CONTRIBUTIONS TO THE IMPROVEMENT OF THE FORAGE CHOPPING TECHNIQUE AND METHODS FOR DETERMINING THE QUALITY OF THE CHOPPING PROCESS AND THE ENERGY CONSUMPTION

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ABSTRACT

The results of the trials on a laboratory stand of the cutterhead chopping of a multi-knife type pointed out the superior performances of this tool, in comparison with classical cutterhead. Using modern methods of investigation and modern technical experiments, the mathematical models elaborated for determination of the required energy and the average length of chopping, pointed out significant influences of all the studied factors. Compared with classical mathematical models which don't take into account the spatial orientation of the plant stems, the elaborated models point out a series of actions such as the influence of the alimentary rate on the quality of the chopping process or that of the angle of stems orientation on the band carrier upon the energy consumption. In order to optimize the chopping process, the current analysis of the surface of response was used.

INTRODUCTION

The permanent increase of the food funds and the permanent improvement of the people's supplied consumption structure are influenced by the development of the fodder base and the mechanized work of zootechnic area, factors with deep implications in economic and social aspect with direct contribution in increasing the quality and quantity and in reducing the costs of the animal food.

The silage maize, valuable forage, from the point of view of the nourishing value as well as of its production has an important position in the structure of the forage crops, this importance being pointed out by the permanent increase of the fields cultivated with these crops in the most European countries.

For pre-determining the quality of the chopped silage maize, we have taken into consideration many factors: those which determine a stimulation of the gastric microfauna in the sense of a better assimilation of the digestion proteins as well as those which favourize the obtaining of a high quality silage.

Chopping devices, big users of energy, approximately 38-45% of the total energy (O'Dogherty, 1982), have known a slow development first of all, due to the impossibility of pointing out all factors that influence the energy consumption for forage chopping and the quality of the chopping process.

For improving the construction of the chopping devices and for the optimization of the chopping process, modern experimental programmes are necessary to point out the simultaneous effects of the most important factors that have significant influences on the consumption of energy and the quality of the chopping process.

MATERIALS AND METHODS

The result of the chopping process of the vegetable materials is the obtaining of a lot of small sized particles with very varied surfaces.

For effectuating the research concerning the chopping process we made a lab stand fitted with all the necessary devices having the required precision for this specific scientific researching process that allowed us to reproduce the lab conditions for a real process of the chopping devices (Figure 1).

A too small forage chopping length determines an abundant detachement of vegetable juices, needs important energy consumption and at the same time needs a great complexity of the working elements of the chopping devices, so, for silage maize, the recommended medium chopping length is situated between 6 and 20 mm (Neculãiasa, 1995).

The medium forage chopping length (l_m) is bigger than the theoretical chopping length (l_t) as the real chopping length is influenced by a series of factors such as: the diameter of the stems, the amount of the fed material, the depth of the stem layers, the

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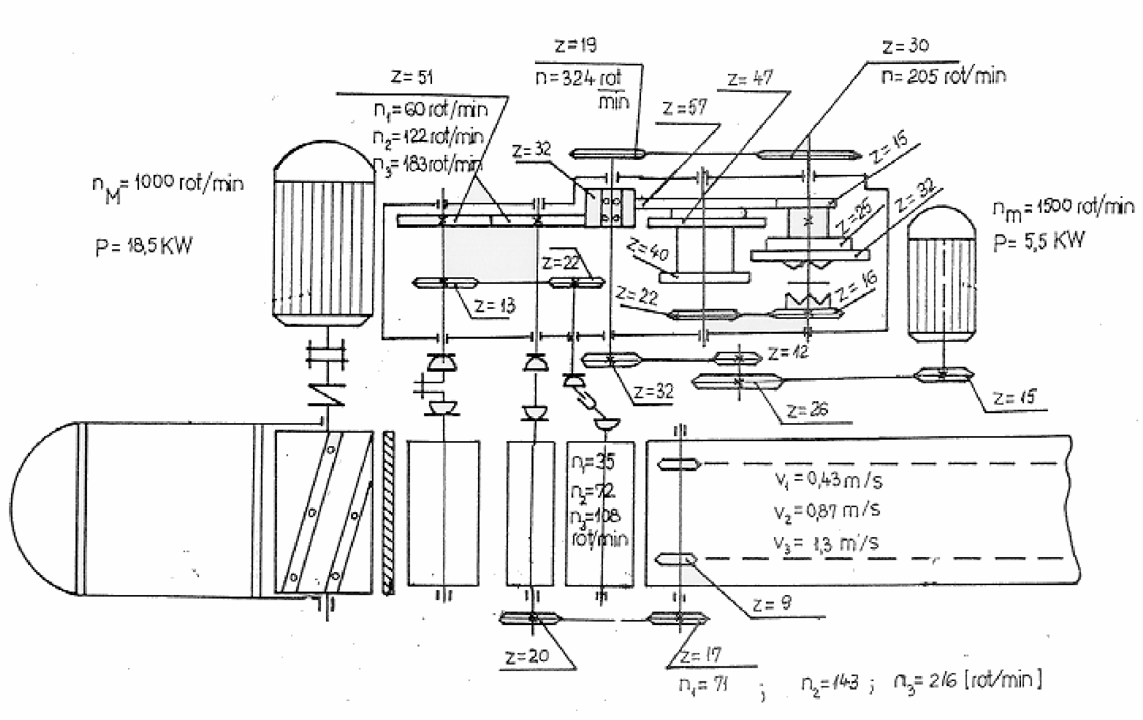


Figure 1. Laboratory stand for the study of the chopping process

moisture of the vegetal material, the clearance distance, the knife dulness, the rake angle (the angle between the knife and the horizontal plane that passes through the axis of the cutterhead) and other factors unqualificated by the classical relation of the determination of the theoretical chopping length.

In the context of the nowadays preocupations all over the world concerning the improvement of the building and the functionality of the chopping devices for increasing the working capacity of these tools and the quality of the chopped material and taking into account the deficiencies of the classical cutterheads (Moldovan and Ignea, 1996), a new chopping cutterhead of a multi-knives type was made (Figure 2).

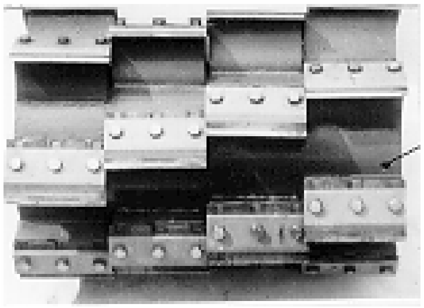


Figure 2. Cutterhead chopping of the multi-knives type

The construction parameters for this cutterhead are:

- type of knife: straight and short with setting inclination $\gamma = 3^0$ (degree) ;
- number of knives: z = 24;
- the diameter of the cutterhead: $D_t = 410$ mm;
- the length of the cutterhead: L= 580 mm;
- knives sharpening angle: $\beta = 25^0$
- the rake angle: $\varphi_f = 55$ (degree);
- the helical line angle of knives: $\varphi_{inf} = 60^0$.

The physical properties of the silage maize used in the experiments are presented in table 1.

Table 1. The physical properties of the silage maize

Average production (t/ha)	Percentage of the corn-cobs (%)	Average height of the stems (cm)	Average thickness of the stems (mm)	Moisture content (%)
40....46	24...26	200	23...24	72...74

By the halving method and then by dividing testing material in size groups with the aid of the relation (1) and the initial data presented in table 2, an example for the

Table 2. Dimensional analysis of the chopped material (mm)

0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-...
21%	32%	19%	14%	3,6%	2,6%	2,2%	1,4%	1,2%	1,0%	0,9%	1,1%

calculation method of the medium forage chopping length “ l_m” is given:

$$l_m = \frac{\sum_{i=1}^{N} m_i l_i}{\sum_{i=1}^{N} m_i} = 12.6\,[\mathrm{mm}] \qquad (1)$$

where:

N – number of dimensional classes;

m_i: = the mass of particles in the size group “i”;

l_i: = the central value of the interval of the class “i” calculated as a mean of the marginal values of this interval. The results in table 2 are obtained in the next conditions: average feeding rate: g = 3 kg/s, cutterhead rotative speed ω = 1000 rpm and the theoretical length (adjusted) lt = 8,7 mm.

For studying the chopping process of the silage maize and for determining the optimal values of the factors that carry the “answer” to an interesting approach from the technical and economical and other points of view, as well as for new directions of future researches, it is very important to know the “geography” of the response surface through canonical transformation.

RESULTS AND DISCUSSIONS

For effectuating the analysis of the chopping process quality which is appreciated with the medium chopped length indicator (l_m) and for making a mathematical model for determining this indicator, we have used the active experimental planes such as “The compound centre programme”.

The experimental matrix of “The compound centre programme” for determination of the medium chopping length depends on the studied factors (Table 3).

For the entire factorial programme, at

Table 3 The experimental matrix of “ The compound rotary central programme” for determination of the medium chopping length

x_0	x_1	x_2	x_3	x_1^2	x_2^2	x_3^2	x_1x_2	x_1x_3	x_2x_3	y_u(mm)
1	-1	-1	-1	1	1	1	1	1	1	6.19
1	1	-1	-1	1	1	1	-1	-1	1	6.51
1	-1	1	-1	1	1	1	-1	1	-1	18.72
1	1	1	-1	1	1	1	1	-1	-1	19.67
1	-1	-1	1	1	1	1	1	-1	-1	4.00
1	1	-1	1	1	1	1	-1	1	-1	4.21
1	-1	1	1	1	1	1	-1	-1	1	12.40
1	1	1	1	1	1	1	1	1	1	13.04
1	-1.682	0	0	2.828	0	0	0	0	0	9.78
1	1.682	0	0	2.828	0	0	0	0	0	10.28
1	0	-1.682	0	0	2.828	0	0	0	0	1.65
1	0	1.682	0	0	2.828	0	0	0	0	18.66
1	0	0	-1.682	0	0	2.828	0	0	0	15.27
1	0	0	1.682	0	0	2.828	0	0	0	7.63
1	0	0	0	0	0	0	0	0	0	10.13
1	0	0	0	0	0	0	0	0	0	10.29
1	0	0	0	0	0	0	0	0	0	9.98
1	0	0	0	0	0	0	0	0	0	10.2
1	0	0	0	0	0	0	0	0	0	10.14
1	0	0	0	0	0	0	0	0	0	9.94

Factor levels

Code	Factors	Coding level				
		-1.682	-1	0	+1	+1.682
x_1	Average feeding rate q (kg/s)	2.300	3.00	4.00	5.00	5.68
x_2	Feeding speed, v_a (m/s)	0.150	0.43	0.87	1.30	1.60
x_3	Cutterhead rotative speed (rpm)	830	1000	1250	1500	1670

two levels, with $N_1 = 2^k$ experimental determinations or in case of fractional programmes with $N_1 = 2^{k-2}$ experimental determinations, the calculation formula for regression coefficients is:

$$b_i = \frac{1}{\sum_{i=1}^{N} x_{ij}} \cdot \sum_{i=1}^{N} x_{ij} y_i \qquad (2)$$

For the second order coefficients calculation, we added to the basic programme $N_2 = 2k + n_0$ experimental determinations.

Under uniform planning conditions, the constants c, θ* and A, that stay, according to the methodology, at the base of the calculation for the second order terms, are calculated as follows:

$$c = N / \sum_{u=1}^{N} x_{iu}^2 = 1.464;$$

$$\theta^* = \frac{n}{n+2} \cdot \frac{n_0 + n_c}{n_c} = 0.857\ ;$$

$$A = [2\theta^* \ ((n+2)\ \theta^* - n))]^{-1} = 0.464;$$

$$N = 2^n + 2n + n_0;\ n_c = N - n_0$$

where :

x_{iu} = the term of the matrix from the line “i”;

n = the number of studied factors ;

n_0 = the number of replicates in the centre of the experiment;

N = the number of variants.

Using the above relations and the experimental matrix (Table 3) the codified mathematical model of the average chopping length is:

$$l_m = 10.110 + 0.217x_1 + 5.237x_2 - 2.218x_3 - 0.026x_1^2 + 0.018x_2^2 + 0.476x_3^2 + 0.132x_1x_2 - 1.057x_2x_3$$

The adequancy of the model is determined as follows :

$$SS_R = \sum_{u=1}^{N} (\bar{y}_u - y_u)^2 = 0.509$$

SS_R = residual dispersion

$$S_E = \sum_{u=1}^{n_0} (y_{0u} - \bar{y}_0)^2 = 0.087$$

SS_E = experimental error dispersion

$SS_{NE} = SS_R - SS_E = 0.422$

SS_{NE} = unadequacy dispersion

$$f_{NE} = N - \frac{(n+2)\,(n+1)}{2} - (n_0 - 1) = 5$$

f_{NE} = grades of liberty

$f_E = n_0 - 1 = 5$

f_E = grades of error liberty

$$F_C = \frac{SS_{NE} / f_{NE}}{SS_E / f_E} = 4.85 < F_{tab.} = 5.05$$

⌋ ADEQUATE model.

The decodiffied mathematical model of the average chopping length is:

l_m = 11,579 + 0,158q + 23,071v_a- 0,0194N- 0,026q^2+ 0,0973v_a^2+ 0,00000N^2+ 0,307qv_a- 0,0098v_aN [mm] and from the geometrical point of view it represents a hypersurface whose extreme points are interesting, as well as the surface from next to the extreme point.

For optimizing the chopping process, the canonical analysis of the response surfaces was used.

The feeding input is given by the formula: $q = B_1 v_m c_{\$} P(1 - >)$ where:

B_1 = the working wide of the combine;

v_m = the average working speed of the combine;

$c_{\$}$ = utilization coefficient of the working wide ($c_{\$}$ = 0.8 ..... 0.9);

P = the plant production;

> = the losses coefficient (> = 0.01 ... 0.02).

For an average working capacity combine, the feeding input is comprised between 5 and 6 kg/s and taking in calculations the value q = 5 kg/s we obtain:

l_m = 11.719 + 24.606v_a – 0.0194N + 0.0973v_a^2 + 0.000008N^2 – 0.0098v_aN and det $b_{11} = b_{11}b_{22} - b_{12}'b_{12}' = 0.0973 \cdot 0.000008 - (-0.00049) \cdot (-0.0049)$? 0

from where results that the response surface is well determined.

The centre of the new axes system $\{x_e, y_e\}$ is determined by the formulae:

$x_e = (-1/2) \cdot b_{11}^{-1} \cdot b_1^T = (2555\ ;\ 2.22)$;

$y_e = b_0 + b_1 \cdot x_{e+x} e^T \cdot b_{11} \cdot x_e = 14$ [mm].

To avoid an abundance detachement of juices as well as a great consumption of energy during the chopping process and at the same time to realize the requirements concerning the ensilage, the average chopping length is limited between 6 and 20 mm, which supposes that: x_e = (1500; 0.45) ⌋

y_{min} ~ 6 [mm]; x_e' = (1000; 1.3) J y_{max} ~ 20 [mm].

The necessary translation for eliminating the linear terms is made by transforming x' = x – x_e. The rotation of axes around the new origin, for obtaining the co-ordinates, is effectuated by transformation of variable x' = U·X, where U is the unitary orthogonal matrix and X represents the new co-ordinates.

The characteristic equation is: det (b_{11} - 8 · I) = 0 J 8_1 = 0.097 and 8_2 = 0.00023.

The canonical form of the original response surface is:

$$Y-14 = 0.097X_1 + 0.00023X_2.$$

The contour curves have an elliptical form, the elongation being on the X_2 axis direction. From the geometrical point of view, the response surface is an “eliptical valley”.

Analysing the mathematical model of the average chopping length one can see that all the studied factors have a significant influence on the quality of the chopping process.

For effectuating the researches concerning the energy consumption during the chopping process, the most significant terms with preponderant influences on the energy consumption were chosen.

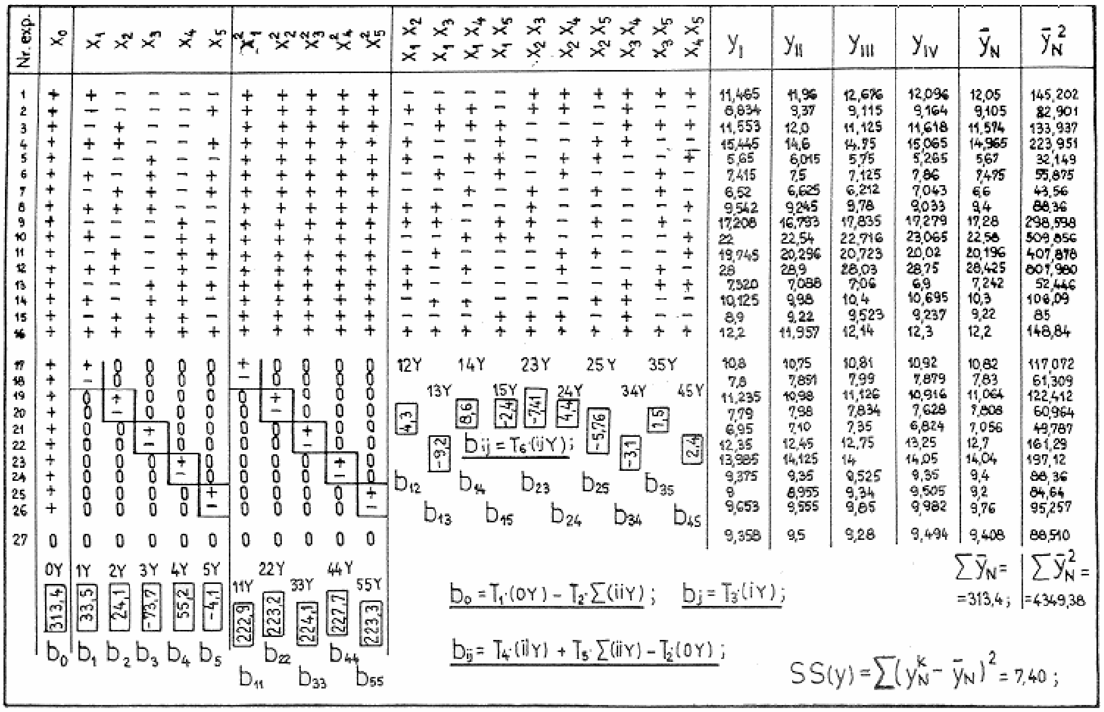
Unlike the classical models which describe the chopping process taking into account that the stems layer moves perpendicularly on the cutterhead, a new factor x_5 was introduced which takes into account the spatial orientation of the stems on the band carried (Table 4).

The experiment took place in four replicates and the experimental matrix is presented in table 5.

Table 4. Factors, natural values and coding levels

Factors	U.M.	Factor code	Natural values			)Xj interval	Coding level		
			Xj_{min}	Xj_0	Xj_{max}		Lower	Center	Highest
Average feeding rate	kg/s	x_1	3	4	5	1	-1	0	+1
Cutterhead rotative speed	rpm	x_2	1000	1250	1500	250	-1	0	+1
Feeding speed	m/s	x_3	0.43	0.87	1.30	0.43	-1	0	+1
The number of knives	pieces	x_4	12	-	24	-	-1	-	+1
The angle of orientation	deg.	x_5	0	9	18	9	-1	0	+1

Table 5. The experimental matrix



Nr. exp.	x_0	x_1	x_2	x_3	x_4	x_5	x_1^2	x_2^2	x_3^2	x_4^2	x_5^2	x_1x_2	x_1x_3	x_1x_4	x_1x_5	x_2x_3	x_2x_4	x_2x_5	x_3x_4	x_3x_5	x_4x_5	y_I	y_{II}	y_{III}	y_{IV}	$\bar{y}_N$	$\bar{y}_N^2$
1	+	+	−	−	−	−	+	+	+	+	+	−	−	−	−	+	+	+	+	+	+	11,465	11,96	12,676	12,096	12,05	145,202
2	+	−	−	−	−	+	+	+	+	+	+	+	+	+	−	+	+	−	+	−	−	8,834	9,37	9,115	9,164	9,105	82,901
3	+	−	+	−	−		+	+	+	+	+	−	+	+	+	−	−	−	+	+	+	11,553	12,0	11,125	11,618	11,574	133,937
4	+	+	+	−	−	+	+	+	+	+	+	+	−	−	+	−	−	+	+	−	−	15,445	14,6	14,75	15,065	14,965	223,951
5	+	−	−	+	−	−	+	+	+	+	+	+	−	+	+	−	+	+	−	−	+	5,65	6,015	5,75	5,265	5,67	32,149
6	+	+	−	+	−	+	+	+	+	+	+	−	+	−	+	−	+	−	−	+	−	7,415	7,5	7,125	7,86	7,475	55,875
7	+	−	+	+	−	+	+	+	+	+	+	−	−	+	−	+	−	+	−	+	−	6,52	6,625	6,212	7,043	6,6	43,56
8	+	+	+	+	−	−	+	+	+	+	+	+	+	−	−	+	−	−	−	−	+	9,542	9,245	9,78	9,033	9,4	88,36
9	+	−	−	−	+	−	+	+	+	+	+	+	+	−	+	+	−	+	−	+	−	17,208	16,793	17,835	17,279	17,28	298,598
10	+	+	−	−	+	+	+	+	+	+	+	−	−	+	+	+	−	−	−	−	+	22	22,54	22,716	23,065	22,58	509,856
11	+	−	+	−	+	+	+	+	+	+	+	−	+	−	−	−	+	+	−	−	+	19,745	20,296	20,723	20,02	20,196	407,878
12	+	+	+	−	+	−	+	+	+	+	+	+	−	+	−	−	+	−	−	+	−	28	28,9	28,03	28,75	28,425	807,980
13	+	−	−	+	+	+	+	+	+	+	+	+	−	−	−	−	−	−	+	+	+	7,320	7,088	7,06	6,9	7,242	52,446
14	+	+	−	+	+	−	+	+	+	+	+	−	+	+	−	−	−	+	+	−	−	10,125	9,98	10,4	10,695	10,3	106,09
15	+	−	+	+	+	−	+	+	+	+	+	−	−	−	+	+	+	−	+	−	−	8,9	9,22	9,523	9,237	9,22	85
16	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	12,2	11,957	12,44	12,3	12,2	148,84
17	+	+	0	0	0	0	+	0	0	0	0	12Y -4,3 b_{12}	13Y -9,21 b_{13}	14Y 8,6 b_{14}	15Y -2,4 b_{15}	23Y -7,41 b_{23}	24Y -4,4 b_{24}	25Y -5,76 b_{25}	34Y -3,1 b_{34}	35Y 1,5 b_{35}	45Y 2,4 b_{45}	10,8	10,75	10,81	10,92	10,82	117,072
18	+	−	0	0	0	0	−	0	0	0	0											7,8	7,851	7,99	7,879	7,83	61,309
19	+	0	+	0	0	0	0	+	0	0	0											11,235	10,98	11,126	10,916	11,064	122,412
20	+	0	−	0	0	0	0	−	0	0	0											7,79	7,98	7,834	7,628	7,808	60,964
21	+	0	0	+	0	0	0	0	+	0	0											6,95	7,10	7,35	6,824	7,056	49,787
22	+	0	0	−	0	0	0	0	−	0	0											12,35	12,45	12,75	13,25	12,7	161,29
23	+	0	0	0	+	0	0	0	0	+	0											13,985	14,125	14	14,05	14,04	197,12
24	+	0	0	0	−	0	0	0	0	−	0											9,375	9,35	9,525	9,35	9,4	88,36
25	+	0	0	0	0	+	0	0	0	0	+											9	8,955	9,34	9,505	9,2	84,64
26	+	0	0	0	0	−	0	0	0	0	−											9,653	9,555	9,85	9,982	9,76	95,257
27	0	0	0	0	0	0	0	0	0	0	0											9,358	9,5	9,28	9,494	9,408	88,510
	0Y 313,4 b_0	1Y 33,5 b_1	2Y 24,1 b_2	3Y -73,7 b_3	4Y 55,2 b_4	5Y -4,1 b_5	11Y 222,9 b_{11}	22Y 223,2 b_{22}	33Y 224,1 b_{33}	44Y 222,7 b_{44}	55Y 223,3 b_{55}															$\sum\bar{y}_N$ = =313,4;	$\sum\bar{y}_N^2$ = =4349,38

$$b_{ij} = T_6\cdot(ijY);$$

$$b_0 = T_1\cdot(0Y) - T_2\cdot\sum(iiY); \quad b_j = T_3\cdot(iY);$$

$$b_{ii} = T_4\cdot(iiY) + T_5\cdot\sum(iiY) - T_2(0Y);$$

$$SS(y) = \sum(y_N^k - \bar{y}_N)^2 = 7,40;$$

For data processing the known methodology was used, obtaining the encoded form of the mathematical model for energy consumption during the chopping process: $y = 9.4 + 1.9x_1 + 1.34x_2 - 4.1x_3 + 3x_4 - 0.25x_5 + 0.75x_3^2 + 2.64\ x_4^2 + 0.27x_1x_2 - 0.6x_1x_3 + 0.54x_1x_4 - 0.15x_1x_5 + 0.46x_2x_3 + 0.27x_2x_4 - 0.36x_2x_5 - 1.94x_3x_4$.

Analysing the mathematical model obtained, one can on the basis of the regression coefficients, the significant influence of all the studied factors on the energy consumption during the chopping process, remarking the x_5 factor's action as well as the simple interaction, the speed of material and number of knives.

CONCLUSIONS

After the laboratory experimentation of multi-knives cutterhead, its superior performances in comparison with the classical cutterhead were evidenced. This cutterhead is superior both from the point of view of the processed material and the energy consumption, having as a result the possibility of evacuating the chopped material without any other auxiliary device.

The multiknives cutterhead type produces a chopping degree of the silage maize aprox. 6,5...9% higher than the classical cutterhead with helicoidal knives.

Analysing the mathematical models made for determining the chopping average length (l_m) as well as for determining the energy consumption, one can see significant influences of all the studied factors and especially of the feeding input on the quality of the chopped material and of the stems orientation angle on the energy consumption. These influences were not described in classical models.

The experimental results obtained show that the average chopping length (l_m) is bigger than the theoretical length (lt) due to the influence of some factors unquantified by the classical formula of determining the theoretical chopping length (lt).

For determining the optimal values of the studied factors, that carry the "answer" to an interesting technical and economical approach and to give an orientation to the direction of the next researches, the canonical analysis of the "response" surfaces was used.

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Table 1

The physical properties of the maize

Average production (t/ha)	Percentage of the corn-cobs (%)	Average height of the stems (cm)	Average thickness of the stems (mm)	Moisture content (%)
40....46	24...26	200	23...24	72...74

Table 2.

Dimensional analysis of the chopped material (mm)

0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-...
21%	32%	19%	14%	3,6%	2,6%	2,2%	1,4%	1,2%	1,0%	0,9%	1,1%

Table 3

The experimental matrix of “ The compound rotary central programme” for determination of the medium chopping length

x_0	x_1	x_2	x_3	x_1^2	x_2^2	x_3^2	x_1x_2	x_1x_3	x_2x_3	y_u(mm

										)
1	-1	-1	-1	1	1	1	1	1	1	6,19
1	1	-1	-1	1	1	1	-1	-1	1	6,51
1	-1	1	-1	1	1	1	-1	1	-1	18,72
1	1	1	-1	1	1	1	1	-1	-1	19,67
1	-1	-1	1	1	1	1	1	-1	-1	4,00
1	1	-1	1	1	1	1	-1	1	-1	4,21
1	-1	1	1	1	1	1	-1	-1	1	12,40
1	1	1	1	1	1	1	1	1	1	13,04
1	-1,682	0	0	2,828	0	0	0	0	0	9,78
1	1,682	0	0	2,828	0	0	0	0	0	10,28
1	0	-1,682	0	0	2,828	0	0	0	0	1,65
1	0	1,682	0	0	2,828	0	0	0	0	18,66
1	0	0	-1,682	0	0	2,828	0	0	0	15,27
1	0	0	1,682	0	0	2,828	0	0	0	7,63
1	0	0	0	0	0	0	0	0	0	10,13
1	0	0	0	0	0	0	0	0	0	10,29
1	0	0	0	0	0	0	0	0	0	9,98
1	0	0	0	0	0	0	0	0	0	10,2
1	0	0	0	0	0	0	0	0	0	10,14
1	0	0	0	0	0	0	0	0	0	9,94

Factor levels