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Research of parameters of cutting the stems of giant miscanthus on the resistance force

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Abstract: *Research of parameters of cutting the stems of giant miscanthus on the resistance force.* The process of shredding plants using assemblies of agricultural machines is the most energy intensive stage of production. Utilization of classic shredding machines for harvesting energy plants requires investigation and explanation of energy expenditures needed to obtain the biomass. Therefore an important factor is acquisition of knowledge on the cutting force required to cut stems of giant miscanthus for different angles of the stem in relation to the cutting edge and the water content of the plants. Analysis of variance showed that the cutting force was varied in a statistically significant manner depending on the angle between the stem and the cutting edge and the water content of the stem. With increase of the angle the force decreased, while it increased with increased water content.

Key words: cutting force, giant miscanthus

INTRODUCTION

Striving for minimal energy intensity of plant shredding is related to the ongoing quest to determine optimal conditions of the cutting process. The process must ensure both a properly fragmented material, suitable for feed, material for production of biogas or for combustion [Nowakowski and Ślesiński 2012, Lisowski et al. 2012, 2014). The process of shredding is, however, a very complex phenomenon. It is dependent on a large number of factors related to: physical and mechanical properties of the plant material and the operating-technical parameters of the shredding equipment. The key physical and mechanical properties of the plant are: water content, species, development stage, morphology of structure [Lisowski et al. 2009b, Nowakowski 2010, Chlebowski 2012a, 2012b]. The operational-technical factors related to the shredding equipment include: thickness of the processed batch, angle of the stems, theoretical length of the cut, type and shape of the blade, sharpness of the cutting edge, shape and sharpness of the cutting board, the gap between the blade and the shear bar, angle of the blade, angle of the knife [Kanafojski 1980, Lisowski et al. 2009a, Bochat and Korpal 2013]. Cutting equipment with a drum based shredding system use 75–85% of their total installed power [Kanafojski 1980, Chlebowski 2011, 2012c]. Therefore searching for optimal process conditions for shearing of plant material is the goal of many empirical works of scientific character.

Utilization of giant miscanthus as an energy plant is justified if the energy balance is optimized. The energy expenditure during all the stages of production and energy production must be lower than the energy yield of the product. One of the stages of production in case of giant miscanthus is shredding the plants using the lowest possible energy expenditure. Therefore the aim of this research was the relation between the resistance observed when cutting the stems of the giant miscanthus and their orientation in relation to the cutting knife and the water content of the water.

MATERIAL AND METHODS

The study utilized stems of giant miscanthus. The plants were collected from the fields of an Experimental Station in Skierniewice of the Warsaw University of Life Sciences. Before measurements the stems were cleared of leaves and divided into sections at internodes. In order to realize the aim of the study the water content of the giant miscanthus' stems were measured as well as the cutting force.

The average water-content was established using weighting-drying method according to standard ASABE S358. The material remaining after the cutting was shredded and subsequently three 20 g (each) were collected. The samples were weighted using electronic scale with accuracy of 0.01 g and dried in temperature of 103 ±2°C for 24 h. This way four distinct water content levels were obtained: 6.83 ±0.23, 21.85 ±0.63, 31.20 ±0.55 i 49.83 ±0.23%, for which the measurement was realized.

In order to determine the cutting force utilized was a standard tensile testing machine TIRAtest controlled via MATEST software. Stem elements were affixed in a special clip that allowed for setting any desired angle between the stems and the cutting angle. The study analyzed seven different angles between the stems of the giant miscanthus and the cutting edge. Angle 0° was representative of the classical cutting angle present in most shredding devices, i.e. the longitudinal axis of the stem perpendicular to the edge. The subsequent cutting angles were changed by 15° increments up to 90° (cutting edge parallel to the longitudinal axis of the stem). To measure the cutting force utilized was a steel knife with width of 60 mm, thickness of 10 mm and point angle of 30°. The measurements of cutting were realized with the speed of 10 mm·min^{-1}. During the cutting process obtained were diagrams of force and deflection. Subsequent analysis utilized the maximal obtained value. For each combination of the variables 10 repetitions were realized.

RESULTS AND DISCUSSION

In result of the realized empirical research the cutting force was determined for the seven tested angles between the cutting edge and the four levels of water content of the giant miscanthus stems. In order to check the significance of variability of the working resistance component (F_x) at different test settings, a two-way variance analysis with repetitions was realized. The analysis took into consideration the two-factor interactions between the tested parameters. The results of the variance analysis are given in Table 1. At level $\alpha = 0.05$ the analysis determined a significant impact of the tested parameters on the cutting force although joint interaction between the angle and water content proved insignificant.

TABLE 1. Variance analysis of factors impacting the value of the cutting force

Source variable	Total squares	Number of degrees of freedom	Medium square	Value statistics (F_{obl})	Significance level
k: angle	$5.60944 \cdot 10^6$	6	934,907.0	20.03	<0.0001
w: water content	$1.86485 \cdot 10^6$	3	621,616.0	13.32	<0.0001
k × w	$1.04036 \cdot 10^6$	18	57,797.6	1.24	0.2309

In order to realize a detailed result analysis the cutting force results were divided into homogeneous groups using a Duncan test, depending on the angle between the stem and the cutting edge and the water content of the giant miscanthus (Table 2). Differences between the possible pairs of average values of the cutting force, divided according to the angle of the stem are significantly differentiated except the following pairs: 0–15, 0–30, 15–30, 30–45, 30–45, 60–75°. Analogously, no differentiation of the average cutting force divided by the water content of the stems was observed for the following pairs: 21.63–31.20 and 31.20–49.83%. We can observe that increasing the cutting angle results in a degressive change of cutting resistance. For angles 0–45° the decrease was about 20% and further increase in the 45–90° range resulted in resistance being lower by 2.5 times. This is clearly visible in the graphical representation on Figure 1. This means that in the classical feeder systems for the plant shredders where the stems are not turned in relation to the feeding direction achieving significant changes in the cutting resistance is impossible. Therefore we can observe

TABLE 2. The division of the cutting force into homogeneous groups according to: angle between the stem and the cutting edge and water content of the giant miscanthus

Angle between the stem and the cutting edge						
Angle [°]	number	average [N]	group similarity			
0	40	659.0				×
15	40	559.8			×	×
30	40	562.5			×	×
45	40	538.0			×	
60	40	427.8		×		
75	40	361.0		×		
90	40	206.0	×			
Water content of giant miscanthus						
Humidity [%]	number	average [N]	group similarity			
6.83	70	344.57	×			
21.63	70	478.43		×		
31.20	70	501.14		×	×	
49.83	70	569.57			×	

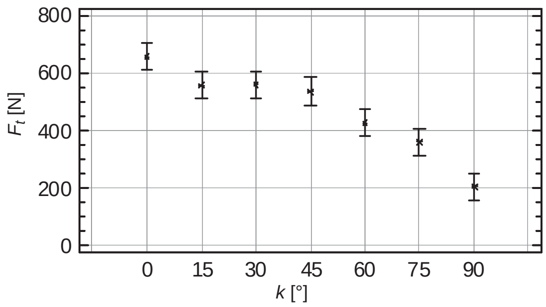

FIGURE 1. Changes of the cutting force (F_t). The study analyzed seven different angles between the stems of the giant miscanthus (k) and the cutting edge

works on new shredding equipment that will cut the stems at a given set angle. Such a cutting system was utilized in a bevel-worm devices [Zbytek 2009]. A different solution is creating a drum that consists of a shaft to which affixed are three discs, where the middle one has a larger diameter than the side disks. The disks hold blades in "v" orientation. This construction is currently researched and ensure cutting of material at an angle and should significantly decrease the energy expenditures needed by the cutting assemblies [Zastępowski et al. 2014]. According to Bochat [2010], when cutting rye straw with a cutting assembly where the cut angle is diagonally inclined, the energy intensity decreased by 15–20%.

The impact of water content on the cutting force was lower than the impact of the angle between the stem and the cutting edge. Lowest cutting resistance was observed for water content of 6.83% (Fig. 2). Increasing the water content to 31% resulted in increase of the cutting force by about 45% and further increase of water content to 49.83% resulted in the force increasing by yet another 20%. In case of many organic materials the density increases when the water content decreases, which results in increased hardness and cutting resistance [Kozakiewicz 2006]. However, with dry materials in many cases a clear cut is not present as the brittle plant material breaks before the actual cut. Such pro-

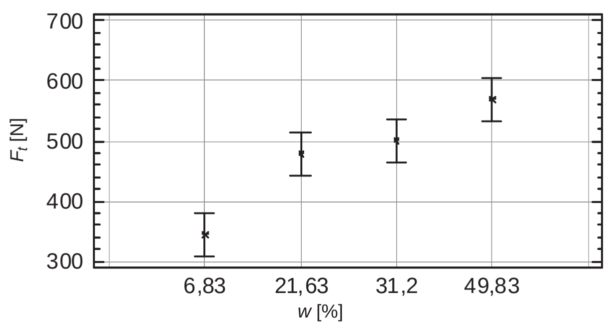

FIGURE 2. Changes of the cutting force (F_t) depending on the water content (w) of the stems for the giant miscanthus

cess was observed by Lisowski et al. [2009a] for corn, Nazari Galedar et al. [2008] for lucerne stems, İnce et al. [2005] for sunflower stems, Lisowski et al. [2010] for giant miscanthus or Nowakowski [2012] for willow shoots.

CONCLUSIONS

1. Cutting resistance when cutting giant miscanthus depend, among other factors, on the angle between the cutting edge and the longitudinal axis of the stem. As the angle increases from 0 to 90° the cutting resistance decreases. Conversely, with increased water content the cutting resistance increase.
2. The cutting angle and water content of the plants were not correlated in relation to the cutting resistance when processing the giant miscanthus.
3. Changing the cutting angle to 45° results in decreasing the cutting force by about 20% and justifies work on new shredding devices where the plants will be feed at an angle and not just perpendicular to the cutting edges.

REFERENCES

ASABE Standards. 2011: Moisture measurement – forages ASABE S358.2 (R2008). In: ASABE Standards 2011, American Society of Agricultural and Biological Engineers, St. Joseph, MI, USA: 780–781.

BOCHAT A. 2004: Bębnowy zespół tnący. Patent PL 63603 Y1. Filling date 23.12.2004.

BOCHAT A. 2010: Teoria i konstrukcja zespołów tnących maszyn rolniczych. Wyd. UTP, Bydgoszcz.

BOCHAT A., KORPAL K. 2013: Problematyka badawcza cięcia warstwy materiału anizotropowego. Inżynieria i Aparatura Chemiczna 52(2): 51–53.

CHLEBOWSKI J. 2012a: Mathematical models for energetic loads of withdrawing–compacting rolls set and chopping unit in the forage harvester. Annals of Warsaw University of Life Sciences – SGGW, Agriculture (Agricultural and Forest Engineering) 60: 59–73.

CHLEBOWSKI J. 2012b: Simulation investigations of energetic loads of the headers for long-stem plants harvesting. Annals of Warsaw University of Life Sciences – SGGW, Agriculture (Agricultural and Forest Engineering), 59: 59–69.

CHLEBOWSKI J. 2012c: Simulation investigations on energetic loading of the withdrawing–compacting rolls and the chopping unit of forage harvester. Annals of Warsaw University of Life Sciences – SGGW, Agriculture (Agricultural and Forest Engineering) 60: 75–87.

CHLEBOWSKI J. 2011. Wyznaczanie obciążeń energetycznych zespołów roboczych sieczkarń polowych. Postępy Nauk Rolniczych 4, 193–210.

INCE A., UĞURLUAY S., GÜZEL E., ÖZEAN M.T. 2005: Bending and shearing characteristics of sunflower stalk residue. Biosystems Engineering 92(2): 175–181.

KANAFOJSKI Cz. 1980: Teoria i konstrukcja maszyn rolniczych. Tom 2. Cz I. PWRiL, Warszawa.

KOZAKIEWICZ P. 2006: Fizyka drewna w teorii i zadaniach wybrane zagadnienia. Wyd. SGGW, Warszawa.

LISOWSKI A. (Ed.), KLONOWSKI J., STRUŻYK A., NOWAKOWSKI T., SYPUŁA M., CHLEBOWSKI J. 2010: Technologie zbioru roślin energetycznych, Wyd. SGGW, Warszawa.

LISOWSKI A. (Ed.), KOSTYRA K., KLONOWSKI J., CHLEBOWSKI J., NOWAKOWSKI T., SYPUŁA M., ŁOZICKI A., BULIŃSKI J., GACH S., KOTECKI L., ŚWIĄTEK K. 2009a: Efekty działania elementów wspomagających rozdrabnianie roślin kukurydzy a jakość kiszonki. Wyd. SGGW, Warszawa.

LISOWSKI A., KLONOWSKI J., DĄBROWSKA-SALWIN M., POWAŁKA M., ŚWIĘTOCHOWSKI A., SYPUŁA M., CHLEBOWSKI J., STRUŻYK A., NOWAKOWSKI T., KRZYSZTOF K., KAMIŃSKI J., STASIAK P. 2014: Size of plant material particles designer for biogas production. Annals of Warsaw University of Life Sciences – SGGW, Agriculture (Agricultural and Forest Engineering) 63: 31–39.

LISOWSKI A., NOWAKOWSKI T., SYPUŁA M., CHOŁUJ D., WIŚNIEWSKI G., URBANOVIČOVÁ O. 2009b: Suppleness of energetic plants to chopping. Annals of Warsaw University of Life Sciences – SGGW, Agriculture (Agricultural and Forest Enginering) 53: 33–40.

LISOWSKI A., STASIAK P., POWAŁKA M., WIŚNIEWSKI G., KLONOWSKI J., SYPUŁA M., SZCZĘSNY W., CHLEBOWSKI J., NOWAKOWSKI T., KOSTYRA K., STRUŻYK A., KAMIŃSKI J. 2012: Charakterystyki rozdrobnionej biomasy przeznaczonej na biogaz. Autobusy, Technika, Eksploatacja, Systemy Transportowe 10: 55–61.

NAZARI GALEDAR M., TABATABAEEFAR A., JAFARI A., SHARIFI A., O'DOGHERTYM. J., RAFEE S., RICHARD G. 2008: Effects of moisture content and level in the crop on the engineering properties of alfalfa stems. Biosystem Engineering 101(2): 199–208.

NOWAKOWSKI T. 2010: Strength of Miscanthus sinensis giganteus. Annals of Warsaw University of Life Sciences – SGGW, Agriculture (Agricultural and Forest Engineering) 56: 21–27.

NOWAKOWSKI T. 2012: Specific energy for cutting stems of the basket willow (*Salix viminalis* L.). Annals of Warsaw University of Life Sciences – SGGW, Agriculture (Agricultural and Forest Engineering) 60: 25–33.

NOWAKOWSKI T., ŚLESIŃSKI K. 2012: Morphometric characteristic of the energetic plant chaff. Annals of Warsaw University of Life Sciences – SGGW, Agriculture (Agricultural and Forest Engineering) 60: 51–57.

ZASTĘMPOWSKI M., BOCHAT A., KORPAL K. 2014: Analiza możliwości badań stanowiskowych procesu cięcia materiału roślinnego. Inżynieria i Aparatura Chemiczna 53(2): 133–135.

ZBYTEK Z., SPYCHAŁA W., WĄCHALSKI G., PAWŁOWSKI T., TALARCZYK W. 2009: Badania symulacyjne wpływu procesu rozdrabniania wierzby krzewiastej na ramę maszyny do jej zbioru. Problemy Inżynierii Rolniczej 3: 49–55.

Streszczenie: *Badania wpływu parametrów cięcia łodyg miskanta olbrzymiego na wartość siły oporu*. Proces rozdrabniania roślin w zespołach maszyn to najbardziej energochłonny etap w produkcji. Zastosowanie klasycznych maszyn rozdrabniających do zbioru roślin energetycznych wymaga poznania i wyjaśnienia nakładów energetycznych ponoszonych na proces pozyskania biomasy. Dlatego istotne stało się pozyskanie wiedzy o wielkości siły cięcia łodyg miskanta olbrzymiego dla różnych kątów ułożenia łodygi miskanta olbrzymiego względem krawędzi ostrza tnącego i wilgotności badanych roślin. Analiza wariancji wykazała, że wartość siły cięcia była zróżnicowana, w sposób statystycznie istotny, od zmian kąta ułożenia łodygi względem krawędzi ostrza tnącego i wilgotności łodyg miskanta olbrzymiego. Ze wzrostem kąta malała wartość siły odwrotnie niż dla wilgotności łodyg.

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