Conference Paper

Results of Theoretical Studies to Substantiate the Parameters of Multi-blade Rotary-type Working Bodies

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Abstract

The article presents the results of theoretical studies of the technological process of operation of multi-blade working bodies of rotary type, intended for the distribution of solid organic fertilizers. To determine the length of the blades of the last row of rotors, and accordingly the overall dimensions of the spreader, theoretical dependences of the range of fertilizer particles on the radius of the blades are obtained, which made it possible to determine the size of the blades that provide the required performance of the rotary spreader. Considering the uniform distribution of fertilizer particles over the sieving width, the dependences of the ``limiting'' zone of loading of the blades (the maximum thickness of the layer of fertilizers captured by one blade) on the angle of their inclination at different lengths of the blades were obtained, which showed that when applying fertilizers with medium and large doses, several rows of blades. Computational experiments were carried out, during which, the number of rows of blades and the ratio of the lengths of the blades of different rows were determined to obtain the smallest unevenness depending on different doses of fertilizer application. As a result of mathematical modeling, the dependences of the working insertion width on the angle of inclination of the blades of the rotor rows relative to the radial position are obtained for various second-time supply of material, using which rational values of the angle of inclination of the blades are found.

Keywords: organic fertilizers, fertilizer spreader, rotary working bodies, theoretical studies.

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1. Introduction

Productivity is an important indicator of the operation of any machine, on which its technical and economic indicators (cost of work performed, labor costs) largely depend. Improving the productivity of machines can be achieved through technological methods, organizational measures, as well as the improvement and use of promising working bodies.

The working bodies of the rotor type are used in machines for various purposes. Currently, they are used in the construction of excavators, logging, uprooting, snow throwing and dredging machines. In agricultural production, rotary-type working bodies are used in grain-sowing and tillage machines [1, 2]. Also, rotary (rotational) working bodies are widely used in the design of spreaders of organic and mineral fertilizers [3, 4].

The use of rotary type working bodies when applying solid organic fertilizers allows achieving high work productivity several times higher than the performance of body fertilizer spreaders. This ensures the introduction of fertilizers of large volumes in the required agricultural time.

A significant drawback of mass-production rotary spreaders is the high uneven distribution of fertilizers on the field surface, which does not meet agricultural requirements, which leads to a decrease in the technological and biological properties of the future crop, to crop loss during mechanized harvesting, to a decrease in the productivity of harvesting aggregates and to environmental pollution. The main reason for the poor quality of the rotary spreaders is the imperfection of the designs of the rotary distributors.

Enough works has been devoted to the improvement of the technological process of work of rotary working bodies [5--10]. Numerous theoretical and experimental studies of the working bodies of the rotor type for applying solid mineral fertilizers [11--15] made it possible to achieve acceptable results of their work, corresponding to agrotechnical requirements. However, with regard to the application of solid organic fertilizers, the issue remains open.

2. Methods

In order to search for the design of rotary working bodies, the technological process of which would satisfy agrotechnical requirements, a spreader of solid organic fertilizers with multi-blade working bodies of rotary type has been developed (RF patent No. 2222883). To substantiate the design and operational parameters of the designed structure, a mathematical model of the process of the distribution of fertilizer particles by multiblade rotors has been developed [16, 17]. Based on the obtained expressions, using the standard Maple 7 programming tools, a mathematical program was created that allows you to vary (change): design parameters of the rotors (number of rows of blades, length of the blades of each row, angle of installation of the blades relative to the radial position, angle of installation of the guide plate under the blades the last row, the height of the rotors above the field surface); kinematic parameters of rotors (speed); parameters of the formed roll (height and width of the roll); physical and mechanical properties of fertilizers (angle of repose, coefficient of friction, range of windage coefficient).

3. Results

When substantiating the overall dimensions of the developed design of the spreader, the following factors were considered. Firstly, at increased application doses, a fertilizer roll is formed having the largest dimensions (height and width). For the smooth supply of such a roll to the rotors, the front wall of the spreader frame should provide such an opportunity. Secondly, the last rows of rotor blades are installed without overlapping, and the material is supplied to them by a lifting knife and a flow divider. Accordingly, the dimensions of the spreader (height and width) will depend on the radius of the blades (their length) of the last rows of the rotor.

According to the accepted restrictions, the length of the blades of the last row was determined based on the required width of the fertilizer sifting. The working width of the serial rotary spreaders is 30--35 m. Given that these machines work with overlapping adjacent passages, the total distribution width should be 45--50 m, or 20--25 m in one direction.

Using the developed mathematical program, the dependences of the flight range of fertilizer particles on the radius of the blades of the last row of rotors are determined for different angles of installation relative to the radial position (Figure 1). Under the flight range of the particles, a path was taken that was overcome by a particle of material moving away from the center of rotation of the rotor to a maximum distance. In the calculations, the following parameter values were set: rotor speed -- n = 500 min^{-1}; fertilizer friction coefficient on metal -- f = 0.6; angle of repose -- $\varphi = 55°$. Humidity of ready-to-spread manure (half-matured) can be in the range of 40--80 %, and the particle size after interaction with the working bodies of the spreaders is from 2 to 40 mm. For a given moisture content and size, the speed of manure particles soaring is 6--23 m/s, which corresponds to a windage coefficient of the order of 0.02...0.3 m^{-1}.

The analysis of the dependences shows that with an increase in the radius of the blades, the maximum range of the particles increases. With the same blade size, the range of the particles can be different for different angles of installation of the blades relative to the radial position. Moreover, the larger the radius of the blade is, the greater is the difference in the range of the particles at its different angles of inclination. So, at R = 0.25 m, the maximum casting distance was L_{max} = 12.2 м (θ = +15°) and L_{max} = 14.5

м (θ = –15°) with a difference of 2.3 m, and at R = 0.55 m, the flight range L_{max} = 27.3 м (θ = +15°) and L_{max} = 30.2 м (θ = –15°) with a difference of 3 m.

Naturally, when choosing the radius of the blades of the last row, there was a need to strive to achieve the greatest sieving width of the fertilizer particles, with an increase in the radius of the blade, since this increases the rate of descent of the particles, and, accordingly, the flight range. All this would increase the working width of the spreader. In this case, the critical speed of the movement of manure particles would be a limitation in this case. However, an increase in the radius of the blades from 0.4 to 0.5 m leads to an increase in power consumption by 7 %, and an increase in the radius from 0.5 to 0.6 m increases the power consumption by 60 %. Therefore, the radius of the blades of the last rows of rotors was chosen equal to R = 0.4 m, which provides a theoretical flight range of 20.4–23.5 m in one direction, which corresponds to a total sieving width of 41–47 m.

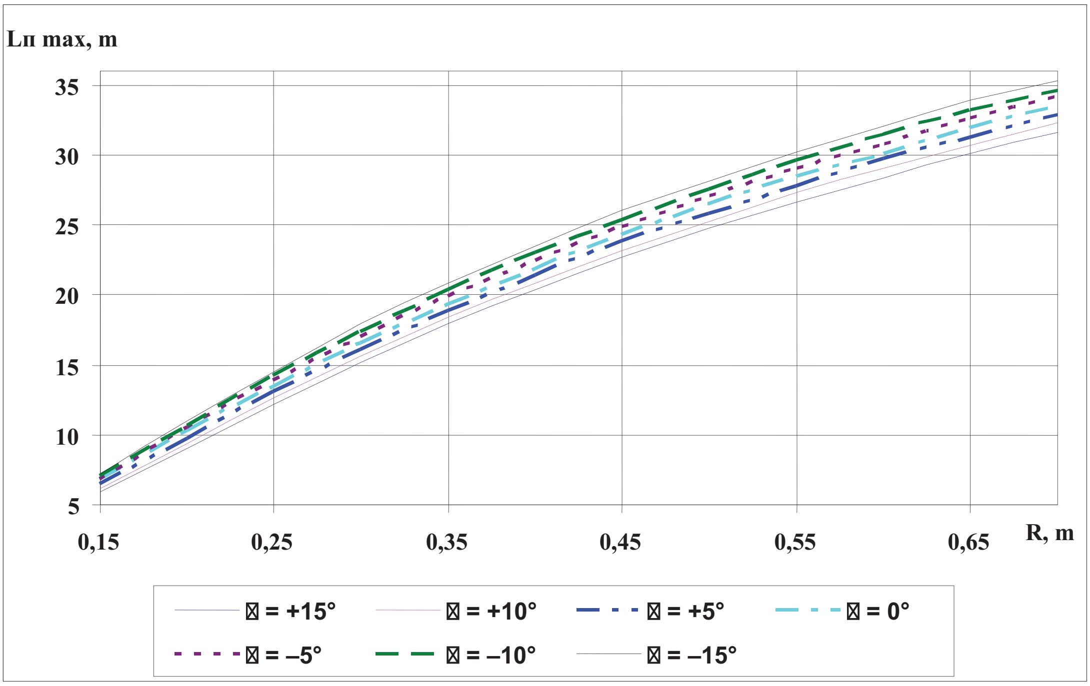

Figure 1: Theoretical dependences of the maximum flight range of fertilizer particles L_{max} depending on the radius of the blades R of the last row of rotors at different angles of inclination of the blades θ relative to the radial position.

When determining the number of rows of blades maximum necessary for the study, the results of previous studies were considered. The number of rows of rotor blades depends on the maximum loading of the blades with fertilizers (the maximum thickness of the fertilizer layer captured by one blade, which will ensure the most high-quality distribution of fertilizers near the blades on the field surface).

In order to determine the maximum load of the rotor blades, based on the conditions of the directed emission of fertilizer particles with vanishing angles within the limits that ensure the maximum flight range and dispersion over the field surface, theoretical studies have been carried out. As the initial data accepted: rotor speed n = 500 min^{-1}; coefficient of friction f = 0.6; average windage coefficient k = 0.15 m^{-1}. The following parameters were adopted as variable parameters: radius of the blade R = 0.4; 0.35; 0.3; 0.25 and 0.2 m; the angle of inclination of the blade from the radial position θ = --15°, --10°, --5°, 0°, 5°, 10°, 15°; roll height h = 0.05--0.35 m in increments of 0.01 m.

For calculations, a mathematical program was used, with the help of which the following calculations were carried out. For a given radius of the blades of the R_i of the ith row, the loading zone was gradually increased, while changing the height of the roll with a step of 0.01 m. At the same time, at each stage, the program automatically evenly distributed 20 fertilizer particles in the resulting loading zone. Further, for each of the 20 particles, the parameters of motion along the blade, the descent from the blade, and free flight in a resisting air medium were calculated. To control the calculations for each selected fertilizer particle, the program calculated and displayed the following parameters: absolute particle descent velocity V_a, angle between the horizontal line and absolute velocity direction γ_0 (take-off angle), particle flight range L.

The calculation results showed that with a small roll height, when the blade leaves the fertilizer roll and further rotation, the particles begin to move along the guide blade. In this case, the first particle located at the edge of the blade comes down and is located at a minimum distance from the rotor. Each subsequent particle located closer to the center of rotation, overcoming the friction resistance, moves along the blade, leaves it later than the previous one and carries out a flight with a greater range. Thus, the particles are evenly distributed over a certain sieving band (this is even more true if the material on the blades is evenly spaced).

However, as the height of the roll increases, and, accordingly, the loading zone of the blade, at a certain value of these parameters, the uniformity of the distribution of particles is violated (the beginning of the redistribution of particles). This value of the loading zone of the blades was called the "limiting" loading zone. Table 1 presents the calculation results of such parameters as V_a, γ_0, L and the ``limiting'' zone of loading of the blades located radially relative to the axis of rotation, with a radius R = 0.4 m with an average windage coefficient k = 0.15 m^{-1}.

An analysis of the table shows that for given initial parameters given above, when loading the blade L = 0.119 m, a uniform distribution of fertilizer particles is observed in the strip 4.1 m from the center of rotation to 11.1 m. With an increase in the loading

Table 1: Definition of the ``marginal'' blade loading zone.

Blade loading area, m	L = 0.119 m			L_p = 0.12 m		
Particle number	Options					
	V_a, m/s	γ_0, gr.	L, m	V_a, m/s	γ_0, gr.	L, M
1	21,58	3,34	4,1	21,58	3,35	4,1
2	21,77	4,77	5,1	21,78	4,79	5,1
3	21,95	6,25	5,9	21,95	6,29	6,0
4	22,11	7,78	6,7	22,12	7,83	6,7
5	22,26	9,35	7,4	22,27	9,42	7,4
6	22,4	10,96	8,0	22,41	11,05	8,0
7	22,53	12,62	8,5	22,53	12,72	8,5
8	22,65	14,31	9,0	22,65	14,42	9,0
9	22,76	16,04	9,4	22,76	16,17	9,4
10	22,86	17,8	9,7	22,87	17,96	9,7
11	22,95	19,61	10,0	22,96	19,78	10,0
12	23,04	21,45	10,3	23,05	21,64	10,3
13	23,12	23,33	10,5	23,13	23,54	10,5
14	23,2	25,26	10,7	23,21	25,48	10,7
15	23,27	27,22	10,8	23,28	27,47	10,9
16	23,34	29,22	11,0	23,35	29,5	11,0
17	23,4	31,27	11,0	23,41	31,57	11,1
18	23,46	33,36	11,1	23,46	33,68	11,1
19	23,51	35,5	11,1	23,52	35,85	11,1
20	23,56	37,69	11,1	23,56	38,06	11,0

zone to L = 0.12 m, ``redistribution'' begins to be observed fertilizer particles, which consists in the fact that, as the particles move away from the edge of the blade along the loading zone, when the blade rotates, their residence time on the blade increases, and, accordingly, the departure angle γ_0 and the flight range L (particles 1--17 of Table 1). At the same time, the maximum range of the particles is ensured at departure angles in the range ofγ_0 = 30--35°. However, at a certain distance of the particles to the edge of the blade, they move along the blade and descend from the blade at angles to the horizon of more than γ_0 = 35°, which first leads to the cessation of the increase in flight range (particles No. 17--19), and then to its decrease (particle No. 20). Accordingly, with the given design and operational parameters of the rotor, the blade loading zone with the value L = 0.12 m will be the ``limit''.

It should be noted that the operation of the blade at the loading zone greater than the ``limit'' will be accompanied by increased energy consumption, since the power spent on the friction of the material on the blade will increase, as well as the power to communicate the kinetic energy to the fertilizer particles that will fly up from the blade. In addition, a decrease in the flight range of the particles of material that descended from the blade last will disrupt the uniform distribution of fertilizers along the sieving width.

The value of the ``limiting'' zone of the blade loading will depend on such design parameters as the radius of the blades, the angle of inclination of the blade relative to the radial position, and on the rotational speed of the rotor.

Using the developed mathematical program, the dependence of the ``limiting'' loading zone on the angle of inclination of the blades θ was determined for their different radius R (Figure 2).

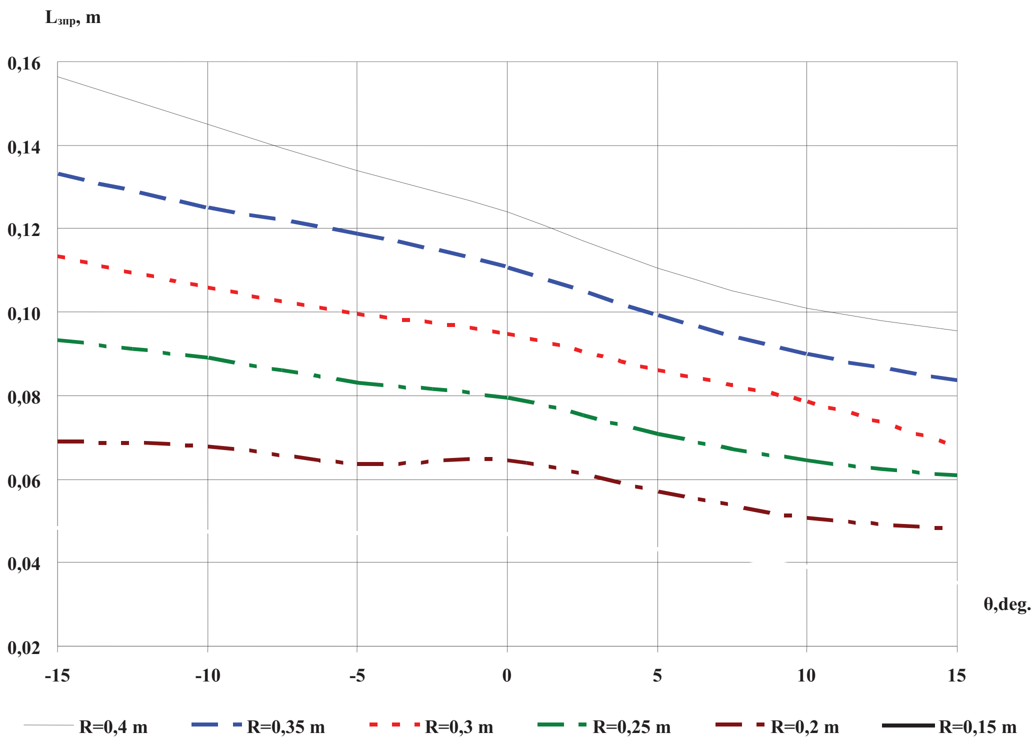

Figure 2: Theoretical dependences of the ``limiting'' zone of loading of the blades L_p from the angle of their inclination θ for different blades length R.

The analysis of the given dependences shows that for the maximum radius of the radially mounted blades R = 0.4 m, the "limiting" loading zone is $L_{p.}$ = 0.124 m. Thus, at the maximum roll height h = 0.4 m, the number of rows of blades should be 3--4. This reduced to the use of several rows of different radius blades. But a change in such a design parameter as the radius of the blade, obviously, will affect the "limiting" zone of loading. As the graphs show (Figure 2), a decrease in the radius of the blades leads to a decrease in the ``limiting'' loading zone. When the radius of the blade changes from R = 0.4 m to R = 0.15 m, the ``limiting'' loading zone decreases to 0.047 m (2.5 times). The installation of the blade at different angles of inclination to the radial position also leads to a change in the "maximum" load. For the blade R = 0.4 m at an angle of inclination θ = --15°, the ``maximum'' load was $L_{p.}$ = 0.156 m, and at θ = 15° it decreased to $L_{p.}$ = 0.19 m. From the graphs it is seen that the intensity of the decrease in the ``maximum'' load at angles of inclination of the blade from --15° to + 15° with a decrease in the radius of the blade is reduced. Moreover, with the length of the blades R = 0.2--0.15 m, the ``limiting'' load is practically equal for both positive and negative angles of inclination of the blade.

The results of the data obtained by previous researchers show that when the spreader moves with a translational speed V_p (m / min), during the movement (1 min) it passes a certain section of the roll, the length of which in absolute value is equal to the speed of the aggregate V_p. During this time, a rotary working body having Z blades, b (m) wide, makes n revolutions. Thus, the above parameters are interconnected. To ensure stable operation of the spreader, it becomes possible to select one or more parameters at specified (fixed) values of other parameters.

To justify some design parameters of the rotors using a mathematical model implemented in the form of a computer program, mathematical modeling was carried out.

The first stage of modeling was to justify, first, such design parameters as the number of rows of blades and the length (radius) of the blades in each row of the rotor.

With an increase in the application dose from the minimum to the maximum value, the overall dimensions of the roll (height and width) will increase accordingly, as the mass of its running meter will increase. According to the hypothesis, multilobed rotors, layer-by-layer capturing the material of the roll with blades of different rows, distribute it at different distances from the passage line of the spreader, depending on the radius of the blades of each row. If you do not consider the redistribution of material during the flight of fertilizer particles, it can be assumed that each individual row of rotor blades forms a certain distribution diagram on the spreading width. During the operation of the plot, from each row, overlapping each other, form the final distribution plot, which has certain unevenness. Therefore, there was a need to determine how many rows of blades should participate in the work, and what should be the ratio of the lengths of the blades of different rows to obtain the smallest unevenness depending on different doses of application of the material.

The experimental solution of the presented multivariate problem is unjustified and entails large material and labor costs. Therefore, considering the adequacy of the mathematical model, the justification of the above parameters was carried out using computational experiments.

In order to cover the entire possible range of doses of organic fertilizers (D_{Bp} = 2--6 kg/m^2), five rolls with certain characteristics (roll height and width) presented in Table 2 were selected for calculations.

For the further designation of different fertilizer rolls, it is convenient to use such a characteristic as the second feed to the rotors of the spreader q_c (kg/s) depending on the mass of a running meter of the roll m (kg\m) and the operating speed of the spreader V_p (m\s).

Since it is not possible to calculate the theoretical application dose by options, to simplify the designation of the rolls, the theoretical second feed $q_c$for each option is calculated (table 2).

Table 2: Characteristics of roll options selected for calculations.

Name of indicator	Fertilizer roll options, q_c (kg/s)				
	99	161	222	283	348
Height roll h, m	0,23	0,27	0,31	0,35	0,39
Width roll B, m	0,75	0,93	1,19	1,3	1,49
Mass of running meter m roll, kg	60	97	134	171	210

In subsequent calculations, the following parameter values were set rotor speed --- n = 516 min^{-1}; fertilizer friction coefficient -- f = 0.6; angle of repose -- φ = 55°; coefficient of windage in the range 0.05 -- 0.3 m^{-1} in increments of 0.01 m^{-1}. The length of the blades varied from 0.15 to 0.4 m. The angle of inclination of the blades relative to the radial position was assumed to be θ = 0°. In this case, the following condition was met for example, if the length of the first row of blades was assumed to be R1 = 0.2 m, then the length of the second row varied within R2 = 0.2--0.4. If R1 = 0.18 m, R2 = 0.22 then the length of the third row varied within R3 = 0.22--0.4. To comply with this condition, the following assumption was made: the amount of fertilizer captured by the blades remains completely on their surface until the blade leaves the fertilizer roll without moving.

Preliminary calculations showed that in the internal programming cycle for points along the blade loading zone, varying their number from 1 to 18--20 points per loading zone is accompanied by a change in the theoretical diagram of the distribution of material particles. With an increase in the number of received points over 20 visual changes in the distribution diagrams were not observed.

A change in the radii of the blades of an individual row with a step of 0.01--0.04 m had practically no effect on the change in the distribution diagrams. When the step is increased to 0.04 m, the distribution plots changed.

Thus, for the main calculations accepted: the number of points in the loading zone -- 21; variation of the radii of the blades in increments of 0.04 m.

Based on the theoretical distribution diagrams obtained as a result of calculations, the theoretical non-uniformity of sieving of the relative amount of material (particles) that fell into individual points of the capture width, which was estimated by the coefficient of variation(ν, %)was determined. hen, by applying the diagrams, the theoretical working spreading width (B_p, m)was calculated. In this case, a methodology was used to determine the unevenness and working spreading width used in GOST R 52759-2007 ``Machines for applying solid organic fertilizers: Test methods''.

According to the authors, this is quite acceptable, since the coefficient of variation not only characterizes the relative measure of deviation of the obtained values from the arithmetic mean, but is also used in cases where it is necessary to compare the standard deviations expressed initially in different units of measurement for different populations. In addition, the working width of the application depends only on the nature of the distribution of the material. Therefore, the above indicators can be used to evaluate theoretical graphs of the distribution of fertilizer particles.

In total, more than 300 calculations were performed for all variants of the selected rolls. The simulation results are presented in Figures 3--7. On the coordinate grids along the ordinate axis, the percentage of particles that fall into a distribution zone along the aggregate capture width (abscissa axis) is plotted.

Presenting graphs for all calculations is impractical, therefore, for each selected roll with a certain second feed, the best options are presented when using one, two, three or four rows of blades at the same time.

We assumed that the distribution of material by two-rotor multi-blade working bodies is symmetrical. This assumption applies only to ideal conditions (lack of crosswind, well-aligned horizontal surface of the field, uniformity of the laid roll, etc.). Under real operating conditions, due to several factors, including those listed above, the distribution graph symmetry will be broken. However, about the mathematical model, such an assumption is possible and justified, since it is not possible in advance to consider all

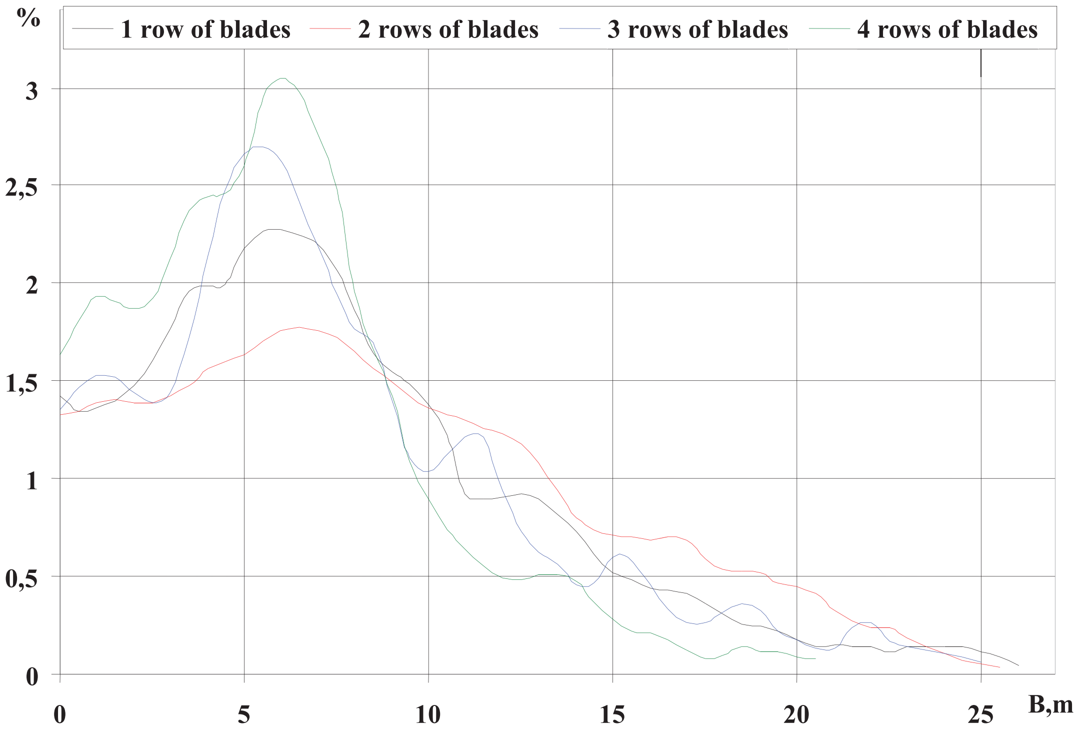

Figure 3: Particle distribution pattern using a different number of rows rotor blades for roll q_c = 99 kg\s.

the above random factors. The graphs (figures 3--7) show only the right half of the total distribution, the left part in our mathematical model has a mirror image.

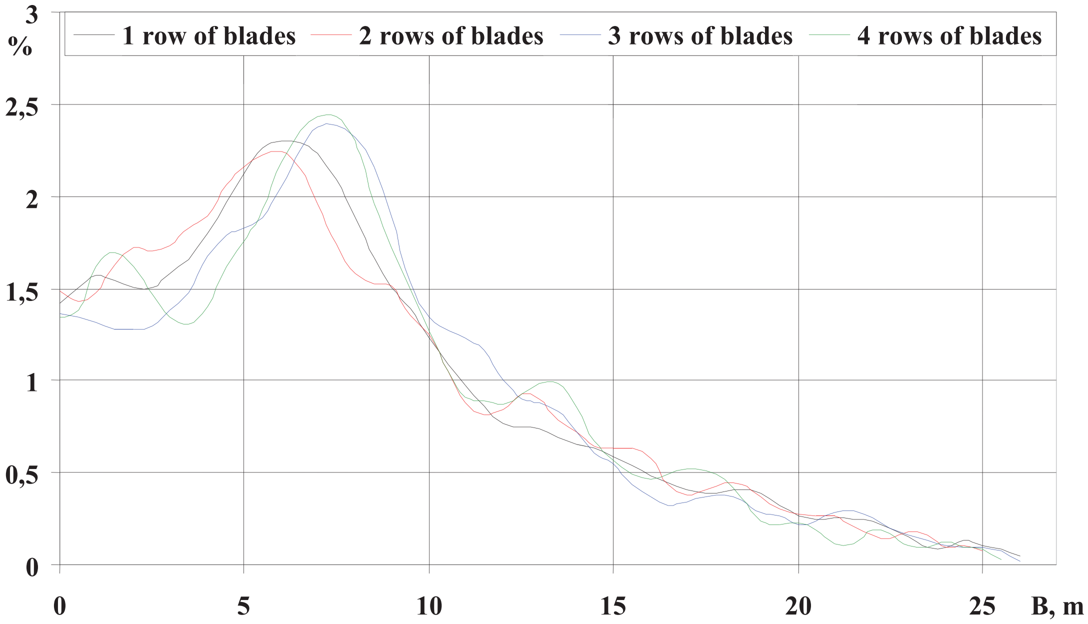

Figure 4: Particle distribution pattern using a different number of rows rotor blades for roll q_c = 161 kg / s.

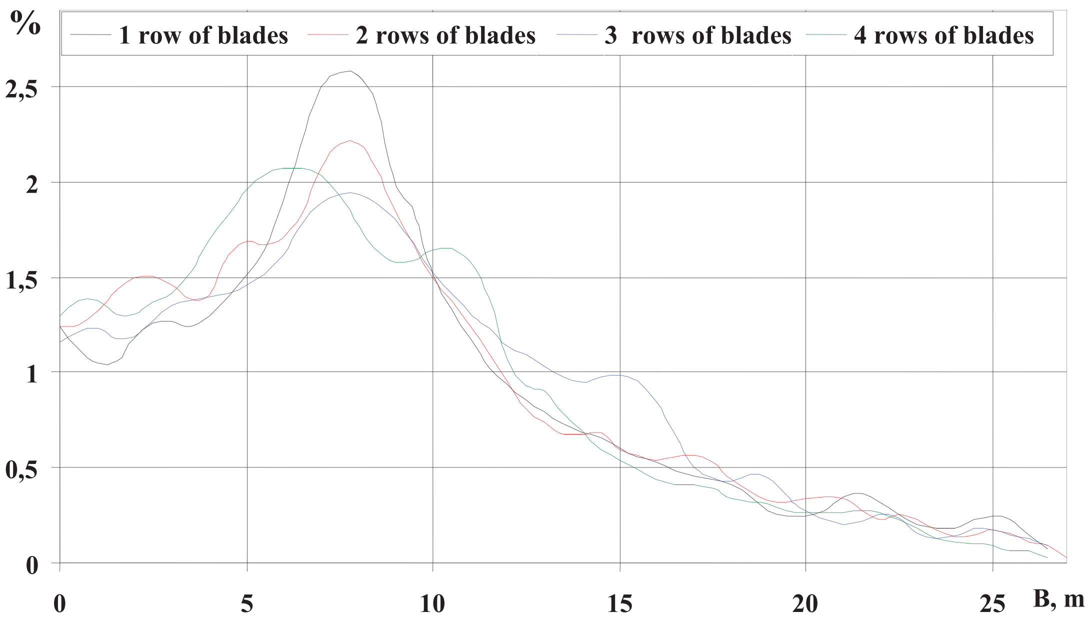

Figure 5: Particle distribution pattern using different numbers of rows rotor blades for roll q_c = 222 kg\s.

The results of computer simulation in numerical form are presented in table 3. Analysis of the data in table 3 showed that for rolls with a second feed q_c = 100--160 kg\sit is advantageous to use rotors with two rows of blades, for q_c = 200--300 kg\s -- three a number of blades provide the best distribution quality, for q_c = 300--350 kg\sit is necessary to use rotors with four rows of blades. This can be explained as follows. As noted earlier, each row of rotors forms its distribution diagram. Ultimately, the program overlays distribution plots from each row of blades. In the calculations of rolls q_c = 99 and 161 kg\s, they are characterized by a relatively small mass of running meter, and, accordingly, by small values of the height of the rolls. When using one row of rotors (R4 = 0.4 m), the distribution diagram has a pronounced maximum of material in the sieving zone of 6--8 m from the center of rotation of the rotors (Figures 3--7). This is since the height of the roll forms a significant zone of loading of the blades leading to an increase in the sieving sector of fertilizer particles. Therefore, particles located on the blades closer to the center of rotation fly out with vanishing angles in the range of γ_0 = 56--182°, which ultimately determines the shape of the distribution diagram. If two rows of rotors are involved in the calculations, the loading zone of the blades decreases, and the material sieving sector decreases. The vanishing angles of the particles are γ_0 = 2--46°. In this case, the zone of the greatest accumulation

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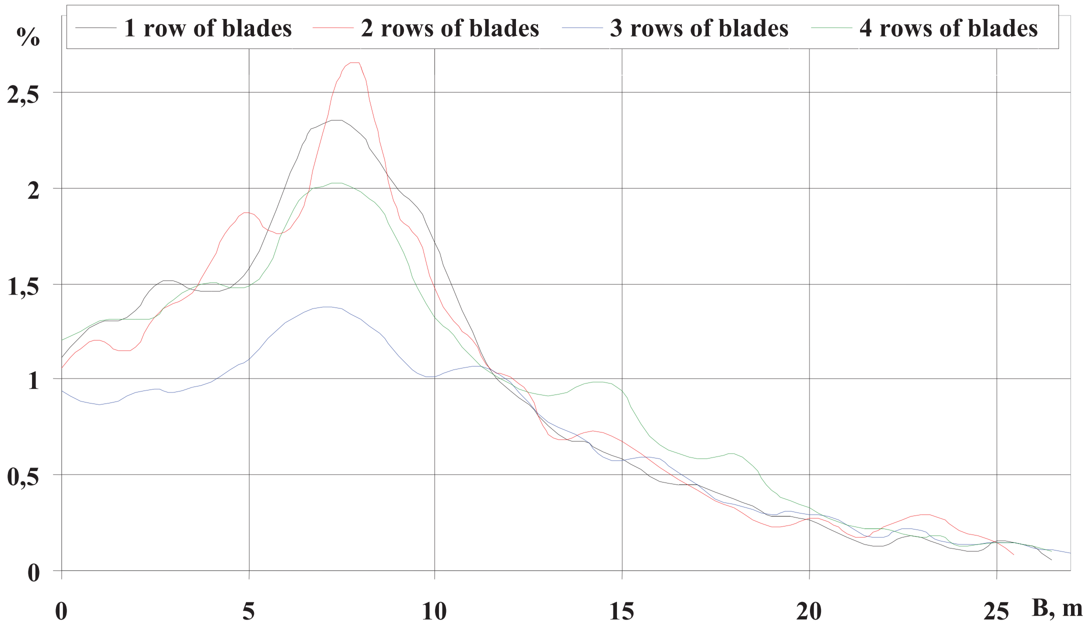

Figure 6: Particle distribution pattern using different numbers of rows rotor blades for roll q_c = 283 kg/s.

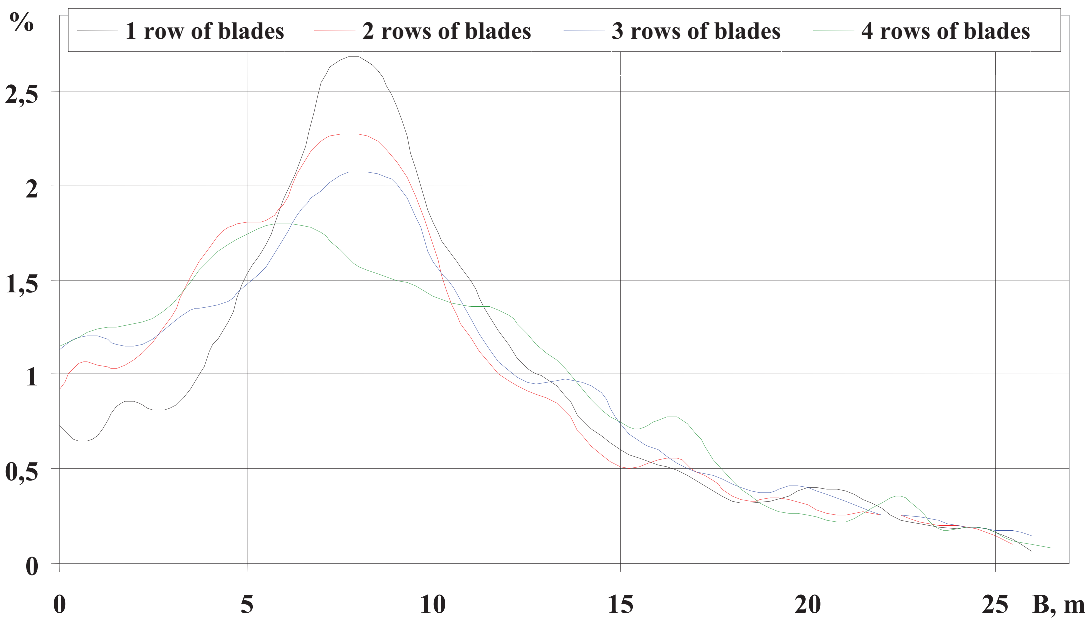

Figure 7: Particle distribution pattern using different number of rows rotor blades for roll q_c = 348 kg\s.

operating conditions, due to several factors, including those listed above, the distribution graph symmetry will be broken. However, about the mathematical model, such an assumption is possible and justified, since it is not possible in advance to consider all the above random factors. The graphs (figures 3--7) show only the right half of the total distribution, the left part in our mathematical model has a mirror image.

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When three and four rows of blades are included in the calculations, the particle array is divided into three or four streams, the loading zones of the blades become insignificant. Particles have a relatively low absolute take-off speed. The vanishing angle varies between γ_0 = 1--35 °. Therefore, the sieving is carried out on the site near the center of rotation of the rotor, which increases the uneven distribution. Equally important is the ratio of the lengths of the blades of each row. The number of particles in a certain sieving zone and the nature of the distribution diagram depend on this. In the considered option, the use of double-row rotors with given ratios of blade lengths gives the most high-quality overlay of diagrams.

The above factors are also valid for rolls q_c = 222, 283 и 348 kg\s. An increase in the second feed increases the height and width of the rolls. To ensure uniform sieving of particles, it is necessary to separate the material into a larger number of flows. Therefore, in this case, it is advantageous to use three or four-row rotors.

In order to determine the effect on the uniformity of distribution of such a parameter as the angle of the blades relative to the radial position θ, additional computational experiments were performed for the selected rational parameters of the rotors for each calculation roll (table 3).

Table 3: Results of theoretical studies to substantiate the number of rows of blades and the length of the blades.

q_c, kg\s	The number of rows of blades involved in the calculation											
	1 row			2rows			3 rows			4rows		
	Blade dimensions	v, %	B_p, m	Blade dimensions	v, %	B_p, м	Blade dimensions	v, %	B_p, m	Blade dimensions	v, %	B_p, m
99	R_4 = 0.4 m	78,9	26	R_4 = 0.4 m R_3 = 0.32 m	**73,4***	**27,5***	R_4 = 0.4 m R_3 =0.32 m R_2 = 0.28 m	81,3	24	R_4 = 0.4 m R_3 = 0.36 m R_2 =0.32 m R_1 =0.28 m	84,1	24,5
161	R_4 = 0.4 m	75,9	28	R_4 = 0.4 m R_3 = 0.24 m	**70,2***	**29***	R_4 = 0.4 m R_3 = 0.24 m R_2 = 0.2 m	76,6	27	R_4 = 0.4 m R_3 = 0.32 m R_2 = 0.24 m R_1 = 0.2 м	75,3	28,5
222	R_4 = 0.4 m	75,7	29,5	R_4 = 0.4 m R_3 = 0.2 m	71,4	30	R_4 = 0.4 m R_3 = 0.16 m R_2 = 0.12 m	**63,2***	**33,5***	R_4 = 0.4 m R_3 = 0.32 m R_2 = 0.2 m R_1 = 0.16 m	73,7	29,5
283	R_4 = 0.4 m	77,9	29,5	R_4 = 0.4 m R_3 = 0.28 m	73,4	31	R_4 = 0.4 m R_3 = 0.28 m R_2 = 0.16 m	**60,7***	**35***	R_4 = 0.4 m R_3 = 0.2 m R_2 = 0.16 m R_1 = 0.12 m	64,3	32,5
348	R_4 = 0.4 m	79,2	30	R_4 = 0.4 m R_3 = 0.2 м m	71,6	32,5	R_4 = 0.4 m R_3 = 0.28 m R_2 = 0.12 m	65,4	33	R_4 = 0.4 m R_3 = 0.32 m R_2 = 0.18 m R_1 = 0.16 m	**61,9***	**37,5***

* Selected as the best options for further experimental research.

Figure 8 shows the theoretical dependences of the working spreading width on the angle of inclination of the blades θ. In the calculations, the value of θ ranged from --15° to + 15° with an interval of 5 °.

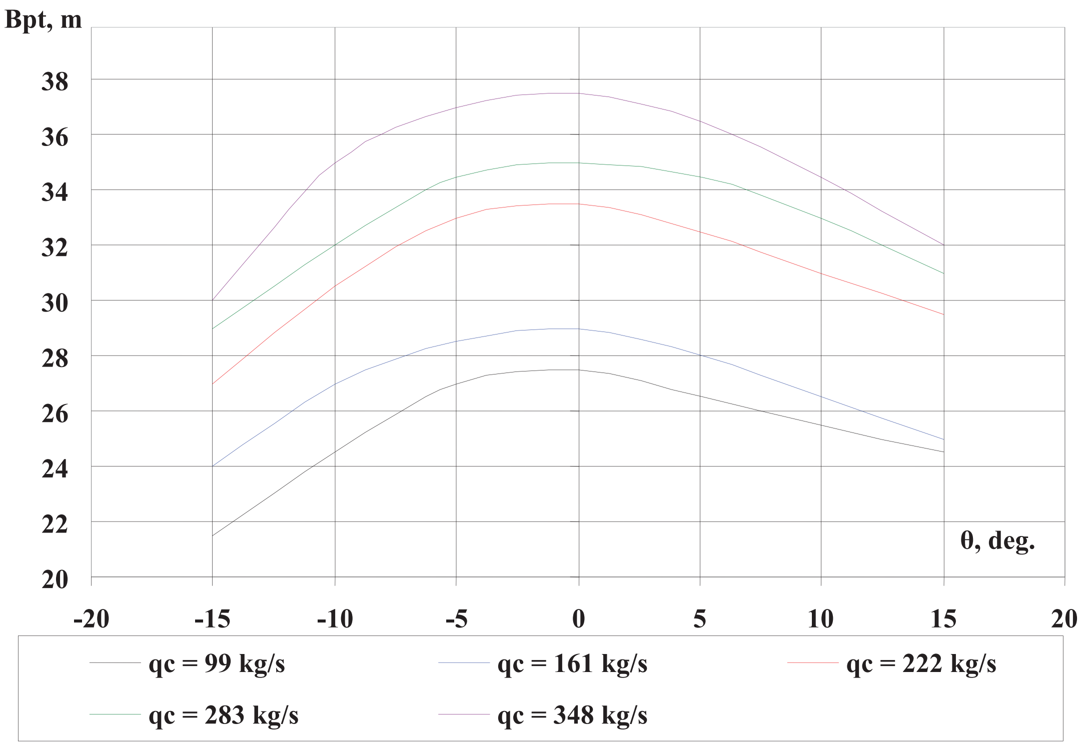

Figure 8: Theoretical dependencies of the working spreading width on the angle of inclination of the rotor blades.

From the graphs in almost the entire range of second feeds, the largest working spreading width is obtained when the blades are oriented at an angle θ = 0°...--5° relative to the radial position.

The results can be explained as follows. At positive angles of installation of the blades, due to the action of the component of the centrifugal force, the friction force of the particles of the spreading material on the blades increases. Consequently, their residence time on the blades increases. In this case, the angle of the sieving sector is shifted to the zone of large values of the angles of particle ejection relative to the horizon. All this leads to the fact that a certain number of particles is thrown vertically upward or is thrown through the rotor, which affects the distribution. At negative installation angles in the range θ = --10°...--15°, the friction force decreases. The sieving sector is shifting in the opposite direction. Therefore, the particles leave the blade earlier and are located close to the axis of rotation of the rotor, which also affects the distribution.

4. Conclusion

The performed mathematical modeling of the technological process of operation of multi-blade rotary-type working bodies allowed us to substantiate the design and operating parameters of the developed design at the stage of theoretical research.

To determine the length of the blades of the last row of rotors, and, accordingly, the overall dimensions of the spreader, a theoretical dependence of the flight range of fertilizer particles on the radius of the blades is obtained. To ensure the required performance of the spreader, the radius of the blades of the last row is taken equal to R4 = 0.4 m.

Considering the uniform distribution of fertilizer particles over the sieving width, the dependences of the ``limiting'' zone of loading of the blades (the maximum thickness of the layer of fertilizers captured by one blade) on the angle of inclination at different blade lengths are obtained. Based on the maximum possible height of the fertilizer roll, the required number of rows of blades equal to Z = 3--4 is determined when large doses of material are introduced.

Computational experiments were carried out to determine the number of rows of blades and the ratio of the lengths of the blades of different rows to obtain the smallest unevenness depending on the different doses of the material. As a result, it was found that for fertilizer rolls with a second feed q_c = 90--180 kg\s double-row rotors should be used, for rolls with a feed q_c = 190--320 kg\sit is advantageous to use three-row rotors, and for second rolls higher than q_c = 330 kg\s four-row rotors should be used.

As a result of computer experiments, the dependences of the working spreading width on the angle of inclination of the blades of the rotor rows with different second feed of material are obtained. The dependences show that for the angles of inclination of the rotor blades within $\theta = 0°...--5°$ relative to the radial position, the minimum theoretical non-uniformity of the distribution of fertilizer particles was obtained, and accordingly the maximum theoretical working width. This trend is visible in the entire range of second fertilizer feeds.

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