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Unit energy of *Miscanthus ×giganteus* stem cutting

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Abstract: *Unit energy of Miscanthus ×giganteus stem cutting.* The objective of the study was to explain the impact of moisture content in *Miscanthus ×giganteus* stem and the angle of positioning of the stem in relation to the cutting blade edge on unit energy of cutting. Research was conducting using *Miscanthus ×giganteus* plants of moisture content ranging from 6.83 to 49.83%. The stems were placed in a gripper, which allowed for changing of the angle of positioning of the stems in relation to the cutting knife blade edge (the angle was changed by 15° each time). To measure the cut, a steel knife of the width of 60 mm, thickness of 10 mm and blade angle of 30° was used. The average unit energy values of the cut for the examined conditions ranged from 0.10 to 60.18 $mJ \cdot mm^{-2}$. It was shown that modification of the angle of positioning of the stem in relation to the edge of the cutting blade from perpendicular to parallel results in a substantial decrease in the unit energy of the cut. Increasing of the moisture content above 21.63% did not bring a statistically significant difference in the unit energy value of the cut.

Key words: cutting angle, unit energy of the cut, *Miscanthus ×giganteus*

INTRODUCTION

Miscanthus ×giganteus is a perennial grass, encompassing more than twenty different species, characterized by substantial morphological variability. It has a very strong root system, reaching 2.5 m into the ground, which facilitates absorption of water and nutrients [Jankowski 1994]. It belongs to the group of energy crops with the photosynthesis cycle of C4, which is characterized by greater daily gains and biomass yields in comparison with C3 photosynthesis cycle plants. It is characterized by fast growth (in particular, during hot summers), high biomass yield per area unit and resistance to low temperatures. Depending on the habitat conditions, the yield of *Miscanthus ×giganteus* may reach 8–30 $t \cdot ha^{-1}$ of dry biomass [Dalianis et al. 1994, Lewandowski et al. 2000, Faber et al. 2007, Majtkowska and Majtkowski 2008, Chołuj et al. 2010, Francik and Knapik 2010, Kowalczyk-Juśko 2010, Tworkowski et al. 2010, Matyka and Kuś 2011, Gizińska et al. 2013, Pietkiewicz et al. 2014, Stępień et al. 2014]. Development of *Miscanthus ×giganteus* is reasonable, as calculations with regard to accumulated unit energy consumption per hectare indicate lower energy expenditures. According to Hryniewicz and Grzybek [2010], cultivation of this plant for energy production purposes requires much less energy consumption in comparison with corn seeds (83.88–91.78%), barley seeds

(82.55–84.74%), winter wheat (83.54%) and winter oilseed rape (79.25%). In the cultivation process, harvesting is the most energy-consuming stage of biomass production. Therefore, research has been initiated to gather more knowledge on optimizing and modeling of energy crop harvesting [Nowakowski 2012a].

Cutting resistance is the basic parameter that influences the operation of the cutting and grinding unit. It is determined by a number of factors, including physical properties of the plants: moisture content, maturity, rigidity and dimensions [Kanafojski 1980, Gach et al. 1991, Lisowski et al. 2013]. Physical properties are a specific feature of the cell material examined, and they change along with the stage of development, maturity and stem height [Chattopadhyay and Pandey 1999, Lisowski et al. 2009c, Yilmaz et al. 2009, Gendek et al. 2010, Nowakowski 2010]. Research indicates a high level of variability of the properties examined for plants picked up from the same field, which may reach 0.7 [McRandal and McNulty 1980]. Cutting resistance is a result of phenomena, which take place during the process, and it is associated with cutting, bending, as well as stretching of the stems [Frączek and Mudryk 2009, Lisowski et al. 2009a, Chlebowski 2012, Bochat and Korpal 2013].

With reference to stems of *Miscanthus ×giganteus*, no detailed research has been conducted to determine their resistance properties. Therefore, the objective of this work was to clarify the impact of moisture content in the material and the angle of positioning of the stem in relation to the cutting blade edge on the unit energy of the cut.

MATERIAL AND METHODS

Research was conducted using *Miscanthus ×giganteus* plants obtained in November of 2014 from the Experimental Station of the Faculty of Agriculture and Biology of Warsaw University of Life Sciences in Skierniewice. The plants were picked randomly from the standing crop cut just above the ground. After tearing off the leaves, the stems were divided into samples, containing stem sections with undamaged internodes. Due to the shape of the cross-section of the stem, which is almost elliptical, measurement of the diameter was conducted in two mutually perpendicular directions. The measurement was conducted using a digital slide caliper type MAUa-E24F of range of 0–150 mm with the accuracy of 0.01 mm.

The highest moisture content was obtained for samples collected directly after harvesting. Later on, it was reduced due to drying of the stems. In this manner, the moisture content obtained amounted to: 49.83 ±0.23% (during harvest), 31.20 ±0.55%, 21.85 ±0.63% and 6.83 ±0.23%. The moisture content was determined on the basis of the dry oven test according to ASABE Standard S358 as the average of three readings.

Measurement of the unit energy of the cut was calculated as the quotient of the total energy of deformation and area of the stem cross-section [Chattopadhyay and Pandey 1999, Skubisz et al. 2001, Tavakoli et al. 2009, Lisowski et al. 2010, Nowakowski 2012b, Nowakowski and Wróbel 2015].

$$E_{jt} = \frac{1}{S_t} \int F_t \mathrm{d}x$$

where:
E_{jt} – unit energy of the cut [mJ·mm^{-2}];
S_t – sample cross-section in the cut location [mm^2];
F_t – cut strength [N];
x – deformation (knife travel) [mm].

The cutting force value was established using the universal testing machine TIRAtest controlled by MATEST software, with the accuracy of 1 N. Technical parameters of the cutting knife include: width of 60 mm, thickness of 10 mm and blade angle of 30°. The knife movement speed was constant for all variants, amounting to 10 mm·min^{-1}. The cutting knife cooperated with the gripper, which maintained the appropriate angle of positioning of the stem in relation to the cutting blade edge. This angle was changed every 15°, starting from 0° (longitudinal axis of the stem perpendicular to the blade edge).

RESULTS AND DISCUSSION

Figure 1 presents changes in unit energy of the cut (E_{jt}) depending on the angle of positioning of the stem in relation to the cutting blade edge (k) within the examined range of moisture content of the stems of *Miscanthus ×giganteus*. A complex analysis of the research results indicates that modification of the angle of positioning of the stem in relation to the cutting blade edge from perpendicular to parallel results in a substantial drop in the value of unit energy of the cut. This has been confirmed by variance analysis, which has indicated a significant impact of the moisture content of the stem and the stem angle in relation to the cutting blade on unit energy

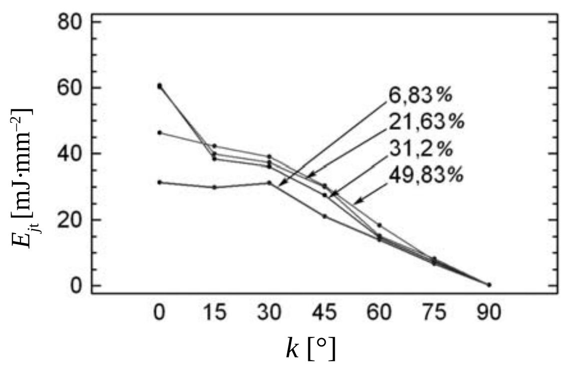

FIGURE 1. Changes in the cut unit energy (E_{jt}) depending on the angle of positioning of the stem in relation to the cutting blade edge (k) and the examined moisture content in the *Miscanthus ×giganteus* stem

of the cut (Table 1). The analysis took into account two-factor interaction between the parameters examined, which has turned out to be insignificant. (after Kramarenko 1980), when cutting plant material characterized by fibrous structure, skew positioning of the knife in relation to a single stem results in reduction of resistance and cutting work by 30–40%. Use of a cutting unit that allows for performance of a skew-oblique cut allowed for reduction of energy consumption in the process by 15–20% in comparison with a traditional unit with the perpendicular direction of feeding of stems to the unit [Bochat 2010]. For lucerne stems, Shinners et al. [1987] have stated that longitudinal positioning of the stems during cutting requires ten times less energy in comparison with the perpendicular positioning.

TABLE 1. Analysis of variance of factors that influence the cut unit energy

Variability source	Sum of squares	Number of degrees of freedom	Average square	Value of statistics F_{obl}	Significance level
k: angle	76 249.5	6	12 708.2	57.18	<0.0001
w: moisture content	2 952.4	3	984.1	4.43	0.0046
Interaction *k* to *w*	4 706.7	18	261.5	1.18	0.2809

Average values of unit energy of the cut for the examined conditions were within the range of 01.0 – 60.18 mJ·mm^{-2}. For instance, for cutting of corn stems with a blade at the angle of 30°, perpendicular to the stem longitudinal axis, the range of modification was within 9.82––22.41 mJ·mm^{-2} [Lisowski et al. 2009a], for mallow stems 20.18–45.19 mJ·mm^{-2} [Lisowski et al. 2009b] and for sugar cane – 37.42–64.25 mJ·mm^{-2} [Taghijarah et al. 2011]. When setting the knife at the angle of 45°, the unit energy of the cut is reduced, regardless of the stem moisture content, on the average by 43.1%. The most substantial decrease in energy was observed for the *Miscanthus* ×*giganteus* stem of moisture content of 31.2%, amounting to 54.7%, and the lowest – for the moisture content of 6.83% – amounted to 33.17%. Within the examined range of the stem moisture content level, it can be stated that the greater the cutting angle, the smaller the range of changes in the unit energy. According to Kanafojski

The detailed Duncan's test, for every examined angle of positioning of the stem in relation to the cutting blade edge, except for angles of 15° and 30°, isolated separate homogeneous groups (Table 2). This confirms the necessity to conduct works aimed at searching for grinding unit solutions that would feed the plants at the appropriate angle in relation to the cutting components [Gach et al. 1989, Bochat 2010, Zastempowski and Bochat 2013, Zastempowski et al. 2014]. The

TABLE 2. Division of the value of unit energy into uniform groups according to: stem positioning angle in relation to cutting blade edge and moisture content of the *Miscanthus ×giganteus* stem

The angle of positioning of the stem in relation to the cutting blade edge								
Angle [°]	Number	Average [mJ·mm^{-2}]	Similarity of groups					
0	40	49.63	×					
15	40	37.54		×				
30	40	35.88		×				
45	40	27.22			×			
60	40	15.49				×		
75	40	7.404					×	
90	40	0.112						×
Stem moisture content								
Moisture [%]	Number	Average [mJ·mm^{-2}]	Similarity of groups					
6.83	70	19.16			×			
21.63	70	27.22				×		
31.20	70	26.36				×		
49.83	70	26.26				×		

impact of humidity turned out to be less significant, as the detailed analysis identified two homogeneous groups. The first one was identified for the lowest moisture content level of 6.83% and the average unit energy value of 19.16 mJ·mm^{-2}, and the second – for the moisture level range of 21.6–49.8% with the average unit energy value of 26.6 mJ·mm^{-2}. The unit energy value for the cut was greater by 38.8% for stems with higher moisture content in comparison with those with lower moisture content. A significant impact of moisture content on variability of the cut unit energy has been confirmed by Chlebowski [2009] for corn. For the cutting units with rotating blades and a blunt edge, he showed that increasing of the moisture content of the stems from 77 to 82% resulted in increasing of unit energy by 12.5% for the knife rotating speed of 200 rpm and 10% for 400 rpm. Similar effects were achieved by Shahbazi and Nazari Galedar [2012] for safflower. Changes in the moisture content, ranging between 8.61 and 37.2%, resulted in increasing of the cut unit energy from 124.97 to 497.55 mJ·mm^{-2}.

CONCLUSIONS

- For *Miscanthus ×giganteus* plants, the unit energy of the cut depended on the angle of positioning of the stems in relation to the cutting blade edge and the plant moisture content. Interaction between these factors turned out to be statistically insignificant.
- There was no substantial difference in the value of the cut unit energy after exceeding the moisture content level of 21.63%. This result indicates the necessity of obtaining the *Miscanthus ×giganteus* stems at a lower moisture content in order to minimize the requirements with regard to energy needed for the cut.

- For energy consumption purposes, grinding of stems of *Miscantheus ×giganteus* should be performed at the largest possible angle of positioning of the stems in relation to the cutting blade edge.

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Streszczenie: *Energia jednostkowa cięcia łodyg miskanta olbrzymiego (Miscanthus ×giganteus).* Celem pracy było wyjaśnienie wpływu wilgotności łodyg miskanta olbrzymiego i kąta ułożenia łodygi względem krawędzi ostrza tnącego na wielkość energii jednostkowej cięcia. Do badań wykorzystano rośliny miskanta olbrzymiego o wilgotności w zakresie od 6,83 do 49,83%. Łodygi mocowano w imaku, który pozwalał na zmianę kąta ustawienia łodyg względem krawędzi noża tnącego (kąt zmieniano co 15°). Do pomiaru cięcia zastosowano stalowy nóż o szerokości 60 mm, grubości 10 mm i kącie ostrza 30°. Średnie wartości energii jednostkowej cięcia dla badanych warunków zawierały się w przedziale 0,10–60,18 $mJ \cdot mm^{-2}$. Wykazano, że zmiana kąta ułożenia łodygi względem krawędzi ostrza tnącego od prostopadłego do równoległego powoduje istotny spadek wartość energii jednostkowej cięcia. Zwiększenie wilgotności powyżej 21,63% nie powodowało statystycznie istotnych różnic w wartości energii jednostkowej cięcia.

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