DETERMINATION OF SOWING PRECISION IN SIMULATED LABORATORY CONDITIONS
/
DETERMINAREA PRECIZIEI DE SEMĂNAT ÎN CONDIȚII SIMULATE ÎN LABORATOR

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ABSTRACT

In order to obtain a correct and always reproducible image of the performances achieved by a planter (or any agricultural machine), laboratory tests are required, under specified conditions, well controlled, to determine the precision of sowing outside the optimal agricultural periods. The paper presents a theoretical model for estimating sowing precision (feed quality index) as a polynomial function of the second degree, dependent on seed norm per hectare, working speed, depression value, mass of 1000 seeds, as well as combinations thereof.

REZUMAT

Pentru a obține o imagine corectă și oricând reproductibilă a performanțelor atinse de o semănătoare de precizie (sau orice mașină agricolă) se cer inițiate încercări de laborator, în condiții dinainte precizate, bine controlate, pentru determinarea preciziei de semănat în afara perioadelor optime agricole. Lucrarea prezintă un model teoretic pentru estimarea preciziei de semănat (indicele de calitate al alimentării) ca o funcție polinomială de gradul al doilea, dependentă de norma de seminte la hectar, viteza de lucru, valoarea depresiunii, masa a 1000 de seminţe, precum și de combinații ale acestora.

INTRODUCTION

Over time, sowing precision has become a major preoccupation the field of mechanical engineering, with role in optimizing soil processing works and sowing works. Unlike row sowers that conduct seeds distribution in continuous flow on equidistant rows, precision planters achieve the sowing of one or more weeding plant seeds in equally spaced nests on equidistant rows.

In precision agriculture, pneumatic seed meters have been extensively developed to achieve the sowing of different seeds (such as rapeseed, corn, soybean, sugar beet, cotton, etc.), being designed to achieve the introduction of a single seed into the soil at a distance required by agrotechnical norms for precision sowing.

The promotion of researches in the field of sowing precision aim at applying the optimal solutions in the conceptual design of precision planters (precision sowing machines) in order to optimize the qualitative working indices provided in the modern agro-technical norms (*Gângu et al., 2008; Kornienko et al., 2016; Mogilnay et al., 2018)*.

The improvement, modernization, simplification of construction and seed distribution adjustment operations are necessary as there are disturbing factors that can affect the precision of sowing due to seed quality: low volume, low weight, and irregular shapes (*Dobre*, *2010; Li et al., 2013; Yazgi et al., 2010*), as well as the condition of the sowing machine: clogged row unit, blocked seed meter, broken transmission chain, degraded seed scraper, insufficient pressurization, lack of seed in the hopper.

Karayel et al., (2004) proposes a mathematical model for determining the optimum depression of a precision planting using the physical properties of the weight of 1000 seeds, projection area, sphericity and seed density. All possible combinations of the different variables were tested and included in the mathematical regression analysis. The results have indicated that the developed model can be used to estimate the optimum vacuum pressure for a precision planter with an efficiency of 0.98.

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In order to optimize the functional parameters of a seed meter for cotton, *Singh et al., (2005)* analysed its performance through experimental research in the laboratory and in field conditions.
The influence of the disc's rotation speed, of depression and of the initial shape of the distribution disc orifice were determined by examining the sowing precision (precision in achieving seed spacing, the missing seeds index, and the doubles index).

The performances of the electromechanical drive system and the classic drive system were tested at three different operating speeds (5, 7.5, 10 km/h) and ten different seed spacing from 6 to 29.3 cm in the laboratory. Both systems were compared regarding to the seed spacing uniformity (*Cay et al.,2018)*.

To evaluate an acoustic system for online estimation of precision planting indices, a feeding platform was designed being able to apply different patterns of seed spacing with predefined precision planting indices (*Karimi et al., 2018).*

The effects of spatial separation between plants on yields of future crops were studied, the results of research being different, some of them revealing significant effects (*Fanigliulo and Pochi, 2011; Daynard and Muldoon, 1983; Lauer and Rankin, 2004*), while other researchers have achieved reductions in crop yield with increased variability of plant spacing. Even without a consensus, the parameters that influence the performance of precision sowing need to be further studied to guide design engineers' methods of improving future sowing machines (*Kocher et al., 2011; Marin et al., 2014; Miller et al., 2012*).

Glenn and Daynard, (1974), found that a plant spacing reduced by 4.5% resulted in a 5.5% increase in yield of harvested seed, a study conducted on two maize hybrids and two plant densities per hectare.

Nielsen, (2001), conducted researches on large and small parcels obtaining a loss of 62 kg/ha for each 1 cm increase of standard deviation of distances between seeds based on field studies.

Doerge et al. (2002) used spatial analysis to determine the influence of the spacing between maize plant rows on a Midwest farm on yields of future weeding plant crops, concluding that yield could increase by 84 kg/ha for each 1 cm decrease of the standard deviation of the distance between plants.

Liu et al., (2004), states that for each 1 cm increase of standard deviation of distance between plants on a row, the yield decreased by 35.9 kg/ha.

Nielsen, (2004), stated in a later study that the average loss of productivity was 42 kg/ha per cm of standard deviation of distances between seeds in a standard deviation range of 5 to 20 cm.

Fornstrom and Miller, (1989), conducted a study showing that the unevenness of distance between seeds is generally related to the manner in which the seed reaches the channel opened by the coulter and the working speed of the planter.

Liu et al., (2004), conducted a study correlating the degree of soil processing, the working speed of the planter and the type of seed meter. The sowing precision of planters equipped with seed meters with fingers was influenced by the degree of soil processing and the working speed of the planter, while the vacuum seed meters were mainly influenced by the working speed of the planter.

Şerbu, (1998), studied the phenomena governing the distribution process of a pneumatic seed meter by elaborating a mathematical model for determining the time of seed dropping after its detachment from the distribution disc orifice.

Afify, (2009), developed a mathematical model for estimating the optimum vacuum pressure of the seed meter of a precision planter using the properties of onion seeds, vacuum obtaining characteristics, as well as the geometry of the orifices situated on the seed distribution disc.

Xiaoyan, (2010), studied the process of aspirating rapeseed in the distribution disc orifice, aiming at optimizing the parameters that influence it. First, a mathematical model was obtained by minimizing the force of pressing the seed on the orifice, a force that occurs when the seed is aspirated into it. From this model was obtained a relation between the seed diameter, the angle of the orifice walls and the diameter of the orifice.

MATERIALS AND METHODS

In precision agriculture, the field of sowing is thoroughly studied by the realization of mathematical models that characterize the phenomena that govern the seed distribution process in order to achieve the sowing work in due time, to obtain plant densities N (pl/ha) provided by agro-technical norms and to maximize the yield of future crops.

In the analysis of the sowing process, improving the performance of seed meters is a constant concern for researchers in mechanical engineering and beyond. By uniformly spacing the sown seeds, the roots of future plants can reach uniform sizes that will fill the spaces on the sown rows without the risk of being pushed outside of the row of adjacent roots.

The experimental researches were conducted in order to determine the qualitative indices of seed meters (on a fully automated stand) based on the operation principle of the depression created by the exhauster in the seed feeding chamber, for three row units of precision planters, respectively:

- S1 – row unit with individual drive of the seed meter;

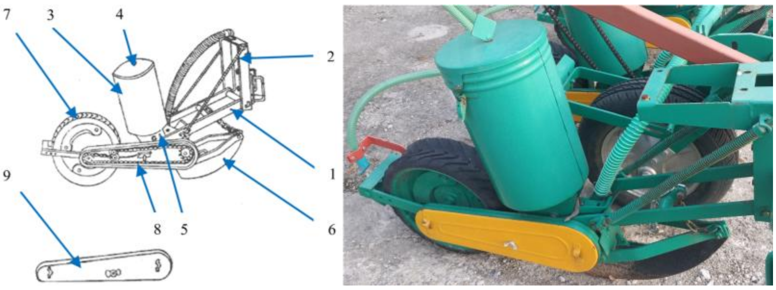

Fig. 1 - S1 row unit with individual driving of the seed meter (*Cujbescu, 2019*)

1-frame; 2-threaded rods; 3-seed supply box; 4-indicator of the level of seeds in the feed box; 5-seed meter with vertical distribution disc with orifices and scarper type - tipping with legs; 6-coulter; 7-drive wheel of the seed meter and soil compaction; 8-chain transmission for driving the seed meter from the compaction wheel; 9-mudguard

- S2 and S3 – row unit with centralized drive of the seed meters.

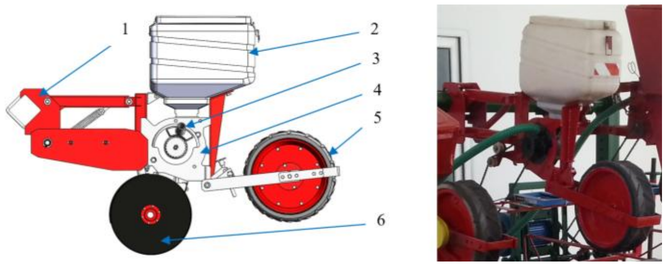

Fig. 2 - S2 row unit (*Cujbescu, 2019*)

1-support; 2-seed hopper; 3-vacuum socket; 4-seed meter with scraper type - fixed serrated; 5-compaction wheel; 6-double disc coulter

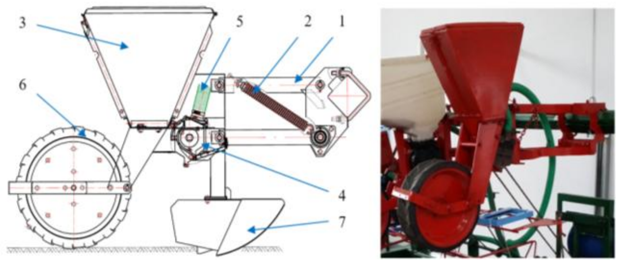

Fig. 3 - S3 row unit (*Cujbescu, 2019*)

1-frame; 2-springs; 3-seed feeding box; 4seed meter with scraper type - lamellar; 5-flexible tube of the vacuum channel; 6-soil compaction wheel; 7-coulter

The methodology for experimental research on the stand involves the following steps: the physical properties of seeds are determined; the physical hopper is fed; the entrance data are introduced (plant density per hectare, distance between rows, number of tested seeds, working speed, number of orifices on the distribution disc); the specialized software calculates (based on the entrance) the theoretical interval between seeds on the row; the motor driving the tested row unit is started; it is waited until the number of seeds tested passes through the transducers; the results are shown in graphic form.

For the experimental determination of the working process indices of pneumatic seed meters, according to ISO 7256/1-92, the theoretical (adjusted) interval between seeds is used as the reference element.

The specialized software for the processing of experimental data is based on a statistical processing system, the reference element being the theoretical (adjusted) interval between the seeds x_{ref} on the row, the real interval between two consecutive seeds x_j being determined on the stand using laser transducers (by transforming the fall time into space by multiplying the falling time with the working speed), considering:

- double (double sowing) - any real interval: $x_j \leq 0.5 \cdot x_{ref}$
- normal interval (correct sowing) - any real interval: $0.5 \cdot x_{ref} < x_j \leq 1.5 \cdot x_{ref}$
- misses (missing sowing) - any real interval: $x_j > 1.5 \cdot x_{ref}$

where: x_{ref} – theoretical interval between seeds, obtained by adjusting the planter, [cm];

x_j – real interval, measured under operating conditions on the stand, [cm].

The percentage frequency of measurements for each type of interval allows the definition of the quality indices that characterize the performance of the planter:

- A – feeding quality index (percentage of distances correctly sown), %;

$$A = \frac{n_1}{N'} \cdot 100 \quad \% \tag{1}$$

where:

n_1 – number of normally sown seeds;

N' – number of theoretical intervals.

- D – doubles index, %;

$$D = \frac{n_2}{N'} \cdot 100 \quad \% \tag{2}$$

where: n_2 – number of doubled nests.

- M – index of missing seeds, %;

$$M = \frac{n_0}{N'} \cdot 100 \quad \% \tag{3}$$

where: n_0 – number of missing nests.

- σ – theoretical deviation;

$$\sigma = \sqrt{\frac{\sum (n_i \cdot X_i^2)}{N_2} - X_{med}^2} \tag{4}$$

- CV – variation coefficient, %.

$$CV = \sigma \cdot 100 \quad \% \tag{5}$$

In order to obtain a correct and always reproducible image of the performances achieved by a precision planter (or any agricultural machine), laboratory tests are required, under specified conditions, well controlled, to determine the sowing precision outside the optimal agricultural periods.

Table 1 presents the functional parameters taken into account in determining the quality indices of the studied row units.

Table 1

Functional parameters for determining the qualitative indices of row studied

Crop	Corn		
Sowing norm N [pl/ha]	50000	65500	69500
Distance between rows [cm]	70		
Number of tested seeds	500		
Working speed v [m/s]	1.18; 1.77; 2.37; 2.96		
Number of orifices on the distribution disc	16		
x_{ref} [cm]	28.57	21.81	20.55

The experiments were carried out in 3 repetitions for each working speed, for each plant density (50000, 65500, 69500 pl/ha) and for 4 working speeds (1.18; 1.77; 2, 37; 2.96 m/s).

From the analysis of the experimental data in the table 2, it results that the sowing precision decreases with the increase of the working speed, which is observed for each of the seed meters investigated. The highest value of the feeding quality index of 97.533% was obtained by the seed meter of row unit S3 at a working speed of 1.18 m/s and a density of 50000 pl/ha.

Table 2

Averages of feeding quality indices of the seed meters studied, (*Cujbescu, 2019*)

		S1	**S2**	**S3**
Working speed [m/s]	**Sowing norm N [pl/ha]**	**A [%]**		
1.18	50000	*94.790*	*96.576*	***97.533***
1.77		*94.566*	*95.636*	*97.028*
2.37		*94.470*	*94.151*	*96.680*
2.96		*94.152*	*93.603*	*95.323*
1.18	65500	*95.155*	*95.951*	*97.309*
1.77		*94.940*	*95.423*	*96.805*
2.37		*94.209*	*95.017*	*96.186*
2.96		*94.163*	*94.652*	*95.860*
1.18	69500	*95.601*	*96.143*	*97.008*
1.77		*95.119*	*95.543*	*96.521*
2.37		*94.421*	*95.083*	*96.327*
2.96		*94.129*	*94.693*	*95.721*

Figure 4 shows the variation of the sowing precision according to the working speed, for section S3, observing the decrease of the sowing accuracy with the increase of the working speed.

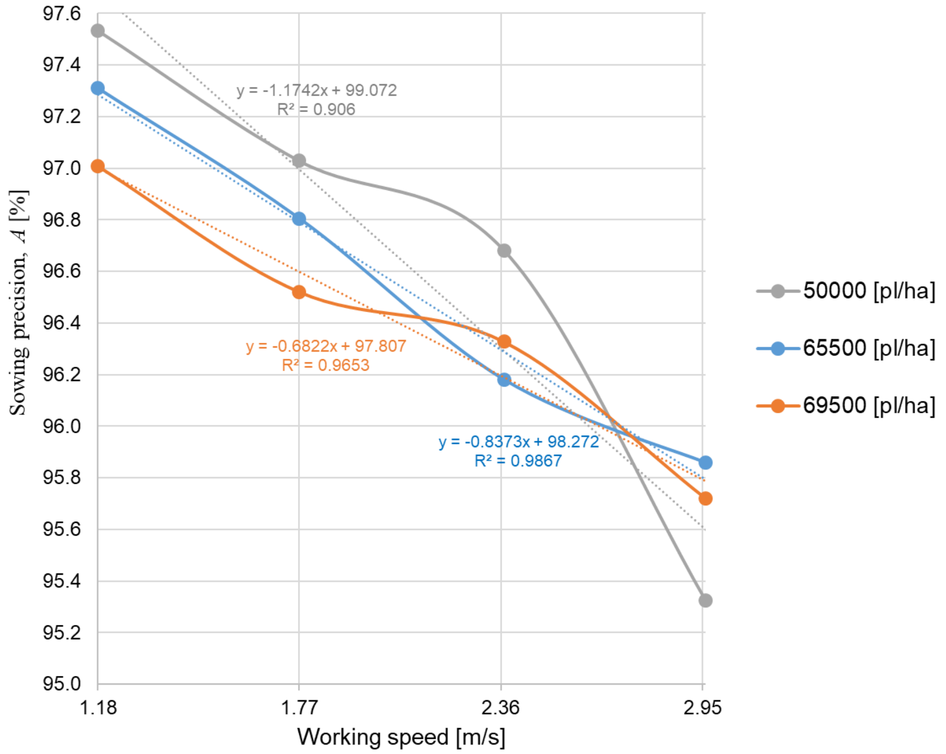

Fig. 4 - Variation of the sowing precision of the S3 row unit depending on the working speed
(*Cujbescu, 2019*)

RESULTS

The development of the mathematical model for the distribution process of the pneumatic seed meter has a key role for a deeper understanding of the phenomena at the basis of this process.

The agricultural technological processes have a special feature that distinguishes them fundamentally from the industrial ones themselves, namely that they are influenced by many disruptive factors, whose study requires complex analysis procedures and mechanisms.

The following equation presents the sowing precision (feeding quality index) as a second-degree polynomial function, dependent on the seed norm per hectare N, working speed v, value of depression Δp, mass of 1000 seeds MMS, as well as combinations between them.

$$A_c = c_0 + c_1 \cdot \Delta p + c_2 \cdot N + c_3 \cdot v + c_4 \cdot MMS + c_{12} \cdot \Delta p \cdot N + c_{13} \cdot \Delta p \cdot v + c_{14} \cdot \Delta p \cdot MMS + \\ + c_{23} \cdot N \cdot v + c_{24} \cdot N \cdot MMS + c_{34} \cdot v \cdot MMS + c_{11} \cdot \Delta p^2 + c_{22} \cdot N^2 + c_{33} \cdot v^2 + c_{44} \cdot MMS^2 \quad (6)$$

where: A_{Ci} represents calculated sowing precision and c_a, c_{ab} regression coefficients (m = 0..4), (n =1..4).

To determine the values of the unknown coefficients noted generically c_i by linear mathematical regression, the T-shaped functional was formed, as a sum of the squares of the differences between the values obtained by applying the polynomial equation and the actual values measured at the experiments noted generically z_i from table 3, where z_i can represent any size obtained during the measurements and by means of which the sowing precision A is expressed, $i=1 \div n$, (n represents the number of unknown coefficients and $j=1 \div m$, (m represents the number of measurements measured in table 3):

$$T = \sum_{i=1}^{n} \left[Ac_i(z_j) - A_i \right]^2 \quad (7)$$

where:

A_i – vector of sowing precision measured experimentally;

$Ac_i(z_j)$ – vector of sowing precision calculated using experimentally measured data.

For the determination of the coefficients but by mathematical regression, the method of the smallest squares was used, imposing the condition that the function T is minimal.

The minimum of the function T with respect to c_i is obtained by cancelling the partial derivatives of T with respect to the same coefficients:

$$\frac{\partial T}{\partial c_i} = 0 \tag{8}$$

The partial derivatives of the functional T were determined according to each of them and the unique system determined was created, from n equations with n unknowns (9):

$$\left\{\frac{\partial T}{\partial c_i} = 0, \ i = 1 \div n\right. \tag{9}$$

For its numerical solution the system equations were explained and the constants eliminated obtaining the equivalent form that can be written as a matrix product:

$$Z \cdot Y = X \tag{10}$$

where:

Z – the system matrix;

X – the matrix of free terms;

Y – the matrix formed by the unknown coefficients k_i, $Y = (k_i)$.

The determination of the vector Y formed by the unknown coefficients, was done by numerically solving by mathematical regression of the equation (11), obtained from the matrix equation (10) by the inverse matrix method, using the data rows obtained from the experiments and presented in the table:

$$Y = Z^{-1} \cdot X \tag{11}$$

The determination of the coefficients of equation (11) was performed using a matrix calculation program in Mathcad, further presenting the coefficients obtained and the numerical form of the polynomial equation:

$$\begin{aligned} A_c &= -1029,29 + 3,233 \cdot \Delta p + 0,005 \cdot N - 5,285 \cdot v + 0,701 \cdot MMS - 0,045 \cdot \Delta p \cdot v - \\ &-0,004 \cdot \Delta p \cdot MMS - 0,029 \cdot v \cdot MMS - 0,001 \cdot \Delta p^2 + 0,359 \cdot v^2 + 0,002 \cdot MMS^2 \end{aligned} \tag{12}$$

The error of the mathematical model was calculated as follows:

$$e = \frac{A_i - Ac_i}{A_i} \cdot 100 \tag{13}$$

where A_i is the vector of sowing precisions determined on the stand, and A_{Ci} is the vector of sowing precisions calculated on the experimentally measured data using relation (12).

Figure 5 shows the diagram representing the experimentally determined sowing precision compared to the calculated sowing precision, (*Cujbescu, 2019*).

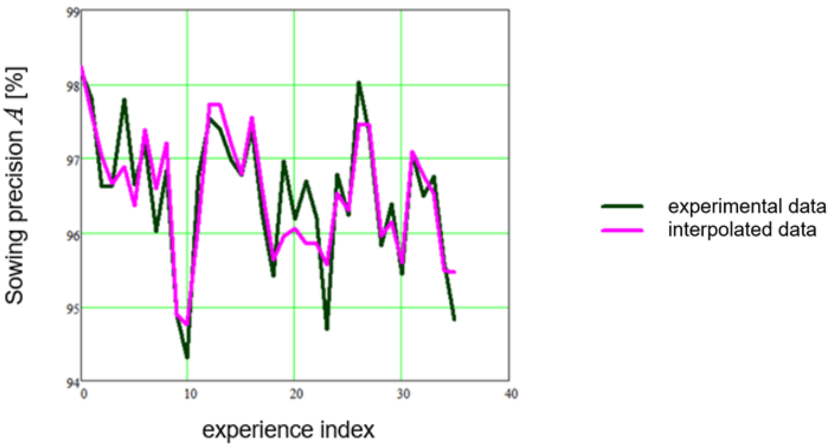

Fig. 5 - Diagram representing experimentally determined (black) and calculated sowing precision (purple)

Figure 6 shows the correlation between the data obtained experimentally and the data obtained by calculation, (*Cujbescu, 2019)*.

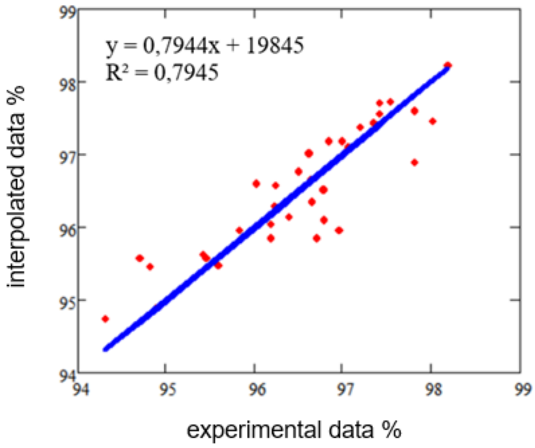

Fig. 6 - Diagram of the correlation of the data obtained experimentally and the data obtained by calculation

CONCLUSIONS

Quality indices are sources of information and criteria for assessing the behaviour of the type of row unit investigated, possibly decision criteria for improving the adopted constructive solutions.

On the basis of the values of the quality indices, conclusions can be drawn on the dominant trends in the operation of row units: a large difference between indices D and M leads to the conclusion of a pronounced tendency to missing seeds (if $M >> D$) or to doubles (overfeeding $D >> M$) , aspects that are inconvenient from the agro-technical point of view, especially since the high values of D and M indices also alter the quality of the feed, expressed by the index A.

From a mathematical point of view, certain constructive requirements must be met to obtain a calculated production on a given area of land, thus, there should be a certain distance between the row units of the planter and between the seeds sown on each row (rows of seeds) the distance should be constant to achieve the norms / densities specific to each crop. Taking into account these specifications, it can be concluded that:

- a method of studying the phenomena underlying the distribution process is the development of a mathematical model of distribution;
- the achieved mathematical model regards kinematically the seed distribution process, taking into consideration the kinematic factors that interfere in its disturbance;
- determining the precision of sowing under simulated conditions in the laboratory led to the elaboration of a mathematical model, the correlation coefficient of the experimental and calculated data being R = 0.891.

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