

ISSN 1392-3196 / e-ISSN 2335-8947

Zemdirbyste-Agriculture, vol. 107, No. 4 (2020), p. 317–322

DOI 10.13080/z-a.2020.107.040

The suitability of perennial grasses for combustion as influenced by chemical composition and plant growth stage

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Abstract

The aim of the study was to evaluate six perennial grass species: lucerne (*Medicago sativa* L.), reed canary grass (*Phalaris arundinacea* L.), tall fescue (*Festuca arundinacea* Schreb.), cocksfoot (*Dactylis glomerata* L.), switchgrass (*Panicum virgatum* L.) and ryegrass (*Lolium perenne* L.), with a balanced composition of organic compounds and minerals, for their suitability for direct combustion in relation to grass species, chemical composition and growth stage. At the regrowth and heading / inflorescence emergence stages, the chemical composition of the biomass of the tested grass species was similar. Before regrowth in spring, the plants contained higher concentrations of carbon, lignin and cellulose and the smallest amounts of ash and nitrogen. Of all the grass species tested, the biomass of lucerne, tall fescue and particularly ryegrass was the most suitable for direct combustion, as it had the highest concentration of carbon (57.55%) and the lowest concentration of nitrogen (0.61%) and ash (4.48%). The findings suggested that the heating value of the biomass was determined by plant growth stage and chemical composition. It was the highest at the heading stage and before regrowth in spring. It was found that the biomass of lucerne produced the highest energy yield of 303 GJ ha⁻¹ (a sum of two harvests). The biomass of tall fescue produced 185.2 GJ ha⁻¹, and that of cocksfoot – 137.3 GJ ha⁻¹. The biomass of reed canary grass produced a lower energy yield of 93.3 GJ ha⁻¹. The analysis of the relationship between the heating value and chemical composition of the biomass showed a strong correlation between the heating value and acid detergent lignin (ADL) 0.548** ($p < 0.01$). The heating value was also found to positively correlate ($p < 0.05$) with cellulose (0.376*) and carbon (0.258*).

Key words: bioenergy potential, biomass, heating value, combustion, energy plant.

Introduction

Perennial grasses are attractive as a source of biomass for Northern Europe, as they meet agronomic, environmental and societal requirements for successful deployment as energy grass crops (Tilvikiene et al., 2016; Kadžiulienė et al., 2017; De Laporte, Ripplinger, 2019). In 2030, the share of energy from renewable sources in the final energy consumption balance of Lithuania will be 45%, although the target will be 80% by the year 2050 (Gaigalis, Katinas, 2020). Lithuania will continue development of the renewable energy sector (Černiauskienė et al., 2018).

Biomass is the most important source to increase the production of energy based on renewable energy sources (Román-Figueroa et al., 2017). Combustion is the main technology applied to produce heat and energy from biomass and is generally economically feasible. The combustion of biomass as fuel has many environmental and economic advantages. It is cheap, clean and renewable source of energy (Erol et al., 2010; Slepetyt et al., 2012; Butkutė et al., 2015).

Biomass types are composed of numerous constituents that have complex structures. With respect to chemical and physical properties, biomass species

and harvest time have large differences. Hemicellulose, cellulose, lignin and extractive matter are the major constituents of biomass, which are present in different ratios and structures in different biomass species. The heating value of biomass is an indicator of the energy chemically bound in it, and in the combustion process it is converted into heat energy (Kadžiulienė et al., 2017; Nazli, Tansi, 2019; Sosa et al., 2019).

Perennial herbaceous plants are of special importance, as their establishment and cultivation costs are generally much lower than those of annual plants. Perennial plants that have been comprehensively studied in Lithuania are indigenous, naturally occurring species such as tall fescue, cocksfoot and reed canary grass (Tilvikiene et al., 2012; Slepetyt et al., 2016; Tilvikiene et al., 2016), switchgrasses (Norkevičienė et al., 2016). Agricultural researchers are focusing their attention on perennial plants (Slepetyt et al., 2012; Butkutė et al., 2014; 2015; Tilvikiene et al., 2016). Solid biofuel from energy plants is considered at least as “C neutral”: CO₂ that is released in burning is returned to the biomass from the atmosphere during photosynthesis and returned for a cycle of new growth (Field et al., 2008; Butkutė et al., 2015).

Please use the following format when citing the article:

Amaleviciute-Volunge K., Slepetyt A., Butkutė B. 2020. The suitability of perennial grasses for combustion as influenced by chemical composition and plant growth stage. Zemdirbyste-Agriculture, 107 (4): 317–322. DOI 10.13080/z-a.2020.107.040

Perennial grasses have the potential to be used as biofuel crops. However, little is known about which perennial grasses can produce high quantity and high-quality biomass in relation to plant growth stage (Porensky et al., 2014). It has been reported that one of the factors, which influences plant chemical composition, is the degree of plant maturity during harvest (Kupryś-Caruk et al., 2019). There is a paucity of information about how much energy can be generated from perennial grasses harvested at different times, considering the growth stage.

The aim of this study was to evaluate the suitability of six perennial grass species with a balanced composition of organic compounds and minerals for direct combustion, and to identify plant bioenergy potential for solid fuel production based on the interaction between plant species and growth stage.

Materials and methods

A field experiment was done in 2018 and 2019 at the Institute of Agriculture ($55^{\circ}23'49''$ N, $23^{\circ}51'40''$ E), Lithuanian Research Centre for Agriculture and Forestry with six perennial grass species: lucerne (*Medicago sativa* L.), reed canary grass (*Phalaris arundinacea* L.), tall fescue (*Festuca arundinacea* Schreb.), cocksfoot (*Dactylis glomerata* L.), switchgrass (*Panicum virgatum* L.) and ryegrass (*Lolium perenne* L.), grown in 1×0.5 m plots on a *Hypocalcic Stagnic Luvisol* (Loamic, Drainic) according to WRB (2015) within three replicates (blocks). Samples were collected for comparison of the influence of harvest time according to plant growth stage on the

biomass quality (Table 1). All biomass samples were cut to 1 cm pieces and fixed at 105°C for 20 min, dried at $65 \pm 5^{\circ}\text{C}$ for 24 h, and ground in a laboratory mill.

Chemical analyses were done at the Chemical Research Laboratory of the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry. Chemical composition of plant samples was determined according to the standard methods as follows: for ash and organic matter content the dried samples were incinerated at 550°C temperature. Before testing, the samples of biomass for direct combustion and determination of chemical composition were ground by an ultra-centrifugal mill ZM 200 (Retch, Germany) using 1 mm mesh size. The content of structural carbohydrates was calculated as differences (Cell) = ADF – ADL, and hemicellulose (HCell) = NDF – ADF. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) in plant biomass were determined using a cell wall detergent fractionation method according to Van Soest et al. (1991) and Slepeliene et al. (2016). NDF and ADF extraction was done on a fibre analyser ANKOM 220 (ANKOM Technology, USA) using filter bags F57 (25- μm porosity). Lignin was determined in beakers on the remaining material from the ADF procedure as a residue insoluble in sulfuric acid (72% w/w). The total organic carbon (C) content was determined by a spectrophotometric measure procedure at the wavelength of 590 nm using glucose as a standard after wet combustion according to Tyurin method modified by Nikitin (1999). Nitrogen (N) content was determined by the Kjeldahl method using a spectrophotometric measure procedure at the wavelength of 655 nm.

Table 1. Sampling dates and growth stages

Perennial grass species	Heading / inflorescence emergence	Flowering	Regrowth	Before regrowth in spring
Lucerne	23 05 2018	05 06 2018	20 06 2018	01 03 2019
Reed canary grass	28 05 2018	07 06 2018	16 08 2018	
Tall fescue	23 05 2018	07 06 2018	16 08 2018	
Cocksfoot	16 05 2018	28 05 2018	20 06 2018	
Switchgrass	10 06 2018	27 08 2018	10 09 2018	
Ryegrass	23 05 2018	07 06 2018	–	

The analyses of energy potential. The heating value was measured with a bomb calorimeter IKA C 200 (IKA, Germany) by the 25°C temperature dynamic heating test method and expressed as MJ kg⁻¹ DM. The energy yield (Q) (GJ ha⁻¹) was calculated according to the equation:

$$Q = (Hd \times Qg) / 1000, \text{ where } Hd \text{ is biomass dry yield, kg ha}^{-1}, Qg - \text{heating value, MJ kg}^{-1}.$$

Statistical analysis. The data structuring analysis and processing were conducted using the software SAS, version 9.4 (SAS Institute Inc., USA); P value <0.05 was considered statistically significant. The associations between chemical composition and heating value were estimated by Pearson's correlation analysis.

Results and discussion

The biomass of perennial grasses tested was found to differ in chemical composition, which depended on the plant species and growth stage at harvesting (Table 2).

Table 2 presents the data of grass biomasses obtained at heading / inflorescence emergence stage: ash content – 5.80–9.17%, C – 44.62–46.82%, N – 1.11–3.45%, C:N – 13.27–42.17%. The highest content of ash (9.17%) and N (3.45%) and at the same time the lowest C:N (13.27%) were recorded in the biomass of lucerne compared with that of other grasses. Biomass of

switchgrass was distinguished from other investigated biomasses as having the highest content of C (46.82%) and the highest C:N (42.17%). Also, the lowest ash (5.80%) and N content was found in the biomass of this grass species at heading / inflorescence emergence stage. These parameters are considered positive for combustion.

Chemical composition of the biomasses tested was analysed at flowering stage: switchgrass and lucerne stood out from the other grass species. The highest content of C (47.01%) and C:N (71.15%) were determined in the biomass of switchgrass, while the highest concentration of ash (7.94%) was established in the biomass of lucerne. The lowest content of ash (4.91%) and N (0.67%) was determined in the biomass of switchgrass.

The biomass harvested at the regrowth stage had a similar chemical composition to that harvested at the heading stage, except for ash content, which was the highest (11.10–8.15%) at regrowth stage compared with the other growth stages. The biomass of lucerne and switchgrass was exceptional in terms of chemical composition compared with the other investigated perennial grasses. The highest content of ash (11.10%) and N (2.91%) and the lowest content of C (47.76%) and C:N (16.43%) were recorded in the biomass of lucerne. The biomass of switchgrass had the lowest content of ash (8.15%) and N (1.24%) and the highest C:N.

Table 2. The composition of chemical components in perennial grasses at different growth stages

Perennial grass species	Ash	C %	N	C:N
Heading / inflorescence emergence				
Lucerne	9.17 aY	45.76 abZ	3.45 aX	13.27 dZ
Reed canary grass	7.43 bY	46.61 aZ	2.20 cX	21.23 cZ
Tall fescue	7.52 bY	44.67 bW	2.46 bX	18.19 cW
Cocksfoot	7.63 bXY	45.77 abZ	2.25 cbX	20.52 cY
Switchgrass	5.80 dY	46.82 aZ	1.11 eY	42.17 aZ
Ryegrass	6.67 cX	44.62 abZ	1.59 dX	28.06 bZ
Flowering				
Lucerne	7.94 aZ	46.32 aYZ	1.21 cZ	38.20 bY
Reed canary grass	6.49 cZ	46.79 aZ	1.41 abZ	33.56 bcY
Tall fescue	6.21 cZ	46.75 aZ	1.37 bcZ	34.12 bcY
Cocksfoot	7.21 bY	46.71 aZ	1.56 aY	30.02 cY
Switchgrass	4.91 dYZ	47.01 aZ	0.67 dZ	71.15 aY
Ryegrass	5.95 cY	45.61 aY	1.18 cY	38.73 bY
Regrowth				
Lucerne	11.10 aX	47.76 aY	2.91 aY	16.43 dZ
Reed canary grass	10.77 aX	51.16 aY	1.96 bY	26.12 cZ
Tall fescue	10.83 aX	48.71 aY	1.75 cbY	28.16 bcZ
Cocksfoot	8.45 bX	49.74 aY	1.59 cY	31.52 bY
Switchgrass	8.15 bX	50.33 aY	1.24 dX	40.51 aZ
Ryegrass	—	—	—	—
Before regrowth in spring				
Lucerne	5.02 bcW	55.96 cX	1.21 aZ	46.43 eX
Reed canary grass	7.80 aY	56.07 bcX	0.79 cW	70.99 dX
Tall fescue	5.60 bZ	56.98 abX	1.04 bW	55.01 deX
Cocksfoot	5.15 bcZ	56.83 abcX	0.66 cdZ	89.18 bcX
Switchgrass	4.56 cZ	56.14 bcX	0.39 eW	144.56 aX
Ryegrass	4.48 bcZ	57.55 aX	0.61 dZ	93.93 bX

Note. The different letters a-e in the column indicate significant differences ($P < 0.05$) in the concentrations of biomass components among grasses at the same growth stage, and the different letters X, Y, Z and W indicate significant differences ($P < 0.05$) in component concentrations of the same grass species between plant growth stages; C – organic carbon, N – nitrogen, C:N – C to N ratio.

Biomass harvesting before regrowth in spring had the most marked effect on its chemical composition. After winter, the biomass had more C (57.55–55.96%) and higher C:N (144.56–46.43%) and less ash (7.80–4.48%) and N (1.21–0.39%). Three perennial grasses were distinguished from the other grasses tested: lucerne, switchgrass and ryegrass. The biomass of lucerne and switchgrass showed the same trend as at previous harvests: switchgrass had the highest C:N (144.56%) and the lowest contents of ash (4.56%) and N (0.39%).

Summarizing the chemical composition of plants by growth stage, it can be inferred that the biomass harvested before regrowth in spring is the most suitable for direct combustion, since it has a low ash content but a high C:N. High ash content can cause slagging; this is a problem that herbaceous energy crops pose during combustion. High concentration of N in combusting biomass can promote greenhouse gas NO_x emissions (Baxter, 2011; Butkutė et al., 2015). Biomass of ryegrass harvested before regrowth in spring would be a highly suitable raw material for combustion, because it contained more C (57.55%) and less N (0.61%) and ash (4.48%) than the other perennial grasses.

Biomass of plants contains varying amounts of cellulose, hemicellulose, lignin and small amounts of lipids, proteins, simple sugars, starches and inorganic constituents and a fraction of water as well (Porensky et al., 2014; Kupryš-Caruk et al., 2019; Nazli, Tansi, 2019). Cellulose, hemicellulose and lignin are the three main constituents of these compounds (Zhang et al., 2010; Saidur et al., 2011; Sosa et al., 2019). One of the most important biomass components for burning is lignin, because it contains a high content of C (Prochnow et al., 2009; Pocienė, Kadžiulienė, 2016). Biomass with high content of lignin is best suited for incineration (Boscaro et al., 2015).

Table 3 shows the contents of fibre components in the biomass at heading / inflorescence stage, flowering, regrowth and before regrowth in spring. The

highest content of lignin (19.02%) was determined in the biomass of lucerne and ryegrass before regrowth in spring. Conversely, the lowest concentration of lignin was found in the biomass of ryegrass at heading stage (3.97%) and in the biomass of tall fescue at heading, flowering and regrowth stages 4.02, 4.30 and 4.43 %, respectively. Before regrowth in spring, the biomass had higher concentrations of lignin compared with the other growth stages.

In contrast to lignin, cellulose concentration was the lowest in the biomass of lucerne (24.08–24.42%) at inflorescence emergence and flowering stages. The highest cellulose concentration in the biomass of switchgrass (34.24–36.76%) was determined at heading and flowering stages. The composition of the biomass of all the tested grasses before regrowth in spring differed from that harvested at the other growth stages. It had the highest concentration of cellulose ranging from 35.51 to 44.21%. Cocksfoot and switchgrass had the highest cellulose concentration (44.21 and 42.37%), while ryegrass had the lowest cellulose concentration (35.51%).

Analysis of hemicellulose of the six perennial grasses showed the same trend as cellulose. Lucerne biomass had the lowest concentration of hemicellulose at all four growth stages (2.07–15.45%). The highest amount of hemicellulose was determined in the biomass of switchgrass (26.45–30.54%).

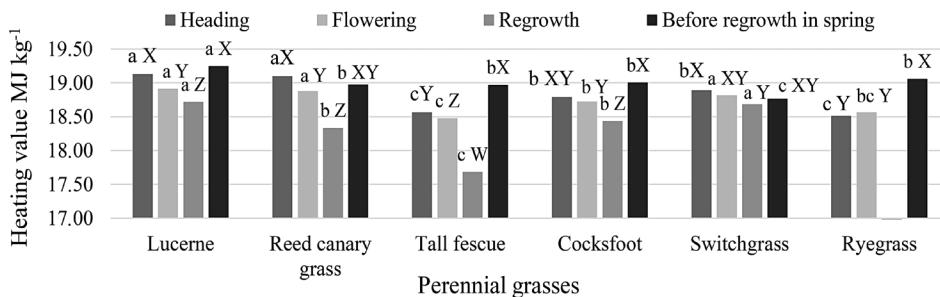
The biomass of lucerne, ryegrass and tall fescue harvested before regrowth in spring was most suitable for direct combustion, because it had the highest concentration of C, lignin and cellulose and the smallest amounts of ash and N.

Chemical composition analysis of biomass is particularly important for assessing the energy potential of plants. In addition, chemical composition plays an important role in assessing the heating value of biomass. According to the literature (Saidur et al., 2011; Butkutė et al., 2015), plant biomass has a heating value ranging from 17 to 21 MJ kg⁻¹.

Table 3. The content of fibre components in perennial grasses at different growth stages

Perennial grass species	ADL %	CEL	HCel
Heading / inflorescence emergence			
Lucerne	10.89 aY	24.42 dZ	2.07 dZ
Reed canary grass	4.67 bcZ	33.08 aY	24.96 bX
Tall fescue	4.02 cY	27.30 cZ	20.88 cX
Cocksfoot	4.18 cZ	29.04 bZ	22.04 cX
Switchgrass	5.70 bZ	34.24 aZ	30.54 X
Ryegrass	3.97 cZ	28.85 bZ	20.68 cX
Flowering			
Lucerne	8.61 aZY	27.46 dY	7.65 cY
Reed canary grass	5.71 cY	34.31 bY	23.54 bX
Tall fescue	4.30 eY	30.71 cY	21.75 bX
Cocksfoot	5.35 cdY	34.05 bY	22.92 bX
Switchgrass	7.07 bY	36.76 aY	29.20 aXY
Ryegrass	4.92 deY	30.95 cY	23.80 bX
Regrowth			
Lucerne	10.45 aY	24.08 dZ	6.55 cY
Reed canary grass	4.43 cZ	29.82 bZ	25.04 abX
Tall fescue	4.58 cY	30.84 bY	23.04 abX
Cocksfoot	5.66 bY	27.19 cW	20.95 bX
Switchgrass	5.74 bZ	34.49 aZ	26.68 aY
Ryegrass	—	—	—
Before regrowth in spring			
Lucerne	19.02 aX	41.55 bcX	15.45 cX
Reed canary grass	9.30 cX	39.60 cX	22.33 bX
Tall fescue	9.76 bX	40.29 cX	21.26 bX
Cocksfoot	9.27 cX	44.21 aX	22.71 bX
Switchgrass	9.15 cX	42.37 abX	26.45 aY
Ryegrass	19.02 aX	35.51 dX	23.57 bX

Explanation under Table 2; ADL – acid detergent lignin, CEL – cellulose, HCel – hemicellulose



Explanation under Table 2

Figure 1. Heating value of the perennial grasses at different growth stages

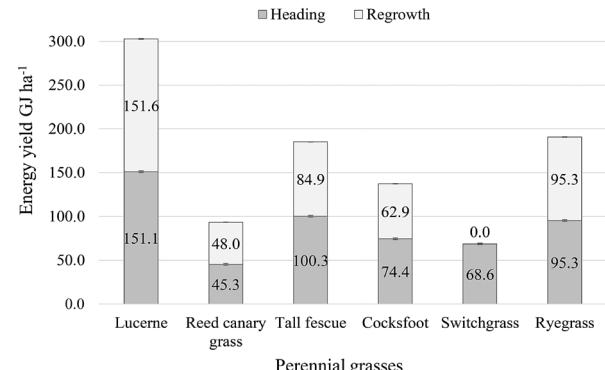
In the current study, the energy yield (GJ h^{-1}) of two harvests (heading / inflorescence emergence and regrowth) was calculated based on the heating value and biomass yield (Fig. 2).

Energy yield is a more important indicator of biomass suitability for combustion than biomass yield (Sosa et al., 2019). Like biomass yield, its quality and heating value were affected by grass species and growth stage (Fig. 2). According to the biomass yield and heating value, the biomass of lucerne produced the highest energy yield 303 GJ ha^{-1} (a sum of two harvests). The biomass of tall fescue produced 185.2 GJ ha^{-1} , and that of cocksfoot – 137.3 GJ ha^{-1} . The biomass of reed canary grass produces lower energy yield – 93.3 GJ ha^{-1} . A dry summer in 2018 resulted in a low yield of switchgrass, cocksfoot and ryegrass biomass. The research data obtained reflected the general trend of yield. Different from annual average 18–20% set in biomasses of cocksfoot, switchgrass and ryegrass, 14–17% – tall fescue and reed canary grass, and the smallest different were set of lucerne – 9%. These data corroborate the findings of other researchers: Pocienė and Kadžiulienė (2016) have reported that reed canary grass and tall fescue produced $106\text{--}122 \text{ GJ ha}^{-1}$.

Figure 1 shows the heating value of the biomass of 6 perennial grasses at different growth stages: heading, flowering, regrowth and before regrowth in spring.

The results of our experiment show that harvest time determined the differences in the heating value of the investigated grasses. The heating value ranged from 17.7 to 19.02 MJ kg^{-1} according to grass species and growth stage. It ranged from 18.5 to 19.01 MJ kg^{-1} at the heading stage, from 18.5 to 18.9 MJ kg^{-1} at the flowering stage and from 17.7 to 18.7 MJ kg^{-1} at the regrowth stage. The highest heating value $18.8\text{--}19.02 \text{ MJ kg}^{-1}$ was determined in the biomass harvested before regrowth in spring. According to plant chemical composition and heating value, it can be inferred that biomass of lucerne generated most energy at all growth stages: 19.01 MJ kg^{-1} at the heading stage, 18.9 MJ kg^{-1} at the flowering stage, 18.7 MJ kg^{-1} at the regrowth stage and 19.02 MJ kg^{-1} before regrowth in spring. The heating value of cocksfoot biomass was 18.8 MJ kg^{-1} at the heading stage, 18.7 MJ kg^{-1} at the flowering stage, 18.4 MJ kg^{-1} at the regrowth stage and 19.0 MJ kg^{-1} before regrowth in spring. The lowest heating value was determined for the biomass of ryegrass. The heating value of tall fescue biomass was 17.7 MJ kg^{-1} at the regrowth stage, but before regrowth in spring it was 19.01 MJ kg^{-1} . The results of the heating value showed that the differences were influenced by growth stage of plants. All biomasses had the highest heating value at heading stage and before regrowth in spring compared with flowering and regrowth stages.

The lignin content of the biomass is generally strongly correlated with the heating value. The heating value of lignin is higher than that of cellulose and hemicellulose (Saidur et al., 2011; Pocienė, Kadžiulienė, 2016; Nazli, Tansi, 2019). Butkutė et al. (2015) have found linear relationships between heating value and C



Note. Error bars are shown as standard error.

Figure 2. Energy yield of the biomass of perennial grasses at heading and regrowth stages

as well as lignin concentration values and also showed that the heating value of lignocellulosic fuels was highly correlated with lignin content.

The results provided in Table 4 show the correlations between biomass chemical composition elements (ash, C, N, C:N, ADL, CEL and HCel) and heating value.

Analysis of the dependence of energy value on chemical composition showed the strongest correlation between heating value and ADL 0.548** ($p < 0.01$). Positive correlation ($p < 0.05$) was found between cellulose (0.376*) and C (0.258*) heating value. It has been demonstrated that the heating value is negatively correlated with the ash content: every 1% increase in ash content decreases the heating value of a solid fuel by 0.2 MJ kg⁻¹ (Nazli, Tansi, 2019).

Results of our study confirmed this finding, as negative correlation (-0.604**, $p < 0.01$) between the heating value and ash content was found. It was

Table 4. Pearson correlations between biomass chemical composition elements and heating value

	Ash	C	N	C:N	ADL	CEL	Hcel
Ash							
C	-0.381*						
N	0.641**	-0.538**					
C:N	-0.595**	0.638**	-0.774**				
ADL	-0.394 ns	0.492**	-0.080 ns	0.172 ns			
CEL	-0.647**	0.737**	-0.753**	0.700**	0.218 ns		
Hcel	-0.165 ns	0.178 ns	-0.494**	0.359*	-0.586**	0.542**	
MJ kg ⁻¹	-0.604**	0.258*	-0.124 ns	0.200 ns	0.548**	0.376*	-0.207 ns

*, ** – significant at $P \leq 0.05$ and $P \leq 0.01$, ns – not significant; C – organic carbon, N – nitrogen, C:N – C to N ratio; ADL – acid detergent lignin, CEL – cellulose, Hcel – hemicellulose

is lignin and C as well as ash and N content in plants. The highest contents of lignin and C accumulated in the biomass harvested before regrowth in spring, while N and ash contents were the lowest. For this reason, it is recommended to use grass biomass harvested at this stage for combustion to produce energy. The biomass of switchgrass, ryegrass and tall fescue is best suited for combustion, because it contains the highest amount of lignin, C and the lowest amount of ash and N compared to the other grasses tested. Although lucerne has high amount of lignin and C, it is not recommended to be used for combustion, because its biomass contains high amounts of ash and N.

Conclusions

1. Of the six grass species tested, lucerne and switchgrass were found to be best suited for direct combustion according to their chemical composition. The biomass of these species contained the highest concentration of lignin and carbon (C) and the smallest concentration of ash and nitrogen (N). The biomass harvested before regrowth in spring was found to have the greatest energy potential compared with that harvested at other growth stages tested.

2. Energy value analysis showed that grass species with high concentrations of lignin and C in the biomass (lucerne, reed canary grass and switchgrass) had the highest heating value. The biomass harvested before regrowth in spring had the highest heating value and therefore was best suited for direct combustion compared with the biomass harvested at the other growth stages. This was confirmed by correlations: strong correlation between the heating value and acid detergent lignin (ADL) (0.548**, $p < 0.01$), positive correlation ($p < 0.05$) with cellulose (0.376*) and C (0.258*), and negative correlation (-0.604**, $p < 0.01$) with ash content.

3. Based on annual yields and heating value, it was found that lucerne, tall fescue and ryegrass biomass produced the highest energy yield per hectare.

also found that high ash content correlated with N content (0.641**, $p < 0.01$), but negatively correlated with cellulose (-0.647**, $p < 0.01$), C:N (-0.595**, $p < 0.01$) and C (-0.381*, $p < 0.05$). There set strong relationship C ($p < 0.01$) with cellulose (0.737**), C:N (0.638**), lignin (0.497**) and weakly correlated with N (-0.538**). The N content negatively correlated ($p < 0.01$) with C:N (-0.774**), cellulose (-0.753**) and hemicellulose (-0.494**). Negative correlation ($p < 0.01$) was determined between lignin and hemicellulose (-0.586**), and positive correlation was established between lignin and cellulose (0.542**) (Table 3).

The results of the current study are consistent and in line with those of other researchers (Butkutė et al., 2015; Kupryš-Caruk et al., 2019; Nazli, Tansi, 2019). Biomass energy potential depends on the chemical composition of plants and harvest time. Plant growth stage determined differences in chemical composition of biomass. Significantly important for combustion

Acknowledgment

This project received funding from the European Social Fund (No. 09.3.3-LMT-K-712-02-0061) under grant agreement with the Research Council of Lithuania (LMTLT). Also, a lot of thanks to researchers from Department of Grass Breeding of Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry.

Received 19 11 2019
Accepted 14 08 2020

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ISSN 1392-3196 / e-ISSN 2335-8947

Zemdirbyste-Agriculture, vol. 107, No. 4 (2020), p. 317–322

DOI 10.13080/z-a.2020.107.040

Daugiamečių žolinių augalų tinkamumo biokurui nustatymas vertinant jų cheminę sudėtį ir augimo tarpsnius

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Santrauka

Eksperimento tikslas – nustatyti ir įvertinti subalansuotos organinės bei mineralinės sudėties augalų rūšių: mėlynžiedės liucernos (*Medicago sativa* L.), nendrinio dryžučio (*Phalaris arundinacea* L.), nendrinio eraičino (*Festuca arundinacea* Schreb.), paprastosios šunažolės (*Dactylis glomerata* L.), rykštėtosios soros (*Panicum virgatum* L.) ir daugiametės svidrės (*Lolium perenne* L.), tinkamumą deginimui, priklausomai nuo augalo rūšies ir pjūties laiko. Atolo ir plaukėjimo / butonizacijos tarpsniais tirtų augalų biomasės cheminė sudėtis buvo panaši. Po žemos augalų biomasėje susikaupia daugiau anglies, lignino bei celiuliozės ir kartu mažiausiai kiekiai pelenų bei azoto, todėl iš daugiametų žolinių augalų deginimui yra tinkamos mėlynžiedės liucernos, nendriniai eraičiniai ir ypač daugiametės svidrės, nes jų biomasėje nustatyti didžiausi C (57,55 %) ir mažiausiai N (0,61 %) bei pelenų (4,48 %) kiekiai.

Įvertinus energinę vertę nustatyta, kad ją lėmė skirtinė augalų augimo tarpsniai ir cheminė sudėtis. Augalų biomasė plaukėjimo / butonizacijos tarpsniu ir po žemos yra didesnės energinės vertės nei žydėjimo arba atolo tarpsniai. Augalų (dviejų pjūčių) derliaus duomenimis, didžiausią energijos išeigą iš hektaro duoda mėlynžiedžių liucernų biomasė – 303 GJ ha⁻¹. Iš nendriniių eraičinų biomasės galima išgauti 185,2 GJ ha⁻¹, iš paprastųjų šunažolių – 137,3 GJ ha⁻¹, mažiausiai – iš nendriniių dryžučių – 93,3 GJ ha⁻¹. Įvertinus augalų biomasės cheminę sudėtį ir gautą energinę vertę, nustatyta stipri koreliacija tarp energinės vertės ir lignino (0,548**), $p < 0,01$; energinė vertė taip pat priklauso ($p < 0,05$) nuo celiuliozės (0,376*) ir anglies (0,258*) kiekio biomasėje.

Reikšminiai žodžiai: bioenergijos potencialas, biokuras, biomasė, deginimas, energiniai augalai, šilummingumo vertė.