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MATHEMATICAL MODELS FOR OPTIMIZATION OF THE DISTRIBUTION PROCESS OF STRAW CEREAL SOWING MACHINES WITH CENTRALIZED MEASURING

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Abstract: *Optimization of the sowing machine straw cereal distribution with centralized measuring consists in finding an optimum combination between the main control parameters of the distribution device, respectively between seed flow ratio of the dosing device and the machine working speed, to achieve the seeds rates required by the agro-technique for each type of crop. In this paper was developed a mathematical model that describes the sowing rate variation depending on the working speed of the sowing machine and the active length of the groove dosing device.*
Keywords*: mathematical models, optimization, sowing rate, distribution process.*

1. INTRODUCTION

The seeds dosing and distributing process, has a decisive influence on the main quality indices of the sowing machine: flow rate uniformity, respectively of sowing rate, distribution uniformity on the working row. Therefore, the improvement of sowing machines on rows has been focused primarily on improving distribution devices, which are the main working bodies of the sowing machines and how their operating manner depends on the sowing quality. The use of mechanical-pneumatic distribution devices leads to the machine reduced weight in favor of hopper seed higher capacity and the productivity of the sowing aggregate.

The distributing device of centralized dosing and pneumatic distribution sowing machines consists of a centrifugal fan, a cylinder of dosing device cylinder type with grooves mounted in a metal box attached to the bottom of seed hopper, a vertical pipe for pneumatic transport and a distribution head.

Optimization of the cereals seed distribution with centralized dosing consists to find an optimum combination between the main control parameters of the distribution device, respectively between seed flow ratio of the dosing device and the airflow generated by fan and the working speed of the machine, to achieve the required agro-technique sowing rules for each type of crop. Because in practice, the air flow speed generated by the fan and thus air flow, during the work process, does not vary, being maintained at a constant value to ensure optimal transport of seed, theoretical investigations were carried out taking into account this hypothesis. Thus, the control parameter of the dosing device remains the flow of seeds, given by the active length of grooves, combined with the speed work that leads to obtain optimum sowing rules.

2. MATHEMATICAL MODELING OF SOWING RATE FUNCTION AND CHOOSING THE BEST VARIANT

The seeds volume discharged by the dosing device, to a rotation of the grooved cylinder is determined by relation:

$$V_d = 1,65 \cdot A \cdot L_c \cdot z \cdot \psi \ [\text{m}^3/\text{rot}], \tag{1}$$

where : A is is the cross-sectional area of the groove in m^2 ; L_c - active length of the groove, in m; z – grooves number; ψ - seed filling groove coefficient (ψ = 0,93÷0,98 for small seeds, ψ = 0,60÷0,85 for medium seeds and ψ = 0,45÷0,80 for big seeds).

The seed flow rate of the dosing device with grooved cylinder necessary for a sowing rate N is given by relation:

$$Q_s = V_d n_d \gamma_s = \pi D n_r B_m \frac{N}{10^4} \ [\text{kg/min}], \tag{2}$$

where: n_d is the dosing device speed; γ_s – seeds specific mass; D - the wheel drive diameter, in m; n_r – the wheel drive speed, in rot/min; B_m - machine working width, in m; N – sowing rate, in kg/ha;
From (2) relation results the seeding rate expression, as:

$$N = \frac{V_d \cdot \gamma_s \cdot 10^4}{\pi \cdot D \cdot B_m \cdot i_t} \text{ [kg/ha]}, \tag{3}$$

where i_t is the ratio between drive wheel and dosing device.
It is introduced in (3) relation the (1) expression of the volume of seeds distributed to a rotation of the grooved cylinder and the seeding norm function $N(L_c,v)$ is defined, as:

$$N(L_c, v) = \frac{1,65 \cdot A \cdot z \cdot \gamma_s}{\pi \cdot B_m \cdot D \cdot i_t} \cdot \psi \cdot L_c \cdot 10^4 \text{ [kg/ha]} \tag{4}$$

The (4) equation shows that if the parameters A, z, γ_s, B_m, D and i_t are constant, then the rate N does not depend on working speed. From experimental research conducted by authors, was found that for the increase of the working speed for a constant flow of seeds, the norm value applied decreases, which the theory does not show. However, experimental data show that the increase of the seeding norm with the groove active length has a slightly non-linear aspect.
Given these observations, we appealed for modeling, to the approximation rational function, with the general form:

$$N(L_c, v) = \sum_{i=0}^{n} \sum_{j=-k}^{m} a_{ij} L_c{}^i v^j \tag{5}$$

As shown in equation (5) was made for speed and negative integer exponents to model decreases with increasing speed sowing. Active length of the groove is taken into account only positive integer exponents. The method of calculation is the method of least squares, shape approximation (5) leading to a minimized functional form relatively simple:

$$F(a_{ij}) = \sum_{l=1}^{n} \left(\sum_{i=0}^{n_{L_c}} \sum_{j=-k}^{n_v} a_{ij} L_{cl}{}^i v_l{}^j - N_l \right)^2 \tag{6}$$

for the system of equations obtained by canceling the partial derivative is linear. Solving the system leads then to obtain the coefficients a_{ij}.
Using this method is a form of polynomial time (with a finite number of terms to be specified), that according to the approximation that minimizes the functional (6). Functional (6) is actually defined on a infinite variety of shapes of features, but in this work I stopped in terms of maximum 2 in L_c and minimum -2 in v. In fact, considering the higher degree terms (mode) is not necessary due to the shape dependence suggested by experimental data.
For mathematical modeling of the function (4) were chosen two versions of rational functions (N_1 and N_2) and after comparing their approximation degree, was chosen the option that best approximates the theoretical data. Based on the constructive solutions analysis for dosing device with grooved cylinder, was chosen a theoretical range variation of the active groove length between 0.01÷0.1 m, and under the agro-technical requirements which a cereals sowing machine should meet, was chosen a theoretical variation range of the work speed between 1.38÷2.77 m/s (5÷10 km/h).

Variant I. Rational approximation function is:

$$N_1(L_c, v) = a_0 \cdot \frac{L_c}{v} + a_1 \cdot \left(\frac{L_c}{v} \right)^2 \tag{7}$$

After calculating the a_{ij} coefficients the function (6) becomes:

$$N_1(L_c, v) = 1,266 \cdot 10^4 \frac{L_c}{v} - 1,149 \cdot 10^5 \left(\frac{L_c}{v} \right)^2 \tag{8}$$

whose approximation degree is $G_1 = 7,744 \cdot 10^3$.
In figure 1 is given the comparative graphic representation between the theoretical sowing rate values and the ones obtained by applying the rational approximation function (8) theoretical values for L_c and v.

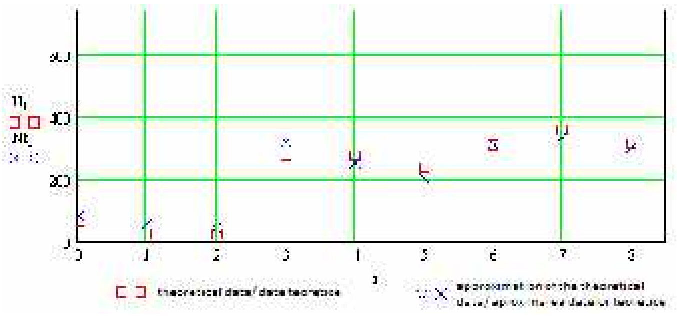

Figure 1: Comparative graphic representation between sowing rate theoretical values and the ones obtained with rational approximation function $N_1(L_c, v)$

Variant II. Rational approximation function is :

$$N_2(L_c,v)=a_0\cdot L_c+a_1\cdot\frac{1}{v}+a_2\cdot L_c^2+a_3\cdot\frac{1}{v^2}+a_4\cdot\frac{L_c}{v}+a_5\cdot\left(\frac{L_c}{v}\right)^2. \tag{9}$$

After calculating the a_{ij} coefficients the function (8) becomes:

$$N_2(L_c,v)=3,358\cdot 10^3\cdot L_c-85,568\cdot\frac{1}{v}-1,891\cdot 10^4\cdot L_c^2+0,69\cdot\frac{1}{v^2}+8,704\cdot 10^3\cdot\frac{L_c}{v}-7,662\cdot 10^4\cdot\left(\frac{L_c}{v}\right)^2 \tag{10}$$

whose approximation degree is $G_2=930,003$.

Figure 2 shows the comparative graphic representation between the theoretical sowing rate values and the ones obtained by applying the rational approximation function (11) theoretical values for L_c and v.

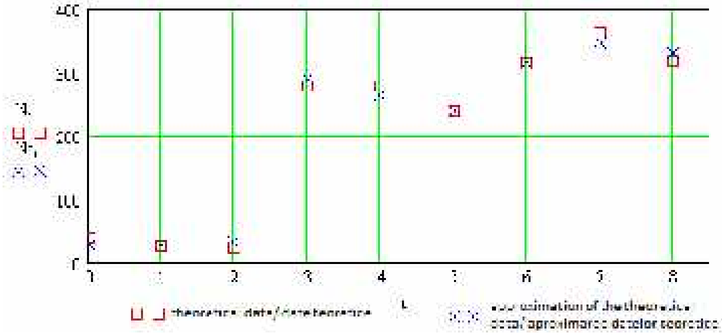

Figure 2: Comparative graphical representation between theoretical sowing rate values and the ones obtained with the rational approximation function $N_2(L_c, v)$

Comparing the results for the approximation degree, shows that $G_2<G_1$, namely, the value of the function approximation degree $N_2(L_c, v)$ is less than the approximation degree of the function $N_1(L_c, v)$. In addition, analyzing the graphs in figures 1 and 2, there is a better approximation of the theoretical data by the function $N_2(L_c, v)$ whose 3D variation diagram is shown in figure 3.

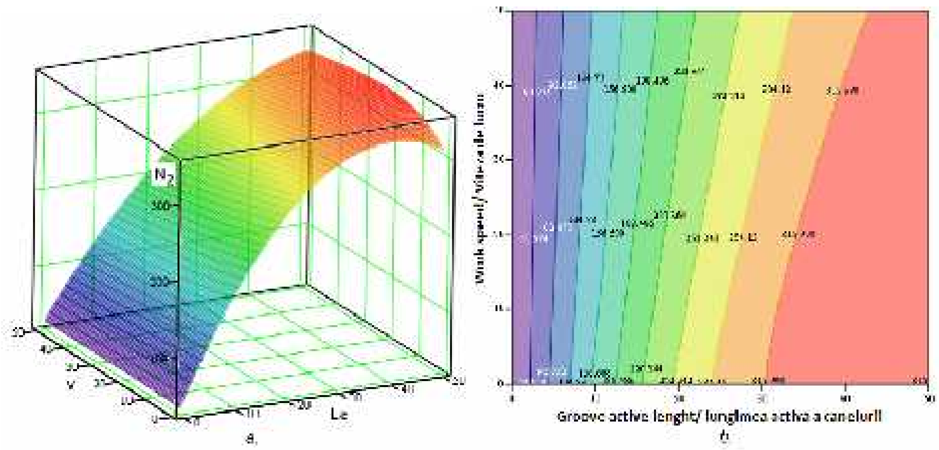

Figure 3: Variation diagram of the rational approximation function $N_2(L_c, v)$:
a - surface generated for $N_2(L_c, v)$; b – projection of $N_2(L_c, v)$ surface in plan, viewing constant sowing rate

3. MATHEMATICAL MODELING OF THE FUNCTION ψ = ψ (v)

Analyzing the relation (4), we see that besides the groove filling factor ψ, the other parameters have no reason to depend on the L_c or v. Taking into account the observation earlier that work to increase speed for a flow seeds consistently applied normal value decreases, it follows that the only parameter that can vary the speed of filling the groove is the coefficient ψ. In support of this hypothesis comes that in the literature, this groove not filling factor is given a value, but a range of variation, whose size depends on the type of seed used. Therefore, with experimental data showing normal variation with speed, we hypothesize that ψ is a function of working speed:

$$\psi=\psi(v) \tag{11}$$

The hypothesis set out above, defined function $\psi(v, \alpha)$, where α is a positive constant:

$$\psi(v,\alpha)=1-e^{v-\alpha} \tag{12}$$

Under these conditions, equation (4) of sowing rate can be expressed as a function approximation exponential form:

$$Nf(Lc, v) = k \cdot L_c \cdot \psi(v, \alpha)\,, \tag{13}$$

where k is a constant that depends on parameters A, z, γ_s, B_m, D and i_t ($k = \dfrac{1{,}65 \cdot A \cdot z \cdot \gamma_s \cdot 10^4}{\pi \cdot B_m \cdot D \cdot i_t}$).

Using the method of least squares approximation form (13) leads to a functional relationship calculated minimized:

$$F(\alpha) = \sum_{i=0}^{n} (k \cdot Lc_i \cdot \psi(v_i, \alpha) - N_i)^2 \tag{14}$$

Functional (14) reaches its minimum for a value of α, which was calculated using the MathCad13 program. For a range of positive values of α, to graph the changes in the functional $F(\alpha)$, shown in figure 4.

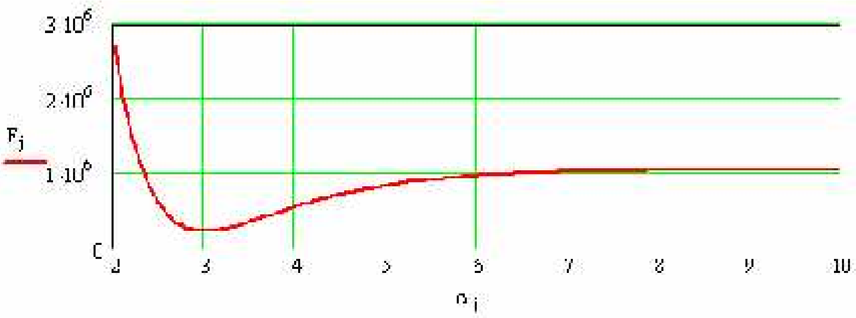

Figure 4: Graphical representation of changes in the functional *F(α)*

From figure 4 we see that the functional *F(α)* reaches its minimum for α = 3.011. With α determined function (11) becomes:

$$\psi(v, 3.011) = 1 - e^{v-3.011}\,, \tag{15}$$

whose variation depending on the speed of theoretical work is presented in figure 5.

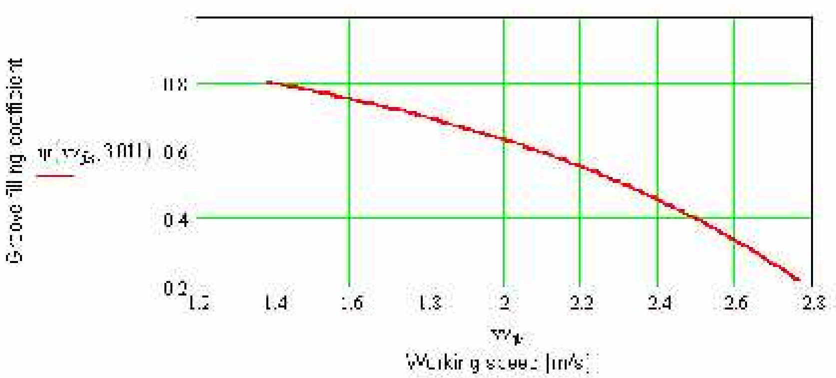

Figure 5: Variation of groove filling coefficient depending on the theoretical working speed

Figure 5 is a groove filling coefficient decreases with increasing working speed, so the assumption made is verified. For theoretical ranges of variation of grooves active length and working speed , in figure 6 is the 3D diagram of variation of the exponential approximation function given by (12).

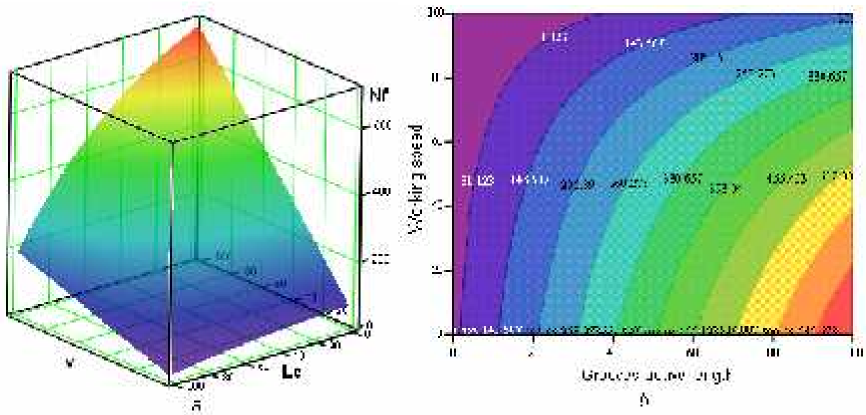

Figure 6: Variation diagram of the rational approximation function Nf(L_c, v):
a - surface generated for Nf(L_c, v); b – projection of Nf(L_c, v)surface in plan, viewing constant sowing rate

For a clearer visualization of normal variation of sowing rate exponential function approximation (12), figures 7 and 8 are presented in turn, schedules change depending on the working speed and the groove active length.

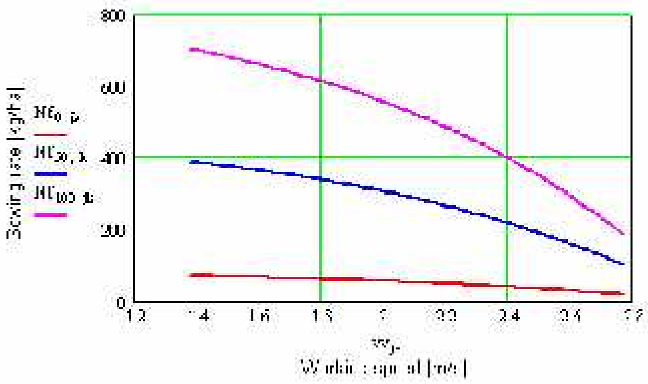

Figure 7: Sowing rate variation depending on the working speed

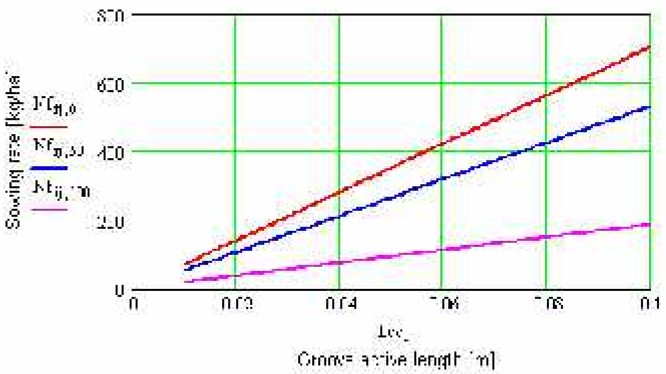

Figure 8: Sowing rate variation depending on the groove active length

Looking at the two graphs, the sowing rate decreases with increasing working speed, the constant flow of seeds (fig. 7), confirming the observation from the assumption that we left, and sowing rate growth with increasing active length of the groove, at constant working speed (fig. 8), a phenomenon that is normal to happen.

4. CONCLUSIONS

- The seeds dosing and distribution determine the quality working indices of mechanical-pneumatic equipment and implicitly those of sowing machine, therefore the calculation and sizing of these devices are very important;
- Sowing rate decreases with increasing working speed, at constant flow of sowing and starting from this assumption have been defined two types of rational approximation functions that have taken in consideration for speed also negative exponents to model the norm decrease with increasing speed;
- Following the graphs comparing of the results obtained for the two functions and their degrees of approximation, the optimum mathematical modeling variant of theoretical sowing rate has been chosen depending on the active length of groove and working speed;
- Through mathematical modeling, it was verified the assumption that the only parameter in the formula of sowing rate, which can vary with the working speed is the groove filling coefficient.

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