ASSESSMENT OF UNCONVENTIONAL TALL GRASSES CULTIVATION AND PREPARATION FOR SOLID BIOFUEL

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Abstract. The paper provides the research results of unconventional tall grasses: sida (*Sida hermaphrodita*), cup plant (*Silphium perfoliatum* L.) and common mugwort (*Artemisia vulgaris* L.) cultivation and preparation for solid biofuel. These investigations were carried out in the fields and laboratories of the Aleksandras Stulginskis University and the Lithuanian Research Centre for Agriculture and Forestry in 2009-2012. The work of plant cultivation was aimed to assess the impact of nitrogen and liming application on dry matter productivity and the evaluation of the technological process for biofuel production. The four years of field investigations revealed that growing conditions and 120 $kg \cdot ha^{-1}$ nitrogen rate had the highest impact on common mugwort and cup plant dry mass (DM) productivity. The use of 6.0 $t \cdot ha^{-1}$ $CaCO_3$ liming material had a positive effect on cup plant productivity, only. For the assessment of unconventional tall grasses preparation for solid biofuel the methodology of solid biofuel preparation for unconventional bioenergy plants was approved, and the technique for plant chopping, milling, pressing, and determination of plant chaff, mill and pellet quality was selected. There were presented research results of unconventional tall bioenergy plants chaff and mill physical-mechanical properties – moisture content, bulk density and in justice of use the drum chopping and hummer milling equipment prepared chaff and mill fractional composition. The average calorific value of these plants was determined, which is varied from 17.2 to 18.7 $MJ \cdot kg^{-1}$.

Keywords: sida, cup plant, common mugwort, biological productivity, chaff, mill, fractional composition, pellets, calorific value.

Introduction

Various unconventional tall grasses can be used for cultivation and preparation for solid biofuel in Lithuania: sida (*Sida hermaphrodita*), cup plant (*Silphium perfoliatum* L.), common mugwort (*Artemisia vulgaris* L.), etc. Sakhalin, Japanese and hybrid sida (*Sida hermaphrodita*) is the non-traditional big stem plant, which is not yet widespread in Lithuania, it is grown and used only for research purposes.

Drier climate conditions are also suitable for sida growing. This plant can perfectly grow in those areas where only 500-600 mm precipitation falls annually. Sida may reach the height of 3-4 metres. The plant propagates itself by seeds. However, it is possible to breed this plant like elephant grass – by tuber. Considerably worse shooting results are reached if planting seeds, and higher results – if planting tubers. Sida is planted in April-May by special planters (usually, potato planters). Sida is planted in the distance 0.75x0.75 or 0.9x0.9 m, 45 or 70 cm row-spacing [1; 2]. From 10000 to 40000 sida plants are planted in one hectare. Annual sida harvest may vary from 8 to 20 $t \cdot ha^{-1}$ dry material [3].

Sida (*Sida hermaphrodita*) is a plant of warmer climate conditions – it is grown in research fields of the Lithuanian Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry. According to the scientists, even if the majority of imported energetic plants grow in Lithuania, it is necessary to take into consideration the purpose of green mass. Conventional permanent grasses are also suitable for biogas production. It is considered that the energetic value of sida is similar to that of pine and fir (about 18.7 $MJ \cdot kg^{-1}$). However, taking into consideration the growth velocity of sida, from one hectare annually it may give twice higher amount of energy than from one hectare. The same machinery may be used for collection of other big stem tall plants [4].

Cup plant (*Silphium perfoliatum* L.) – is a plant belonging to aster family *Silphium* genus. According to various calculations, this genus contains up to 33 sorts. Till now, these unconventional to agriculture plants attracted attention as decorative and suitable for forage plants. The following sorts have been mostly researched: *S. perfoliatum* L., *S. integrifolium* Michx., ir *S. laciniatum* L. [5; 6]. It is characteristic that these plants accumulate up to 28.8 $t \cdot ha^{-1}$ of dry materials (DM) [3]. According to the data of long-term research made in Russia, the average annual harvest of cup plant is 15.6 $t \cdot ha^{-1}$. Cup plant was researched as possible forage for pets. However, it was proven by the research that, comparing to corn (another big-stem plant), cup plant is characterised by lower forage value. In the recent years, much attention has been paid to possible usage of cup plant for production of biofuel [7]. Still, there are not enough data on this issue and it is purposeful to continue research in this field.

Research on growing common mugwort (*Artemisia vulgaris* L.) and cup plant (*Silphium perfoliatum* L.) has been performed in the Lithuanian Research Centre for Agriculture and Forestry, Vezaiciai Branch and the Aleksandras Stulginskis University. The research period: 2009–2012 [8; 9]. The aim of this research was to evaluate the effect of lime and nitrogen fertilisers on biological productivity of both sorts. Also, it was vital to perform searching research for biofuel production technological evaluation. The research results of common mugwort and cup plant dry matter productivity ($kg \cdot ha^{-1}$) in dependence on nitrogen and liming application are presented in Table 1 [8].

Table 1

Common mugwort and cup plant dry matter productivity ($kg \cdot ha^{-1}$) in dependence on nitrogen and liming application

Treatment	2009	2010	2011	2012
Common mugwort				
Nitrogen fertilization ($kg \cdot ha^{-1}$)				
0	3354	2842	2398	2753
120	5249	3747	3760	4580
Liming ($t\ ha^{-1}$ $CaCO_3$)				
0	3824	3288	3079	3809
6.0	4652	3376	3449	3367
LSD_{05}/LSD_{01}	*1035/1426*	*420/580*	*578/796*	*267/367*
Cup plant				
Nitrogen fertilization ($kg \cdot ha^{-1}$)				
0	5438	15905	16531	9152
120	7731	19231	19932	12692
Liming ($t \cdot ha^{-1}$ $CaCO_3$)				
0	6169	14269	16284	10390
6.0	7128	20570	20698	11624
LSD_{05}/LSD_{01}	*753/1037*	*3029/4173*	*1248/1719*	*1717/2366*

The data presented in Table 1 show, that the highest efficiency of both liming and nitrogen application for common mugwort was achieved in the first 2010 harvestable season; the application of 120 $kg \cdot ha^{-1}$ N caused the increase of the dry matter yield up to 5.2 $t \cdot ha^{-1}$. Cup plant achieved highest dry matter productivity at the 2^{nd} and 3^{rd} vegetation seasons. The peak of dry matter accumulation was achieved in 2011, when the application of 120 $kg \cdot ha^{-1}$ N rate increased the dry matter yield to 19.9 $t\ ha^{-1}$, on average. Similarly, 6.0 $t \cdot ha^{-1}$ $CaCO_3$ increased the dry matter yield up to 20.7 $t \cdot ha^{-1}$, on average. The results are very comparable to the yield data in 2010. There was a sharp decrease of dry matter yield in 2012.

Out of two crops, the highest was the common mugwort calorific value, which averaged from 17.84 $MJ \cdot kg^{-1}$ (in 2011) to 17.97 $MJ \cdot kg^{-1}$ (in 2010); meanwhile the average cup plant calorific value varied from 17.19 $MJ \cdot kg^{-1}$ (in 2010) to 17.48 $MJ \cdot kg^{-1}$ (in 2012).

Heinrich, P., Jahraus, B. *et al.* presented biomass harvesting and storage technologies. They affirm that unconventional biomass harvesting technology may be used only under favourable weather conditions. Chopped non-pressed biomass takes higher density, but in rainy weather conditions, it absorbs more moisture, so it is used more rarely [1]. The choice of unconventional crop harvesting technology is affected by a number of factors: biologic characteristic of the plants, maturity, moisture, meteorological conditions, *etc*. Having performed literature analysis, it was determined that usually the direct stem harvesting technology is used. In this case plant stems are cut down, chopped, pressed in rolls or packs and transported away from the field.

The possibilities of unconventional tall grasses: sida, cup plant and common mugwort preparation and usage for energy purposes in Lithuania has not been widely investigated, researches have been carried out in the Lithuanian Institute of Engineering of the Aleksandras Stulginskis University and the Lithuanian Institute of Agriculture of the Lithuanian Research Centre for Agriculture and Forestry.

The aim of this work is to investigate the technical means of unconventional tall grasses: sida, cup plant and common mugwort preparation for biofuel, to assess the physical-mechanical properties and quality indicators of the investigated unconventional tall grasses chaff and mill.

Materials and methods

The chopping quality of plant stem chaff, mill and prepared pellets used for fuel should satisfy the requirements for the combustion chamber, chopped and pressed mass transportation machinery and storage. During the experimental research of unconventional tall grasses, the drum chopper of forage harvester *Maral 125* was used for chopping of tall grasses: sida, cup plant and common mugwort [10].

The fractional composition of chopped with the drum chopper mass was determined using the system which is widespread in the European Union countries [11; 12]. Fractional composition of chopped plants was determined using a set of 400 mm diameter sieves. Sieves with round holes are placed one on another (in succession starting from the upper sieve): 63 mm, 45 mm, 16 mm, 8 mm, 3.15 mm and 1 mm diameters. When sieving a 5 kg mass sample with a special sieve shaker *Haver EML Digital plus*, a set of sieves in horizontal surface is turned in semicircle for 2 minutes. The mass remaining on the sieves is weighted, and a sample part of every fraction in percentage is calculated.

Further on, wishing to use the prepared chopped chaff for production of pellets, it is necessary to chop it to mill consistency (to 1-2 mm particles). The mill *Retsch SM 200* was used to this purpose. The milling quality was determined analogously as in the case with plants chopped in the drum chopper. The mass fraction composition of these plants was determined using the sieve shaker *Retsch AS 200* and sieves with holes of various diameters: 0.25 mm, 0.5 mm, 0.63 mm, 1 mm and 2 mm. The mass remaining on the sieves is weighted, and a sample part of every fraction in percentage is calculated.

Density of chaff and mill was determined in the 6 dm^3 cylinder vessel, which was filled by mass till the upper edge and weighted. Moisture of chopped chaff is determined in chemical laboratories according to the standard methodology [13]. For mill pressing and pellet production the low-power granulator with a horizontal array was used. Calorific value of investigated unconventional tall grasses pellets was determined by a calorimeter C 2000 (IKA, Germany), by the standard methodology [10].

Each test is repeated 3 times. The analysis of variance with three replications design was performed on the data of the fulfilled experiments, using the analysis of variance (ANOVA) to determine the significance at 95 % probability level (LSD_{05}).

Results and discussion

Having performed the experimental research, the physical-mechanical characteristics were determined – moisture content and bulk density of chopped by the drum chopper and milled by the hammer mill unconventional tall grasses – sida, common mugwort and cup plant. These characteristic are needed for projecting and choosing the supply-transportation and storage equipment.

The determined moisture content and bulk density of unconventional tall plant stems chopped by the forage harvester *Maral 125* drum chopper and milled by the mill *Retsch SM 200* are presented in Table 2.

Table 2

Physical-mechanical characteristics of plant stems chaff and mill

Unconventional tall grasses		Moisture content, %	Bulk density, kg·m^{-3}
Sida	Chaff	14.1±0.3	81.0±4.8 (69.6 DM)
	Mill	5.9±0.6	238.6±4.1 (224.5 DM)
Cup plant	Chaff	15.2±0.7	102.9±0.4 (87.3 DM)
	Mill	8.2±0.4	239.2±6.1 (219.6 DM)
Common mugwort	Chaff	15.8±0.9	87.1±3.2 (73.3 DM)
	Mill	7.8±0.8	214.1±4.8 (197.4 DM)

As it may be seen from Table 2, bulk density of sida chopped by the forage harvester *Maral 125* drum chopper is the smallest – 69.6 $kg \cdot m^{-3}$ DM, and the density of cup plant is almost 1.2 times bigger – 87.3 $kg \cdot m^{-3}$ DM.

Fraction composition of the chopped unconventional tall grasses mass was determined applying methodology widespread in the EU countries; it was done using sieves with holes of various diameters. The plant chaff factional composition (%) dependence on the sieve hole diameter (mm) is shown in Fig. 1, Fig. 2 and Fig. 3. Fraction composition of sida stem chaff is presented in Fig. 1.

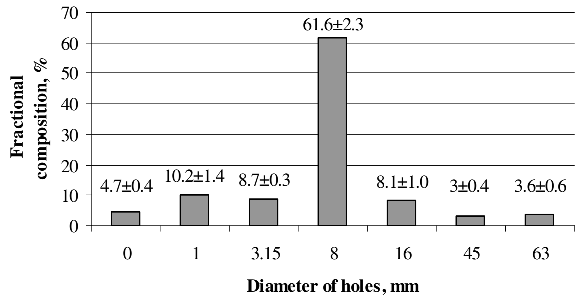

Fig. 1. **Fraction composition of sida stem chaff**

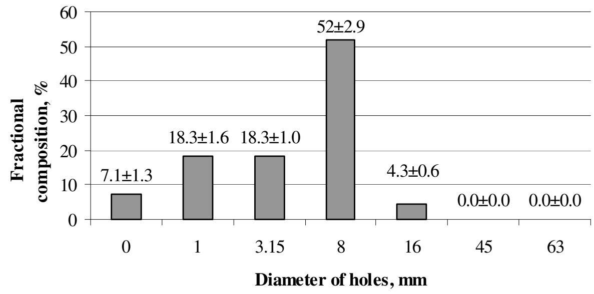

Fig. 2. **Fraction composition of cup plant chaff**

Sida chaff fraction chopped by the drum chopper dispersed on a sieve rather evenly. However, bigger fraction of sida chaff accumulated on the sieve with round holes 8 mm diameter – 61.6±2.3 %. When sieving chaff of sida, the quantity of dust was 4.7±0.4 %.

Fraction composition of cup plant chaff is presented in Fig. 2. The character of cup plant chaff dispersion on the sieve is very similar like sida chaff dispersion. The biggest fraction of cup plant accumulated on the sieve with round holes 8 mm diameter – 52.0±2.9 % of the chaff mass, and bigger than 45 mm fractions did not appear. When sieving chaff of cup plant, rather high quantity of dust was got – 7.1±1.3 %. It proves that chopping cup plant by a drum chopper you may get rather fine chaff fraction.

Fraction composition of common mugwort chaff is presented in Fig. 3. The character of common mugwort chaff dispersion on the sieve is similar like sida and cup plant chaff dispersion – big amount of common mugwort fraction accumulated on the sieve with round holes 8 mm diameter – 26.1±2.6 % of the chaff mass, but biggest amount of common mugwort fraction accumulated on the sieve with round holes 63 mm diameter – 57.3±4.8 %. The smallest quantity of dust was got when sieving chaff of common mugwort – only 2.8±1.3 %. It proves that during chopping common mugwort by a drum chopper you may get coarse chaff fraction.

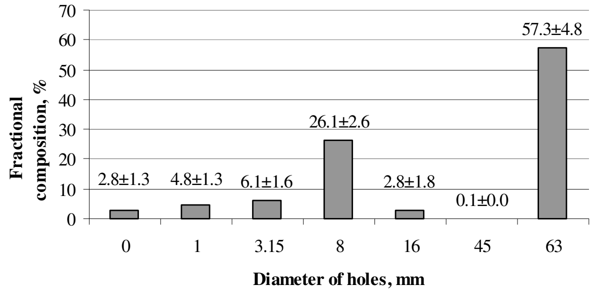

Fig. 3. **Fraction composition of common mugwort stem chaff**

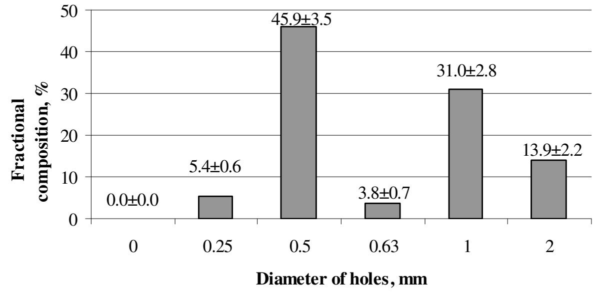

Fig. 4. **Fraction composition of sida mill**

When preparing chaff for pellet production it was broken up in the form of mill using a hammer mill. Fractional composition of prepared mill (%) dependence on the sieve hole diameter (mm) is presented in Fig. 4, Fig. 5 and Fig. 6. Dependance of a part of sida mill fraction (%) from the holes of the sieves is presented in Fig. 4.

Having evaluated the fraction composition of mill, we may see that the highest fraction of sida mill accumulated on the sieve with holes 0.5 mm diameter – 45.9±3.5 %, and high amount of fraction accumulated on the sieve with holes 1 mm diameter too – 31.0±2.2 %. When sieving mill of sida, dust was not found.

Dependance of a part of cup plant mill fraction (%) from the holes of sieves is presented in Fig. 5. After evaluation of the factional mill composition from the chart we can see that the highest fraction of cup plant mill accumulated on the sieve with holes 0.63 mm diameter – 37.6±2.9 %, little less on 2 mm diameter holes sieve – 29.6±2.5 %. There was no fraction on the sieve with holes 0.25 mm diameter, and too big amount of dust was found – 17.4±2.2 %.

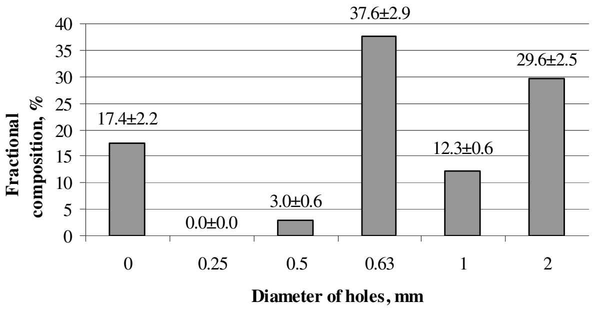

Fig. 5. **Fraction composition of cup plant mill**

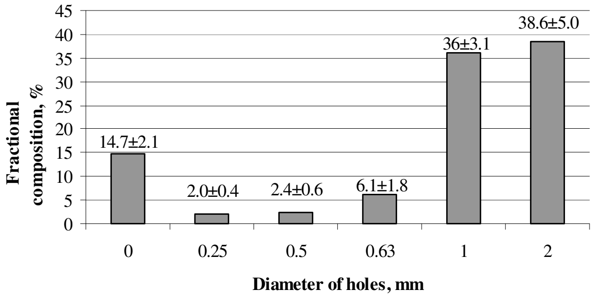

Fig. 6. **Fraction composition of common mugwort mill**

Dependance of common mugwort mill fraction (%) from the holes of the sieves is presented in Fig. 6. Having evaluated the fraction composition of mill, we may see that the highest fraction of common mugwort mill accumulated on the sieve with holes 2 mm diameter – 38.6±5.0 %, little less on 1 mm diameter holes sieve – 36.0 ±3.1 %, and too big amount of dust was found – 14.7±2.1 %. It proves that during milling common mugwort by the hummer mill we received coarse mill fraction.

Evaluating the chopping and milling quality of unconventional tall grasses, the fraction composition of chaff and mill of sida, cup plant and common mugwort was determined on sieves with holes of various diameters. The highest chaff fraction accumulated on the sieve with holes 8 mm diameter (from 26.1 to 61.6 %), and the biggest amount of common mugwort chaff fraction accumulated on the sieve with round holes 63 mm diameter – 57.3±4.8 %. The highest mill fraction accumulated on sieves with holes 0.5-2.0 mm diameter: fraction of sida mill accumulated on the sieve with holes 0.5 mm diameter (45.9±3.5), fraction of cup plant mill – on the sieve with holes 0.63 mm diameter (37.6±2.9 %) and fraction of common mugwort mill – on the sieve with holes 2 mm diameter (38.6±5.0 %).

All investigated unconventional tall plants are suitable for burning after appropriate preparation. In order to continue using for energy purposes, the investigated unconventional tall grasses were pressed in pellets and the pellet caloric value when burning them was determined. The average calorific value of the investigated unconventional tall grasses varied from 17.2 to 18.0 $MJ \cdot kg^{-1}$. The research results of sida, cup plant and common mugwort pelleting and usage for energy purposes will be presented in a separate article.

Conclusions

1. In Lithuania, wood is the most widely used biomass fuel (firewood, kindling, sawdust) which may be changed by various unconventional energetic plants – sida, cup plant and common mugwort.
2. In all experimental years, 120 $kg \cdot ha^{-1}$ nitrogen rate significantly increased the common mugwort and cup plant dry matter productivity; meanwhile liming (6.0 $t \cdot ha^{-1}$ $CaCO_3$) had a positive affect only to cup plant dry matter increment. Although the dry matter yield was notably uneven in different vegetation years, the cup plant productivity was far superior than that of common mugwort.
3. Evaluating the chopping and milling quality, the fractional composition of chaff and mill of sida, cup plant and common mugwort was determined on sieves with holes of various diameters. The highest chaff fraction accumulated on the sieve with holes 8 mm diameter (from 26.1 to 61.6 %),

and the biggest amount of common mugwort chaff fraction accumulated on the sieve with round holes 63 mm diameter – 57.3±4.8 %. The highest mill fraction accumulated on sieves with holes 0.5-2.0 mm diameter.

4. Unconventional tall grasses give way to wood biofuel insignificantly – their calorific value reaches 17.2-18.7 $MJ \cdot kg^{-1}$. However, their growing and usage for biofuel has a number of advantages: crop capacity reaches 7-20 $t \cdot ha^{-1}$; it is possible to cut them every year; forage preparation machinery is suitable for harvest and processing.

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