POWER REQUIREMENT FOR PROCESSING OF MAIZE PLANT BY FORAGE HARVESTER

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Abstract

The aim of this study was to investigate the influence of the chosen technical parameters on the effective power needed to the process of cutting, feeding and picking-up of the material from maize plants by the forage harvester. The studies were conducted in the stationary conditions, using pulled forager equipped with a chopping flywheel unit with 5 or 10 knives, sensors to the measurement of the rotational speed and the torque of the PTO and pick-up shaft, and pressure and oil flow intensity transducers in the hydraulic actuator. The moisture content of the plants were 68 and 57%, the samples mass were 5, 10 and 15 kg (the material feeding of 1.13, 2.25 and 3.38 $kg \cdot s^{-1}$, respectively). It was found that the requirement for effective power for cutting was inverse than for the power to feeding. The maximum and minimum values, respectively were obtained under optimal material moisture content (65%), at which the rigidity of the plants is the lowest. The doubled cutting frequency do not generates the same increase of requirement for power for cutting unit work, because the smaller particles require lower kinetic energy to overcome their lower inertia.

Key words: forage harvester, biomass, cut, compression, feeding.

INTRODUCTION

The preparation process of plant material for ensilage with the use of forage harvesters requires considerable energetic expenditures. Since the most energy-consuming process, using up even 85% of total energy, is chopping the plant material (O'DOUGHERTY, 1982; SAVOIE ET AL., 1989), therefore a detailed analysis of the chopping process is very important. The power requirement for cutting of plant material depends not only on its properties and technical parameters of the cutting unit, but also on the initial compression of the material by the feed rolls or picking-up of swath by header (ROBERGE ET AL., 1998). The work of these units also requires energetic expenditures, which should be considered together.

Hitherto existing investigations focused on the influence of basic constructional and exploitation parameters of the cutting unit on its energetic loads. The load sources related to cutting, accelerating and material friction of the unit housing were determined. The optimum design parameters of individual unit elements – the micro-, the macro-geometry of knives and anti-cutting edge were established. The influence of kinematic parameters – the speed of particles movement and direction of cut and exploitation parameters – the theoretical length of cut were studied. Impact of plant physical properties and moisture content on energy consumption of the chopping process were also analysed (REZNIK, 1967; SHINNERS ET AL., 1994; CHATTOPADHYAY AND PANDEY, 2001).

One of the development trends in agricultural engineering is precision farming, based on the knowledge of yield variability, physico-chemical soil properties, weed content, pests, etc., within a given field (AUERNHAMMER, 2001).

The mass flow intensity is often measured with the use of indirect mechanical methods, based on measurements of dynamical pressure in the forage harvester discharge spot or the torque or power needed for driving the knife disk of machine chopping unit.

The analysed references point out that investigations on monitoring of mass flow intensity for the plants harvested with forage harvesters, based on power or torque measurements (VANSICHEN AND DE BAERDEMAEKER, 1993; KROMER ET AL., 1999; SCHMITTMANN ET AL., 2000) did not considered the effect of plant material parameters or machine parameters on physical quantities being measured.

Authors (KLONOWSKI ET AL., 2005) presented the effect of material mass flow rate, knife disc rotational speed, and number of cutting knives on dynamic pressure force of mass in the discharge spot and power requirements for driving forage harvester units during grass chopping. It was found that power values were statistically different for all the analyzed factors, while the varied dynamic pressure force has depended on the mass stream and knife disc rotational speed.

It was also found (Klonowski and Lisowski, 2007) that application of knife disk power measurement to determination of harvested grass yield calls for consideration of number of knives, knife disk rotational speed and the constant measurements on plant material moisture content and tractor outfit ground speed, as a component of the mass flow.

At another paper of authors (Lisowski et al., 2007) were presented the research results of the operational effect of additional elements used in the chopping unit of forage harvester on breaking-up of maize grain harvested for silage. It was found that application of bottom beater plate and plain thrower paddles, working at working clearance between them set to 8 mm at the inlet and 2 mm at the outlet, allowed for effective increase in grain breaking-up. Application of other additional elements in the form of bottom plate with beater and bar notches, the thrower paddles of notched and plain surfaces, and the radial notched and plain bars resulted in lower effectiveness of maize grain breaking-up.

Because of permanent improvement of the investigations methods, the undertaken investigations aimed at determination of significance of the effect of selected plant material parameters and machine parameters on effective power requirements for driving the knife disk, feed rolls and pick-up unit during maize chopping with the pulled forage harvester.

MATERIALS AND METHODS

Plant material

All experimental measurements were performed for maize, variety Inagua FAO 240, cut by a manual brush cutter. For the purpose of the research, the plant material was described by establishing the chopped material moisture content and geometric mean value of particle size.

The average moisture contents (wet basis) of two groups of plant material 68 ± 2% (higher moisture) and 57 ± 2% (lower moisture) were determined by the dried-weight method according to standard S358.2 ASABE for silage (ASABE Standards, 2011b). Five samples of 20 g each were collected daily from the cut material. The samples were weighed on the electronic scales with an accuracy of 0.01 g and dried at 103 ± 2 °C for 24 h.

A sieve separator (Lisowski et al., 2014) meeting the requirements of ASABE Standard S424.1 (ASABE Standards, 2011a) was used to evaluate the particle size distribution of cut plant material. Five averaged, uncompressed samples of 10 dm^3 were used for measurements. Screening time of 120 s was controlled with a stopwatch and individual particle fractions were weighed on the electronic scales with an accuracy of 0.01 g. For moisture content of 68% and cutterhead rotational speed of 1000 rpm and 10 knives and 5 knives the geometric mean value of size particles were 12.04 mm and 8.54 mm, respectively and for moisture content of 57% with the same working parameters were a little higher and amounted to 13.34 mm and 10.25 mm, respectively. The geometric mean value of particle size was not depended on material mass flow rate in the range of 1.13 kg s^{-1}–3.38 kg·s^{-1} and the geometric mean value had a narrow range of 10.95 mm–11.20 mm.

2.2. Power measurements

The principal study was carried out on a test stand designed around a Z 374 pulled forager (SIPMA, Lublin, Poland) with a chopping flywheel unit (Fig. 1). Conveyor belt was used for the transport of whole corn shoots. Forage harvester was equipped with a pick-up. Rotational speed of the PTO shaft of a tractor 1234 Ursus was recorded with a tachometer (accuracy ± 0.1 rpm) integrated with an MIR 1000 induction torque meter (accuracy ± 0.5 N·m) (Laboratory of Electronics, Poznań, Poland).

The PC-28 pressure (accuracy ± 0.05 MPa) and the FT12 oil flow (accuracy ± 1 dm^3·min^{-1}) intensity transducers (APEK, Marki, Poland) were installed in the duct bleeding oil to sump to measure power requirements of feed rolls. The power requirement of a pick-up unit was measured by a tachometer (accuracy ± 0.1 rpm) integrated with a torque meter (accuracy ± 0.1 N·m) (APEK, Marki, Poland).

The chaff measurements were carried out with the use of the CLP 500/LC510 electronic scales (Radwag, Radom, Poland) with the analog output of the measuring signals, on which the bearing structure of tarpaulin container was mounted; the cut plant material from harvester's discharge spot was collected in this container.

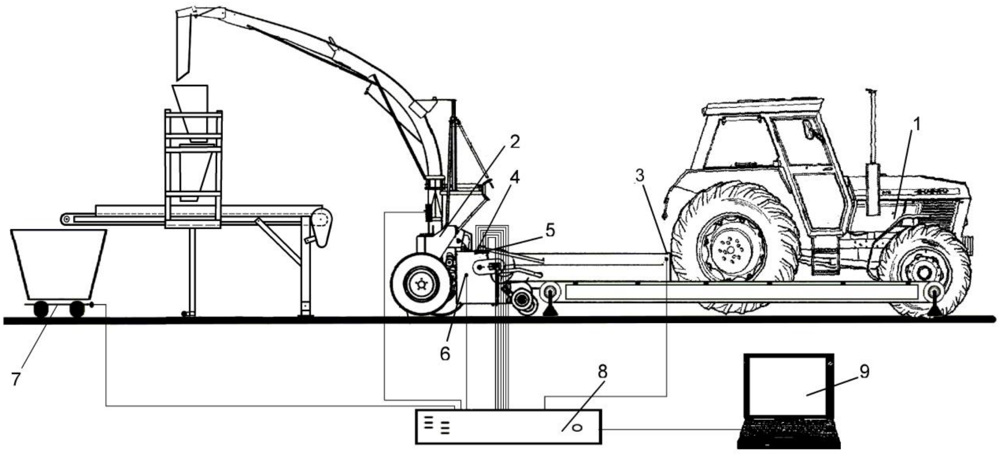


Fig. 1. – The measurement stand: 1 – tractor, 2 – cutter tachometer, 3 – PTO tachometer and torque meter, 4 – pressure and oil flow transducers of hydraulic drive to feed rolls and pick-up, 5 – tachometers on the feed rolls shafts (for control only), 6 – tachometer and torque meter on the pick-up shaft, 7 – electronic scales, 8 – amplifier, 9 – computer

The transducers worked with a Hottinger DMCplus amplifier (HBM, Darmstadt, Germany) and a computer equipped with special software.

On a four-meter section of the conveyor belt the samples of maize shoots of 5 kg, 10 kg and 15 kg were placed (weighing accuracy of ± 0.2 kg). At a constant speed of the conveyor belt of 0.9 m s^{-1} the material mass flow rate of 1.13 kg s^{-1}, 2.25 kg s^{-1} and 3.38 kg s^{-1}, respectively, were obtained. Cutterhead rotation speed was 1000 rpm and the number of knives were 2 and 10. For each measuring system three tests were carried out.

In order to determine the effective power to cutting and feeding and picking-up of the material were taken into account the kinematics of the forage harvester drive.

The power requirement of the flywheel cutter unit was calculated as the difference of the tractor PTO power and the power consumed by the feed rolls and pick-up.

$$P_t = 10^{-3} M_p \frac{\pi n_p}{30}\left(1 - \frac{n_p - n_t}{n_p}\right) - \left(\frac{Q_{shg}(p_{shg} - p_o) + Q_{shd}(p_{shd} - p_o)}{60}\right)\frac{1}{\eta_p \eta_c} \tag{1}$$

The power requirement of the feed rolls was calculated as the difference of power absorbed by the hydraulic drive both units and the power require by the pick-up.

$$P_w = \left(\frac{Q_{shg}(p_{shg} - p_o) + Q_{shd}(p_{shd} - p_o)}{60}\right)\eta_s \eta_{cg} \eta_{cd} - 10^{-3} M_a \frac{\pi n_a}{30} \eta_{c1} \eta_{c2} \tag{2}$$

The power requirement of the pick-up was calculated from the formula.

$$P_a = 10^{-3} M_a \frac{\pi n_a}{30} \eta_{c1} \eta_{c2} \tag{3}$$

where: P_t, P_w, P_a – power of cutting, feeding, picking-up, respectively, kW; M_p, M_a – PTO and pick-up shaft torque, respectively, N·m; n_p, n_t, n_a – PTO and cutter and pick-up shafts rotational speed, respectively, rpm; Q_{shg}, Q_{shd} – oil flow to upper and lower hydraulic motors, respectively, dm^3·min^{-1}; p_{shg}, p_{shd} – pressure of oil flowing to upper and lower hydraulic motors, respectively, MPa; p_o – oil pressure at the outlet of the hydraulic motors, MPa; η_p, η_s – overall hydraulic pump and motor efficiency, respectively, $\eta_p = \eta_s = 0.8$; η_s, η_{s1}, η_{s2}, η_{sg}, η_{sd}, effciency of different transmission chains,

$\eta_s = \eta_{s1} = \eta_{s2} = \eta_{sg} = \eta_{sd} = 0.98$.

Calculations were made for the two conditions: under load and idling of the forage harvester and on the basis of the difference the effective power for cutting and feeding and picking-up were designated.

The investigation results were analysed statistically with the use of computer statistical package STATGRAPHICS V.12.5.

From each test sample, recorded with a frequency of 50 Hz were obtained about 150 records. After its transformation by the coefficients of the transducer calibration and determination of the power, the assumptions of variance analysis were verified, i.e. normality (Kolmogorov-Smirnov and Lilliefors and Shapiro-Wilk tests and skewness and kurtosis coefficients) and the equality of variance tests (Levene and Brown-Forsythe).

For the power values the analysis of variance relative to the studied factors (moisture content, sample mass, number of knives) was done and then a detailed analysis of the Duncan test was done.

Based on the results of variance analysis and correlation matrix the non-linear regression models of power were evaluated, and its characteristics relative to the main parameters were presented graphically.

RESULTS AND DISCUSSION

On the basis of the carried out tests (Tab. 1) it was stated that the distributions of the values of power for cutting the material can be include to the normal distributions, because in the all cases the p-values at least for one of the Kołmogorow-Smirnow test were not lower than 0.01. More differentiated results were received for tests by Lilliefors and the most powerful by Shapiro-Wilk.

Tab. 1. – The results of the normality test of power cutting (P_t) by Kołmogorow-Smirnow (K-S, D) and Lilliefors (p-Lillifors) and Shapiro-Wilk (WS, W) tests and the skewness and kurtosis coefficients for the power distributions (*w* – moisture content, %; *z* – number of knives; *m* – sample mass, kg; N – number)

Power	*w*	*z*	*m*	N	max D	K-S	p-Lillief.	WS	p-value	Skewness	Kurtosis
P_t	68	5	5	483	0.047872	$p > 0.20$	$p < 0.01$	0.9886	0.0008	0.37	0.09
P_t	68	5	10	483	0.048529	$p > 0.20$	$p < 0.01$	0.9798	<0.0001	0.53	0.21
P_t	68	5	15	483	0.034326	$p > 0.20$	$p < 0.20$	0.9913	0.0062	0.18	–0.45
P_t	68	10	5	644	0.028172	$p > 0.20$	$p > 0.20$	0.9946	0.0230	0.27	0.07
P_t	68	10	10	483	0.045982	$p > 0.20$	$p < 0.05$	0.9830	<0.0001	0.49	0.17
P_t	68	10	15	483	0.049372	$p < 0.20$	$p < 0.01$	0.9866	0.0002	0.15	–0.64
P_t	57	5	5	322	0.073975	$p < 0.10$	$p < 0.01$	0.9804	0.0002	0.47	–0.15
P_t	57	5	10	483	0.025433	$p > 0.20$	$p > 0.20$	0.9972	0.5903	0.10	–0.20
P_t	57	5	15	483	0.030517	$p > 0.20$	$p > 0.20$	0.9930	0.0248	0.23	–0.18
P_t	57	10	5	483	0.045728	$p > 0.20$	$p < 0.05$	0.9879	0.0005	0.41	0.10
Pt	57	10	10	483	0.033617	$p > 0.20$	$p < 0.20$	0.9899	0.0021	0.36	0.25
Pt	57	10	15	483	0.024129	$p > 0.20$	$p > 0.20$	0.9895	0.0015	0.28	0.64

In relation to the values of power feeding and picking-up of the material a slightly weaker test results were obtained (Tab. 2). However it should be emphasized that for all groups of the values of power cutting, feeding and picking-up, the values of skewness and kurtosis coefficients do not exceed the values from the range of <–3,3>. On the basis of the guidelines in the literature (STANISZ, 2007) results that distributions of that skewness and kurtosis indicators can be consider as normal distributions. In the power distributions dominate these with a slight right-skewed, because the values of skewness coefficient *A* are positive (except of one case for P_w, $w = 67\%$, $z = 5$, where the skewness coefficient $A = –0.04$ – it is a very small left-hand skewness, Tab. 2). The power distributions are generally more slender, so they are leptokurtic and for these cases the kurtosis coefficients have positive values. Six from the 24 power distributions are less slender (the values of kurtosis coefficients *K* are negative, Tables 1 and 2), that means they are flattened in relation to the normal distribution – they are platykurtic.

Tab. 2. – The results of the normality test of power feeding (P_w) and picking-up (P_a) by Kołmogorow-Smirnow (K-S, D) and Lilliefors (p-Lillifors) and Shapiro-Wilk (WS, W) tests and the skewness and kurtosis coefficients for these power distributions (*w* – moisture content, %; *z* – number of knives; *m* – sample mass, kg; N – number)

Power	*w*	*m*	N	max D	K-S	p-Lillief.	WS	p-value	Skewness *A*	Kurtosis *K*
P_w	68	5	1127	0.022783	$p > 0.20$	$p < 0.20$	0.9976	0.0961	0.10	0.21
P_w	68	10	966	0.061425	$p < 0.01$	$p < 0.01$	0.9758	<0.0001	0.58	1.58
P_w	68	15	966	0.040728	$p < 0.10$	$p < 0.01$	0.9956	0.0072	0.15	–0.23
P_w	57	5	805	0.017938	$p > 0.20$	$p > 0.20$	0.9983	0.6236	–0.04	0.00
P_w	57	10	966	0.038118	$p < 0.15$	$p < 0.01$	0.9943	0.0010	0.21	0.19
P_w	57	15	966	0.047819	$p < 0.05$	$p < 0.01$	0.9846	<0.0001	0.47	0.54
P_a	68	5	1127	0.127746	$p < 0.01$	$p < 0.01$	0.8850	<0.0001	1.48	2.86
P_a	68	10	966	0.083538	$p < 0.01$	$p < 0.01$	0.9273	<0.0001	1.04	1.08
P_a	68	15	966	0.076961	$p < 0.01$	$p < 0.01$	0.9462	<0.0001	0.88	0.78
P_a	57	5	805	0.110716	$p < 0.01$	$p < 0.01$	0.8834	<0.0001	1.47	2.79
P_a	57	10	966	0.095900	$p < 0.01$	$p < 0.01$	0.9182	<0.0001	1.16	1.66
P_a	57	15	966	0.072785	$p < 0.01$	$p < 0.01$	0.9446	<0.0001	0.84	0.37

The test results of the analysis of equality of variance (Tab. 3) allow to inference that all of the parameters meet this assumption, because the values of the critical level of significance are not lower than 0.01.

Tab. 3. – The results of the variance equality analysis by Levene and Browna-Forsythe and Welch tests for the power cutting (P_t), feeding (P_w) and picking-up (P_a) of plant material (*w* – moisture content, %; *z* – number of knives; *m* – sample mass, kg).

Parameter	*w*	*z*	*m*	Levene'a test	p-value	Brown-Forsythe test	p-value
P_a	68	5	5	2.92	0.0886	1.55	0.2138
P_a	68	5	10	2.72	0.1002	1.64	0.2013
P_a	68	5	15	6.87	0.0106	6.45	0.0110
P_a	68	10	5	1.60	0.2070	1.08	0.3002
P_a	68	10	10	1.26	0.2712	1.11	0.2776
P_a	68	10	15	0.93	0.3354	1.14	0.2855
P_a	57	5	5	3.20	0.0747	2.09	0.1495
P_a	57	5	10	5.96	0.0152	4.46	0.0355
P_a	57	5	15	5.20	0.0232	4.41	0.0365
P_a	57	10	5	1.87	0.1726	0.67	0.4125
P_a	57	10	10	1.07	0.3019	0.43	0.5105
P_a	57	10	15	0.36	0.5517	0.11	0.7459
P_t	68	5	5	2.59	0.1082	2.29	0.1309
P_t	68	5	10	0.01	0.9234	0.01	0.9267
P_t	68	5	15	0.49	0.4842	0.49	0.4839
P_t	68	10	5	1.32	0.2523	1.24	0.2671
P_t	68	10	10	2.37	0.1588	2.24	0.1696
P_t	68	10	15	3.42	0.0654	3.25	0.0722
P_t	57	5	5	0.29	0.5903	0.32	0.5718
P_t	57	5	10	6.96	0.0101	6.70	0.0102
P_t	57	5	15	3.82	0.0516	3.60	0.0588
P_t	57	10	5	3.10	0.0792	3.11	0.0787
P_t	57	10	10	6.64	0.0101	6.61	0.0101

Parameter	*w*	*z*	*m*	Levene'a test	p-value	Brown-Forsythe test	p-value
P_t	57	10	15	0.06	0.8002	0.12	0.7241
P_w	68	5	5	1.97	0.1616	1.82	0.1779
P_w	68	5	10	0.23	0.6317	0.10	0.7471
P_w	68	5	15	6.19	0.0105	6.77	0.0107
P_w	68	10	5	0.27	0.6057	0.67	0.4128
P_w	68	10	10	5.23	0.3036	3.94	0.2102
P_w	68	10	15	5.89	0.0116	5.21	0.0176
P_w	57	5	5	0.48	0.4878	0.50	0.4785
P_w	57	5	10	6.73	0.0102	6.80	0.0102
P_w	57	5	15	6.79	0.0101	6.68	0.0101
P_w	57	10	5	0.28	0.5981	0.23	0.6292
P_w	57	10	10	6.45	0.0114	6.17	0.0116
P_w	57	10	15	0.95	0.3298	0.92	0.3393

After the verification of assumptions, that the values of power have distributions close to the normal and the equality of variances and considering the large number of observations in the trial ($n_i > 30$), the multivariate analysis of variance was carried out (Tab. 4). On the basis of the test results it can be concluded, that all of the main factors (moisture content, number of knives and sample mass for the power of cutting, or moisture content and sample mass for the power of feeding and picking-up) and the most of double interactions and the triple interaction had statistically significant influence on the power values differentiation ($p < 0.05$). Only for power cutting, the double interaction of the number of knives and sample mass was statistically insignificant ($p = 0.3788$).

Tab. 4. – The results of the variance analysis for the power cutting (P_t), feeding (P_w) and picking-up (P_a) relative to the moisture content (*w*) and number of knives (*z*) and sample mass (*m*)

Power	P_t		P_w		P_a	
	F	p-value	F	p-value	F	p-value
w	134.34	$<0.0001^a$	136.24	<0.0001	19.41	<0.0001
z	120.35	$<0.0001^a$				
m	3156.97	$<0.0001^a$	2057.49	<0.0001	478.40	<0.0001
$w \times z$	37.71	$<0.0001^a$				
$w \times m$	5.60	0.0037^a	28.17	<0.0001	12.06	<0.0001
$z \times m$	0.97	0.3788				
$w \times z \times m$	3.92	0.0200^a				

[a] – statistically significant difference at $p < 0.05$.

For the identified significance of the Fisher-Snedecor statistic ($p<0.05$), the further detailed analysis of the differences between the values of independent means was conducted. For this purpose the Duncan test was used (Tab. 5). In the Tab. 5 the results for moisture content and number of knives were summarized, although the inference about differentiation for the two levels of factor is possible directly from the analysis of variance (Tab. 4). The results of the Duncan test allow to inference that the differences between the power values are statistically significant differentiated between all of the factors levels.

The developed matrix of the correlation indicators for the variable input parameters of power (Tab. 6) allows to inference, that all of the values combinations are characterized by cohesion between themselves. Although in some cases the values of correlation coefficients are low, they are statistically significant, because the critical value of the correlation coefficient is 0.0021. The values of the correlation coefficients between the power and the moisture content are negative. It is logical, because the plant material of higher moisture content (68%) was characterized by lower rigidity than the material of less moisture content

(57%). The higher moisture content (68%) was near the value identified as an optimal value (65%), when the rigidity of the plant, calculated as a product of the modulus of elasticity and the moment of inertia, is the lowest one. At this moisture content, the plant deformation consisting in the compaction, compressing or bending, requires the lowest energy expenditures (KANAFOJSKI, 1980).

Tab. 5. – The results of a detailed analysis of the average values made by Duncan test

Parameter	Level	P_t, kW	P_w, kW	P_a, kW
Moisture w, %	68	9.39^a	0.70^a	0.13^a
	57	11.28^b	0.80^b	0.16^b
Sample mass m, kg	5	4.91^a	0.41^a	0.05^a
	10	10.39^b	0.74^b	0.13^b
	15	15.56^c	1.10^c	0.24^c
Knive z	5	9.98^a		
	10	10.56^b		

Tab. 6. – Correlation matrix of variables and power parameters

Parameter	w	z	m	P_t	P_w	P_a
w	1.0000					
z	0.0399	1.0000				
m	–0.0492	–0.0681	1.0000			
P_t	–0.1555	0.0474	0.7174	1.0000		
P_w	–0.1688	0.0340	0.6419	0.6105	1.0000	
P_a	–0.0731	–0.0311	0.3763	0.3249	–0.0691	1.0000

The critical values for the number of 5796 at the significance level of α=0.05 are 0.0021.

The very high (rating by STANISZ, 2007) positive (0.7174) correlation was also obtained between the power cutting and the sample mass and between the power feeding and the sample mass (0.6419). Noteworthy is also a very high cohesion (0.6105) between the power cutting and the power feeding. The power picking-up rather weakly correlates with the input parameters, and with the rest of power cutting and feeding values.

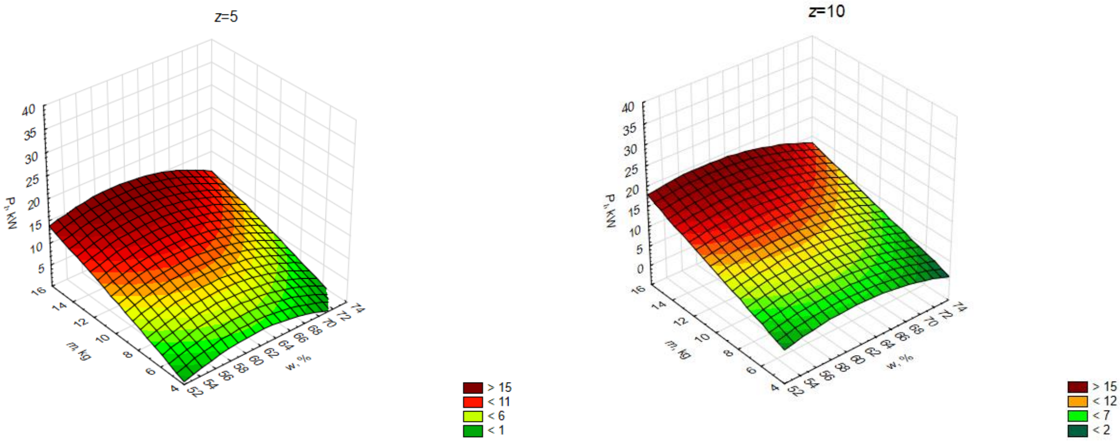
On the basis of the previous conclusion, the nonlinear models of regression for power cutting, feeding and picking-up were developed (Tab. 7). Only formulas for which statistically significant regression coefficients were obtained, were summarized in that table. The best evaluation (R = 0.735) has the model of power cutting and afterward the model of power feeding (R = 0.667). Although the model of power picking-up has statistically significant regression coefficients, the general evaluation of this model is weak (R = 0.383) and it should be taken and interpreted with caution.

Tab. 7. – Analysis of regression for power cutting, feeding and picking-up

Parameter	P_t				P_w				P_a			
	estimate	error	t-value	p-value	estimate	error	t-value	p-value	estimate	error	t-value	p-value
b_0	–2.280	0.226	–10.10	<0.001	5.7044	0.742	7.68	<0.001	–0.1817	0.0741	–2.45	0.014
$b_1(w^2)$					0.0015	<0.001	8.08	<0.001				
$b_2(m^2)$					0.0008	<0.001	2.11	0.035				
$b_3(w)$	–0.006	0.002	–2.42	0.016	–0.1856	0.024	–7.82	<0.001	0.0021	0.0012	1.79	0.073
$b_4(m)$	1.576	0.125	12.61	<0.001	0.1566	0.014	11.36	<0.001	0.0444	0.0068	6.55	<0.001
$b_5(wm)$	–0.008	0.002	–4.09	<0.001	–0.0017	<0.001	–9.14	<0.001	–0.0004	0.0001	–3.76	<0.001
$b_6(z)$	0.598	0.147	4.06	<0.001								
Equation	$P_t = b_0 + b_3 w + b_4 m + b_5 wm + b_6 z$				$P_w = b_0 + b_1 w^2 + b_2 m^2 + b_3 w + b_4 m + b_5 wm$				$P_a = b_0 + b_3 w + b_4 m + b_5 wm$			
R	0.735				0.667				0.383			

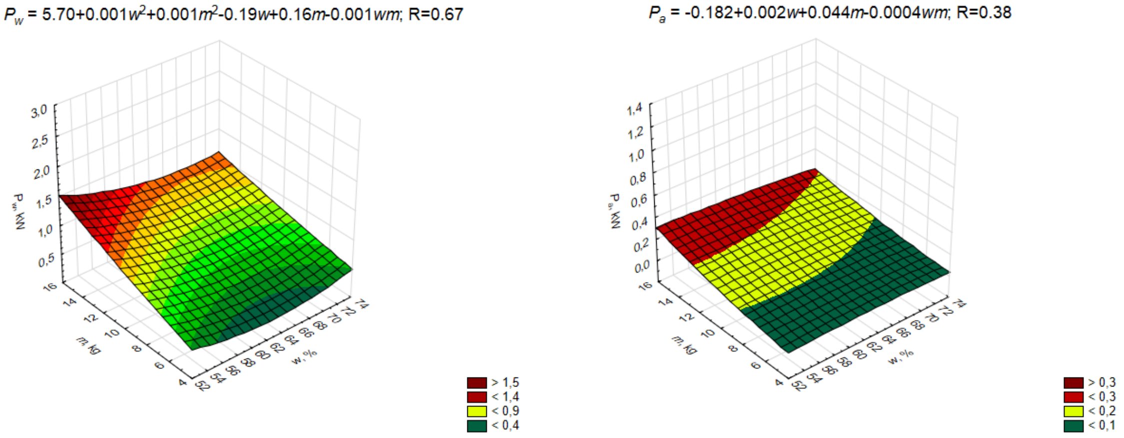
The graphic interpretation of these models were presented on the Fig. 2 and 3. The waveforms of the power cutting graphs are different from the power feeding ones. In the optimal range of the material moisture content of 65%, the power cutting has reached the highest value. It results from the plants rigidity. In the cutting process occur phenomena involved with a convertible compression of the material and its cutting, namely the fragmentation under influence of the knife-edge pressure and exceeding of the acceptable material stresses. At this moisture content, the material has compacted easier but it was harder to divide it. From the cutting theory results (REZNIK, 1967; KANAFOJSKI, 1980), that in that process dominates fragmentation of the material under influence of the knife-edge pressure and it is easier to compact and cut thinner layers of the material. With a smaller number of knives ($z = 5$), the frequency of cutting is lower and because of that the power request for cutting was lower than with a higher number of knives ($z = 10$) and it was 9.98 kW and 10.56 kW, respectively (for average values of the moisture content and sample mass). The doubling of knives number did not increase directly proportional the request for power, because the smaller particles require lower kinetics energy for their ejection to overcome their lower inertia. LISOWSKI ET AL. (2005) found that during cutting the material for longer sections there is required a lower torque, but the ratio of the top request for the torque to average value is higher. That indicates that in this conditions the tractor of lower power can be used, but the higher engine power reserve is necessary.

The mathematical model of the effective power requirement for work of the chopping unit reflecting the phenomena occurring during the cuts, friction, ripping, compression and the dynamic influence of the working elements on corn plant.


z=5

z=10

Fig. 2. – Power cutting (P_t) regarding to the moisture content (w) and the mass of the material (m) during work by unit with 5 and 10 knives


P_w = 5.70+0.001w^2+0.001m^2-0.19w+0.16m-0.001wm; R=0.67

P_a = -0.182+0.002w+0.044m-0.0004wm; R=0.38

Fig. 3. – Power feeding (P_w) and picking-up (P_a) regarding to the moisture content (w) and the mass of the material (m)

The wide review of research works relating to chopping, conducted by O'DOGHERTY (1982), contained also similar information on an energetic model structure of work of the chopping unit.

All those works also considered components of idle running power which is related to the friction resistances at kinematic pairs of working elements and movement resistances of the driving gear and air resistances. O'DOGHERTY (1982) clearly pointed out that both components of power were related to the work resistances on idle running of the unit.

Because the material is compacted, compressed and bent between the feed rolls, under optimal moisture content of the material (65%), when it has the lowest rigidity, the request for the power feeding was the lowest (Fig. 3). The plant material of the lowest moisture content has generated higher resistances and it was harder to compact it and in the consequence this has translated into increase of the request for the feeding power by feed rolls.

The share of the effective power for the cutting unit was 92%, for the feed rolls 7%, and for the pick-up unit 1% only.

GARBERS AND FRERICHS (2001) indicate that the power needed to rolling the machine is 9% of the total power, and the cutting units of maize consume 7% of that power, the feed and bent rolls – 4%, the chopping trammel – 54%, and the additional chopping devices – 26%, including 8% for the power used to the actuator of the chopped material discharge spout.

KLONOWSKI ET AL. (2005) proved that the total power measured on the PTO during picking-up the grass from the shaft, under the full load of the machine, was 40.8 kW, whereof 3.6 kW was on the units feeding the plant material to the cutting unit and 4.2 kW on the rolling the machine. Because in the forage harvester the additional devices or elements that support chopping were not used, it can be accept that the power taken on the chopping process is the difference of the total power and the power of feeding units and the power involved with the rolling. This difference is 35.4 kW, which is 86% of the power request for the entire machine. The total idle running power was approximately 8 kW, where was 50% for the flywheel chopping unit.

The obtained results from the conducted tests indicate that the share of the power cutting is significantly higher than it results from previous tests, but these investigations were conducted in the stationary conditions and therefore the share of the power needed to feeding the material was significantly lower than in the natural conditions.

At increasing load of the forage harvester by pant material, under constant feeding speed, the relative request on the process of cutting and picking-up has increased and for the sample mass of 5, 10 and 15 kg was 0.982, 1.039 and 1.037 $kW \cdot kg^{-1}$, and 0.010, 0.013 and 1016 $kW \cdot kg^{-1}$, respectively, and for feeding – it has decreased and was 0.082, 0.074 and 0.073 $kW \cdot kg^{-1}$, respectively. These results confirm the theoretical considerations that the thicker layers of the material are more difficult to cut.

CONCLUSIONS

1. The characteristics of the request for the effective power for cutting and feeding processes of the maize plant material in the units of the forage harvester were inverse in relations to each other and had the maximum and minimum values, respectively, under optimal material moisture content (65%), at which the rigidity of the plants is the lowest.
2. The doubled cutting frequency doesn't generate the same increase of requirement for power for cutting unit work, because the smaller particles require lower kinetic energy to overcome their lower inertia.

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