Investigations Into the Process of Rotary Mowing of Selected Energy Crops

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Summary. The paper discusses the influence of plant moisture and linear and rotational speeds of the blades of a rotary cutting assembly on the unit energy needed for cutting the stems of Virginia Mallow (Sida Hermaphrodita) and Miscanthus giganteus. The optimum operating parameters of the rotary cutting assembly have been selected in terms of minimum energy demand in the cutting process of the said crops.
Key words: Virginia Mallow, Miscanthus Giganteus, cutting process, energy crops, unit cutting energy, moisture, linear speed of the cutting assembly, rotational speed of the cutting assembly.

INTRODUCTION

Biomass, aside from solar energy and wind, is considered the most important source of renewable energy on our planet [3, 7, 8]. The most popular and most widely explored plant for the production of biomass is willow [1, 4, 5, 9, 21, 23, 24]. Other energy plants are also worth attention, since their cultivation under certain conditions may render similar or even better results [2]. Such plants are Virginia Mallow and Miscanthus Giganteus.

Mowing of the plant shoots can be done upon vegetation, when the leaves fall. The end of the cutting period should take place prior to new vegetation. In practice, harvesting is performed manually or using mower systems from half of November until the end of March [6, 11]. In the case of Virginia Mallow or Miscanthus giganteus grown on small plantations, classical mowing systems can be used (used in typical rotary mowers) [12, 13], which is why it is necessary to seek the most optimum operating parameters of the rotary cutting assembly in the cutting process of these plants [10, 15, 25]. The determination of these parameters will be possible upon an analysis of the results of the investigations conducted on a laboratory stand designed for tests of energy demand in the plant mowing process.

THE RESEARCH AIM

The aim of the research was to find the optimum operating parameters of a rotary cutting assembly in terms of energy demand for the stem cutting process of Virginia Mallow and Miscanthus giganteus. The investigations were conducted for:

– different linear speeds of the cutting assembly,
– different rotational speeds of the cutting assembly,
– different moistures of the plant material.

The investigations were conducted on a laboratory test stand designed for testing rotary cutting of energy crops located in the Department of Mechanical Systems Engineering and Automation at the Institute of Mechanical Engineering, Warsaw University of Technology – the Płock Campus, as a continuation of research works conducted at this facility for many years [16, 17, 18, 19, 27, 28, 29].

OBJECT OF THE RESEARCH

Energy crops are characterized by a rapid growth at the beginning of vegetation and a multitude of stems in the dry part of the supra-terrestrial part of the plant (its greater energy potential compared to leaves), low soil requirements and high yield of biomass [2]. Because of these factors, Virginia Mallow and Miscanthus giganteus were selected for the investigations.

Virginia Mallow was imported to Poland in the 1950s of the last century. It is highly resistant to severe soil and climate conditions. It multiplies generatively (through seeds) or through vegetation (plant seedlings). It grows to the height of up to 350 cm. From 1 ha of crop up to 250 GJ of energy can be obtained [22].

Miscanthus giganteus is a perennial grass built of rigid blades having a spongy core of the height reaching 300 cm (intense growth of mass). It is pest and disease resistant. It does not grow on swamp and wet soils. It multiplies through vegetation (plant seedlings). From 1 ha of crop 300 GJ of energy can be obtained [22].

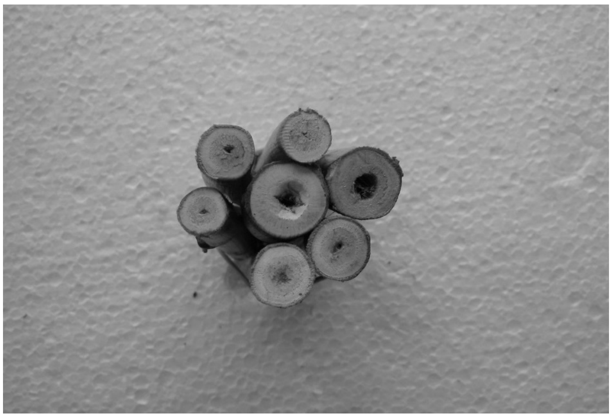

Fig. 1. Cross-section of the Stem of Virginia Mallow

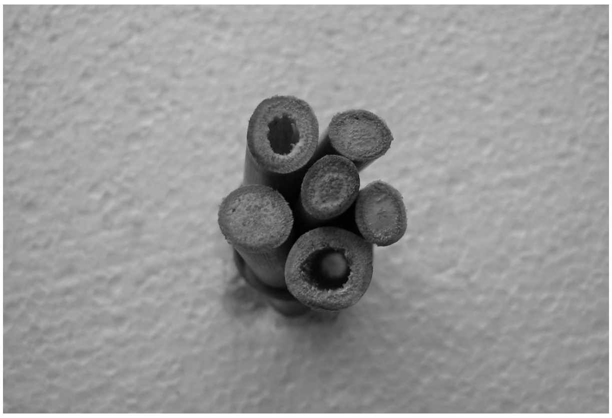

Fig. 2. Cross-section of the Stem of Miscanthus giganteus

THE TEST STAND

The test stand includes a frame structure on which the cutting assembly taken from a classical rotary mower is fitted [20, 26]. The working disc of the cutting assembly has two symmetrical inertia blades fixed to blade holders. The rotary cutting assembly is driven by a three-phase electric motor. The motor is controlled by an inverter programmed from a PC. The mower movement is simulated by a progressive motion of a trolley carrying energy crops.

During the tests, the computer records the increase in the electric power consumption as a function of time and, on this basis, the unit energy demand to cut the energy crops is calculated. Unit energy for cutting is the total energy needed for the process of cutting per unit of cross-section area of the cut stems.

METHODOLOGY AND COURSE OF THE TEST

Virginia Mallow and Miscanthus Giganteus were selected for the rotary cutting tests. The plants came from an experimental station at the Department of Agriculture and Biology at Warsaw University of Life Sciences (SGGW) in Skierniewice. Samples of the length of 250 mm were prepared from the stems of the energy plants. Then a selection in terms of moisture level was performed (20%, 40%, 60%). Such samples were fixed in the trolley simulating the motion of the cutting assembly under actual field conditions. The cross-section area of the mowed plant was 0.0038 m². Each measurement was repeated a minimum of three times [14]. The cutting of the plant was done under the following conditions:

- temperature 20 ºC,
- ambient pressure 768 mm Hg,
- weight of the inertia blade m = 65.05 g,
- angle of the blade edge α = 29º20',
- type of the blade edge: cut upwards,
- number of cutting blades: 2 blades located symmetrically on the circumference of the working disc,
- diameter of the working disc f = 680 mm,
- speed of the trolley simulating the linear motion of the cutting assembly: V=0.031 m/s, V=0.063 m/s, V=0.105 m/s,
- rotational speed of the cutting assembly: n= 1424,1824, 2108 rpm.

RESULTS

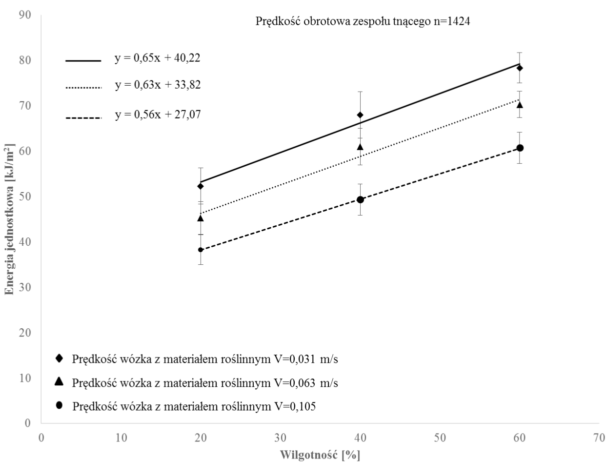

Fig. 3. Comparison of the course of changes of the unit cutting energy of Virginia Mallow as a function of moisture for 3 linear speeds of the trolley carrying the plant material at the rotational speed of the cutting assembly of n=1424 rpm.

Key:– unit energy [kJ/m2]; moisture – [%], speed of the cutting assembly – [rpm], · 5t speed of the trolley carrying the plant material [m/s]

The unit cutting energy of the Virginia Mallow as a function of moisture grows for each of the tested linear speeds of the trolley carrying the plant material (Fig. 3).

The greater the linear speed of the trolley carrying the plant material, the lower the unit cutting energy. A change in the linear speed of the trolley from 0.031 m/s to 0.063 m/s results in a drop of the unit cutting energy by 11 % on average and a further change of the speed from 0.063 m/s to 0.105 m/s results in a drop of the unit cutting energy by another 15 %.

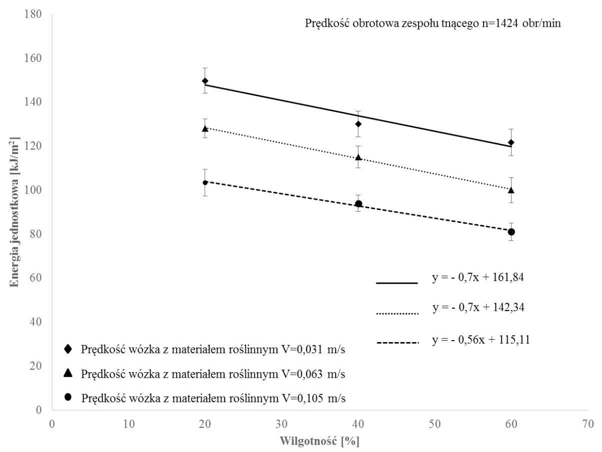

Fig. 4. Comparison of the course of changes of the unit cutting energy of Miscanthus giganteus as a function of moisture for 3 linear speeds of the trolley carrying the plant material at the rotational speed of the cutting assembly of n=1424 rpm.

The unit cutting energy of Miscanthus giganteus as a function of moisture decreases for each of the tested linear speeds of the trolley carrying the plant material (Fig. 4).

The greater the linear speed of the trolley carrying the plant material, the lower the unit cutting energy (Fig. 4). A change in the linear speed of the trolley from 0.031 m/s to 0.063 m/s results in a drop of the unit cutting energy by 19 %, on average and a further change in the speed from 0.063 m/s to 0.105 m/s results in a drop of the unit cutting energy by another 22 %, on average.

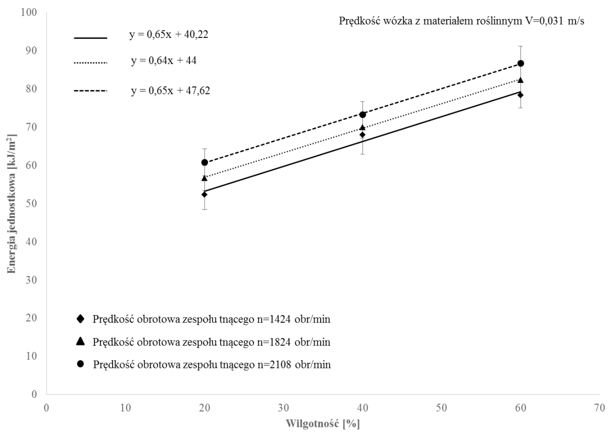

Fig. 5. Comparison of the course of changes of the unit cutting energy of Virginia Mallow as a function of moisture for 3 rotational speeds of the cutting assembly at the linear speed of the trolley carrying the plant material of V=0.031 m/s.

Key: unit energy [kJ/m²]; moisture [%]; speed of the trolley carrying the plant material [m/s]; · 5t rotational speed of the cutting assembly [rpm]

The unit cutting energy of Virginia Mallow as a function of moisture grows for each of the tested rotational speeds of the cutting assembly (Fig. 5).

The greater the rotational speed of the cutting assembly, the greater the unit cutting energy (Fig. 5). An increase in the rotational speed from 1424 rpm to 1824 rpm results in an increase in the unit cutting energy by 4% on average and a change from 1824 rpm to 2108 rpm results in a further increase in the cutting energy by 6 %, on average.

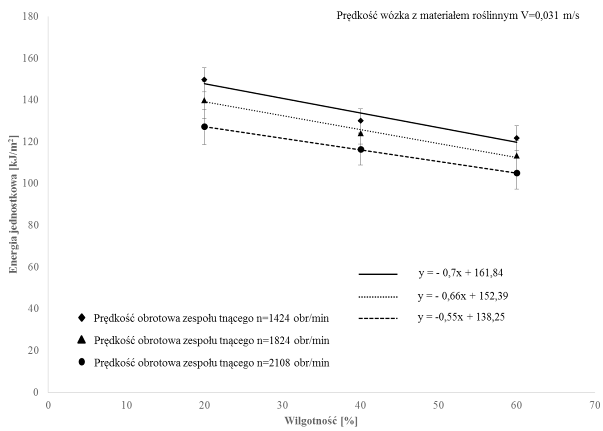

Fig. 6. Comparison of the course of unit cutting energy changes of Miscanthus giganteus as a function of 3 rotational speeds of the cutting assembly at the linear speed of the trolley carrying the plant material of V=0.031 m/s.

The unit cutting energy of Miscanthus giganteus as a function of moisture decreases for each of the tested rotational speeds of the cutting assembly (Fig. 6). The greater the rotational speed of the cutting assembly, the lower the unit cutting energy (Fig. 6). An increase in the rotational speed of the cutting assembly from 1424 rpm to 1824 rpm results in a decrease of the unit cutting energy by 14% on average and a change of the speed from 1824 rpm to 2108 rpm results in a further drop of the energy by 16 %, on average.

CONCLUSIONS

1. The unit energy needed for cutting of the stems of Virginia Mallow grows as the moisture of the stem increases. This may be attributed to the morphology of the plant. In the cross-section of Virginia Mallow, fibrous tissue prevails.
2. An increase in the moisture of Miscanthus giganteus results in a reduction of the unit cutting energy for this plant. This may be attributed to a lower energy demand for squeezing of the moist plant. The stem of Miscanthus giganteus assumes a shape of a pipe as its cross-section diameter increases.
3. Because of the energy demand for the mere process of cutting, it is best to cut low moisture Virginia Mallow. Miscanthus giganteus is best cut when moist. These trends are independent of the linear and rotational speeds of the cutting assembly.
4. The unit energy of Virginia Mallow grows along with the rotational speed of the cutting assembly. In the cutting process of Miscanthus giganteus a reverse relation takes place, i.e. a drop in the unit cutting energy following the increase in the rotational speed of the cutting assembly. This phenomenon is attributed to different morphologies of the stems of these plants.

5. The most energetically advantageous operating parameters of the rotary cutting assembly for mowing of Virginia Mallow and Miscanthus giganteus are: rotational speed of the cutting assembly n=2108 rpm and its linear speed V=0.105 m/s. Harvesting of Virginia Mallow should be done when its moisture level is low while that of Miscanthus giganteus – when it is high.

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BADANIE PROCESU CIĘCIA ROTACYJNEGO WYBRANYCH ROŚLIN ENERGETYCZNYCH

Streszczenie. W pracy omówiono wpływ wilgotności rośliny oraz prędkości liniowej i prędkości obrotowej noży rotacyjnego zespołu tnącego na energię jednostkową cięcia łodyg ślazowca pensylwańskiego i miskantusa olbrzymiego. Dokonano doboru najkorzystniejszych wartości parametrów roboczych rotacyjnego zespołu tnącego ze względu na minimalne zapotrzebowanie na energię w procesie cięcia badanych roślin.
Słowa kluczowe: ślazowiec pensylwański, miskantus olbrzymi, proces cięcia, rośliny energetyczne, energia jednostkowa cięcia, wilgotność, prędkość liniowa zespołu tnącego, prędkość obrotowa zespołu tnącego.