NUMERICAL SIMULATION OF SEED DISTRIBUTION OF A PNEUMATIC SEED METER
/
SIMULAREA NUMERICĂ A PROCESULUI DE LUCRU AL UNUI DISTRIBUITOR PNEUMATIC

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ABSTRACT
Studies and research carried out on seed meters of precision planters whose operating principle is based on the depression / suction of the air created during the work by the exhauster (vacuum generator) in the vacuum chamber have the role of helping to improve their performance. With the advancement of sowing technology, the emphasis on the ability of seed meters to accurately and consistently distribute seeds in the soil increases. The singularization of the seeds by means of the seed meters and their distance along the channels opened by the coulter is essential to ensure the achievement of the maximum yield of the crop sown on a certain area of land. The paper presents the numerical simulation of the working process for a pneumatic seed meter by means of a mathematical model, analysing the movement of the seeds according to the angle of detachment, the height of detachment of the seed, as well as the speed of the seed in its trajectory towards the channel opened by the coulter.

REZUMAT
Studiile şi cercetările efectuate pe distribuitoarele semănătorilor de precizie al căror principiu de funcţionare are la bază depresiunea/aspiraţia aerului creată în timpul lucrului de către exhaustor în camera vacuumatică au rolul de a ajuta la îmbunătăţirea performanţelor acestora. Odată cu avansarea tehnologiei de semănat, accentul pus pe capacitatea aparatelor de distribuţie a semințelor de a distribui cu precizie și în mod consecvent semințele în sol, crește. Singularizarea semințelor prin intermediul aparatelor de distribuţie și distanțarea acestora de-a lungul şanţurilor deschise de brăzdare este esențială pentru a asigura obţinerea producției maxime a culturii semănate pe o anumită suprafață de teren. În lucrare este prezentată simularea numerică a procesului de lucru pentru un distribuitor pneumatic prin intermediul unui model matematic, analizându-se deplasarea seminţelor în funcţie de unghiul de desprindere, înălţimea de desprindere a seminţei, precum şi de viteza seminţei în traiectoria sa spre şanţul deschis de brăzdar.

INTRODUCTION

Precision sowing is a phenomenon in which two processes must be carried out, the objective being the precise placement of seeds in a row at the distance required by the agrotechnical norms. The first process consists in aspirating the seeds in the orifices of the distributor disc, without them doubling or missing from the orifices in the disc, the second process consisting in releasing the seeds from the orifices of the distribution disc and incorporating them into the soil (*Han et al., 2020; Staggenborg et al., 2004; Yazgi et al, 2010*).

Engineering calculation is the scientific tool used for the design, development and verification of technical systems. Mathematical modelling was developed through the means of experimental research performed on real models or laboratory models, the aim being to verify the analytical calculation, as well as to confirm the hypotheses and calculation models used (*Marin C., 2009*). The engineering language represented by mathematical modelling aims to describe the different aspects of the real world, their interaction and dynamics. It can be said, therefore, that mathematical modelling and scientific calculus are gradually and steadily expanding into various fields, becoming a unique tool for qualitative and quantitative analysis (*Biriș et al., 2018; Gupta et al., 2020*; *Quarteroni and Valli, 1999*).

In the analysis of the sowing process, improving the performance of seed meters is a constant concern for researchers in mechanical engineering and beyond. (*Kornienko et al., 2016, Zubrilina et al., 2019*). 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 (*Li et al., 2013*, *Marin et al., 2014*). Precision planters are designed to place the seeds evenly, on the row, if properly operated and adjusted. The quality of the sowing work conducted using precision equipment is constantly analysed during the operation, in order to be able to quickly remove any deficiencies, because after sowing it is no longer possible to intervene (*Miller et al., 2012*; *Soyoye, 2020*).

The lateral distribution of seeds is registered perpendicular to the working direction of the precision planter, this being influenced by the mass of the seeds reaching each coulter of the row unit. In contrast, the basis for the longitudinal distribution of seeds is constituted by the distances between seeds in a row. Therefore, it will be recorded in the working direction of the precision planter (*Heege, 1985*).

In general, the lateral distribution does not constitute a problem, its coefficient of variation being less than 4%. Exceptions may occur for planters with pneumatic seed meters, when sowing on a sloping ground, the sowing norm for row units at the bottom of the slope being higher than for those at the top of the slope. This effect depends not only on the slope, but also on the speed of the air, as well as the size of the seeds. The effect of the slope on sowing accuracy decreases when air speed increases and when the seeds are smaller (*Heege, 1975*).

Precision sowing seeds are generally dredged to facilitate handling, singularization, precise placement and incorporation of beneficial chemicals, being larger, more rounded, finer, heavier and more uniform than unedged ones (*Kaufman, 1991, Sauder and Schaefer, 2016*).

Usually, several sets of distribution discs are used in precision planters, each with orifices adapted to the size of the seed to be planted. There are several factors that contribute to maintaining the distance between seeds sown on a row. In the design process, it is assumed that the distance between the seeds will probably be uniform, but the uniformity may differ depending on the degree of tillage, the sowing characteristics, but the most important are the physical properties of the seeds (*Srivastava, 1993*).

The spacing of the seeds in the channel is controlled by varying the rotational speed of the distribution disc. Most often, the drive of the seed distribution discs is done by means of a common drive shaft. The drive shaft transmits the movement of each row unit of the planter, being driven by a single electric motor or a wheel in contact with the ground. In this configuration, the sowing norm can be adjusted for all rows of the row units by adjusting the rotational speed of the common drive shaft. In general, an optimal sowing rate for a certain area is selected before the sowing work is conducted and maintained at that rate, regardless of the soil conditions.

In the paper, a mathematical model was developed for the distribution process of a pneumatic seed meter for weeding plants, provided with a vertical distribution disc with orifices, and then the simulation of the distribution process was performed according to the detachment angle which was varied between 0-90°, taking into account three values of the seed height of detachment (0.10-0.20 m), and the speed of the seed in its trajectory towards the channel opened by the coulter had values between 0.5-4.44 m/s.

MATERIAL AND METHODS

The working process of the pneumatic seed meter is as follows: the vertical distribution disc (with orifices) is driven by means of a chain transmission from a drive wheel of the seed drill, the depression in the working chamber of the seed meter being achieved through the suction pipe (vacuum socket). The row unit is supported on the ground on the compaction wheel and on the coulter.

Each orifice on the distribution disc drives a seed, as a result of the depression that is created near the orifice. The evacuation of the seeds from the seed meter is done under the action of their own weight, when the orifices of the distribution disc (to which the seeds have adhered) are no longer in the area where the depression is created.

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

Considering a sequence of the seed distribution phenomenon (Fig. 1), the seed detached from the orifice of the distribution disc, after passing the depression chamber, in its trajectory towards the channel opened by the coulter, has a horizontal movement Δ_x relative to the point of detachment, analysis based on the xOy reference system.

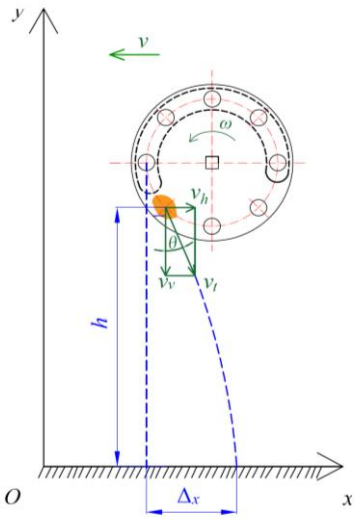

Fig. 1 - Schematic diagram of the distribution kinematics

v_h – the horizontal component of seed speed in its trajectory toward the open channel; v_v – *the vertical component of seed speed in its trajectory toward the open channel;* v_t – seed speed in its trajectory towards the open channel before colliding with the soil; θ – the angle of seed detachment relative to the vertical; ω – angular speed of the distribution disc

The components of the seed's speed in its trajectory towards the channel opened by the coulter will be:

$$v_h = v_t \cdot \sin\theta \tag{1}$$

$$v_v = v_t \cdot \cos\theta \tag{2}$$

$$v_t = v \cdot i_{tr} \cdot \frac{R_{dd}}{R_{rs}} \tag{3}$$

where:

i_{tr} – gear ratio, [-];
R_{dd} – distribution disc pinion radius, [mm];
R_{rs} – the radius of the pinion of the seed drill support wheel, [mm].

The equations of movement of the seed having the speed v_t will be:

$$\Delta_x = v_t \cdot t_i \cdot \sin\theta \tag{4}$$

$$h = v_t \cdot t_i \cdot \cos\theta + g \cdot \frac{t_i^2}{2} \tag{5}$$

where:

t_i – time for the seed to fall into the channel opened by the coulter, [s];
g - gravitational acceleration, [m/s²].

From formula (4) results:

$$t_i = \frac{\Delta_x}{v_t \cdot \sin\theta} \tag{6}$$

From formulae (4) and (5) results:

$$h = \frac{\Delta_x}{tg\theta} + g \cdot \frac{\Delta_x^2}{2 \cdot v_t^2 \sin^2\theta} \tag{7}$$

Formula (7) becomes:

$$\frac{g}{2 \cdot v_t^2 \sin^2\theta} \cdot \Delta_x^2 + \frac{1}{tg\theta} \cdot \Delta_x - h = 0 \tag{8}$$

Solving formula (8) we obtain:

$$\Delta_{x_{1,2}} = \frac{-\frac{1}{tg\theta} \pm \sqrt{\frac{1}{tg^2\theta} + \frac{2 \cdot g \cdot h}{v_t^2 \cdot \sin^2\theta}}}{\frac{g}{v_t^2 \cdot \sin^2\theta}} \tag{9}$$

The negative solution is adopted so that the horizontal movement of the seed is in the opposite direction to the movement of the tractor-seed drill aggregate, so that the relative speed of the horizontal component of the seed relative to the ground tends towards zero.

Therefore:

$$\Delta_x = \frac{-\dfrac{1}{tg\theta} - \sqrt{\dfrac{1}{tg^2\theta} + \dfrac{2 \cdot g \cdot h}{v_t^2 \cdot \sin^2\theta}}}{\dfrac{g}{v_t^2 \cdot \sin^2\theta}} \tag{10}$$

It is observed that Δ_x is a function dependent on the angle of detachment, the seed detachment height, as well as the seed speed in its trajectory towards the channel opened by the coulter.

RESULTS

The solving of the mathematical model is done by giving successive values to the influencing factors responsible for its operation.

The mathematical model presented in relation (10) in the form of a computer processable program was used for the analysis of multiple versions of entry data sets.

The numerical simulation for the evolution of the value of movement depending on the influence factors θ, v_t and h is achieved using Excel program.

Table 1 presents the evolution of seed movement depending on the angle of detachment, replacing in equation (10) the height of seed detachment h=0.1 m and the speed of the seed in its trajectory towards the channel opened by the coulter v_t=0.55 – 4.44 m/s.

Table 1

Seed movement Δ_x depending on the angle of detachment θ for h=0.1 m and v_t =0.55 – 4.44 m/s

			Movement Δ_x [m]							
Angle θ [º]	Angle θ [rad]	h [m]	v_t=0.55 [m/s]	v_t =1.11 [m/s]	v_t=1.66 [m/s]	v_t=2.22 [m/s]	v_t=2.77 [m/s]	v_t=3.33 [m/s]	v_t=3.88 [m/s]	v_t=4.44 [m/s]
0	0	0.1	0	0	0	0	0	0	0	0
10	0.174		0.009	0.013	0.015	0.016	0.016	0.016	0.017	0.017
20	0.349		0.018	0.027	0.031	0.033	0.034	0.034	0.035	0.035
30	0.523		0.028	0.041	0.048	0.051	0.053	0.054	0.055	0.055
40	0.698		0.037	0.057	0.067	0.073	0.076	0.078	0.079	0.080
50	0.872		0.047	0.074	0.090	0.099	0.104	0.108	0.111	0.112
60	1.047		0.056	0.093	0.117	0.132	0.143	0.150	0.155	0.158
70	1.221		0.065	0.114	0.150	0.177	0.197	0.212	0.224	0.232
80	1.396		0.072	0.136	0.190	0.238	0.278	0.313	0.343	0.369
90	1.570		0.079	0.158	0.238	0.317	0.396	0.476	0.555	0.634

Figure 2 shows the dependency of seed movement on the horizontal depending on the angle of detachment and the seed's speed in its trajectory towards the channel opened by the coulter for h=0.1 m.

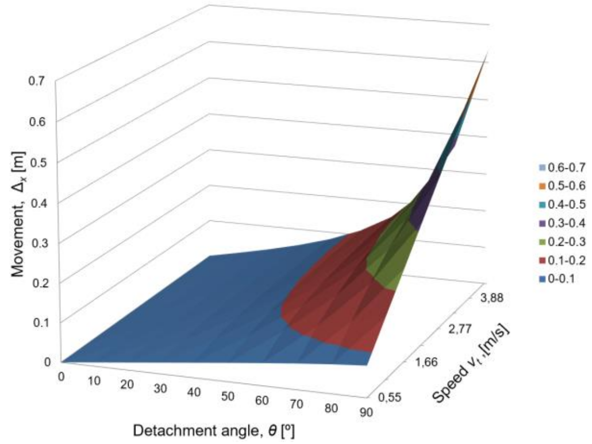

Fig. 2 - Dependence of the horizontal movement of the seed depending on the angle of detachment and on the speed of the seed in its trajectory towards the open channel for h=0.1 m

Table 2 presents the evolution of seed movement depending on the angle of detachment for the height of seed detachment h=0.15 m and the speed of the seed in its trajectory towards the channel opened by the coulter v_t=0.55 – 4.44 m/s.

Table 2

Seed movement Δ_x depending on the angle of detachment θ for h=0.15 m and v_t=0.55 – 4.44 m/s

Angle θ [º]	Angle θ [rad]	h [m]	Movement Δ_x [m]							
			v_t=0.55 [m/s]	v_t =1.11 [m/s]	v_t=1.66 [m/s]	v_t=2.22 [m/s]	v_t=2.77 [m/s]	v_t=3.33 [m/s]	v_t=3.88 [m/s]	v_t=4.44 [m/s]
0	0	0.15	0	0	0	0	0	0	0	0
10	0.174		0.012	0.018	0.021	0.023	0.024	0.024	0.025	0.026
20	0.349		0.024	0.037	0.043	0.047	0.049	0.051	0.051	0.052
30	0.523		0.036	0.056	0.067	0.074	0.077	0.080	0.081	0.082
40	0.698		0.048	0.077	0.094	0.104	0.110	0.114	0.116	0.118
50	0.872		0.060	0.099	0.123	0.139	0.149	0.156	0.161	0.165
60	1.047		0.071	0.122	0.158	0.183	0.200	0.213	0.222	0.229
70	1.221		0.081	0.146	0.197	0.237	0.269	0.293	0.313	0.328
80	1.396		0.090	0.171	0.242	0.306	0.362	0.412	0.456	0.495
90	1.570		0.097	0.194	0.291	0.388	0.486	0.583	0.680	0.777

Figure 3 shows the dependency of seed movement on the horizontal depending on the angle of detachment and the seed's speed in its trajectory towards the channel opened by the coulter for h=0.15 m.

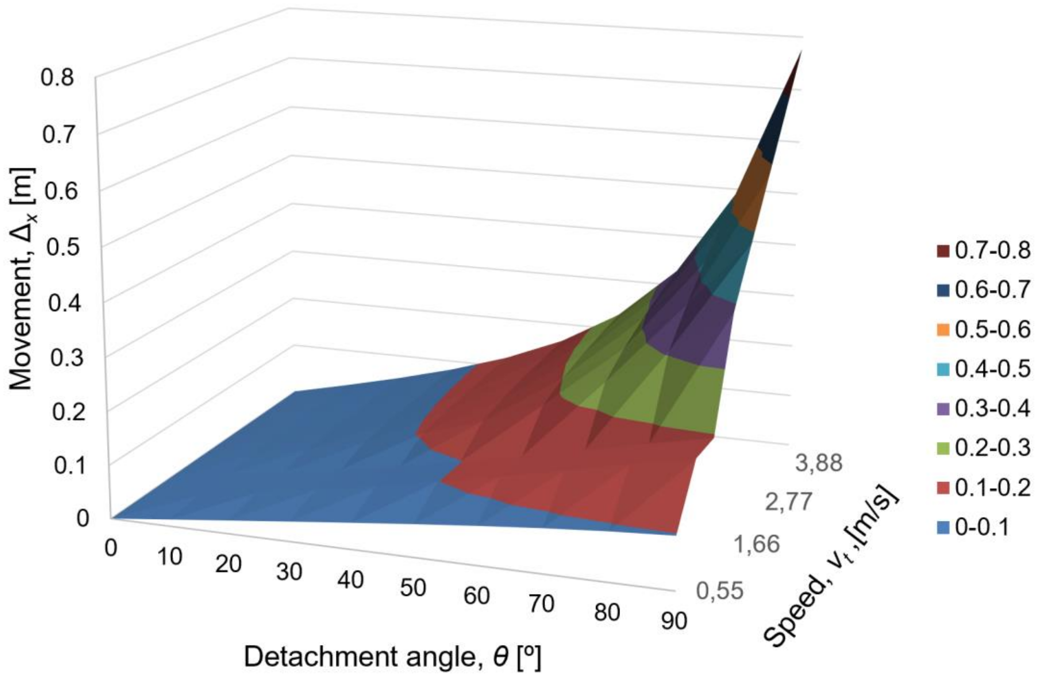

Fig. 3 - Dependence of the horizontal movement of the seed depending on the angle of detachment and on the speed of the seed in its trajectory towards the open channel for h=0.15 m

Table 3 presents the evolution of seed movement depending on the angle of detachment for the height of seed detachment h=0.2 m and the speed of the seed in its trajectory towards the channel opened by the coulter v_t=0.55 – 4.44 m/s.

Table 3

Seed movement Δ_x depending on the angle of detachment θ for h=0.2 m and v_t=0.55 – 4.44 m/s

Angle θ [º]	Angle θ [rad]	h [m]	Movement Δ_x [m]							
			v_t=0.55 [m/s]	v_t =1.11 [m/s]	v_t=1.66 [m/s]	v_t=2.22 [m/s]	v_t=2.77 [m/s]	v_t=3.33 [m/s]	v_t=3.88 [m/s]	v_t=4.44 [m/s]
0	0	0.2	0	0	0	0	0	0	0	0
10	0.174		0.014	0.022	0.027	0.030	0.031	0.032	0.033	0.033
20	0.349		0.029	0.046	0.055	0.061	0.064	0.066	0.068	0.069
30	0.523		0.044	0.070	0.085	0.094	0.100	0.104	0.106	0.108
40	0.698		0.058	0.095	0.117	0.132	0.141	0.148	0.152	0.155
50	0.872		0.071	0.120	0.153	0.175	0.191	0.201	0.209	0.215
60	1.047		0.084	0.147	0.193	0.227	0.252	0.271	0.285	0.296
70	1.221		0.095	0.174	0.238	0.289	0.331	0.365	0.393	0.415
80	1.396		0.105	0.200	0.286	0.364	0.434	0.497	0.553	0.604
90	1.570		0.112	0.224	0.336	0.448	0.561	0.673	0.785	0.897

Figure 4 shows the dependency of seed movement on the horizontal depending on the angle of detachment and the seed's speed in its trajectory towards the channel opened by the coulter for h=0.2 m.

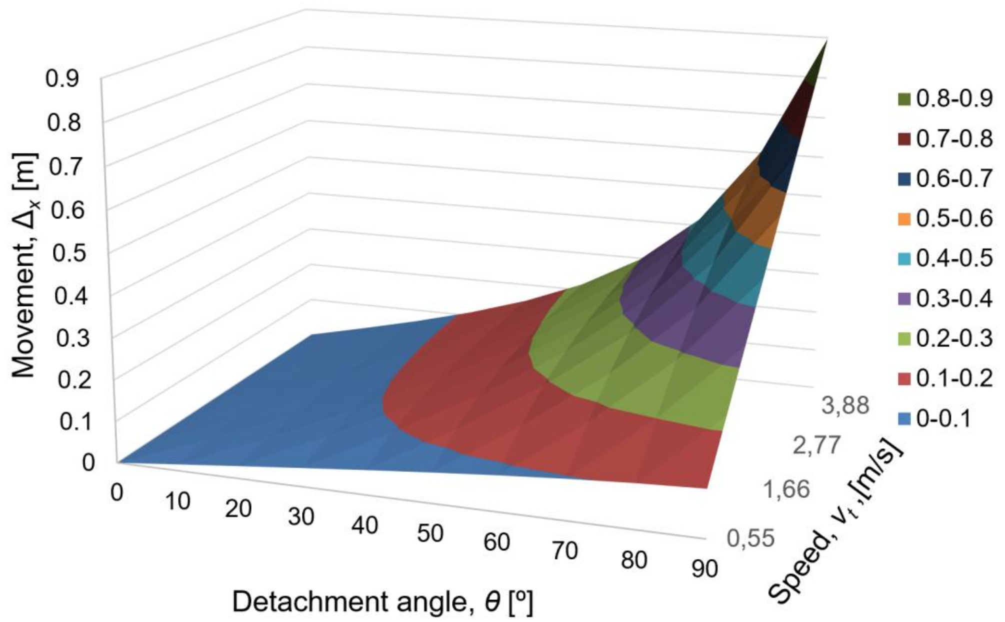

Fig. 4 - Dependence of the horizontal movement of the seed depending on the angle of detachment and on the speed of the seed in its trajectory towards the open channel for h=0.2 m

The numerical simulation program of the distribution process offers the possibility to study it with the help of the mathematical model using the method of modification produced by each disturbing factor, as well as by the method of modifications produced by all disturbing factors.

CONCLUSIONS

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;
- the studied factors influencing the distribution process were: the speed of the seed in its trajectory towards the channel opened by the coulter; the height of seed detachment relative to the ground; the angle of seed detachment.
- the numerical simulation results of the mathematical model show an obvious tendency of increase for the horizontal movement of the seeds with the increase of the angle of detachment and also with the increase of the detachment speed;
- by varying the seed detachment height (similar to the sowing on uneven ground) between 0.1 m and 0.2 m, it is noted that the horizontal movement of the seeds increases as the height increases. This increase is observed for all seed detachment speeds;
- for minimum values of the detachment speed, the horizontal seed movement is minimal (0.009 m for a detachment speed of 0.55 m / s, and a seed detachment height of 0.10 m);
- increasing the speed of detachment leads to an increase of horizontal seed movement (0.897 m for a detachment speed of 4.44 m / s, at a seed height detachment of 0.20 m);
- the increase of the angle of detachment leads to an increase in the horizontal movement of the seeds resulting in a decrease of the sowing precision (0.897 m for a 90° detachment angle, for a seed separation height of 0.20 m);
- around the value of 60º of the seed detachment angle, there is a high increase in the horizontal movement of the seeds, a common aspect for all the detachment heights;
- the mathematical model for estimating the real interval between two consecutive seeds includes kinematic factors that interfere with its disruption, as well as the geometry of some constructive elements of the mechanical system used to conduct the sowing work;
- the soil profile and the geometry of some constructive elements of the row unit used have a role in estimating the rotational effect on the row unit and implicitly the effect on the seed detachment angle.

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REFERENCES

[1] Gupta, M., Abdelsalam, M., Khorsandroo S., Mittal, S., (2020), Security and Privacy in Smart Farming: Challenges and Opportunities, *IEEE Access*, vol. 8, pp. 34564-34584, doi: 10.1109/ACCESS.2020.2975142;

[2] Han T., Changsu X., Wang Z., Wang Q., Wang J., (2020), Optimized Design, Monitoring System Development and Experiment for a Long-Belt Finger-Clip Precision Corn Seed Metering Device, *Frontiers in Plant Science,* DOI=10.3389/fpls.2022.814747;

[3] Heege H. J., (1975), Zaehres W. Pneumatic seed distribution with bulk drilling, *Grundlagen der Landtechnik*: Dusseldorf 25(4), pp. 111–115;

[4] Biriş, S. Şt; Ungureanu, N.; Vlăduţ, V. (2016), Study on the influence of mechanical vibrations to the energy required for soil tillage, *5th International Conference on Thermal Equipment, Renewable Energy and Rural Development*, TE-RE-RD, ISSN 2359-7941, pp. 203-208;

[5] Heege H. J., (1985), Seed distribution over the soil surface with drilled and broadcast cereals, *Translation No. 529 of the National Institute of Agricultural Engineering*, Wrest Park, Silsoe: England;

[6] Kaufman G., (1991), Seed coating: A Tool for Stand Establishment; a Stimulus to Seed Quality, *HortTechnology*, (1), pp. 98–102, 1991;

[7] Kornienko S., Pashenko V., Melnik V., Kharchenko S., Khramov N., (2016), Developing the method of constructing mathematical models of soil condition under the action of a wedge, *Eastern-European Journal of Enterprise Technologies*, Vol. 5, Issue 7, pp. 34–43;

[8] Li D., Geng D., Ma B., Li Q., Wang Zh., (2013), Study on Performance Monitoring System of Corn Precision Seeder, *Journal of Agricultural Mechanization Research*, Vol 11, pp.71–74;

[9] Marin C., (2009), *Modern methods of analysis of mechanical structures (Metode moderne de analiză a structurilor mecanice)*, Valahia University of Târgoviște Faculty of Materials Engineering, Mechatronics and Robotics, Master's course;

[10] Marin E., Bolintineanu Gh., Sorică C., Manea D., Herak D., Croitoru Ş., Grigore I., (2014), Scientific researches on the qualitative working indexes of the sowing body of a modern technical hoeing plants sowing equipment, *INMATEH - Agricultural Engineering*, Vol. 42 (1), pp. 19–26;

[11] Miller E. A., Rascon J., Koller A., Porter W. M., Taylor R. K., Raun W. R., Kochenower R., (2012), Evaluation of Corn Seed Vacuum Metering Systems, *ASABE Annual International Meeting*, Dallas, Texas, July 29 – August 1, Paper Number: 12–1337167;

[12] Sauder D. A., Schaefer T., (2016), *Seed meter*, Patent No. US 2016/0128272 Al;

[13] Soyoye, B., (2020), Development of the Instrumentation Unit of a Motorized Precision Planter, *European Journal of Engineering and Technology*, Research 5, (4), pp. 403-407, doi.org/10.24018/ejers.2020.5.4.1815;

[14] Srivastava A. K., Goering C. E., Rohrbach R. P., (1993), Engineering Principles of Agricultural Machines. *American Society of Agricultural Engineers: ASAE*, St. Joseph-Michigan;

[15] Staggenborg S. A., Taylor R. K., Maddux L. D., (2004), Effect of planter speed and seed firmers on corn stand establishment, *Appl. Eng. in Agric*, 20(5), pp. 573–580;

[16] Stout B. A., Cheze B., (1999), *CIGR Handbook of Agricultural Engineering*, Volume III Plant Production Engineering, Published by the American Society of Agricultural Engineers;

[17] Quarteroni A., Valli A., (1999), *Domain Decomposition Methods for Partial Differential Equations*, Oxford University Press, Oxford;

[18] Zubrilina, E.; Markvo, I.; Novikov, V.; Beskopylny, A.; Vysochkina, L.; Rudoy, D.; Butovchenko, A., (2019), Precise seeding planter with automated monitoring and control system, *IOP Conf. Ser.: Earth Environ*. Sci. 403 012063, pp. 1-10;

[19] Yazgi A., Degirmencioglu A., Bayram E., (2010), Optimisation of the Seed Spacing Uniformity Performance of a Precision Seeder Using Spherical Materials and Response Surface Methodology, *An ASABE Meeting Presentation*, Paper Number: 1008560; DOI: 10.13031/2013.29653.