by optimizing the operating parameters of a seeder with vacuum pressure. Using a high-speed camera, they concluded that an increase in the RPM of the seed disc caused a linear decrease in the quality of planting. Moreover, the quality of planting was directly proportional to plant population, which they consider a key factor of a successful planting as well as Rahman *et al.* (2003) and Singh *et al.* (2005). Meši *et al.* (2008) emphasise a greater dependence of mechanical precision seeders on the operating speed and the uniformity of seed shapes and sizes in comparison with pneumatic seeders. Meši (2000) determines the phenomenon of "the operating pace" as a particularly influential factor. The author defines the operating pace as a disharmonious operating mode of seeder transmission components due to manufacturing faults and various wear-and-tear impacts. Furthermore, he stresses the importance of tillage systems to the percentage of emerged seedlings (Meši *et al.*, 2010). The uniformity of in-row seed distribution is affected, in addition to the planting mechanism, by the sowing speed, adjustment and operability of a seeder, terrain, pre-sowing preparations, seed material shape and size, etc. (Findura *et al.* 2012; Turan, 2011).

Pang *et al.* (2000) defines a sharp distinction between the sowing under laboratory conditions and sowing in the open field. A considerable number of factors affect the sowing in the open field while a negligible number of factors have an impact on the sowing in the laboratory. Paning *et al.* (2000) make a clear distinction between sowing under laboratory conditions and in the open field. Sowing in the open is affected by numerous factors while their impact is minute under laboratory conditions. Kostić *et al.* (2011), while testing a prototype of an optoelectronic sowing monitor, concluded that the error in the system's operation was related to the type of seeds rather than the sowing speed, with an error range up to 4.5% in soybeans, 0.92% in maize and 1.88% in sunflowers.

Wilkins *et al.* (1991) introduced the spacing uniformity index as a sowing quality indicator. This index is a qualitative description of sowing quality according to the in-row seed spacing. It represents one of numerous expressions for the Coefficient of Precision (CP3), which is nowadays a generally accepted coefficient for describing the quality of sowing. The Coefficient of Precision is defined by ISO standards and comprises ISO Miss index and ISO Multiples index. Smith *et al.* (1991) and Searle (2006) define the Coefficient of Precision as the percent of actual seed spacings within ±1.5 cm of the theoretical spacing. ISO Miss index is defined as the absence of a seed where there should be a seed. For the ISO Miss index, the ISO Standard classifies all spaces larger than 1.5 times the theoretical spacing as a miss. A multiple is defined as the presence of two seeds where there should be one. For the ISO Multiples index, the ISO Standard classifies all spacings less than one-half times the theoretical seed spacing as multiples. It should be noted that better seed spacing uniformity is indicated by larger CP3 values and smaller values of both the ISO Miss index and ISO Multiples index. The ISO Miss and Multiples indices are both expressed as percentages of the deviation from the theoretical seed spacing.

The purpose of this paper is to examine the sowing of three different soybean seed fractions under laboratory conditions. The quality measurement of sowing was performed at different values of vacuum pressure and RPM of the seed disc. A seeding unit with vacuum pressure was utilized in the experiment. The aim of the paper is to determine the effect of the RPM of the seed disc and vacuum pressure on the quality of sowing. On the basis of the data obtained, the developed mathematical model can predict the quality of sowing using different sowing parameters.

MATERIALS AND METHODS

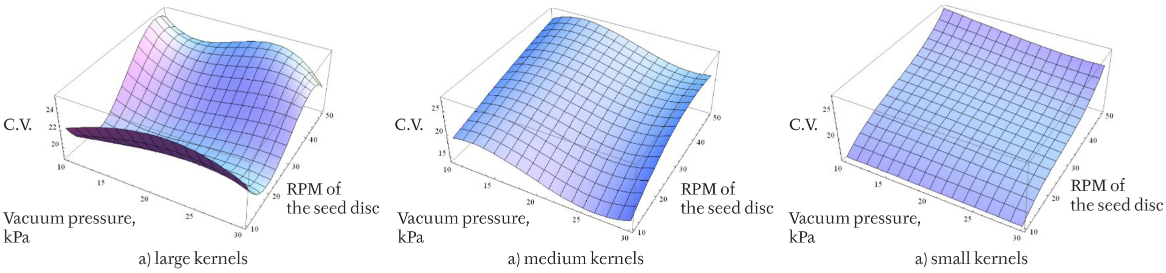
The testing of a seeding unit in operation was conducted in the Laboratory of Mechanisation in Crop Production, Department of Agricultural Engineering, Faculty of Agriculture, Novi Sad, Serbia. The seeding unit was adjusted for the operation in a laboratory by supplanting many original parts of the seeder by parts of similar features. Therefore, the seed disc was driven by an electric motor with the adjustable RPM. Vacuum pressure was generated by a centrifugal (radial) fan driven by an electric motor with the adjustable RPM. The seeding unit adjusted for the operation in a laboratory is shown in Fig. 1.

The displayed seeding unit was tested in operation at 10 different values of the seed disc RPM (11 min^{-1}RPM, 16 min^{-1}RPM, 20 min^{-1}RPM, 24 min^{-1}RPM, 26 min^{-1}RPM, 30 min^{-1}RPM, 34 min^{-1}RPM, 40 min^{-1}RPM, 44 min^{-1}RPM and 47 min^{-1}RPM) and 3 different values of vacuum pressure (10 kPa, 20 kPa and 30 kPa). Consequently, the value pairs were created in such a manner as to combine all the values of vacuum pressure with all the values of the seed disc RPM. Five replications of the measurement were conducted. A mounted sensor registered the flow of seeds exiting the seed disc. In all the tests, the seeding unit was set to plant seeds at an in-row spacing of 0.21 m. The travel speeds of the seeding unit entered in the program ranged from 4.32 $km.h^{-1}$ to 11.16 $km.h^{-1}$. The obtained values of in-row seed spacings were stored in a computer file and subsequently processed using both basic statistical operations and more advanced tests. The data were also recorded and processed using the Wolfram Mathematica 9 programme, by means of which the charts of changes in the coefficient of variation were made according to the changes in the RPM of the seed disc and the values of vacuum pressure. The seeding unit was set to plant in the open field according to the manufacturer's instruction manual. The soybean seeds used were favourable for sowing in the open and were not pretreated. As a result, the obtained mathematical models could calculate the coefficients of variation for different vacuum pressure values.

RESULTS AND DISCUSSION

Using virtual travel speeds of the seeding unit, the computer calculations of in-row seed spacings were done according to the data obtained from the sensor. All the data were statistically processed using the Statsoft STATISTICA 12 software and nested according to a hierarchical model of decision-making. The coefficient of variation was a dependent variable, whereas the value of vacuum pressure and the RPM of the seed disc were independent variables, i.e. factors. A statistically significant difference was recorded in the coefficients of variation calculated for each hierarchical model of the relationship between the vacuum pressure value and RPM of the seed disc. Using Duncan's multiple range test (with a significance threshold of 0.05), it was determined that the RPM of the seed disc affects the coefficient of variation (the quality of sowing) in a statistically significant manner. The quality of sowing (the coefficient of variation) is not affected by vacuum pressure provided its values are within

1: *The tested seeding unit: 1 - mounting frame; 2 - seed metering unit; 3 - vacuum hose; 4 - disc opener; 5 - closing wheel; 6 - press wheels*



2: *Changes in the coefficient of variation depending on the size of seeds*

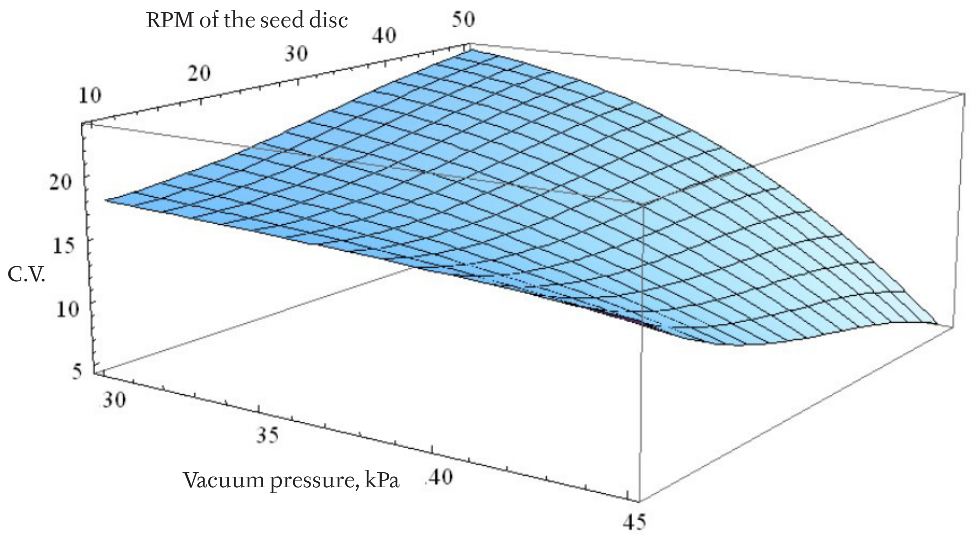
the prescribed limits. The following figure shows the coefficients of variation for a total of 10 tested RPM and 3 vacuum pressure values.

Fig. 2 shows that the coefficient of variation increases with an increase in vacuum pressure until 30 kPa. However, changes in the RPM of the seed disc proved to be the major reason for a deterioration in the quality of sowing. The coefficients of variation ranged from 21.54% at the lowest RPM of the seed disc to 26.16% at the maximum RPM of the seed disc. At the lowest pressure value of 10 kPa, the coefficients of variation were similar for all the tested seed sizes. However, the quality of sowing declined at the highest pressure values with an increase in the RPM of the seed disc as shown in Fig. 2c. The lowest coefficient of variation of 16.37% was recorded with the smallest kernels at a pressure value of 30 kPa and a RPM of the seed disc of 11 min^{-1}. The highest quality of sowing (a coefficient of variation of 15.58%) was achieved with medium kernels at the lowest RPM of the seed disc and a medium pressure of 20 kPa. When sowing small and medium-sized kernels, the quality decreases with an increase in the RPM of the seed disc. Regardless of the vacuum pressure values, the quality of sowing decreases with an increase in the RPM of the seed disc. The highest quality of sowing is achieved with small kernels at the highest vacuum pressure value. On average, the coefficient of variation was 19.48% at the highest pressure value. Consequently, an increase in vacuum pressure increases the quality of sowing. When sowing medium kernels, the average value of the coefficient of variation decreases from 22.56% at a vacuum pressure of 10 kPa to 21.22% at a pressure of 30 kPa. Interestingly, the quality of sowing large kernels was moderate. The coefficient of variation for large kernels at the lowest vacuum pressure was 21.97%, which is less than 1% higher than the coefficient of variation of 21.18% at the highest vacuum pressure. Fig. 2b shows that with an increase in vacuum pressure the coefficient of variation decreases under all test conditions.

The resulting surface can be defined by a function of output values of the coefficient of variation depending on the factor values. As the coefficient of variation is dependent on the RPM of the seed disc and vacuum pressure, all the input data were entered into a hierarchical model, using the Wolfram Mathematica 9 program, in order to obtain a tool for predicting changes in the coefficient of variation. The mathematical model of changes in the coefficient of variation in soybean sowing can be approximated by the following functions:

Large seeds: $29.57 + 73.47\,x - 518.65\,x^3 - 2.13\,y + 0.11\,y^2 - 0.44\,x\,y^2 + 1.07\,x^2\,y^2 - 0.03\,x^3\,y^3$

Medium seeds: $354.08\,x - 2259.68\,x^2 + 3943.5\,x^3 + 2.3\,x\,y - 0.09\,x^2\,y^2$



3: *A graphical representation of mathematical model*

Small seeds: $9.18 + 0.9\ y - 0.024\ y^2 - 0.05\ x^2\ y^2$

The values of x and y in the mathematical model are the values of vacuum pressure and the RPM of the seed disc, respectively. The displayed model will calculate the approximate value of the coefficient of variation for the entered values of x and y since the regression coefficient of the model is 0.95. Therefore, one can predict the quality of sowing for the factors contained in the mathematical model, i.e. the vacuum pressure and RPM of the seed disc. Provided the mean values of all seed fractions were taken into account (with regard to the RPM of the seed disc and vacuum pressure values), the following mathematical model is obtained:

$21 - 9.2\ x - 59.2\ x^2 + 216.3\ x^3 + 2.3\ x\ y + 3.9\ x^2\ y - $
$- 26.4\ x^3\ y + 0.03\ y^2 - 0.17\ x\ y^2 + 0.36\ x^2\ y^2$

Fig. 3 indubitably indicates that an increase in vacuum pressure increases the quality of sowing. Conversely, an increase in the RPM of the seed disc generally decreases the quality of sowing. This model encompassed all the tested seed fractions, which further enhanced its credibility. Admittedly, different condit

Karayel *et al.* (2006) and Yazgi *et al.* (2007) argue that mathematical models for describing the quality of sowing are of immense importance to further development of sowing. The justification of such statements is reflected in the utilization of computer-assisted automatic control for adjusting the RPM of the seed disc and the values of vacuum pressure to terrain conditions.

CONCLUSION

According to the laboratory testing of the seeding unit with vacuum pressure, at different values of vacuum pressure and RPM of the seed disc, the following conclusions can be drawn:

- vacuum pressure affects the quality of sowing especially in the instance of large soybean seeds; RPM of the seed disc is a direct factor of the quality of sowing;
- the coefficient of variation as the main indicator of the quality of sowing indicates higher quality at higher vacuum pressure values;
- an increase in RPM of the seed disc leads to an extremely poor quality of sowing in combination with low vacuum pressure;
- an increase in the RPM of the seed disc significantly impairs the quality of sowing with the coefficient of variation in excess of 25%;
- vacuum pressure values greatly affect the quality of sowing with regard to different seed fractions.

Overall, an increase in vacuum pressure values results in improved sowing quality due to a stronger adherence of seeds to the seed disc (in contrast with the increased RPM of the seed disc). Higher RPM of the seed disc entail an increase in the coefficient of variation. The developed mathematical models can be used for predicting the quality of sowing at different values of vacuum pressure and RPM of the seed disc.

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Contact information

Jan Turan: jturan@polj.uns.ac.rs
Vladimir Višacki: vladimir.visacki@polj.uns.ac.rs
Patrik Burg: patrik.burg@mendelu.cz
Pavol Findura: pavol.findura@uniag.sk
Aleksandar Sedlar: alek@polj.uns.ac.rs
Martin Zach: martin.zach@mendelu.cz