RESEARCH ON THE UNIFORMITY DEGREE OF SOLID ORGANIC FERTILIZERS DISTRIBUTION
/
CERCETARI PRIVIND GRADUL DE UNIFORMITATE A DISTRIBUTIEI INGRASAMINTELOR ORGANICE SOLIDE

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ABSTRACT
In this paper are presented the results of experimental research conducted in order to improve the uniformity of organic fertilizers distribution (compost and semi-fermented manure) used for soil fertilization, if the administration is done with a machine with a distributor with continuous spiral centrifugal beaters, arranged vertically. The uniformity of organic fertilizers distribution depends on a number of factors such as: the speed and angle of inclination of the distribution device, the distance between the distribution beaters, the humidity and the density of the material, wind speed, the size of the fertilizer particles. The determinations were performed under working conditions and the various parameters were the beaters speed, beaters inclination angle and the feed rate of the distribution device, choosing 3 situations (minimum, average and maximum) for each of them. Based on the obtained results, the multivariable functions of polytropic form was determined, which characterize the degree of uniformity of the spread material, function that can be the basis for the elaboration of constructive solutions to ensure the optimum uniformity of distribution.

REZUMAT
În aceasta lucrare sunt prezentate rezultatele cercetărilor experimentale efectuate în scopul îmbunătăţirii uniformității de distribuție a îngrăşămintelor organice (compost si gunoi de grajd semifermentat) utilizate pentru fertilizarea solului, în cazul în care administrarea se realizează cu o maşină cu aparat de distribuţie cu rotoare centrifugale cu spiră continuă, dispuse în plan vertical. Uniformitatea de distribuție a îngrăşămintelor organice depinde de o serie de factori cum ar fi: turația și unghiul de înclinare a aparatului de distribuție, distanța dintre rotoarele distribuitoare, umiditatea și densitatea materialului, viteza vântului, mărimea particulelor de îngrăşământ. Determinările au fost efectuate în condiții de lucru reale iar mărimile variate au fost turația rotoarelor, unghiul de înclinare a acestora și debitul de alimentare a aparatului de distribuție, alegându-se 3 situaţii (minim, mediu şi maxim) pentru fiecare dintre ele. Pe baza rezultatelor obținute s-a determinat funcția multivariabilă de formă politropică care caracterizează gradul de uniformitate a distribuției materialului, funcţie ce poate sta la baza elaborării soluţiilor constructive care să asigure uniformitatea de distribuţie optimă.

INTRODUCTION
The latest actions implemented by EU regarding climate change and environmental degradation were to adopt the European Green Deal, in order to stop the negative effects. This plan provides strategies to use the resources efficiently by transition to a clean and circular economy and restore biodiversity and cut pollution (*European Commission*, *https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en).*

The use of manure on a larger scale is part of the measures taken by the European Commission to close the nutrient loop in the agricultural sector. It is intended to allow the wider use of recycled manure and other organic nutrients instead of chemical fertilizers, while taking into account the protection of the environment and ecosystems.

Natural organic fertilizers have been and will remain the main source of improving soil quality through the benefits of their turning into humus. At the same time, their improper distribution causes serious damage to the environment, being an important source of pollution if they are administered excessively and unevenly (*Golub et al. 2021*). At the same time, if they are administered in small quantities, the effect on the benefits brought to the plants will not be the expected one.

The benefits of applying the organic fertilizer on soil are very important, both for plant growing and for farmer's income too. The results obtained by *Catur, 2011,* reveal that the productivity is higher with organic fertilizer compared to the chemicals, but the productivity decreases during the first two or three years of organic fertilizer application. That's why it is necessary to increase the application of organic fertilizers and understand its importance.

Geng et al, (2019), studied the replacement of chemical fertilizers with organic ones in a two-year study experiment, which was carried out to assess the effects of substituting equal amounts of mineral fertilizer with organic manure on the yield, dry matter (*DM*), and nitrogen (*N*) uptake of spring maize (*Zea mays* L.) and on the mineral *N* (N_{min}) distribution in the soil profile. The results have shown the increase by 25% nutrient substitution resulted in the best yield increase.

Another study, realized by *Sengottaian K. et al, (2019),* analyses the human effort for manure land spreading and proposes an innovative cost-effective manure spreader that consists in a pulverizing drum and blades. The simple manure spreader helps providing support to farmers who are unable to afford heavy machineries for land application.

Landry et al., (2005), analyses two different conveying systems for manure spreader and the influences of the geometry of the hopper above the material flow. The four augers and the scraper conveyor were part of a prototype land applicator.

It is mandatory for the fertilizer spreading equipment to provide the uniform spreading on the entire working surface. Previous research study made by some authors, present the theoretical aspects regarding fertilizers distribution with a vertical beater spreading equipment. It was found that the particle trajectory is influenced by the beater dimensions and rotational speed, inclination angle, material flow rate, wind speed and characteristics of the material such as humidity and density. By testing the vertical beater spreader, it can be determined if the theoretical aspects are confirmed *(Ștefan et al., 2018; 2019; 2019 a; Cârdei et al., 2018)*.

Modern fertilizer distribution systems should include monitoring and control systems through which the operator is continuously informed on how the fertilization work is being carried out and can intervene when necessary. These monitoring systems are mainly applied on machines that distribute chemical fertilizers and less or not at all, on those that distribute organic fertilizers *(Petcu et al., 2015; Popa et al., 2009)*. Although this equipment have been developed continuously, the uniformity of the distribution over the total spreading width does not fall within the agrotechnical requirements, because in the lateral extremities of the spreading strips, the quantities of distributed material are much smaller than in its centre. It is therefore necessary that the data obtained at a single pass of the machine be processed in order to establish an optimal working width, by the method of overlapping at a next pass.

MATERIALS AND METHODS

The experimental tests were performed at INMA Bucharest and aimed to determine the degree of uniformity of the distribution for two materials (compost and semi-fermented manure) distributed with four vertical helical beaters (Fig. 1).

Fig. 1 - Four beaters spreader

Three distributing beater speed, three beater inclination angle and three material feed flow were chosen, for each material. For the experiments performed in effective working conditions, the forward speed of the machine was kept constant, namely 1 m/s.

The dimensions of the distribution device but also the adjusted sizes were:

- The maximum diameter of the helical coil - 0.345 m;
- The minimum diameter of the helical coil - 0.114 m;
- Helical coil pitch - 0.3 m;
- Total height of the beater - 1.1 m (of which 0.9 m with helical coil);
- Inclination angle of the distributor beater α = 5°, 10° and 15°;
- Beater speed n = 360, 440 and 540 rpm;
- Compost feed flow rate Q = 6, 15 and 26 kg/s;
- Semi-fermented manure flow rate Q = 10, 23 and 40 kg/s;
- Number of beaters - 4;
- Distance between beaters - 0.5 m.

The machine for solid organic fertilizer spreading with vertical helical beaters used for carrying out the experimental research is intended for fertilizing lowlands with a maximum slope of 6°, for cereal crops, industrial plants, vegetables, etc. During the tests, the machine was fully loaded (Fig. 2) and the fertilizer was distributed on a geotextile material, arranged transversely on the direction of movement of the machine as it can be seen in Fig. 3. The samples were collected in plastic bags, on surfaces of 1 m^2 measured with the help of a square metal frame with a side of 1 m, numbered and weighed.

Fig. 2 – The machine loaded with manure

Fig. 3 - The machine working

The purpose of processing the experimental data was to obtain multivariable regression functions that have a polytrophic and/or polynomial form with which to appreciate the functional and qualitative indicators of the fertilizer machine.

The form of multivariable functions is the following:

$$y = f(x_i, a_0, a_i, a_{ii}, a_{ij}) \qquad (1)$$

which expresses the dependence of the function y on the independent variables x_i and on the constants a_0, a_i, a_{ii}, a_{ij}.

It was necessary to perform several steps to determine the constants, as follows

- an adequate program of organizing the experiences was drawn up;
- the values of the constants were determined;
- the significance of the variables was tested;
- the adequacy of the function form was tested.

The structure of the experimental research programs used to determine the y function was as follows:

- the number $n^* = 14$ represents the number of experiments that were performed for distinct values of the independent variables, these being necessary to determine coefficients;
- the number $n_o = 4$ represents the number of identical experiments for the same value of the independent variables, these being necessary to determine the experimental errors;
- the total number of experiments performed $n=n^*+n_o=18$.

The polytropic regression function, with three independent variables, has the form *(Păunescu and David, 1999):*

$$y = a_0 \cdot x_1^{a_1} \cdot x_2^{a_2} \cdot x_3^{a_3} \cdot \quad (2)$$

where: x_1, x_2, x_3 are the independent variables and y is the dependent variable;

In this case $y = G_{ud}$, $x_1 = n$, $x_2 = \alpha$ and $x_3 = Q$, *and* a_0, a_1, a_2, a_3 are the constants of the independent variables, Q being the manure feed flow.

Using the calculation algorithm described by *Păunescu and David, 1999*, a special program was created, which calculates the above mentioned, for both types of multivariable functions.

The degree of uniformity of the distribution was calculated with relation 3, for each proposed variant *(Popescu et al., 1983).*

$$G_{ud_j} = \left[1 - \frac{\sqrt{\frac{\sum_{i=1}^{j} (\sigma_i - \bar{\sigma})^2}{j-1}}}{\bar{\sigma}} \right] \cdot 100 \quad (3)$$

where G_{ud} is the spreading uniformity [%];

σ_i - quantities of material collected from the ground following the experiments [kg],

$\bar{\sigma}$ - collected material arithmetic mean [kg],

j is the total number of samples collected.

RESULTS

The conditions under which the research was carried out were determined in advance.

The *slope of the two lands* where the experiments were carried out was determined with a clinometer, which registered 1° and 2° which falls within the maximum of 6° provided by the national standard. The average *wind speed* was 1.62 m/s, which is in line with the recommendations of the cited standards. *Density* of organic fertilizers: the density of the compost used was ρ=510 kg/m^3 obtained as an average of the 5 samples of material taken from the platform and that of the semi-fermented manure was 800 kg/m^3. The measured *humidity* was 72.33% for compost and 81.73% for semi-fermented manure.

Based on the research conducted, several data were obtained.

Determination of multivariable functions for the degree of distribution uniformity for compost

To determine the coefficients of the multivariable functions needed to calculate the uniformity degree of compost spreading, three independent variables influencing the dependent variable were chosen, as well as their range of variation:

A minimum, a maximum and a medium level were chosen for each independent variable n, α and Q. The experimental test program used to determine the multivariable functions for the degree of compost distribution uniformity is presented in Table 1.

Table 1

The test program of experimental data used to determine the degree of uniformity for compost distribution

Den. no.	Rotational speed, n [rpm]	Beater inclination angle, α [°]	The feed flow rate, Q [kg/s]	Degree of distribution uniformity, G_{ud}, [%]
1	360	5	6	77.67
2	540	5	6	79.16
3	360	15	6	78.43
4	540	15	6	79.78
5	360	5	26	78.21
6	540	5	26	78.99
7	360	15	26	83.70
8	540	15	26	84.30
9	360	10	15	78.99
10	540	10	15	75.50
11	440	15	15	83.11

Table 1
(continuation)

Den. no.	Rotational speed, n [rpm]	Beater inclination angle, α [°]	The feed flow rate, Q [kg/s]	Degree of distribution uniformity, G_{ud}, [%]
12	440	5	15	75.96
13	440	10	26	83.39
14	440	10	6	79.07
15	440	10	15	81.78
16	440	10	15	82.21
17	440	10	15	79.49
18	440	10	15	81.02

The obtained polytrophic regression function with three independent variables, n, α, Q which expresses the uniformity degree of the spreading is:

$$G_{ud} = 68.6706 \cdot n^0 \cdot \alpha^{0.0427} \cdot Q^{0.0221} \tag{4}$$

where G_{ud} is the spreading uniformity [%];
n – beater rotational speed 360 - 540 [rpm];
α – inclination angle of the beaters 5 - 15 [°]
Q – beater feed flow 6 - 26 [kg/s]

It is observed that in the range n = 360-540 rpm, the degree of uniformity of the distribution does not depend on the beater rotational speed, the speed coefficient being zero.

For three considered values of the beater inclination angle, the degree of uniformity of the fertilizer distribution, depending on the flow rate, can be expressed as follows:

- for α = 5°: $$G_{ud} = 68,6706 \cdot 5^{0,0427} \cdot Q^{0,0221} \tag{5}$$
- for α = 10°: $$G_{ud} = 68,6706 \cdot 10^{0,0427} \cdot Q^{0,0221} \tag{6}$$
- for α = 15°: $$G_{ud} = 68,6706 \cdot 15^{0.0427} \cdot Q^{0.0221} \tag{7}$$

Deviation of distribution uniformity values calculated with relation 4, compared to the experimental values from table 1, is calculated and a maximum 6.5% is achieved. This shows that the form of the function 4 is precise enough.

Figure 4 shows the distribution uniformity for compost spreading comparing the experimental results and those calculated using the polytropic regression function obtained previously, for each experiment.

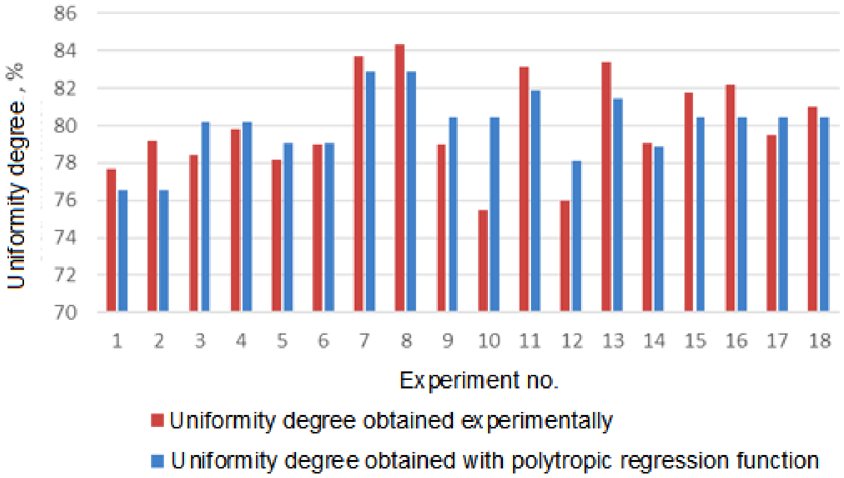

Fig. 4 - The degree of distribution uniformity for compost

Fig. 5 shows graphically the uniformity degree depending on the inclination angle of the beaters and the flow of compost spreading.

From the graph shown in Fig. 5, the degree of uniformity can be determined for any inclination angle of the distributor beaters with values of 5° - 15° and for any flow Q in the range 6 - 26 kg/s.

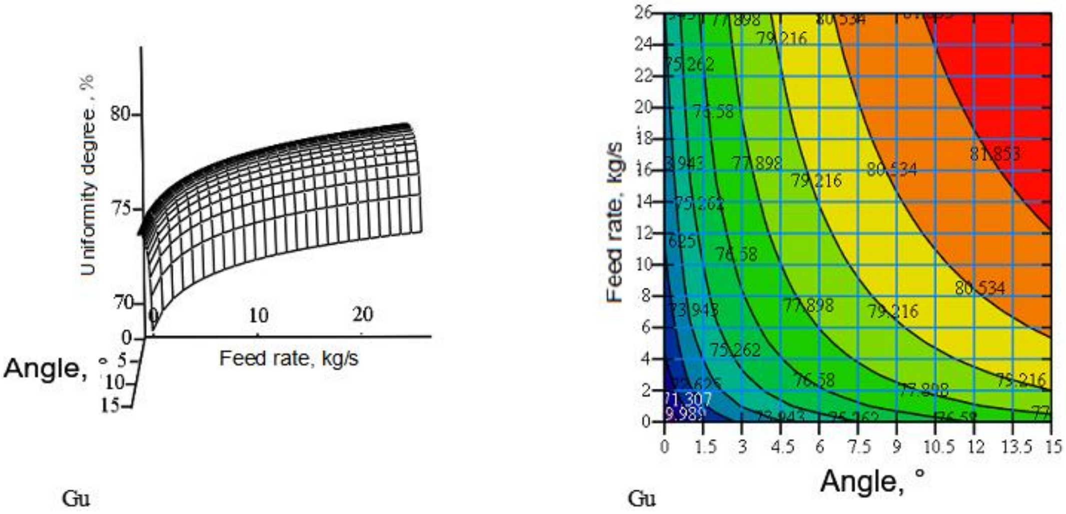

Fig. 5 - Graphical representation of the uniformity degree $G_{ud} = f(\alpha, Q)$ when spreading compost

Fig. 6 shows the variation of the uniformity degree for compost distribution depending on the feed rate for α =5°, 10° and 15°.

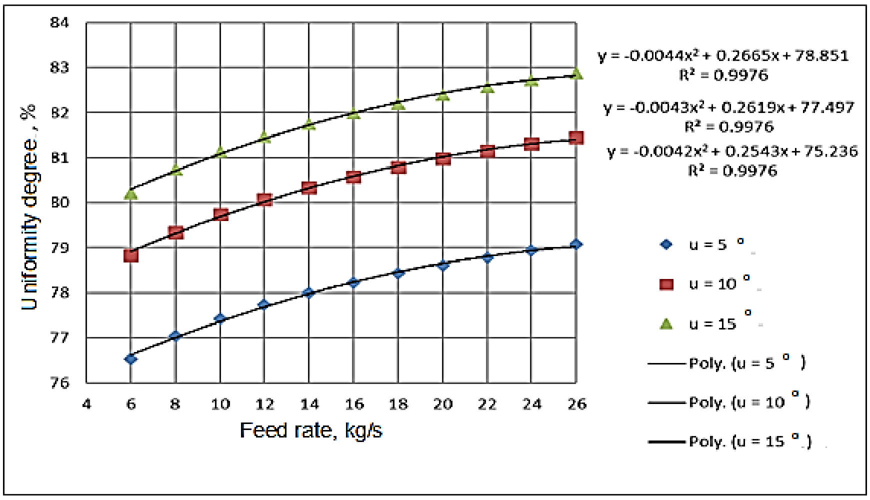

Fig. 6 - Variation of uniformity degree for compost distribution depending on the feed rate for α =5°, 10° and 15°

From the graph in Fig. 6, it is observed that the degree of uniformity obtained at an inclination of 15° is higher than that obtained at 10° and 5°. For the distributor beaters inclination of 15°, uniformities between 80.21% and 82.97% are obtained. For the inclination of 10°, values between 78.84% and 81.44% are obtained and at the inclination of 5°, values between 76.54 and 79.07% are obtained.

The degree of uniformity in the distribution of compost can be calculated as a function of flow, Q, for the constant angle of inclination of the beaters, with the relations:

- for 15°: $$G_{ud} = -0.0044 \cdot Q^2 + 0.2665 \cdot Q + 78.851$$ R^2=0.9976 (8)
- for 10°: $$G_{ud} = -0.0043 \cdot Q^2 + 0.2619 \cdot Q + 77.492$$ R^2=0.9976 (9)
- for 5°: $$G_{ud} = -0.0042 \cdot Q^2 + 0.2543 \cdot Q + 75.236$$ R^2=0.9976 (10)

It is recommended to incline the beaters of the machine to distribute solid fertilizer at an angle of 15° because it ensures a degree of distribution uniformity of the maximum compost in the range 80.22% - 82.97%.

Determination of multivariable function for the degree of distribution uniformity for semi-fermented manure

For the second type of fertilizer used for tests, the same procedure was applied. In order to determine the coefficients of the multivariable function that calculate the *spreading uniformity degree*, G_{ud}, the following independent variables were considered to be influencing the dependent variable, but also the range of their variation:

- Beater speed: n = 360; 440; 540 rpm;
- Beater inclination angle: α = 5°; 10°; 15°;
- Feed flow: Q = 10; 23; 40 kg/s

For each independent variable n, α and Q, a minimum and a maximum level were chosen, these being located at equal distances from a central level considered as the origin.

The experimental test program, used to determine the multivariable functions for the uniform distribution of semi-fermented waste is presented in Table 2.

Table 2

The test program of experimental data used to determine the degree of uniformity for semi-fermented manure distribution

Den. no.	Speed, n,[rpm]	Beater inclination angle α [°]	The feed flow rate Q [kg/s]	Degree of distribution uniformity G_{ud} [%]
1	360	5	10	80.52
2	540	5	10	80.17
3	360	15	10	83.94
4	540	15	10	82.65
5	360	5	40	88.21
6	540	5	40	84.16
7	360	15	40	82.76
8	540	15	40	82.57
9	360	10	23	83.50
10	540	10	23	76.19
11	440	15	23	83.11
12	440	5	23	82.10
13	440	10	40	83.18
14	440	10	10	83.13
15	440	10	23	83.27
16	440	10	23	81.35
17	440	10	23	80.52
18	440	10	23	80.17

The regression function that approximates the experimental results was found with a Turbo Pascal routine. This function is:

$$G_{ud} = 62.7978 \cdot n^{0} \cdot \alpha^{0.0521} \cdot Q^{0.0483} \tag{11}$$

The distribution uniformity of the semi-fermented manure does not depend on the beater speed in the range 360-540 rpm.

Figure 6 shows the experimental values of the uniformity degree of semi-fermented manure distribution, compared to the values calculated using the polytropic regression function obtained previously, for each experimental test.

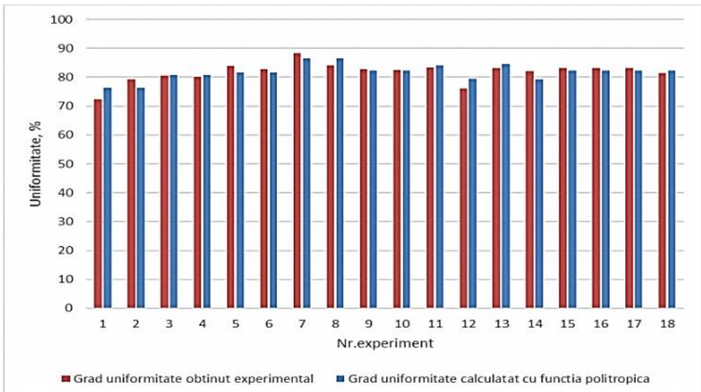

Fig. 6 - Degree of distribution uniformity for experimental and calculated values for semi-fermented manure

The deviation of the calculated values of the uniformity degree for the distribution between the experimental values and calculated ones, is maximum 4.29%, value that shows that the form of the function is quite precise.

Fig. 7 shows graphically the uniformity degree of semi-fermented manure spreading.

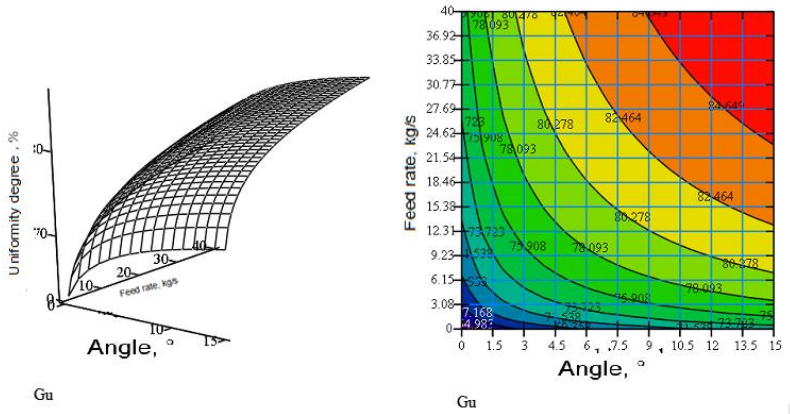

Fig. 7 - Graphical representation of the uniformity degree G_{ud} = f (α, Q) when spreading semi-fermented manure (polytropic function)

Consider the inclination angle of the beaters to be constant and from relation 9 the calculation relations of the uniformity degree as a function of the feed rate Q are obtained:

- for α = 5°: $$G_{ud} = 62,7978 \cdot 5^{0,0521} \cdot Q^{0,04832} \quad (12)$$
- for α = 10°: $$G_{ud} = 62,7978 \cdot 10^{0,0521} \cdot Q^{0,04832} \quad (13)$$
- for α = 15°: $$G_{ud} = 62,7978 \cdot 15^{0,0521} \cdot Q^{0,04832} \quad (14)$$

Fig. 8 shows the variation of the uniformity degree of the semi-fermented manure distribution depending on the feed rate for α =5°, 10° and 15°.

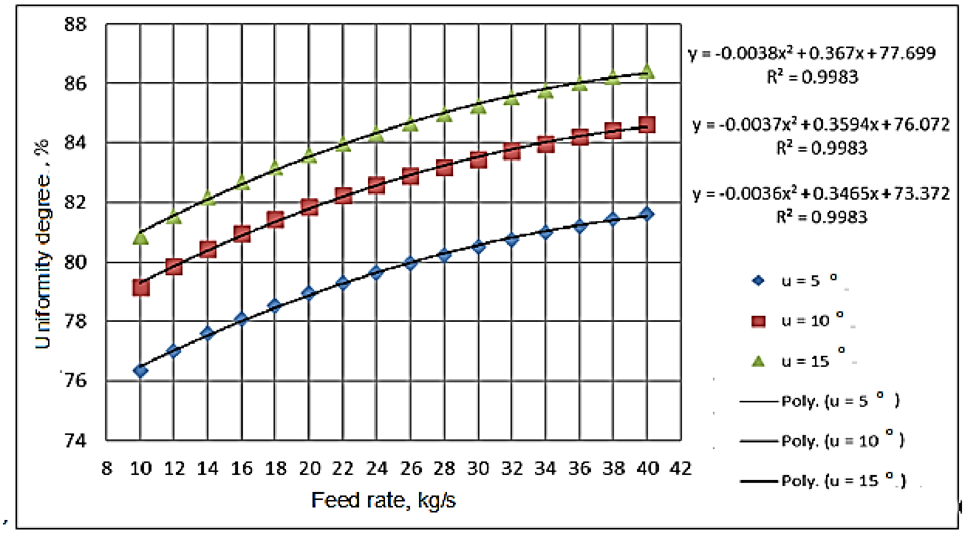

Fig.8 - Variation of the uniformity degree of semi-fermented manure distribution depending on the feed rate for α =5, 10 and 15 °

The degree of uniformity in the distribution of semi-fermented manure can be calculated as a function of flow (Q), for the constant angle of inclination of the beaters, with the relations:

- for 15°: $$G_{ud} = -0.0038 \cdot Q^2 + 0.3670 \cdot Q + 77.699 \quad R^2=0.9983 \quad (14)$$
- for 10°: $$G_{ud} = -0.0037 \cdot Q^2 + 0.3594 \cdot Q + 76.072 \quad R^2=0.9983 \quad (15)$$
- for 5°: $$G_{ud} = -0.0036 \cdot Q^2 + 0.3465 \cdot Q + 73.372 \quad R^2=0.9983 \quad (16)$$

It is recommended that the inclination of the beaters of the solid fertilizer spreading machine be 15° because it ensures maximum degree of uniformity (G_{ud} ∈ 82.69% - 86.43%).

From the graph in Fig. 8 it is observed that the degree of uniformity obtained at an inclination of 15° is better than that obtained at 10° and 5°. At an inclination of 15°, uniformities between 80.83% and 86.43% are obtained, at an inclination of 10° values between 79.14% and 84.63% are obtained and at an inclination of 5° values between 76.33% and 81.62% are obtained.

CONCLUSIONS

The deviation of the values of the compost distribution uniformity degree, calculated with the polytropic form function, compared to the experimental values is of maximum 6.56%, which shows that the form of the obtained function is quite precise. The degree of uniformity of the compost distribution has the maximum value at the inclination of the beaters of 15° and has the minimum value for the angle of 5°. At the inclination of the distributor beaters of 15° uniformities between 80.22% and 82.97% are obtained, at the inclination of 10° values between 78.84% and 81.45% are obtained and at the inclination of 5° values between 76.54 and 79.07% are obtained.

The deviation of the values of the uniformity degree of semi-fermented manure distribution calculated with the polytropic form function compared to the experimental values is of maximum 4.294% which shows that the form of the function is quite precise. At an inclination of 15° uniformities are obtained between 80.84% and 86.44%, at an inclination of 10° values between 79.15% and 84.63% are obtained and at an inclination of 5° values between 76.34% and 81.63% are obtained.

It is recommended to incline the beaters of the fertilizer spreader to 15°, considering that the research results showed a degree of uniformity between 80.22 ... 82.97%, when distributing the compost and 80.84 ... 86.44%, when distributing semi-fermented manure.

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