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Theoretical and experimental research on sowing rate optimization of grassland drills

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Abstract. In this paper, sowing rate optimization of grassland drills consisted in finding an optimum combination between the seed flow of the seed metering device and the drill working speed, in order to achieve the sowing rates required by agro-technique for herbs seeds. It was developed a mathematical model that describes the seed flow variation depending on the working speed of the grassland drill and the active length of the groove cylinders. The experimental research was conducted using a grassland drill with eight metering devices and an automated installation, which simulates the working speed of the drill, collects and weighs seeds from each individual metering device. By using MathCad 14.0, it have been drawn the variation diagram of seed flow depending on active length of the groove and working speed. The comparative study of the variation diagrams based on experimental data and the variation diagrams obtained from mathematical modelling highlighted that the downward trend of the seed flow was observed in 66,67% of the results. Based on the mathematical model presented in this paper, it might be developed an algorithm enabling for fast obtain the optimal combination between the adjustment parameters, in order to apply a desired sowing rate.

1 Introduction

Improving and diversifying grasslands drills is the task of great importance to scientific research in the field of power and machinery systems. Development of the seed metering devices as main parts of drills was studied in some scientific works [1, 2].

Several authors [3,4] performed researches regarding optimization of drills seed flow, concluding that the cylinder dimension, flutes number, flutes length and revolution had important effects on the uniformity of seeds distribution.

Guler [5] investigated the seed flow distribution from drills meter rollers, concluded that the meter roller diameter should be between 6...8 mm and the flutes length should be between 15..25 mm at a rotation speed of 20...40 rotation per minute.

Gervais et al. [6] developed a method for test the performance of seed metering devices. This method was based on the metering roller flow continuity during operation and included an experimental procedure using testing devices.

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Maleki et. al. [7] focused on how to increase the uniformity of seed placement by optimising the auger configuration, design parameters being derived to configure the auger groove depth and width, number of grooves, auger outer diameter and rotation speed.

Song et. al. [8] used *Festuca arundinacea* seeds and analyzed the effects of combing teeth space, rotation speed, inclining angle of flutes on the rate and uniformity. They observed that the variation of uniformity coefficient was based on the above four influencing factors.

The seeds metering and distributing process, has a decisive influence on the main quality indices of the drill: seed flow respectively of sowing rate uniformity, distribution uniformity on the working row. Therefore, the improvement of grasslands drills has been focused primarily on improving distribution devices, which are one of the main working part of the drill.

Theoretical and experimental researches worldwide performed, relating to grassland drills metering devices, have been more focused on their role in providing a wide range of flow rates that fully meet agro-technical requirements and less on concrete influence on the structural and functional parameters on the working process.

In this paper**,** optimization of the seeding rate of grassland drills, consisted in finding an optimum combination between the seed flow of the seed metering device and the drill working speed, to achieve the properly sowing rates required by agro-technique for herbs seeds.

2 Theoretical research

The main adjustment index of the metering roller is the seed discharge, which is given by the flutes active length in combination with the working speed of the grasslands drill. The seed flow (*F*) of the groove cylinder may be calculated with the following equation [9]:

$$F = \frac{V \cdot n_m \cdot \gamma_s}{60}\text{, (kg/s)} \tag{1}$$

where: V is the seeds volume discharged at one rotation, in m^3/rot; n_m - the flute cylinder rotation speed, in rpm; γ_s – seeds specific mass, in kg/m^3.

$$V = 1{,}65 \cdot S \cdot l \cdot z \cdot \psi\text{, (m}^3\text{/rot)} \tag{2}$$

where: S is the flute section area in m^2 ; l - flute active length, in m; z – number of flutes; ψ - flute filling coefficient ($\psi = 0{,}93 \div 0{,}98$ for small seeds).

According to [10], the relation between the seed flow (*F*) of the metering device and the sowing rate (*N*) is:

$$F = V \cdot n_m \cdot \gamma_s = \pi \cdot d \cdot n_w \cdot W \cdot \frac{N}{10^4} \tag{3}$$

where: d - diameter of the drive wheel, in m; n_w – the driving wheel rotation speed, in rpm; W - drill working width, in m.

The rotation speed of metering device was calculated with formula:

$$n_m = \frac{60 \cdot s}{\pi \cdot d \cdot i_t}\text{, (rad/s)} \tag{4}$$

where: s is the drill working speed, in m/s; $i_t = n_w / n_m$ - the transmission ratio between driving wheel and metering device.

By introducing the equations (2) and (4) into equation (1), were obtained the equation of the theoretical seed flow *(F_t),* which is:

$$F_t(l,s) = \frac{1{,}65 \cdot S \cdot z \cdot \psi \cdot \gamma_s}{\pi \cdot d \cdot i_t} \cdot l \cdot s\text{, (kg/s)} \tag{5}$$

The equation (5) shows that if we maintain parameters S, z, ψ, γ_s, W, d and i_t constant, then the theoretically seed flow depends directly proportional on the flute active length and working speed. From the experimental researches, authors observed for increasing working speed the seed flow decreases, which the theory does not show.

Following these observations, was used for modelling the approximation equation (6):

$$F_t(l,s)=\sum_{i=0}^{n}\sum_{j=-k}^{m} x_{ij} l^i s^j \tag{6}$$

Data approximation by rational functions is an option dictated by the accuracy with which these functions can model the experimental data [11]. In equation (6) have been taken negative integer exponents for working speed, in order to modelling seed flow decrease.

The method of calculation is the method of least squares [11,12], form of approximation (6) leading to the following minimized function:

$$f(x_{ij})=\sum_{p=1}^{n}\left(\sum_{i=0}^{n_l}\sum_{j=-k}^{n_s} x_{ij} l_p{}^i s_p{}^j - F_{tp}\right)^2 \tag{7}$$

The equations system obtained by cancelling the partial derivative is linear and leads then to obtain the coefficients x_{ij}. The function (7) was defined on a infinite variety of functions. In this paper we considered terms of maximum 2 in l and minimum -2 in s. Using this method, we found the rational approximation function which minimizes the function (7):

$$F_t(l,s)=x_0\cdot l+x_1\cdot\frac{1}{s}+x_2\cdot l^2+x_3\cdot\frac{1}{s^2}+s_4\cdot\frac{l}{s}+x_5\cdot\left(\frac{l}{s}\right)^2 \tag{8}$$

The values of coefficients x_{ij} have been calculated with MathCad 14.0 program. The function (8) becomes:

$$F_t(l,s)=2.5\cdot10^3\cdot l-62.5\cdot\frac{1}{s}-2{,}6\cdot10^4\cdot l^2+0{,}7\cdot\frac{1}{s^2}+5{,}4\cdot10^3\cdot\frac{l}{s}-4{,}3\cdot10^4\cdot\left(\frac{l}{s}\right)^2 \tag{9}$$

Figure 1 shows the comparative chart between the theoretical seed flow values and the seed flow values obtained by applying the equation (8) to theoretical values for l and s.

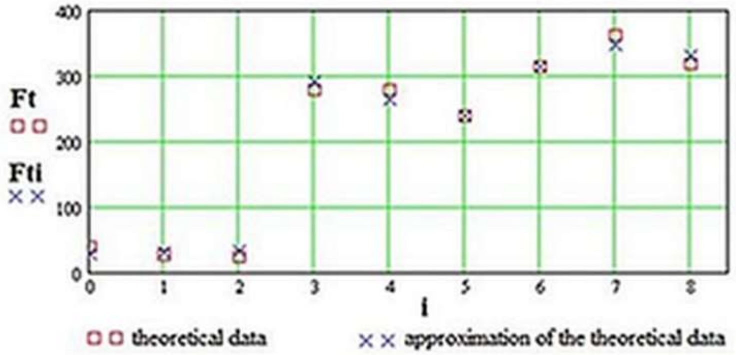

Fig. 1. Comparative chart between theoretical seed flow values and the ones obtained with the rational approximation function $F_t(l, s)$

Analyzing the graphs in figure 1, was observed a good approximation of the theoretical data by the function $F_t(l, s)$.

3 Experimental research

The aim of the experimental researches was to validate the theoretical model, in order to optimize the working process and to obtain mathematical relations helpful in making optimal adjustment of the grassland drills.

The experimental researches were performed at National Institute of Research - Development for Machines and Installations designed to Agriculture and Food Industry - INMA Bucharest. Tests were conducted on the test bench presented in Figure 2, which is made of: the grasslands drill MSP (*1*), having eight metering devices; an electric gear motor (*2*) with variable speed continuously adjustable, to simulate the working speed of the drill; two bands provided with seed collection boxes (*3*), powered by two electric motors; an electronic scale (*4*) for measuring quantity of seeds collected from each individual metering roller and the entire seeds quantity; an automated control and monitoring panel, having an PLC (programmable logic controller) and four frequency converters. Transmission of the motion to the metering devices axis is made through a gearbox with camshaft mechanism and with a chain transmission.

Fig. 2. Experimental installation used for tests

The seed used was *Trifolium repens,* with the main characteristics: 98 % purity ; 2.4 g mass of one thousand seeds; 1.04 g/ cm3 specific mass . Tests were performed in five repetitions for 3 seed flows (minimum, medium and maximum) and 3 working speeds (1.94 m/s; 2.36 m/s; 2.77 m/s). Data obtained from tests operations were processed by using MathCad 14.0.

In figure 3 there are presented variation diagrams of average seed flow obtained experimentally (F_e) versus theoretically seed flow (F_t).

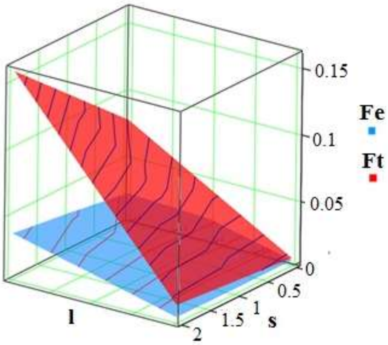

Fig. 3. The variation of experimentally and theoretically seed flow

Analyzing the charts in Figure 3, it was noted that the surfaces generated by experimental data have an aspect similar to the surfaces generated theoretically, and by plotting the curves of constant seed flow, could be observed that those obtained experimentally are very close to the theoretical.

In order to validate the experimental data, were compared on the same diagram, the variation of theoretically and experimentally seed flow, for the three values of the active length of grooves and working speed (Figure 4).

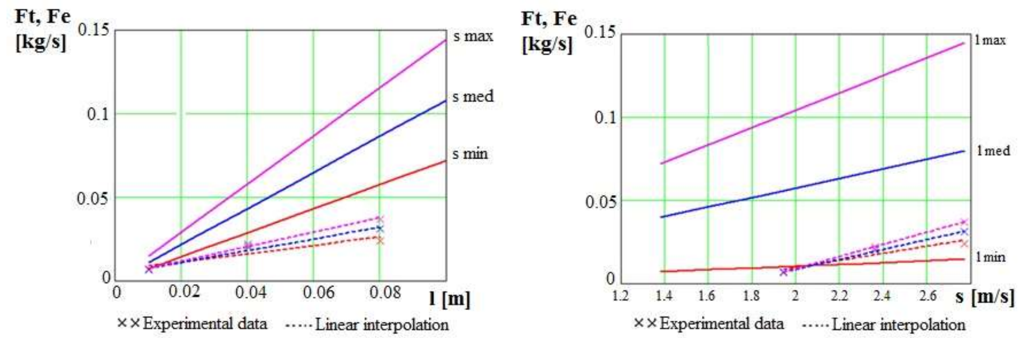

Fig. 4. Seed flow variation, theoretically and experimentally, in terms of: active length of grooves (*left*); working speed (*right*)

The theoretical values for the working speed and active length of grooves were given by theoretical limits of the variation intervals chosen for the study, as well as the average values located in the middle ranges. By linear interpolation of the experimental data, was observed similarity with the theoretical data.

The *deviation in relation to the average of probes (U)* was calculated with the eqaution:

$$U = \frac{U_{\max} - U_{\min}}{\overline{U}}, [\%] \tag{10}$$

where: U_{max} is the maximum value of seed flow at five repetitions*;* U_{min} – the minimum value of seed flow at five repetitions; $\overline{U}$ - average of seed flow at five repetitions.

The calculated values for the deviation in relation to the average of probes, are presented graphically in Figure 5.

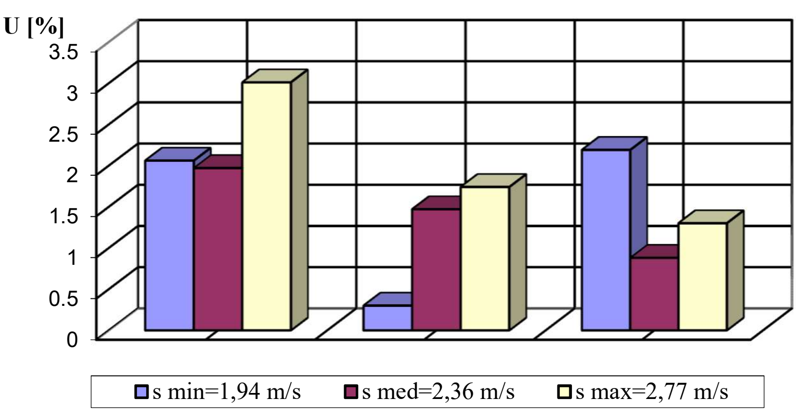

Fig. 5. Deviation in relation to the average of probes, for minimum, medium and maximum working speed

According to the requirements of Romanian National Standard [13], deviation in relation to the average of probes must not exceed 5% for grasses seeds. Experimental data presented comply with the requirements of the national standard, in conclusion the seed flow test was validated.

In order to validate the mathematical model of the seed flow, the rational approximation function chosen in the previous section, noted with $F_t(l, s)$ was applied to experimental data obtained for the seed flow. The equation describing the seed flow dependence on the grooves active length and working speed is:

$$F(l,s) = -65.3 \cdot l + 1.4 \cdot 10^{-5} \cdot \frac{1}{s} + 0.7 \cdot 10^{3} \cdot l^{2} + 0.2 \cdot \frac{1}{s^{2}} + 1.4 \cdot 10^{3} \cdot \frac{l}{s} - 2 \cdot 10^{4} \cdot \left(\frac{l}{s}\right)^{2} \quad (11)$$

Figure 6 are plotted the experimental values for seed flows and the values obtained by applying the function (11) on experimental values for active length of grooves and working speed. It can be seen a good approximation of experimental data by function (11).

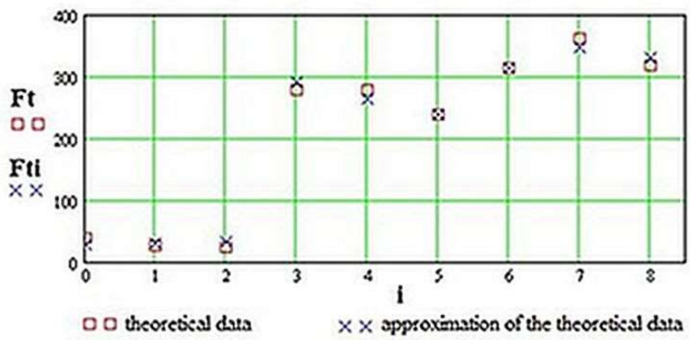

Fig. 6. Comparative chart between experimental seed flows and seed flows obtained with the approximation function

The seed flow variation, by using the equation (11), in terms of each adjustment parameter (working speed and active length of grooves) is presented in Figure 7.

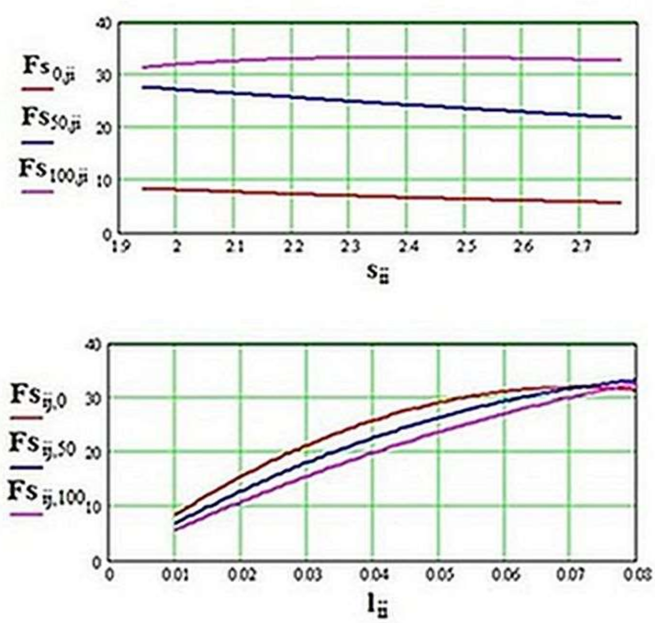

Fig. 7. Seed flow variation in terms of working speed (*up*) and active length of grooves (*down*)

Analyzing the graph in Figure 7, we have found up that at minimum and medium values of the active length of grooves, the seed flow decreases with increasing working speed, it has a slight increase for the maximum value of groove active length, then returns to the downward trend.

In order to verify the theoretical hypothesis according to which the seed flow decreases with increasing working speed and to validate the mathematical model, were studied in comparison, the variation diagrams of seed flow depending on working speed, based on experimental data and the variation diagrams of seed flow depending on working speed obtained by applying theoretical mathematical model on experimental data (Figure 8).

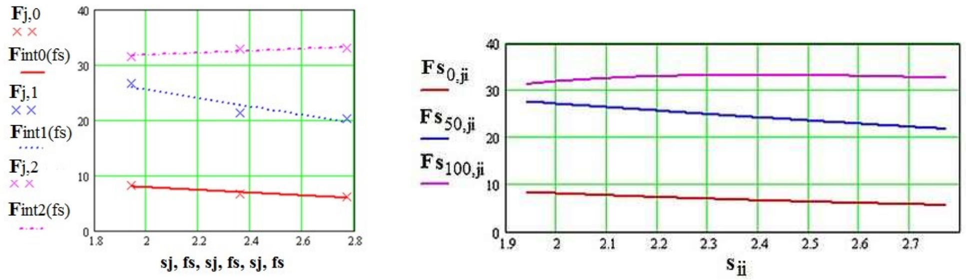

Fig. 8. Graphical comparison between seed flow based on experimentally data (*left*) and on mathematical model (*right*)

Observations which can be drawn from the comparative study are:

- the downward trend of the seed flow with increasing working speeds is observed in 66,67% of the results obtained both experimentally and by mathematical modelling;
- the remaining of 33,33 % covers the maximum seed flow, which have a tendency to increase with increasing working speed.

4 Conclusions

Seed flow of grassland drills decreases with increasing working speed. Starting from this hypothesis have been defined an approximation function.

It have been drawn the variation diagram of seed flow depending on flute length and working speed, using the approximation function derived from mathematical modelling applied on experimental data. The seed flow of the metering device determined experimentally for three working speeds and three active lengths of grooves, confirms theoretical variation law, and the deviation in relation to the average of samples comply with the requests of national standard.

The initial hypothesis has been verified and the theoretical mathematical model of seed flow has been validated, experimental data confirming its usefulness and correctness.

Were obtained the adjustment curves for the seed flow. These curves provide a clear image on the possibilities of achieving the desired seed flows or sowing rates for each type of grass seed, by the combination of the two adjustment parameters (grooves active length and working speed).

Based on the mathematical model presented in this paper, it might be developed an algorithm enabling for fast obtain the optimal combination of the adjustment parameters (grooves active length and working speed), of the grassland drills, in order to apply desired sowing rates.

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