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METHODOLOGY FOR STUDYING OF SOME BASIC PARAMETERS IN THE GRANULATION PROCESS OF POULTRY MANURE PART 2 ANALYSIS OF THE RESULTS OF THE STUDY

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Analysis of the results of the study*:*

The results of the study of the granulation process of poultry manure are presented in this paper. The correlation between the parameters has been evaluated. The degree of influence of the controllable factors has been determined. Adequate mathematical models of basic process parameters have been derived.

Key words*:* *granulation of poultry manure, specific energy consumption, granule strength, optimization of the process*

INTRODUCTION

Applying the methodology of the first part, laboratory tests of a device for granulation of poultry manure with a flat matrix have been carried out [1]. An optimal value of the peripheral speed of the axis of the compaction rolls equal to 0,365 m/s was set, based on prior information and preliminary studies. The number of channels with different diameter in each of the three tested matrices has been selected in such a way that the cumulative light crosssection for each matrix to be the same. There is a continuous dosing of the fertilizer, of the prepared for granulation poultry manure, providing a layer with a thickness of 50…60 mm on the matrix. The diameter of the channels in the three matrices X_3, mm has been added to the described controllable factors in the first part. The results of the multi-factual planned experiment in natural form are presented in Table 1.

Table 1 Plan of the experiment and results in natural form

№	X_1, %	X_2, mm	X_3, mm	Mc, Nm	ω, s-1	P, W	t, s	M, kg	Y_1, kg/h	Y_2, kWh/kg	Y_3, days	Y_4, t/m^3	Y_5, t/m^3	Y_6, %
1	20	0	6	9.38	99.43	932.16	60	0.19	11.20	0.083	34	1.54	0.81	98.00
2	30	0	6	4.38	99.43	435.01	190	1.42	26.82	0.016	70	1.64	0.78	99.10
3	20	2	6	8.75	99.43	870.01	420	0.04	0.32	2.719	32	1.72	0.86	98.50
4	30	2	6	3.75	99.43	372.86	400	0.24	2.12	0.176	52	1.72	0.86	97.90
5	20	0	10	7.50	99.43	745.73	260	1.01	13.98	0.053	35	1.55	0.81	97.90
6	30	0	10	3.75	99.43	372.86	90	1.05	42.00	0.009	70	1.64	0.76	99.10
7	20	2	10	6.25	99.43	621.44	90	0.02	0.80	0.777	32	1.71	0.86	98.20
8	30	2	10	3.12	99.43	310.47	480	0.65	4.88	0.063	59	1.72	0.87	98.20
9	25	1	6	6.88	99.43	683.58	190	0.79	15.00	0.046	46	1.59	0.79	97.80
10	25	0	8	6.88	99.43	683.58	120	0.67	20.22	0.034	56	1.61	0.82	99.10
11	20	1	8	7.50	99.43	745.73	300	1.07	12.80	0.058	33	1.59	0.83	97.20
12	30	1	8	3.75	99.43	372.86	120	1.23	36.86	0.010	61	1.67	0.80	98.20
13	25	2	8	6.25	99.43	621.44	420	0.17	1.43	0.435	48	1.70	0.85	97.20
14	25	1	10	5.00	99.43	497.15	180	1.25	25.00	0.020	53	1.64	0.83	98.50
15	25	1	8	6.88	99.43	683.58	130	0.61	16.80	0.041	49	1.66	0.87	98.80

The controllable factors and their interactions have been introduced in encoded form for a more accurate and precise analysis of the results and for greater precision of the regression model [2]. Thus, the experimental plan and the obtained results for the parameters acquire the expression, shown in table 2.

Plan of the experiment (x_1, x_2, x_3) in encoded values,
Expanded matrix of the experiment and experimental values of the parameters
Table 2

№	X_1	X_2	X_3	X_1*X_1	X_2*X_2	X_3*X_3	X_1*X_2	X_1*X_3	X_2*X_3	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
1	-1	-1	-1	1	1	1	1	1	1	11.2 0	0.08 3	34	1.5 4	0.8 1	98.0 0
2	1	-1	-1	1	1	1	-1	-1	1	26.8 2	0.01 6	70	1.6 4	0.7 8	99.1 0
3	-1	1	-1	1	1	1	-1	1	-1	0.32	2.71 9	32	1.7 2	0.8 6	98.5 0
4	1	1	-1	1	1	1	1	-1	-1	2.12	0.17 6	52	1.7 2	0.8 6	97.9 0
5	-1	-1	1	1	1	1	1	-1	-1	13.9 8	0.05 3	35	1.5 5	0.8 1	97.9 0
6	1	-1	1	1	1	1	-1	1	-1	42.0 0	0.00 9	70	1.6 4	0.7 6	99.1 0
7	-1	1	1	1	1	1	-1	-1	1	0.80	0.77 7	32	1.7 1	0.8 6	98.2 0
8	1	1	1	1	1	1	1	1	1	4.88	0.06 3	59	1.7 2	0.8 7	98.2 0
9	0	0	-1	0	0	1	0	0	0	15.0 0	0.04 6	46	1.5 9	0.7 9	97.8 0
10	0	-1	0	0	1	0	0	0	0	20.2 2	0.03 4	56	1.6 1	0.8 2	99.1 0
11	-1	0	0	1	0	0	0	0	0	12.8 0	0.05 8	33	1.5 9	0.8 3	97.2 0
12	1	0	0	1	0	0	0	0	0	36.8 6	0.01 0	61	1.6 7	0.8 0	98.2 0
13	0	1	0	0	1	0	0	0	0	1.43	0.43 5	48	1.7 0	0.8 5	97.2 0
14	0	0	1	0	0	1	0	0	0	25.0 0	0.02 0	53	1.6 4	0.8 3	98.5 0
15	0	0	0	0	0	0	0	0	0	16.8 0	0.04 1	49	1.6 6	0.8 7	98.8 0

Exposition

Among the six introduced parameters of the object, those which are of crucial importance are the following: Y_2 (specific energy consumption), Y_3 (duration of the digestion of the granule in an aquatic environment) and Y_6 (strength of the granules), because they are very important for the economic evaluation of the granulation process, for the effect of the plant nourishment and for the possibility of the mechanical treatment of the granules.

Studying the correlation between the parameters. The parameterY2is not correlated to any of the other parameters (see Table 3).

Correlation between parametersY1, Y2, ... Y6
Table3

	Correlations (Spreadsheet-B3.sta) Marked correlations are significant at p < .05000 N=15 (Casewise deletion of missing data)							
Variable	Means	Std.Dev.	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
Y_1	15.34833	12.99780	1.000000	-0.476625	0.673985	-0.336262	-0.779392	0.532904
Y_2	0.30268	0.70028	-0.476625	1.000000	-0.455935	0.448210	0.385748	0.014998
Y_3	48.66667	13.26470	0.673985	-0.455935	1.000000	0.204626	-0.436117	0.567361
Y_4	1.64667	0.06114	-0.336262	0.448210	0.204626	1.000000	0.592344	0.070772
Y_5	0.82667	0.03478	-0.779392	0.385748	-0.436117	0.592344	1.000000	-0.282159
Y_6	98.24667	0.61629	0.532904	0.014998	0.567361	0.070772	-0.282159	1.000000

This makes the optimization on Y_2 independent from the optimization on the other parameters. From an economic perspective, the most essential criterion for the optimization is the parameter Y_2. If the other parameters Y_3 and Y_6 have acceptable values at the optimal values of the controllable factors x_1, x_2 and x_3, determined by the condition for the minimum specific energy consumption, we will assume that the object is optimized successfully. We will do this by processing and analyzing the data of the experiment which has been carried out under plan B_3. The mathematical models are sought in the form of a second-degree polynomial:

y = b0 + b1 * x1 + b2 * x2 + b3 * x3 + b12 * x1 * x2 + b13 * x1 * x3 + b23 * x2 * x3 + b11 * x12 + b22 * x22 + b33 * x32

Studying of the specific energy consumption Y_2. The results from the regression analysis of the specific energy consumption Y_2 are given in Table 4.

Results from the regression analysis for the parameter Y^2

Table4

	Regression Summary for Dependent Variable: Y2 (Spreadsheet-B3.sta) R= ,93459869 R?= ,87347471 Adjusted R?= ,64572919 F(9,5)=3,8353 p<,07643 Std.Error of estimate: ,41681					
N=15	b*	Std.Err. of b*	b	Std.Err. of b	t(5)	p-value
Intercept			-0,054120	0,224030	-0,24158	0,818704
X1	-0,412324	0,159076	-0,341645	0,131808	-2,59200	0,048719
X2	0,479710	0,159076	0,397480	0,131808	3,01561	0,029565
X3	-0,255592	0,159076	-0,211780	0,131808	-1,60673	0,169022
X11	0,077971	0,181116	0,111900	0,259928	0,43050	0,684754
X22	0,217678	0,181116	0,312400	0,259928	1,20187	0,283227
X33	0,077274	0,181116	0,110900	0,259928	0,42666	0,687376
X12	-0,424439	0,159076	-0,393194	0,147365	-2,66816	0,044447
X13	0,249836	0,159076	0,231444	0,147365	1,57055	0,177087
X23	-0,272322	0,159076	-0,252275	0,147365	-1,71190	0,147594

It is obvious that only the coefficients $b_1 = -0{,}34$, $b_2 = 0{,}397$ and $b_{12} = 0{,}393$ are important because for them the probability p-value is less than the significance level of 0,05. The factor X_3 has no significant impact on Y_2. Thus the sought mathematical model is:

$$Y_2 = -0{,}34 * X_1 + 0{,}4 * X_2 - 0{,}39 * X_1 * X_2 \qquad (1)$$

The coefficient of determination $R^2 = 0{,}87$ indicates that 87% from the variation of Y_2 is due to the controllable factors and is described by the obtained model. This is a good description. The Fisher criterion $F(9; 5) = 3{,}8$ and its corresponding probability $p < 0{,}07$ indicate that the obtained model is adequate at a level of significance 0,1.

The influence of the individual factors X_1, X_2 and X_3 on the parameter Y_2 is determined by sequentially disengaging these factors one by one from the model. Turning off the strongest factor, the coefficient of determination will have the smallest value. In this case, the ranking of significance factors is as follows: X_2, X_1, X_3.

The influence of the factors X_1 and X_2 on the parameter Y_2 is shown in a graphic way on Figure 1. (the surface of the response) and Figure 2. (the lines of equal response). It can be seen that the surface of the response has no extreme, which is also evident from the lines of the same response.

The lowest specific energy consumption Y_2 is observed at $X_1 = 1$ (upper level) and $X_2 = 0$ (average level). These values comply with the conditions of experiment № 6 and experiment № 12, in which $Y_2 = 0{,}009$ and 0, 01 kWh/kg.

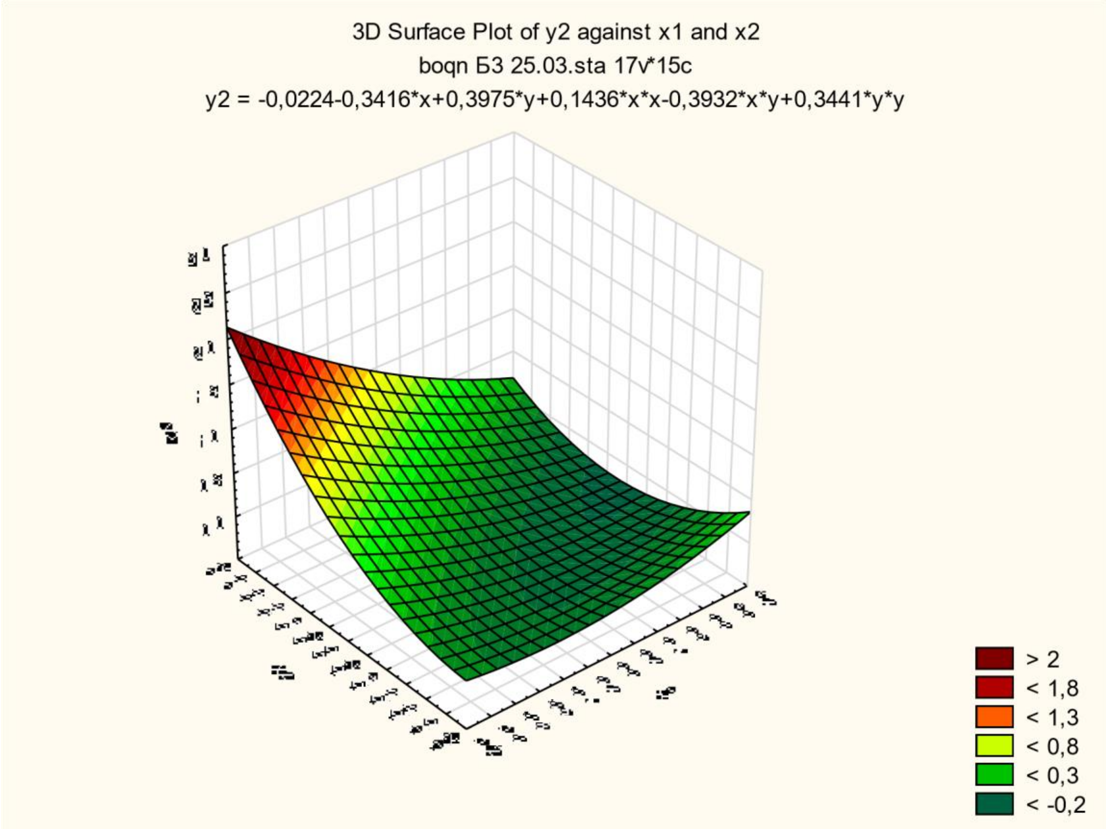

Figure 1. Surface of the response $Y_2 = f(X_1, X_2)$

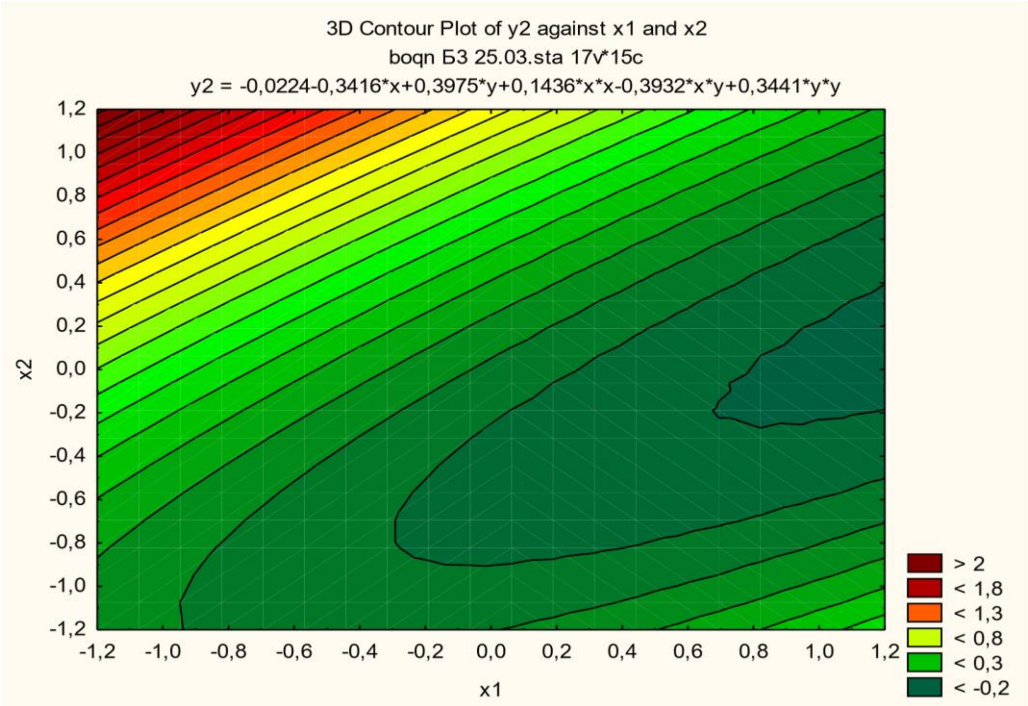

Figure 2. Lines of equal response $f(X_1, X_2) = const$

The optimal values of all the three factors are determined by optimizing in the environment of the MATHCAD software package. It is primarily intended for work in the technical sciences. It is an environment for visual programming. In this environment, modules have been developed to find the optimum of functions, obtained as regression models from a planned experiment. The modules use the built-in functions Minimize and Maximize. In this case we use the Optima 3 module. In this module we insert the regression coefficients for the parameter Y_2 from Table 2 via the function MINImization 1. The theoretical response function adopts a minimum value bending to zero at optimal factor values in coded form as follows: $X_1opt = 1$; $X_2opt = 0$ and $X_3opt = 1$.

Studying of the digestion of the granules in an aquatic environment Y_3. For the parameter Y_3 the factors X_1 and X_2 (Table 5) have an essential influence. The coefficient of determination $R^2 = 0,99$ shows that 99% from the variation of Y_3 is due to these factors and it is described by the model:

$$Y_3 = 49,89 + 14,6*X_1 - 4,2*X_2 - 3*X_1*X_2 \qquad (2)$$

Table 5: **Results from the regression analysis for the parameter Y_3**

N=15	Regression Summary for Dependent Variable: y3 (boqn Б3 25.03.sta) R= ,99590954 R?= ,99183581 Adjusted R?= ,97714028 F(9,5)=67,492 p<,00011 Std.Error of estimate: 2,0055					
	b*	Std.Err. of b*	b	Std.Err. of b	t(5)	p-value
Intercept			49,88889	1,077950	46,28128	0,000000
x1	0,930232	0,040408	14,60000	0,634210	23,02077	0,000003
x2	-0,267601	0,040408	-4,20000	0,634210	-6,62241	0,001182
x3	0,095572	0,040408	1,50000	0,634210	2,36515	0,064339
x12	-0,170964	0,040408	-3,00000	0,709068	-4,23090	0,008241
x13	0,042741	0,040408	0,75000	0,709068	1,05773	0,338582
x23	0,042741	0,040408	0,75000	0,709068	1,05773	0,338582
x11	-0,114444	0,046007	-3,11111	1,250679	-2,48754	0,055328
x22	0,069484	0,046007	1,88889	1,250679	1,51029	0,191357
x33	-0,022480	0,046007	-0,61111	1,250679	-0,48862	0,645784

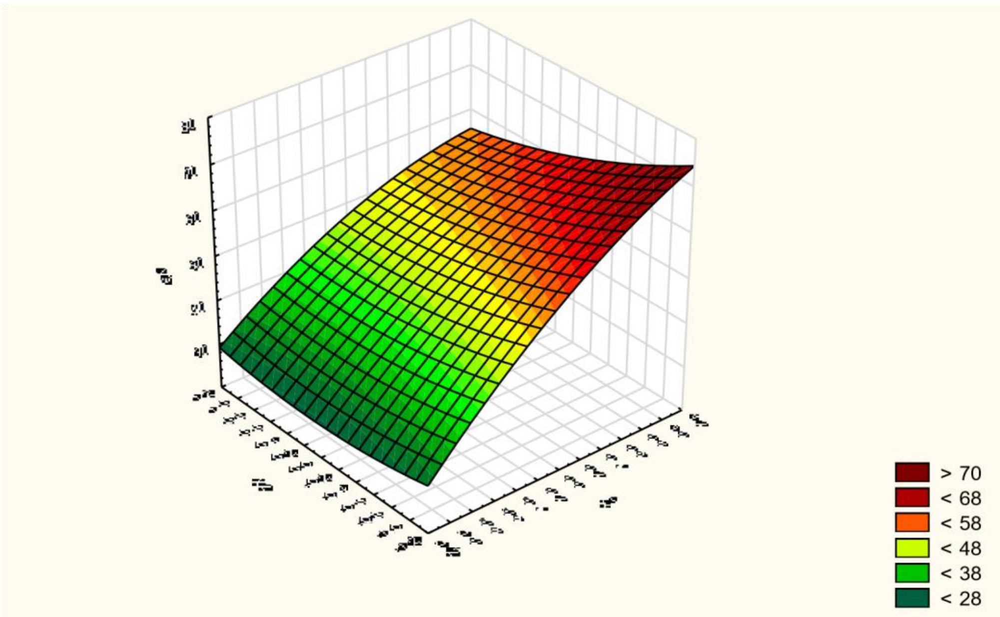

Figure 3. Surface of the response $Y_3 = f(X_1, X_2)$

The Fisher criterion F (9;5) = 67,492 and its corresponding probability p < 0,00011 indicate that the obtained model is adequate. The graphical representation of this model is shown on Figure 3 and Figure 4.

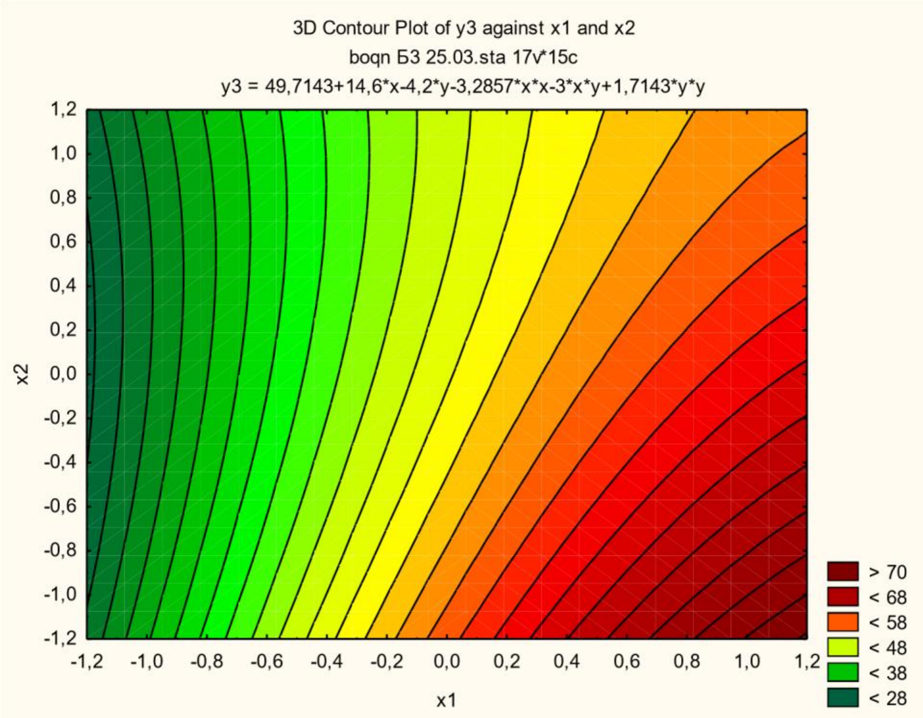

Figure 4. Lines of equal response f (X_1; X_2) = *const*

The influence of the individual factors X_1, X_2 and X_3 on the parameter Y_3 is determined by sequentially disengaging these factors one by one from the complete model from the second degree. From the comparison of the coefficients of determination R^2 follows that the strongest influence on the parameter Y_3 has the factor X_1 (humidity), then is X_2 (the gap) and the least influence has the factor X_3 (practically it does not affect the parameter Y_3). The large values of the factor Y_3 (duration of the digestion of the granule in an aquatic environment) are obtained at $X_1 = 1$ (upper level) and $X_2 = -1$ (lower level). At these values of X_1 and X_2 from the obtained model we get Y_3 = 71, 69 which is close to the maximum experimental value of Y_3 = 70 (Table 1 and Table 2 – experiments № 2 and № 6). If Y_3 replaces $X_1 = 1$ and $X_2 = 0$ (the optimal values where Y_2 has a minimum value), we will get Y_3 = 64, 5, which is close to the maximum value of Y_3.

Studying of the strength of the granules Y_6. If we assume a level of significance of 0,2 we will obtain that the coefficients b_0, b_2 and b_{12} are significant (see Table 6).
We can write for the search model:

$$Y_6 = 98{,}1 - 0{,}32 * X_2 - 0{,}36 * X_1 * X_2 \qquad (3)$$

To determine the strength of the individual factors, we will sequentially disengage these factors one by one from the full second-degree model. The influence of the individual factors is determined by the value of the coefficient of determination R^2. The strongest influence on the parameter Y_6 has the factor X_2, after that follows X_1 and the least influence has the factor X_3. Therefore, we will show the surface of the response (Figure 5) and the lines of equal response (Figure 6) in the coordinate system O, X_1, X_2,

Results from the regression analysis for the parameter Y_6 at level of significance 0,2

	Regression Summary for Dependent Variable: y6 (boqn Б3 25.03.sta) R= ,78379704 R?= ,61433781 Adjusted R?= ----F(9,5)=,88497 p<,58963 Std.Error of estimate: ,64042					
N=15	b*	Std.Err. of b*	b	Std.Err. of b	t(5)	p-value
Intercept			98,10222	0,344216	285,0020	0,000000
x1	0,370269	0,277727	0,27000	0,202519	1,3332	0,239977
x2	-0,438837	0,277727	-0,32000	0,202519	-1,5801	0,174922
x3	0,082282	0,277727	0,06000	0,202519	0,2963	0,778936
x12	-0,444637	0,277727	-0,36250	0,226423	-1,6010	0,170279
x13	0,107326	0,277727	0,08750	0,226423	0,3864	0,715066
x23	0,015332	0,277727	0,01250	0,226423	0,0552	0,958112
x11	-0,180345	0,316206	-0,22778	0,399373	-0,5703	0,593120
x22	0,175946	0,316206	0,22222	0,399373	0,5564	0,601901
x33	0,175946	0,316206	0,22222	0,399373	0,5564	0,601901

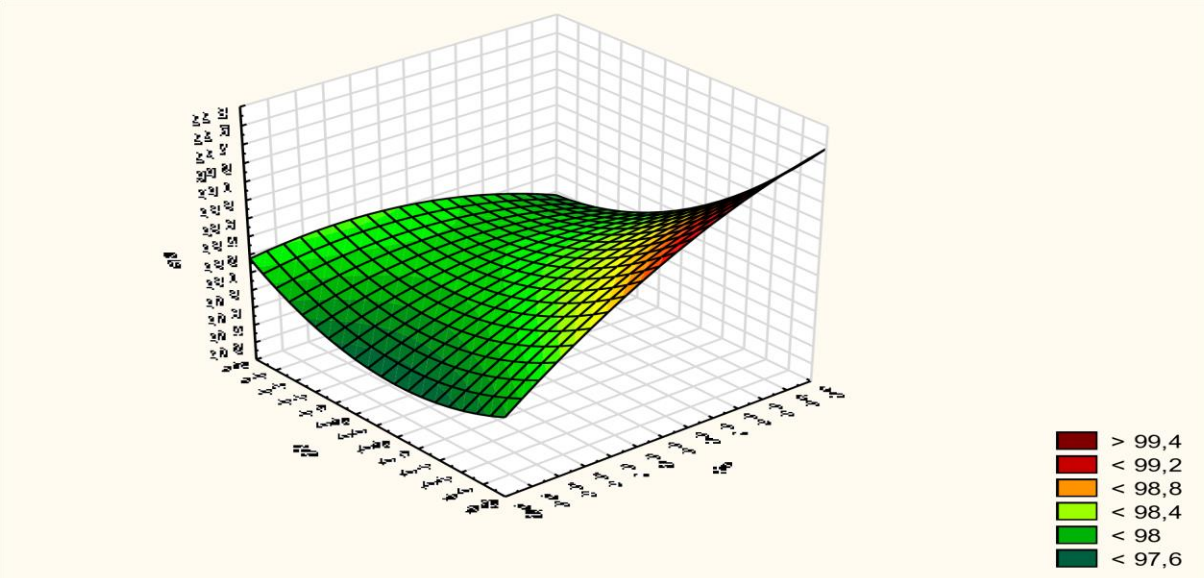

Figure 5. Surface of the response $Y_6 = f(X_1, X_2)$

It is seen that the surface has a Mini-max character (of the type of hyperbolic paroboloid). To determine the zone of the best values of x_1 and x_2 we will build the lines of the same response.

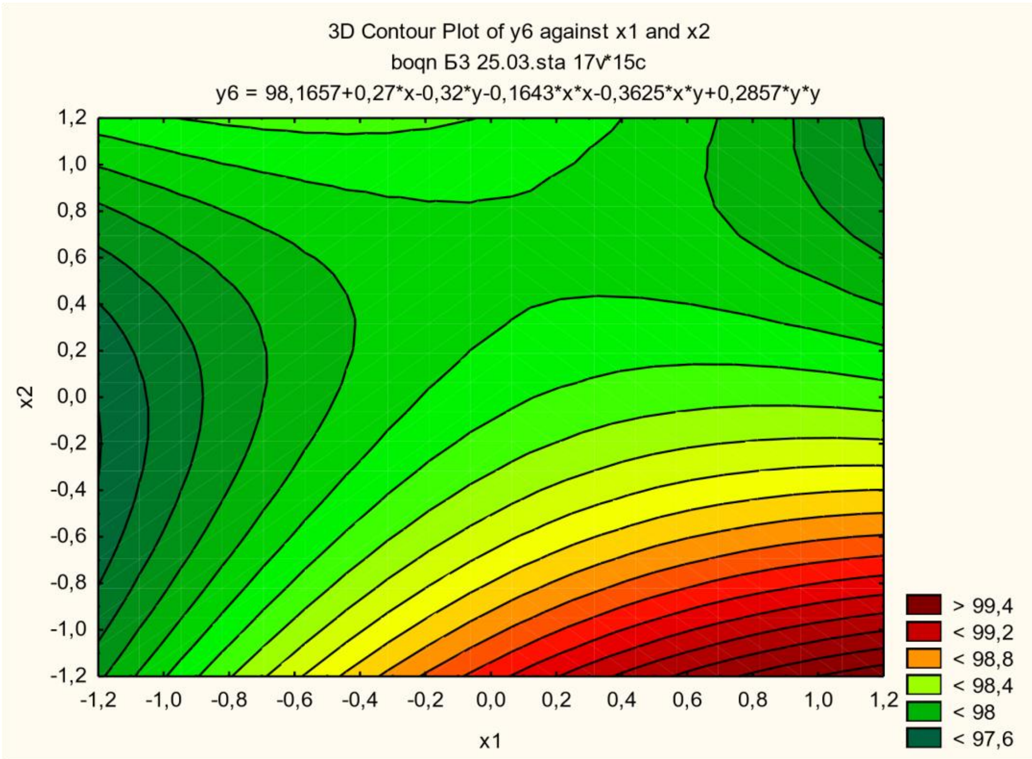

Figure 6. Lines of equal response $f(X_1, X_2) = const$

Obviously, large values of Y_6 are obtained at $x_1 = 1$ (upper level) and $x_2 = -1$ (lower level). Closest to these values are the experiments № 2 and № 6, where the parameter Y_6 has a maximum value 99,1%.
It turns out that at $x_1 = 1$ and $x_2 = 0$ the parameter Y_2 (specific energy consumption) has a value close to the minimum of 0, 01 kWh/kg (regardless of the value of x_3, which has an insignificant influence on Y_2). At these values of x_1 и x_2 the parameters Y_3 and Y_6 have values which are close to their optimal ones ($Y_3 = 70$ and $Y_6 = 99.1\%$).

Studying of the performance of the Y_1 granulator. Here the coefficients b_0 = 20, 11; b_1 = 7, 36; b2 = - 10, 47; b_{12} = - 4, 72 and b_{22} = - 10, 12 (Table 7) are significant because for them the probability p-value is less than the significance level 0, 05. The coefficients connected with the factor X_3 (recorded in Table 7 in black font) are insignificant and we can equate them to zero. This is explained by the fact that the total light section of all matrices is approximately equal. Therefore, it follows that the sought model will be the following one:

$$Y_1 = 20{,}11 + 7{,}36 * x_1 - 10{,}47 * x_2 - 4{,}72 * x_1 * x_2 - 10{,}12 * x_2^2 \quad (4)$$

Results from the regression analysis for the parameter Y_1

	Regression Summary for Dependent Variable: y1 (boqn Б3 25.03.sta) R= ,97977511 R?= ,95995927 Adjusted R?= ,88788597 F(9,5)=13,319 p<,00540 Std.Error of estimate: 4,3531					
N=15	b*	Std.Err. of b*	b	Std.Err. of b	t(5)	p-value
Intercept			20,1138	2,339740	8,59659	0,000351
x1	0,478325	0,089488	7,3580	1,376582	5,34512	0,003076
x2	-0,680434	0,089488	-10,4670	1,376582	-7,60361	0,000625
x3	0,203214	0,089488	3,1260	1,376582	2,27084	0,072363
x12	-0,274442	0,089488	-4,7200	1,539066	-3,06680	0,027885
x13	0,106695	0,089488	1,8350	1,539066	1,19228	0,286645
x23	-0,106986	0,089488	-1,8400	1,539066	-1,19553	0,285483
x11	0,145917	0,101887	3,8878	2,714657	1,43214	0,211530
x22	-0,379721	0,101887	-10,1172	2,714657	-3,72689	0,013615
x33	-0,034238	0,101887	-0,9122	2,714657	-0,33604	0,750487

The coefficient of determination R^2 = 0, 96 shows that 96% from the variation of the performance Y_1 is due to the controllable factors and is described by the obtained model. This is a good description. Only 4% of the change in Y_1 is due to the unmanageable factors. The Fisher criterion F (9;5) = 13,319 and its corresponding probability $p < 0{,}00540 < 0{,}05$ indicate that the obtained model is adequate. By sequentially disengaging the factors one by one with the help of R^2 it is established that the factor X_2 has the strongest influence, after that follows the factor X_1 and the least influence has the factor X_3. The influence of X_1 and X_2 will be shown graphically via the surface of the response (Figure 7) and the lines of equal response (Figure 8).

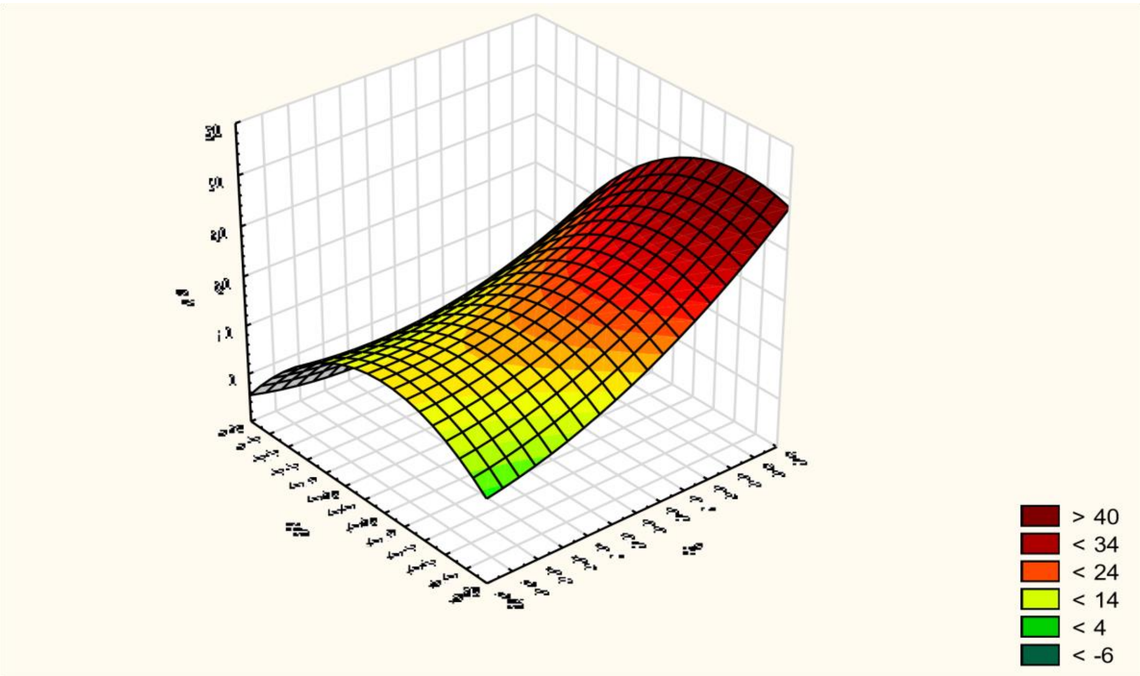

Figure 7. Surface of the response $Y_1 = f(X_1, X_2)$

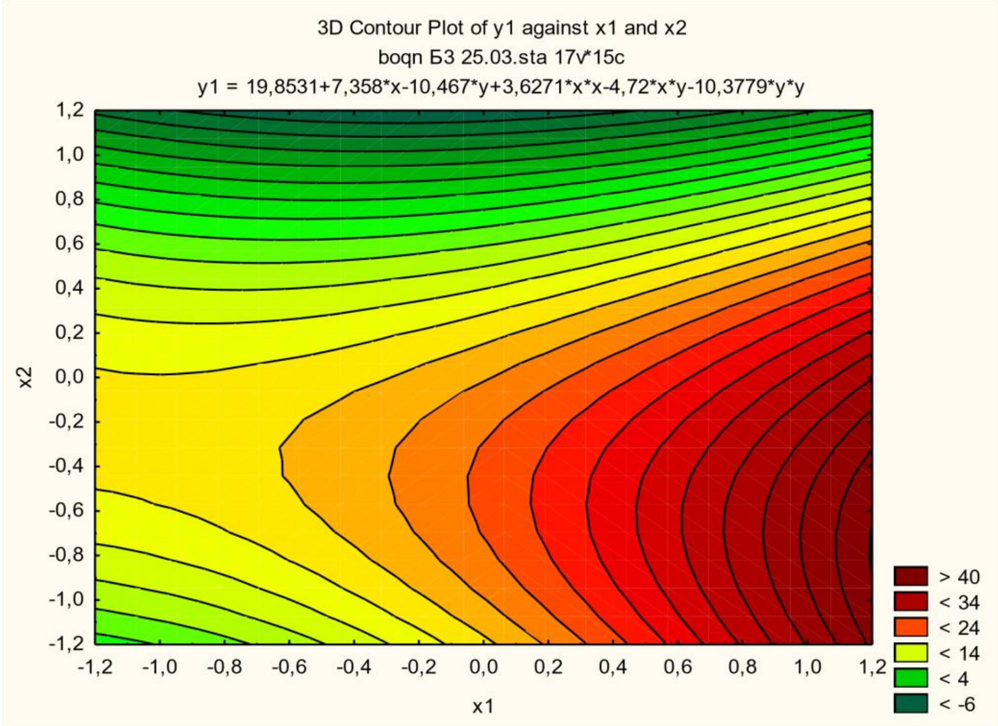

Figure 8. Lines of equal response f (X_1, X_2) = *const* за Y_1

It is obvious that the highest productivity (over 40 kg/h) is realized at $X_1 = 1$ (upper level) and $X_2 = -1$ (lower level).

Studying the parameters density of the granule Y_4 and bulk density of the granulated material Y_5. The values of these parameters give us information about the degree of compaction of the starting material and the reduction of the transported volume of the granules in relation to the volume of the starting material of poultry manure.
The average value of the bulk material of the granulated material $Y_{5cp.}$ For all the experiments is 0,83 t/m^3, which exceeds 2 times the volume of the starting material. This will reduce the transport costs twice.

In studying the experimental values of the density of the granules Y_4 a difference between the maximum and minimum value of 0, 18 t /m^3 has been established. The average value of all the experimental values is Y_{4cp} = 1, 65 t/m^3, and in the optimal values of the factors Y_4 = 1, 64 t/m^3. At a density of the starting material of 0, 39 t/m^3 the degree of sealing in the granules is 4, 23. This is also the main reason for the prolonged degradation of the granules in an aquatic environment, reaching over 60 days.
The latter, in turn, allows the slow release of nutrients (macro- and micronutrients) and the long feeding period of the plants. And by introducing the granules to different horizons in the soil, there will be improvement of the soil structure, an increase in its moisture accumulation capacity, a reduction of the release of hydrocarbons into the atmosphere and evenly stocking the nutrients in depth.

Conclusion
Regression models in the form of second order polynomials of the basic parameters have been obtained: Y_2 (specific energy consumption), Y_3 (duration of the digestion of the granule in an aquatic environment) and Y_6 (strength of the granules); Y_1 (performance of the device for granulation), with the corresponding models (1), (2), (3) and (4). The coefficient of determination R^2 and the Fisher criterion indicate that the models describe well the corresponding data and that they are adequate.

The substantial influence of the factors X_1 (humidity of the starting material of the poultry manure) and X_2 (distance between the matrix and the presser roll) on all the parameters Y_1, Y_2, Y_3 and Y_6 has been proven. The factor X_3 has an insignificant effect on these parameters. On parameters Y_1, Y_2 and Y_6, the factor X_2 is most influential and the factor X_1 is most influential on the parameter ърху параметъра Y_3.

The best results for the Y_2, Y_1, Y_3 and Y_6 parameters have been reported in Experiment № 6, where the factor X_1 is at the upper level (humidity 30%), X_2 at the lower level (zero clearance) and X_3 at the upper level (channel diameter 10 mm).
The optimization performed in the MATHCAD environment for the basic parameter Y_2 (specific energy consumption) shows that the optimal values of the factors in the coded type are: $X_{1opt} = 1$; $X_{2opt} = 0$ and $X_{3opt} = 1$, and in natural type $X_1^* = 30\%$; $X_2^* = 1$ mm; $X_3^* = 10$ mm. At these factor values the other parameters have values close to the optimal ones.

The obtained granules at the optimal values of the factors have an average density of 1,64 t/m^3 occupy twice less space than the un-granulated poultry manure and degrade in the aquatic environment for 70 days.

The obtained granules of poultry manure at optimal values of the factors are suitable for efficient feeding by introducing different soil depths by improving its structure, increasing its moisture accumulation capacity and reducing the release of hydrocarbons into the atmosphere.

Literature

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