MISCANTHUS STALK BEHAVIOR AT SHEAR CUTTING WITH V CUTTING BLADES, AT DIFFERENT SHARPENNING ANGLES

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A high energy consumption, during the plant preparation technological process is taken for cutting and grinding plants. In order to estimate the consumed energy at cutting and grinding it is necessary to know plant behaviour at shear loadings, simple cutting or compression. For this simple, tests can be realized testing machunes in laboratory conditions, with curve recordings for force-deformation and displaying values of these parameters in the important points, which is the bioflow point, respectively the rupture point.

During this paper tests were done out of miscanthus samples from all their internodes, with the help of Hounsfield a testing machine, using cutting blades with a V shaped cutting edge, with different opening angles and different sharpening of the cutting edge.

Keywords: miscanthus stalk, cutting through shear action, V cutting knives, cutting angle, force – deformation curve

1. Introduction

Using energetic plants and agricultural waste as combustible fuel in thermal plants assumes a series of mechanical operations necessary to bring the material in its final phase of pellets or briquettes. If the plant harvesting was done as a grinded material, the technological process continues with drying the plants in special installations and then with milling in more stages for bringing the particles at dimensions at which compaction can be achieved.

If plant harvesting was done as whole plants, only with their cutting and leaving them on the field, then after their natural drying we continue the technological process of grinding and then milling and compaction.

An important energy consumption, during the technological process of plant preparation, is taken to ensure cutting and plant grinding. For estimating this energy consumption we need to know plant behaviour at shear loading, simple cutting or compression. Simple tests can be taken on mechanical testing machines,

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in lab conditions, with curve recordings for force-deformation and displaying values of these parameters in the important points, which is the bioflow point, respectively the rupture point.

In this paper tests were done out of miscanthus samples from all their internodes, with the help of the Hounsfield mechanical testing machine, using cutting blades with a V shaped cutting edge, with different opening angles and different sharpening of the cutting edge

On most tests, we could observe an increase of the specific energy consumption with shrinking of the particle size, [1,2,3]. We can point ont a series of studies on energetic willow, of that have shown an energy specific consumption of 99Mj/Mg for a hammer mill and for orifice mill of 3.2mm the energy specific consumption was of 40 MJ/Mg, [1,2,3].

Another study that seek to establish the energy specific consumption according to the sieve orifices has shown a rise of 1.3 to 2.5% for sieves with orifices from 2.0 at 0.6mm for wood chips, [4].

A series of such tests have their origin since 1964 when Balk used a wattmeter during his researches in order to determine the specific energy consumption correlated with the feed flow of the equipment and the humidity content of the grinded material, [5]. Sieves of different orifices were used as well as different speeds of the hammer mill.

Such an experiment was done using corn stalks, the consumption variation being of 17-46 MJ/Mg for rotation speeds of 54-86 m/s and hammer thickness of 6.4 mm, [6]. During some recent researches, grinded vegetal materials were distributed by class of dimension in order to establish behaviour patterns during the process of cutting/grinding, [2].

In this paper, the authors tried to determine the behaviour of miscanthus plant during the process of cutting with V shaped knives at different sharpening angles. The dependence between the plant physical qualities and their mechanical characteristics was outlined, resulted from the force-deformation curves at cutting through shearing.

2. Material and method

Miscanthus stalks were used for these experiments, harvested from the National Institute of Research-Development for Machines and Installations destined for Agriculture and Food Industry – INMA Bucharest. For extended analyses, both from the point of view of physical-biological characteristics as well as behaviour at cutting, shearing, compression or gross milling, 100 miscanthus plants were harvested between 2010 and 2011, that had the following characteristics: height 130-280 cm, average base diameter 8-12.5 mm, tip diameter 3.5-5 mm, number of internodes between 10-15, plant mass 8.9-37.6 g

For later use, the plants were kept in the laboratory at ambient temperature and humidity (22–25°C; 65–67%). They had a humidity of 8.8-9%.

For cutting tests with shearing, three plants were picked out of the more developed ones, similar at physical-biological characteristics, and in the internode area 5 samples were cut with the length of 30mm (the first 7 internodes for each plant starting from the base). Cutting the samples from the stalk was done with a curved blade in order not to deteriorate or crush the bark and the plant core during cutting.

Table 1

Physical characteristics of miscanthus samples

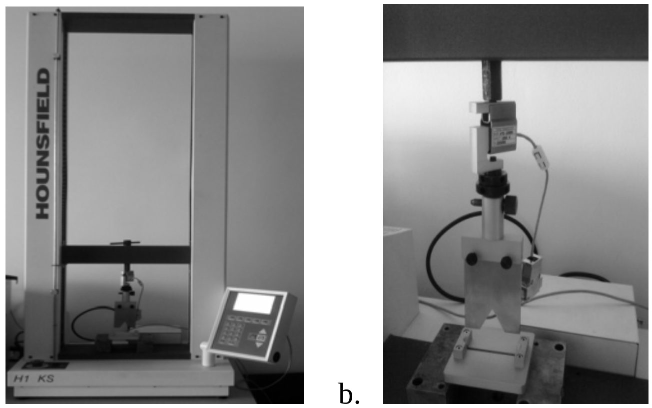
Internode	Stalk 1				Stalk 2				Stalk 3			
	Average diameter	Length	Mass	Bark Average	Average diameter	Length	Mass	Bark Average	Average diameter	Length	Mass	Bark Average
	mm	mm	g	mm	mm	mm	g	mm	Mm	mm	g	mm
1	10.73	23.05	0.88	1.91	11.26	24.13	1.02	1.92	10.98	25.11	0.9	1.84
2	10.44	25.21	0.96	1.63	10.51	25.25	0.98	1.61	9.75	24.63	0.76	1.53
3	9.64	25.86	0.8	1.47	10.05	25.21	0.9	1.31	8.74	24.27	0.6	1.34
4	8,82	25.96	0.7	1.34	9.12	24.70	0.7	1.33	8.90	25.32	0.58	1.30
5	8.43	26.28	0.68	1.27	8.69	24.27	0.6	1,27	8.77	25.25	0.58	1.20
6	8.47	24.32	0.52	1.18	8.77	23.9	0.56	1.11	7.96	24.67	0.42	1.04
7	8.39	24.57	0.42	1.12	8.42	24.36	0.46	1.08	7.90	24.43	0.4	1.01

Physical characteristics of stalk samples used are presented in table 1. We need to mention that the average diameter of the sample was measured at its core and is the average of two perpendicular planes, also, the bark thickness is the average measurements on an internode, measured after the cutting tests.

The Hounsfield apparatus is presented in Fig. 1, together with the adopted solution for the experimental tests. The force cell of the apparatus was of 1000N and the travel speed of the cutter was of 500mm/min ($8.3\cdot10^{-3}$ m/s). In order to determine travel distance, the device has a precision of $\pm 10^{-4}$ mm.

Stalk cutting on the apparatus was done with 5 cutting blades (shearing) with an opening angle of 30 degrees but with edge angles (I = 10, 20, 30, 40 50°).

The cutting blades had identical characteristic dimensions with the shearing blades from the accessories of the Hounsfield L = 100 mm, l = 70 mm, g=3 mm. In the paper we presented only experimental results for the blade with a 30° opening angle.



a. b.

Fig..1. a. Hounsfield equipment; b. Cutting knife

Using the data acquisition software Qmat, the force-deformation curve was plotted, out of which values of the force in the cutting point and the energy necessary for cutting for each experiment were outlined.

In Fig. 2 a graphic model of a force-deformation curve is shown during the experimental determinations. 105 experimental tests were done (equal to the number of samples, 35 for each of the three plants, 7 internodes with 5 samples / internode). In order for each test to be taken under the same conditions we used only the 7 internodes starting from the base of the plant.

On the force-deformation curve (Fig.2) obtained at plant cutting we can observe three distinct areas for the curve:

- Compression area until the plant is crushed, respectively the bark breaks longitudinally, and the core flattens, the curve shows a higher variation with reaching the maximum point after which the value drops for a higher knife movement;
- Compression and cutting area presents a higher variation far exceeding the crushing limit, the value of the force reaching a maximum that represents the maximum cutting force;
- Third area in which the cutting takes place on the length of the plant, the curve presenting either a slight decreasing variation, or the opposite if the plant is trapped between the margins of the orifices where a knife/plant friction appears.

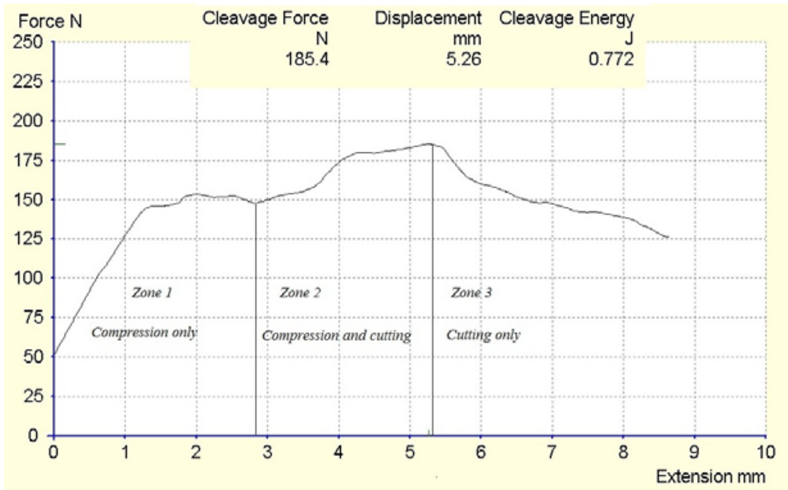


Fig.2. Knife force-displacement curve for random sample

3. Results and discussion

The results of experimental measurements of cutting force and cutting energy required are shown in Table 2.

In Fig.3 the plant design is shown with positioning and internode numbering in the lower to upper plant, and in Fig. 3.b we presented the sample positioning on the table of the Hounsfield device, for shearing cutting.

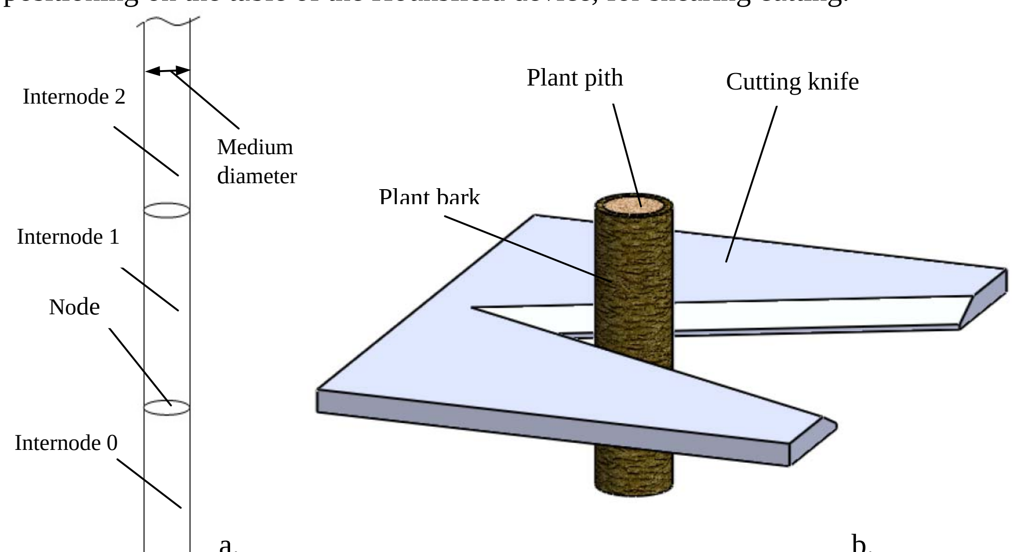


Fig.3. a. Miscanthus stalk; b. Cutting knife and plant

Table 2

Energetic parameters of sample cutting for an opening angle of the blade of 30 ^{o} and five sedge angles

Edge angle of the cutting knife	Internode	Plant 1		Plant 2		Plant 3		Medium	
		Force	Cutting energy	Force	Cutting energy	Force	Cutting energy	Force	Cutting energy
		N	J	N	J	N	J	N	J
10	1	879	5.31	536	2.253	689	4.558	701.3	4.0
	2	753	4.365	525	4.34	536	3.864	604.7	4.2
	3	458	2.801	687	3.474	409.5	2.536	518.2	2.9
	4	332	1.445	597	3.424	364	2.011	431.0	2.3
	5	330.4	1.392	324.8	2.593	334	2.104	329.7	2.0
	6	318.8	1.712	380.8	1.895	336.8	1.862	345.5	1.8
	7	318.8	2.115	536	2.531	302	1.729	385.6	2.1
20	1	577	1.819	531	3.324	429	2.264	512.3	2.5
	2	589	2.331	441.5	1.968	397.6	2.667	476.0	2.3
	3	426.5	1.821	416	2.541	342.4	1.34	395.0	1.9
	4	465.5	1.753	356	0.993	260.4	2.279	360.6	1.7
	5	323.3	0.673	296	0.762	259.2	0.974	292.8	0.8
	6	338	1.328	274	0.951	240.5	0.747	284.2	1.0
	7	210	1.093	209.5	0.004	173.4	0.63	197.6	0.6
30	1	644	4.913	494	3.369	368	4.185	502.0	4.2
	2	523	2.725	516	1.996	353.2	1.317	464.1	2.0
	3	420	1.254	451	2.049	316	1.169	395.7	1.5
	4	321.6	0.955	335.2	1.621	270	1.095	308.9	1.2
	5	215.8	1.749	344.4	2.148	250.4	1.395	270.2	1.8
	6	251.6	0.989	256.4	0.889	203.3	1.214	237.1	1.0
	7	236	0.747	220.5	1.284	182	0.561	212.8	0.9
40	1	782	7.53	530	4.458	683	4.083	665.0	5.4
	2	495.5	3.403	475	2.924	331.2	2.144	433.9	2.8
	3	291.6	1.859	337.6	4.579	294.4	1.405	307.9	2.6
	4	300.8	0.892	328.4	1.803	308.8	1.585	312.7	1.4
	5	312.4	1.061	252	0.614	224.8	1.116	263.1	0.9
	6	222.8	2.101	308.4	1.069	205.3	0.732	245.5	1.3
	7	198.4	0.427	202	0.757	290.4	1.892	230.3	1.0
50	1	710	4.308	538	13.8	662	3.914	636.7	7.3
	2	630	4.572	588	4.014	561	3.033	593.0	3.9
	3	675	4.597	644	4.337	402.5	2.381	573.8	3.8
	4	409	3.22	335.2	2.272	358.8	2.801	367.7	2.8
	5	276.4	1.866	266.8	0.891	348.4	2.437	297.2	1.7
	6	239	1.474	244	1.482	253.2	2.072	245.4	1.7
	7	276.4	1.41	209.5	0.961	284.4	2.143	256.8	1.5

On the basis of values presented in table 2 variation curves of force and cutting energy have been drawn according to internode position on the length of the plant, as well as according the knife angle blade for the three plants, on the same graph is the average variation curve of the parameters, obtained through regression analysis with laws of variation (polynomial 2 degree, exponential or power type).

The variation curves of the parameters according the position of the internodes are presented in figure 4, and the variation curves of the force and energy of the cut according to the sharpening level of the blade with opening angle of 30^{o} are presented in Fig.6.

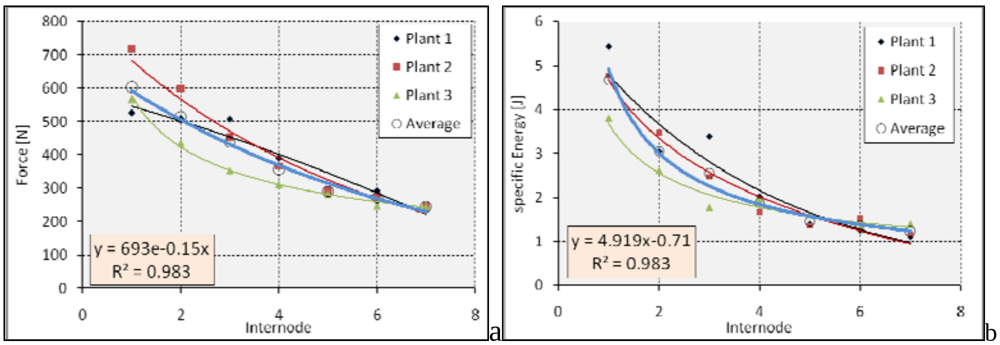


Fig.4. Variation of cutting force and energy of miscanthus stalks according to the position of the internode

Analyzing the fig.4 curves, we can see that the cutting force drops from base to plant tip, with the drop of stalk average diameter. From established findings, also, the thickness of the stalk bark drops from bottom to plant top.

For the plants subjected to this test, the average values of the cutting force drop from 600N at the lower internode to 245 N at internode 7, the variation curve of the cutting force is a decreasing exponential variation, as we can see in figure 4,a. The correlation of the experimental data for the average values of cutting force at the three analyzed plants with the exponential distribution law (*y* = 693·e-0.15·*x*, in which y is the cutting force, and x the internode number) is represented by the correlation coefficient R^2=0.983.

For the energy consumed at height plant cutting, from the base to the top, we can also see the drop of energy values through shearing from the lower internode to the 7th internode (Fig.4.b).

Thus, the average cutting energy drops from 4.74 J for the first internode, to 1.22 J for the last analyzed internode. These values represent the arithmetic average of energy values, for all three plants subjected to experimental determinations.

Correlating the experimental data with the law of variation of power type (y=4.92·x-0.71, in which *y* is the consumed energy for cutting and *x* the number of internode) results a value of correlation coefficient R^2= 0.983.

Analyzing, from a statistical point of view, the values presented by the average cutting force of the plants on their height from bottom to top, mean square deviation of the force values is between 100N at internode 1 and 7N, for internode 7. This means that at lower internodes the cutting force varies in higher limits, unlike the internodes from the top where the cutting force varies very little. This is presented in fig. 5a. For the consumed energy at plant cutting the standard deviation of average values on plant height varies from σ_E=0.82 J for internode 1 to σ_E=0.15 J for internode 7. We can see that the cutting energy varies in high limits at the base internodes in comparison to the upper internodes where the cutting energy has a smaller variation. This can be observed in the graphs below in Fig.5.b.

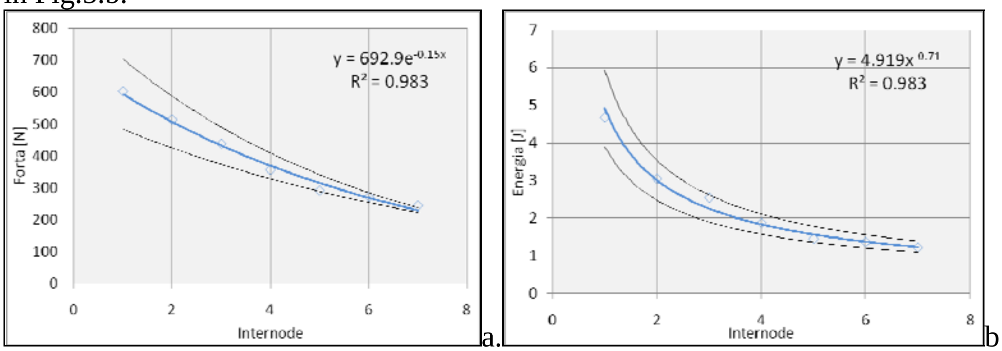


Fig.5. Average value variation of the force and cutting energy of stalks and the curves of mean square deviations (F±σ_F; E±σ_E) according to the position of the internode

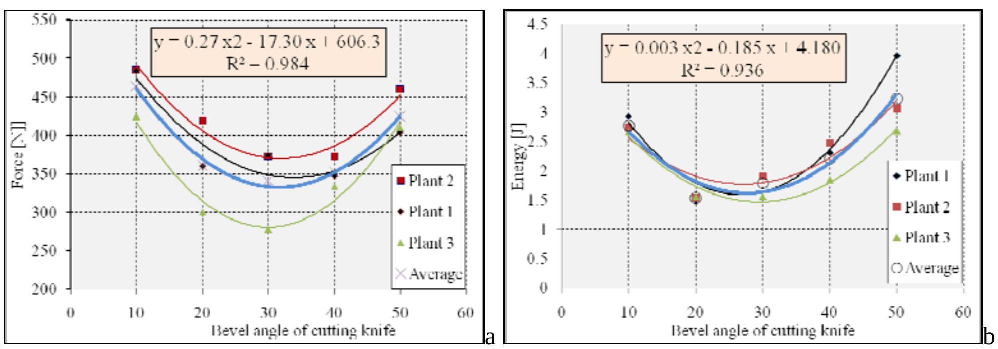


Fig.6. Variation of the force and miscanthus stalk cutting according to the blade sharpening angle

From the analysis of variation curves of miscanthus plants according to the size of the blade edge angle (i=10, 20, 30 40 and 50^o), presented in Fig.6.a we can see a drop in its values until an angle of 30-40, after which the force rises for sharpening values of over 40^o. Also, from the values presented in table 2, but also from fig.6,a the cutting force, at knife speed of 500 mm/min (with support), has average values of 464N at sharpening angles of 10º and 424N at 50º, presenting a minimum between 30º and 40º (at 32º) with the value of 340N.

We can see that sharp blades, of over 30º opening, but also knives with high sharpening angles (over 35-40º) lead to higher values of the cutting force, for a straight cut and small work speeds. We recommend that for low cutting speeds and straight cut with a counter knife, knifes with sharpening angles of 30º±2º to be used.

Dragging the variation curves from Fig.6.a were plotted through regression analysis of the experimental data for cutting force, for each of the three analyzed plants, as well as for force average values, calculated as arithmetical average of force values of the three plants, using the polynomial regression function, second degree, the coefficients of the equation being determined in the analysis ($y=0.27x^2-17.30x+606$, where y is the cutting force, and x- the sharpening angle).

The experimental data, regarding the variation of the cutting force with the sharpening angle of the blade, with the second degree polynomial variation law, is represented by the value of the correlation coefficient $R^2=0.984$.

The same thing is shown for the average cutting energy variation, presented in fig.6,b.

From the analyzed data from table 2 and the curves in fig.6b we can see a decreasing variation of 10º and 3.2 J for angles of sharpening of 50º; for sharpening angles of 20-30º we can see the smallest value of energy, 1.6J (the values are the average of energy values for the three plants, each of these being calculated, as the arithmetical average of the values of energy at the same sharpening angle, for all seven internodes).

The curves from fig.6,b have been determined through regression analysis of experimental values, first for each of the three plants, for all the average values (as arithmetical average of the shearing values of the three plants using the second degree polynomial type regression function with coefficients resulted from the analysis, $y=0.003\cdot x^2-1.185\cdot x+4.180$, where y is the cutting energy, x - edge angle).

Correlating the experimental results in table 2, respectively the consumed energy variation for cutting according to the sharpening angle of the blade, with the distribution law, second degree type polynomial, is represented through a high value of the correlation coefficient $R^2=0.936$

The presented analysis refers to individual cutting of miscanthus plants, at values of the plant diameter shown in table 1. In the situation where more plants are being cut at once, average values presented for the force and cutting energy are quantified with the number of processed plants (if this can be estimated). Still, the force and cutting energy can’t exceed the values presented in the technical characteristics of the equipment.

If we analyze the data presented for the average cutting force variation of the plants according to the sharpening angle of the knife blade, average square deviation of the σ_F force values are between the limits of 19.2N for the sharpening angle of 40º and 59N for the sharpening angle of 20º. For the sharpening angle of 10º, the value of mean average deviation is 34.5N, and for the sharpening angle of 50º the mean average square is 30.5N.

Thus, the cutting force varies in the broader limits to the tighter sharpening limits, presenting smaller variations at higher sharpening angles. This is presented in Fig.7.a

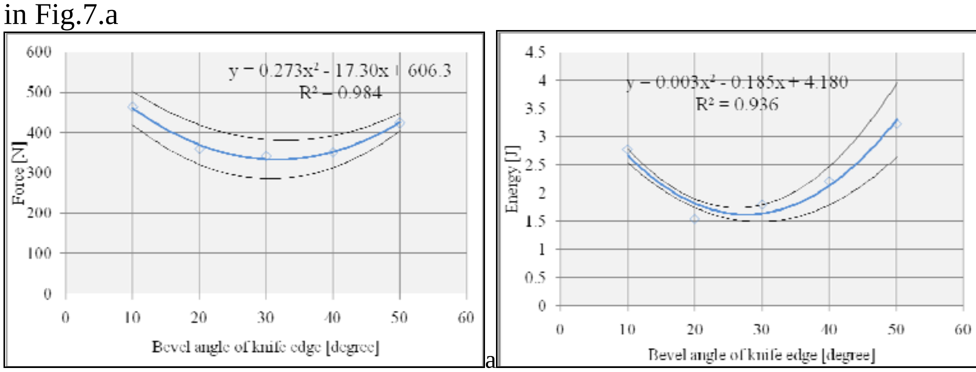


Fig.7. Variation of the average values of force and cutting energy and the mean square deviation ($F\pm\sigma_F$; $E\pm\sigma_E$) according to the sharpening angle of the blade

In the plant cutting energy case, analyzing its variation with the blades sharpening angle, we can see different variations of the mean square deviation for different sharpening angles. So, for sharpening angles of 10º the mean square deviation is σ_E=0.13J, while at angles of 20º, the mean square deviation is 0.02J, presenting increasing values until the sharpening angle of 50º, where σ_E=0.65J. The variation of average energy consumption at shearing cutting and its deviation with ±E is presented in Fig.7.b.

We can say that the cutting energy presents small variations at sharpening angles of 20-30º, which recommends the use of these values for blades with α_v=30º (cutting was done through shearing with support, at low work speed).

In order to estimate the variation of force and cutting energy through shearing the miscanthus stalks according to plant diameter, we measured the average diameter (in two perpendicular planes) for each internode of the three plants and the variation graph of the force average values (as arithmetic average of the values of the force at the five sharpening angles for each internode) according to the average diameter (calculated as an arithmetic average for the three plants), presented in Fig.8.a.

From the analysis of fig.8,a we can see that the experimental points are in a regression line through equation y=132.1·x–837.2 (where y is the cutting force, in N, and x – average diameter of the internodes, in mm), correlation coefficient presenting a relatively high value (R^2=0.990).

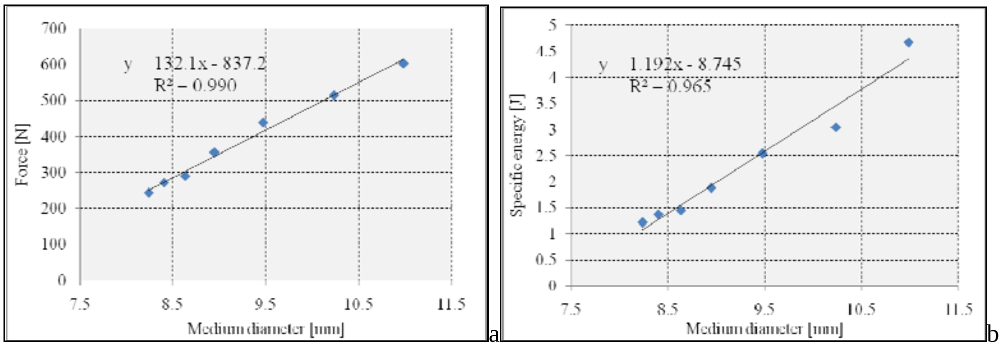


Fig. 8. Variation of the average values of cutting force and cutting consumed energy according to mean diameter

The value of the cutting force rises as it is normal, so, with the increase of the miscanthus stalk diameter, from values of 243 N for an average diameter of ϕ9.2 mm, to values of 600 N for an average diameter of stalks of ϕ11 mm.

The same thing is seen for the plant cutting energy, which has, also, a rising linear variation with the rise of stalk diameter, from values of 1.2 J for an average diameter of ϕ8.2 mm, to values of 4.7 J for average diameters of ϕ11 mm.

The regression curve of the cutting energy average values with the law of linear variation (fig.8,b) is given by the equation y=1.192·x-8.745 (where y is cutting energy, in J, and x is the average stalk diameter, in mm), the correlation being represented by the high value of the correlation coefficient R^2=0.965.

Referring to the force variation and cutting energy through shearing of the miscanthus stalks, according to bark thickness, these are presented in Fig.9.a.

For plotting the experimental points we measured the average bark thickness, in its median region; the values are presented in table 1.

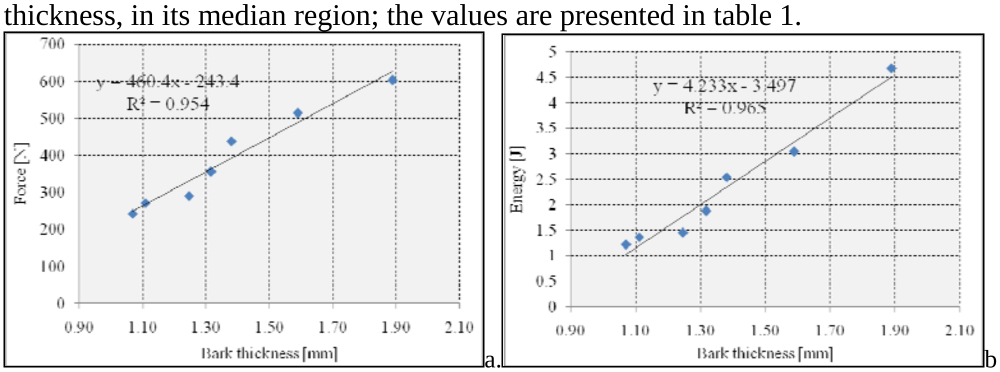


Fig.9. Variation of the cutting force and energy consumed at cutting according to the thickness of the plant bark

Analyzing the graph in Fig.9.a we can see a growing variation of the average cutting force (for the three plants and five angles of sharpening) with the bark thickness (which presented decreasing values from the first internode to the 7th internode) from values of 243 N (the same value as well as the variation according to stalk diameter) for average thickness of 1.07 mm, of 600 N for average thickness of bark of 1.89mm (to the first internode, calculated as an arithmetic average of the average bark thickness from the three types of stalk tested).

The regression curve of the average values of cutting force, according to the average thickness of stalk bark is given by the equation $y=460.4\cdot x-243.3$ (where y is the cutting force expressed in N, and x-bark thickness, in mm) the correlation with the experimental points is represented by the correlation coefficient $R^{2,}$ which had a higher value ($R^2=0.954$).

It is clear that the bark thickness has the most influence on cutting force, because the core is much easier to cut, having a low lignin content, the variation of force being directly proportional with the bark thickness.

In the case of consumed energy variation for shearing cutting of miscanthus plants, according to bark thickness, this also presents, a higher variation with the rise of bark thickness (from the first to the last interval) phenomenon graphically represented in fig.9b.

The values of cutting energy (the same as the variation according to stalk mean diameter) present increases from 1.2 J for bark thickness of 1.07 mm (at the inferior internode).

Doing the experimental points linear regression, a curve equation $y=4.233x-3.497$ is obtained (where y is the cutting energy, in J, and x- thickness of the stalk bark, in mm). The correlation between the regression curve and the experimental points is given by the high correlation coefficient value $R^2=0.964$.

We can make the same remark, once with the shrinking of bark thickness (from the base to the top of the plant), the consumed energy for cutting of miscanthus plants, at small values of cutting speed (500mm/min, using the cut with the support of the plant in two parts, also drops).

For other travel speeds of the cutting blade further experimental determinations are needed, but the presented data during this paper can make for a good starting point and also can be of a real use both to miscanthus processing and harvesting equipment designers, as well as for users of these machines for estimating the functioning regime parameters.

4. Conclusions

Both at harvesting as well as at miscanthus processing, the plant is subjected to complex operations of crushing, shearing, cutting.

Our paper presents the variation of force and cutting energy according to stalk diameter, stalk bark thickness, cutting height (through the internode position on plant height) and the sharpening angle of the knife blade, using blades with a v shaped edge, with 30º opening.

Cutting through shearing was done with supporting the plant in two points, at blade speed of 500mm/min.

The average values of the cutting force, for all studied cases, was between the limits of 240-603N, and of the average cutting energy between the limits of 1.23-4.7J, both according to cutting height, as well as according to the blade sharpening angle.

We outlined the drop in force and cutting energey, with the drop of the stalk average diameter and of its bark, and also, from the lower to the upper part of the stalk, with the cutting height.

Also, we discovered that smaller sharpening angles, but also the biggest ones, led to higher forces and cutting energies, the smaller values of these presenting the sharpening angles of 25-35º, for the cutting blade with written opening (α_v=30^o). For other blade openings further experimental determinations are needed.

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