MATHEMATICAL MODEL FOR SOWING PRECISION ESTIMATION OF VACUUM SEED METERING DEVICE

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The paper presents a mathematical model for sowing precision estimation of weeding crop planters depending on the soil profile, experimentally validated. The study of phenomena at the basis of the process of seed distribution, on two parcels noted P1 and P2 was conducted for the vacuum distributor of the precision planter SEMO8, taking into consideration the degree of soil uniformity and the geometry of some constructive elements of the mechanical system used for conducting the sowing work. It was noticed that the horizontal movement of seeds is influenced by the soil profile, the sowing precision being better on the parcel with a higher degree of soil grinding. The optimal working regime for the studied row unit was obtained at speeds between 1.65 and 1.8 m/s (5.94 and 6.48 km/h) on parcel P1 and 1.7 and 2.1 m/s (6.12 and 7.56 km/h) on parcel P2.

Keywords: planter, uniformity, quality indices, seed spacing, accuracy, precision

1. Introduction

From the point of view of precision sowing technique and for complying to the agrotechnical norms, sown seeds should be placed at equal intervals between them, without causing doubles or misses during sowing [1].

Over time, it has been found in the agro-technical practices that among the quality indices expressing the sowing precision achieved by weeding crop planters determined in laboratory conditions and the ones determined in exploitation (field) conditions there are certain differences for the values obtained, sometimes quite significant [2].

The decrease in value of the quality indices are manifested by increasing the number of errors, either the number of double nests (with at least two seeds), either of the number of absent nests. Both cases are detrimental for the farmer, generating losses in production [3].

In order to determine the influence factors emerging in exploitation conditions and leading to a decrease in the sowing precision, it is necessary to know the variation spectrum of the stresses induced in the mechanical structures of the weeding crop planters at the contact with the soil during the movement on different working parcels with a different degree of seedbed preparation [4].

In the literature were studied the effects of the space between plants on the yield of future crops, the results of researches being different, some revealing

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significant effects, while other researchers obtained decreases in crop yield along with the increased variability of the distance between plants [5, 6, 7]. Even without a consensus, the parameters influencing the performances of precision planters should be deeply studied in order to guide the methods of design engineers for improving the future planters [8, 9, 10].

A study was conducted in paper [11] which correlated the degree of soil processing, the working speed of the planter and the type seed distribution apparatus. The sowing precision of planters fitted with finger distribution devices was influenced by the degree of soil processing and by the working speed of the planter, while vacuum distributors were mainly influenced only by the planter's working speed.

The paper presents a mathematical model of estimation, depending on the soil profile, of the sowing precision of weeding crop planters validated experimentally, taking into consideration the degree of soil leveling and the geometry of some constructive elements of the mechanical system used for conducting the sowing work.

2. Paper contents

In order to determine the influencing factors that appear in exploitation conditions in the mechanical structures of sowing machines at the contact with the soil during the sowing work, the following steps were taken:

- the theoretical interval between seeds was calculated for an imposed plant density, using the relation:

$$x_{ref} = \frac{10^4 \times n_{sc}}{N \times d_{rnd}} = \frac{10^4 \times 1}{50000 \times 0.7} = 0.2857 \quad \text{(m)} \qquad (1)$$

where:

x_{ref} is the distance between seeds on the row, [m];

n_{sc} number of seeds in one nest, [-];

N is the density (norm) of plants per hectare, [pl/ha];

d_{rnd} is the distance between rows, [m].

- two parcels with a different degree of seedbed processing were chosen;
- experimental researches were conducted for four working speeds (1.11; 1.67; 2.22; 2.78 m/s) on 40 m long fields;
- the sown seeds were uncovered and were positioned in space compared to a reference system chosen to be the beginning of the row;
- in the same time, on a SEMO8 planter row unit was fitted a movement transducer, measuring the vertical movement variations and implicitly the degree of soil leveling on the forwarding direction, thus characterizing the real profile of the soil in the form of a string of data *h*, which was subsequently correlated with the distance between the sown seeds;

- subsequently, the profile of the soil was used for estimating the rotation effect on the row unit and implicitly of the effect on the angle of seed detachment by including it in the mathematical model used for estimating the real interval between two consecutive seeds x_j after their detachment from the distributing disc [12].

Figure 1 presents the kinematic diagram of the distribution apparatus used during experiments.

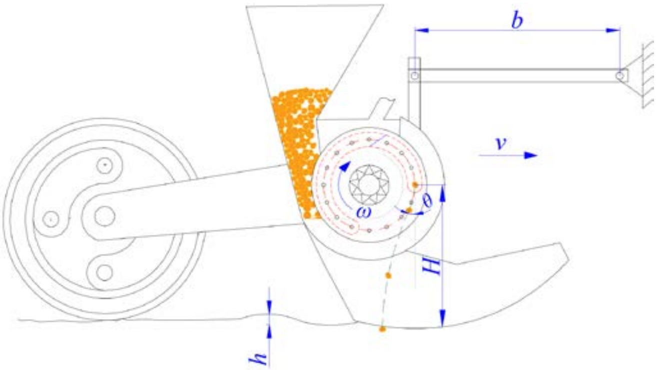


Fig. 1. Discretized diagram for the distribution kinematics

In equation (2) is estimated the distance between seeds depending on the parameters of the working process:

$$x_j = \frac{-\frac{1}{tg\theta} + \sqrt{\frac{1}{tg^2\theta} + \frac{2 \times g \times H}{v^2 \times \sin^2\theta}}}{\frac{g}{v^2 \times \sin^2\theta}} \tag{2}$$

where:

x_j is the real interval between two consecutive seeds, [m];
v is the working speed, [m/s];
H is the height from the ground at which the seed is detached, [m];
θ is the angle at which the seed detaches, [°];
g is the gravitational acceleration, [m/s^2].

From relation (2) it is noticed that:

$$x_j = f(\theta, v, H) \tag{3}$$

Taking into consideration the soil's profile and the geometry of the constructive elements from the mechanical system used to conduct the sowing work, presented in Figure 1, the new estimation model used was [12]:

$$x_j = \frac{-\frac{1}{tg(\theta + \arcsin(h/b))} + \sqrt{\frac{1}{tg^2(\theta + \arcsin(h/b))} + \frac{2 \cdot g \cdot H}{v^2 \cdot \sin^2(\theta + \arcsin(h/b))}}}{\frac{g}{v^2 \cdot \sin^2(\theta + \arcsin(h/b))}} \tag{4}$$

where:

h is the soil profile (measured depending on the theoretical interval between seeds on the row - x_{ref}, from 0.2857 m to 0.2857 m);

b is the length of the investigated row unit arm (0.35 m).

From relation (4) one can notice that:

$$x_j = f(\theta, v, H, h, b) \tag{5}$$

Table 1 presents the experimental conditions in the field.

Table 1

Experimental conditions in the field

No.	**Characteristics**	**Values/Observations**	
		P1	**P2**
1.	Parcel surface	2.14 ha	0.551 ha
2.	Soil type	forest reddish-brown	forest reddish-brown
3.	Previous work	plowed at 25-30 cm followed by harrowing	scarification
4.	Previous crop	corn	corn
5.	Field condition	flat and even	flat and even
6.	Field slope	0.7°	1.9°
7.	Plant residue mass	100-110 g/m^2	360-370 g/m^2
8.	The degree of soil grinding G_m [%] Soil fraction	Average	Average
	> 100 mm	4.63	2.30
	50 – 100 mm	14.00	4.93
	20 – 50 mm	19.93	14.17
	< 20 mm	61.43	78.60

From the field experiments conducted according to the methodology previously mentioned, for the 4 working speeds (1.11; 1.67; 2.22; 2.78 m/s), graphs were obtained showing the influence of the soil profile on the distance between the sown seeds on the two parcels.

Further, the strings of normed values (n) were defined, estimated through the own model (e), and of those actually measured in the field (m) for the measured distances between seeds, in each sample parcel and for each working speed.

Next, for each working parcel were calculated the strings of distances between seeds for the three situations (normed, estimated, measured), obtaining the following strings: Δn, Δe și Δm.

$$\Delta n = n_{i+1} - n_i \tag{6}$$

$$\Delta e = e_{i+1} - e_i \tag{7}$$

$$\Delta m = m_{i+1} - m_i \tag{8}$$

In standard ISO 7256/1-1984, the quality of the sowing work is evaluated based on the distance between consecutive seeds on a row, correlated with the theoretical distance indicated by the planter producer in its calibration diagrams [13].

Taking as reference the theoretical distance between seeds (x_{ref}), it was considered:

- double – any real interval: $x_j \leq 0.5 \cdot x_{ref}$;
- normally sown seed – any interval: $0.5 \cdot x_{ref} < x_j \leq 1.5 \cdot x_{ref}$;
- misses – any real interval: $x_j > 1.5 \cdot x_{ref}$.

The percentage frequency of the measurements appearing in each class allows to define multiple quality indices characterizing the performance of the planter, such as [14]:

- quality index of feeding *A* represents the percentage ratio between the number of seeds normally sown and the number of theoretical intervals,
- index of doubles *D*, represents the percentage ratio between the number of duplications and the number of theoretical intervals,
- index of gaps *M* represents the percentage ratio between the number of missing seeds and the number theoretical intervals,
- theoretical deviation (placement precision) *C*, represented by the ratio between the standard deviation of *A* and the theoretical distance.

Indices *A*, *D*, *M* and *C* represent the clearest comparison criteria for experimental researches conducted in different or similar working conditions on the row unit of weeding crop planters, low values for *D*, *M* and *C* and high values for *A* indicating the achievement of a quality sowing work [15, 16].

For the functional parameters regarding the determination of quality indices for the studied row unit (density 50000 pl/ha, distances between rows 0.7m), according to relation (1), the theoretical interval between seeds is: $x_{ref} = 0.2857$ m.

Next, the diagrams representing the distances between seeds in the three situations observed (theoretical, estimated depending the real soil profile and measured) were created for each working speed and was noticed that they fit in the accepted limits, thus quantifying the quality of the sowing work.

The following ordinary estimators (Table 2) were calculated in order to characterize the sowing process from a quantitative point of view.

Table 2

Theoretical estimators used to quantify the quality of the sowing work

Ordinary estimators, [m]	***n***	***e***	***m***
Average values x_{med}:	Mean (Δn)	Mean (Δe)	Mean (Δm)
Mean square deviations σ:	Stdev (Δn)	Stdev (Δe)	Stdev (Δm)
Percentage relative mean square deviations at the theoretical interval between the seeds σ_{rm}:	Stdev (Δn)·100/ x_{ref}	Stdev (Δe)·100/ x_{ref}	Stdev (Δm)·100/ x_{ref}

3. Results

Based on the experimental researches conducted on the two parcels P1 and P2 (previously mentioned) and on the processing of the experimental data were obtained the diagrams that show the comparation between the distance obtained through the model described by relation (1) and the real distances, measured in the field depending on the soil profile measured experimentally.

Thus, in Figures 2 and 3 are presented the results obtained in parcel P1 which shows a lower degree of soil grinding (a higher percentage of large clods and implicitly a more irregular soil profile), respectively for parcel P2, which shows a degree of soil grinding more uniform than parcel P1 (and implicitly a regular soil profile).

For the sowing speed of 1.11 m/s, it is possible to observe the level differences of up to 0.06 m on the length unit, negatively influencing the real sowing precision (parcel P1), respectively of up to 0.05 m on the length unit, a fact that positively influenced the sowing process (P2).

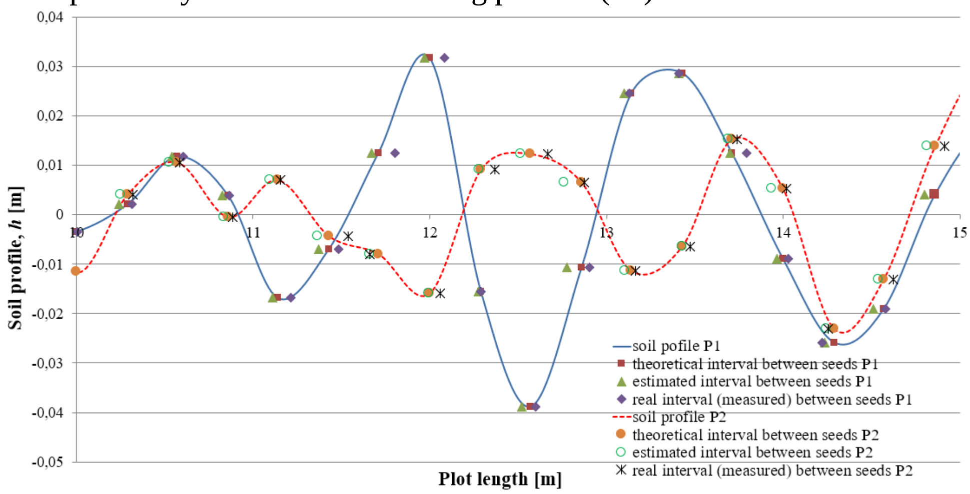


Fig. 2. Influence of the soil profile on the distance between the seeds sown at the working speed of 1.11 m/s, on parcel P1, respectively P2

The distances between seeds in the three studied situations (theoretical, estimated, measured) for each working speed were graphically represented, being noticeable that they fit in the limits accepted for the quality indices, thus quantifying the quality of the sowing work on parcels P1 and P2.

Fig. 3 shows the determination of quality indices for the SEMO8 row unit for a density of 50000 pl/ha and a working speed of 1.11 m/s, on the two parcels, highlighting the misses and doubles for the sown seeds as to achieve a qualitative quantification for the sowing work.

In the case of experiments conducted on parcel P1, there are 2 misses and 4 doubles or a number of 150 sown seeds a fact fitting into the limits of a qualitative sowing work.

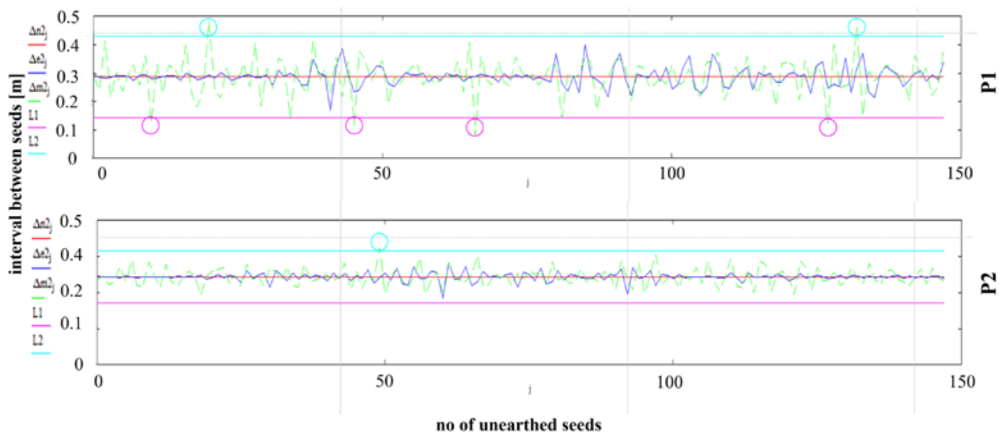


Fig. 3. Quality indices of SEMO8 station for a density of 50000 pl/ha and a working speed of 1.11 m/s, on parcel P1, respectively P2

Δ*n2* –string of normed distances between seeds; Δ*e2* –string of estimated distances between seeds; Δ*m2* –string of measured distances between seeds; L1 – limit between the number of doubles and the number of normally sown seeds; L2 – limit between the number of normally sown seeds and misses; blue circle – misses, magenta circle – double

In the case of parcel P2, there is one miss and no double/triple seeds for 150 sown seeds, highlighting the positive influence of the degree of soil grinding on the sowing precision.

Table 3 presents the calculated ordinary estimators used for quantifying the quality of the sowing work for a density of 50000 pl/ha on parcel P1 for all working speeds used during experiments. These estimators will be further used in the stage of establishing the optimum working regime for the sowing work.

Table 3

Ordinary estimators used to quantify the quality of sowing work for a density of 50000 pl/ha on parcel P1

Ordinary estimators, [m]	*n*	*e*	*m*
	Working speed v_1=1.11 m/s		
x_{med}	0.2857	0.286	0.286
σ	$1.784\cdot10^{-15}$	0.034	0.067
σ_{rm}	$6.245\cdot10^{-13}$	11.678	23.542
	Working speed v_2=1.67 m/s		
x_{med}	0.2857	0.285	0.286
σ	$1.784\cdot10^{-15}$	0.038	0.087
σ_{rm}	$6.245\cdot10^{-13}$	13.165	30.513
	Working speed v_3=2.22 m/s		
x_{med}	0.2857	0.286	0.285
σ	$1.784\cdot10^{-15}$	0.185	0.142
σ_{rm}	$6.245\cdot10^{-13}$	64.59	49.535
	Working speed v_4=2.78 m/s		
x_{med}	0.2857	0.286	0.284
σ	$1.784\cdot10^{-15}$	0.021	0.153
σ_{rm}	$6.245\cdot10^{-13}$	73.73	56.14

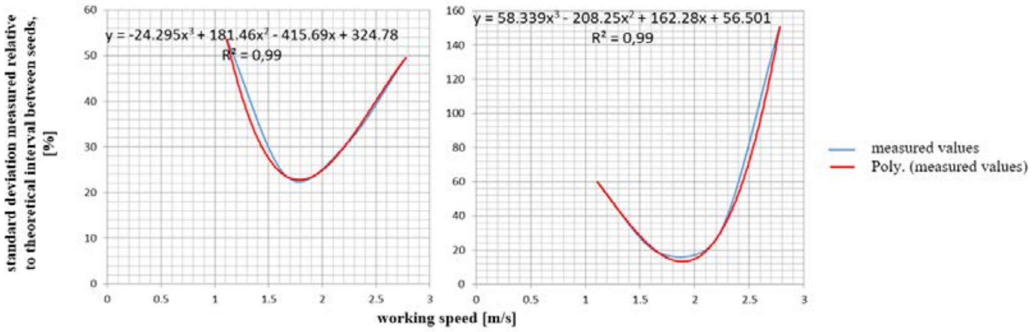
Table 4 shows the calculated ordinary estimators used for quantifying the quality of the sowing work for a density of 50000 pl/ha on parcel P2, for all for all used working speeds

Table 4

Ordinary estimators used to quantify the quality of sowing work for a density of 50000 pl/ha on parcel P2

Ordinary estimators, [m]	*n*	*e*	*m*
	Working speeds v_1=1.11 m/s		
x_{med}	0.2857	0.286	0.286
σ	$1.784 \cdot 10^{-15}$	0.025	0.053
σ_{rm}	$6.245 \cdot 10^{-13}$	8.584	18.575
	Working speeds v_2=1.67 m/s		
x_{med}	0.2857	0.286	0.286
σ	$1.784 \cdot 10^{-15}$	0.056	0.083
σ_{rm}	$6.245 \cdot 10^{-13}$	19.443	28.93
	Working speeds v_3=2.22 m/s		
x_{med}	0.2857	0.286	0.286
σ	$1.784 \cdot 10^{-15}$	0.117	0.145
σ_{rm}	$6.245 \cdot 10^{-13}$	149.243	150.926
	Working speeds v_4=2.78 m/s		
x_{med}	0.2857	0.286	0.286
σ	$1.784 \cdot 10^{-15}$	0.426	0.431
σ_{rm}	$6.245 \cdot 10^{-13}$	149.243	150.926

Using the data in Tables 3 and 4, were represented the diagrams showing the vector of the percentage mean square deviation *measured* relative to the theoretical interval between seeds, depending on the working speeds vector.



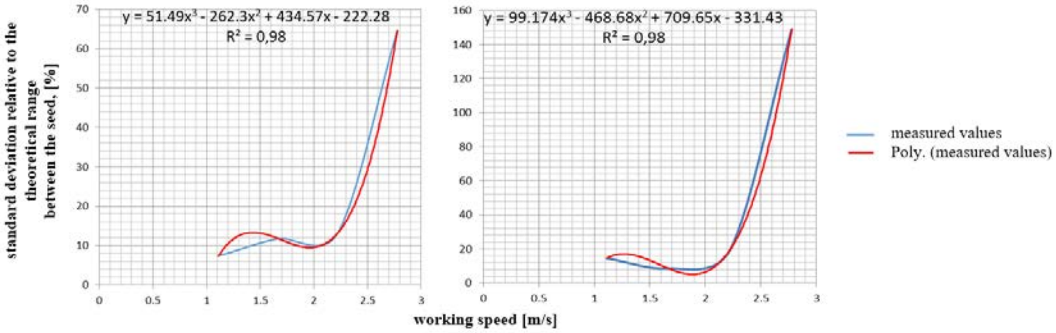
a) Parcel P1 b) Parcel P2

Fig. 4. Diagram representing the vector of the percentage average square deviation *measured* relative to the theoretical interval between the seeds, depending on the working speed vector for parcels P1 and P2

From the graphical representation, it can be observed that for parcel P1, with a coarser soil profile, the mean square deviation is minimum at working speeds between 1.65 and 1.8 m/s (5.94 and 6.48 km/h), and for parcel P2, with a superior soil profile, the mean square deviation in minimum at working speeds situated between

1.7 and 2.1 m/s (6.12 and 7.56 km/h), indicating an optimum working regime for the studied row unit. Therefore, a superior working speed is noticed in the case of the better processed soil, which is well correlated with the sowing precision.

Further, are graphically presented the diagrams representing the vector of the percentage mean square deviations *estimated* by applying the model proposed in relation (4) depending on the soil profile, relative to the theoretical interval between seeds, depending on the vector of working speeds.



a) Parcel P1 b) Parcel P2

Fig. 5. Diagram representing the vector of the percentage average square deviation *estimated* relative to the theoretical interval between seeds, depending on the vector of working speeds for parcels P1 and P2

From the graphical representation it results that the *estimated* mean square deviation is minimum for working speeds between 1.65 and 2.05 m/s (5.94 and 7.38 km/h) for parcel P1, and for parcel P2 for working speeds between 1.65 and 2.1 m/s (5.94 and 7.56 km/h), thus indicating an optimum regime for the studied row unit. In the case of the mathematical model proposed for estimating the sowing precision it is also possible to notice the influence of soil profile on the sowing precision.

4. Conclusions

The quality indices constitute sources of information and criteria for appreciating the behavior of the type of row unit researched, eventually decision criteria for improving the constructive solutions adopted. Thus, based on the results obtained from the experimental researches conducted in this paper, the following conclusions can be given:

1. The results of experimental researches on the row unit tested in the field show an obvious tendency of a decrease of the sowing precision when increasing the working speed, on both parcels where the experiments were conducted.
2. The horizontal movement of seeds is influenced by the soil profile, the sowing precision being better on parcel P2 which had a higher degree of soil grinding.
3. From the analysis of ordinary estimators used for quantifying the quality of the sowing work, is noticed that the optimum working regime for the studied

station is obtained for speeds between 1.65 and 1.8 m/s on parcel P1 and 1.7 and 2.1 m/s on parcel P2.

4. Analyzing the results obtained both experimentally as well as by applying the model proposed in relation (4) for estimating the sowing precision, depending on the soil profile, a very strong correlation is noticed for them, the estimated working regime fitting within the optimum working regime determined experimentally for the sowing speed.

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