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The biomass and biogas productivity of perennial grasses

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Abstract

The current paper presents the results on the biomass and biogas productivity of perennial grasses: tall fescue (*Festuca arundinacea* Schreb.), cocksfoot (*Dactylis glomerata* L.) and reed canary grass (*Phalaris arundinacea* L.). The aim of this study was to evaluate the influence of the timing of the first cut and nitrogen fertilization on biomass and biogas productivity in the first year of sward use. Perennial grasses were grown on an *Endocalcari-Endohypogleyic Cambisol* (*CMg-n-w-can*), light loam. During the vegetation season, from April to October the average air temperature was 13.5ºC in 2008 and 12.9ºC in 2009, the precipitation was 336 and 509 mm, respectively. Three and four cuts of grassland per season were combined with 90 and 180 kg ha^{-1} of mineral nitrogen fertilizer. Our experimental findings suggest that biomass yield differed significantly between grass species. Three-cut and four-cut systems did not influence dry matter (DM) yield significantly. There was no significant difference in productivity of tall fescue and reed canary grass fertilized with N_{90} and N_{180}; however, cocksfoot, cut for the first time at heading stage and fertilized with N_{180} produced significantly higher biomass yield, compared to swards, fertilized with N_{90}. The variation of DM yield of tall fescue ranged from 13.37 to 13.84 t ha^{-1}, of cocksfoot from 10.39 to 11.47 t ha^{-1} and of reed canary grass from 8.27 to 9.41 t ha^{-1}. The specific biogas productivity and energy value of biomass per unit dry matter differed depending on grass species and maturity stage. In biomass of tall fescue it ranged from 10.87 to 14.67 MJ kg^{-1} DM, of cocksfoot from 10.92 to 16.10 MJ kg^{-1} DM, and of reed canary grass from 9.68 to 14.33 MJ kg^{-1} DM. The highest biogas productivity per area was produced by tall fescue swards, cut four times per season, it was 186.1 GJ ha^{-1}. Reed canary grass proved to be the least suitable grass for biogas production from first year use swards research results.

Key words: biogas, biogas productivity, energy potential, perennial grasses.

Introduction

There are many crops or crop residues in agriculture which could be used for the generation of liquid, solid or gaseous fuels (Demirbas, 2001; Petersson et al., 2007; Ceotto, 2008; Kaparaju et al., 2009; Cherubini, Ulgiati, 2010; Heinsoo et al., 2011; Lakaniemi et al., 2011). Anaerobic digestion can be applied to convert biomass to biogas. As an output of this process is digestate and biogas whose main components are methane and carbon dioxide (Wilkie, 2005). The aim of anaerobic digestion of perennial grasses is to achieve as high biogas productivity as possible. The optimisation of biogas production is influenced by many factors which stimulate or limit the process while one of these factors is biomass quality. On the other hand, biomass quality should contribute to biomass yield.

The most promising crops for bioenergy and also biogas are perennials: they can be harvested for several years in succession without reseeding and give high biomass yield with satisfactory biomass quality (Lewandowski et al., 2003; Kryževičienė et al., 2005; Navickas et al., 2006; Jasinskas et al., 2008; Sanderson, Adler, 2008; Seppälä et al., 2009; Heinsoo et al., 2011). It is possible to control biomass quality using different management. The biomass quality is mostly influenced by growing conditions, grass species, cutting frequency and fertilization (Ruzgas, Kadžiulis, 1989; Prochnow et al., 2005). Growing region and management intensity have a great effect on biomass formation and biogas productivity. Amon et al. reported in 2007 that biogas productivity per hectare is more than three times higher in intensively managed valley site compared to hill site. On the other hand, most perennial grasses have different sensitivity to cutting time and frequency. Grasses from landscape management produce significantly lower specific biogas productivity per kg of dry organic matter during the later cuts. It could be reduced more than twice from June till February (Prochnow et al., 2005). Other research shows, that even the early first cut, when specific biogas productivity is the highest, reduces the methane yield per hectare because of very low biomass yield (Amon et al., 2007). This leads to the conclusion that grasses should be cut at the stage, when they produce the highest biomass yield with the best biomass for biogas quality.

The interest in the efficiency improvement of bioenergy feedstock production in northern countries is focused on reed canary grass (*Phalaris arundinacea* L.).

In most countries it is used for pelleting or making briquettes for solid fuels (Heinsoo et al., 2011; Nilsson et al., 2011). There is some research evidence on reed canary grass cultivation for biogas (Geber, 2002; Lakaniemi et al., 2011; Navickas et al., 2011), but the influence of cutting frequency and fertilization on biomass for biogas quality and productivity in different climate zones is still not completely clear. Reed canary grass in different climate and soil conditions produces from 5.5 to 8.6 t ha^{-1} dry matter yield (Kryzeviciene, 2005; Heinsoo et al., 2011).

Less attention is devoted to tall fescue (*Festuca arundinacea* Scherb.); however, there are a few varieties of tall fescue grown in northern countries. In previous experiments, where swards were grown for forage it was noticed that tall fescue produced a high and stable biomass yield (Brencienė, 1995). Recently, tall fescue has been started to be used for bioenergy (Kryzeviciene, 2005; Seppälä et al., 2009; Kanapeckas et al., 2011).

One of the most common perennial grasses in Lithuania is cocksfoot (*Dactylis glomerata* L.), which has been used for many years as raw material for fodder (Vasiliauskienė et al., 1989; Tarakanovas et al., 2006). With changing farming traditions, livestock production has become not popular, which resulted in grasslands not being used for agriculture. The alternative use of cocksfoot could be promising in the future. The selected cocksfoot varieties could be used for biogas production, because of their biomass yield and quality (Prochnow et al., 2009; Seppälä et al., 2009).

No less important than biomass yield is the energy potential of biomass, which could be influenced by biomass quality and conversion technology (Mähnert et al., 2005; Lehtomäki et al., 2008; Seppälä et al., 2009). Navickas et al. (2011) explains the balance of energy input for digestion to biogas of cocksfoot, reed canary grass and tall fescue and analyzes the influence of the organic load on the parameters of anaerobic digestion process.

The aim of this study was to evaluate the influence of the timing of the first cut of tall fescue, cocksfoot and reed canary grass on biomass for biogas production and biomass energy value in the first year of sward use.

Materials and methods

Field experiments were carried out in Lithuanian Institute of Agriculture.

Tall fescue (variety 'Navas'), cocksfoot (variety 'Amba') and reed canary grass (variety 'Chiefton') were sown in 2008 in the soil characterized as *Endocalcari-Endohypogleyic Cambisol* (*CMg-n-w-can*). Before the establishment of the experiment it contained 1.61–1.75% of organic matter, the concentration of available phosphorus varied from 145 to 224 mg kg^{-1} and potassium from 128 to 158 mg kg^{-1}. Soil pH was 6.7–7. Grasses were grown in 15 m^2 plots in a randomized trial design. Four replicates of each treatment were established. Grasses were cut three or four times per season. The swards of the first year of use in 2009 were cut four (first cut at heading stage) and three (first cut at flowering) times per season. All swards were fertilized with mineral nitrogen fertilizer at N_{90} and N_{180}. During the first year, the swards were applied with 1/3 of the annual fertilizer rate at tillering stage. In the second growing year, the fertilization was combined with the cuts: for swards cut three times per season ½ of annual nitrogen rate was applied in spring and the remaining part – after the first cut; for other swards 1/3 of annual nitrogen was applied in spring and after the first and the second cuts. Dry matter content in biomass was evaluated after each cut.

Grass silage was prepared shortly after the cutting. For ensiling, the grass was chopped to 3–8 mm-long pieces. Preservatives were not used. The chopped samples were ensiled in 2 and 3 litre glass jars and sealed. The density of silage varied from 530 kg m^{-3} up to 630 kg m^{-3} with dry matter concentration from 23.3% to 39.2%. Energy evaluation of biomass was carried out at the Lithuanian University of Agriculture. The biogas productivity of grass silage was determined by anaerobic digestion in laboratory trials. Experiments were conducted on laboratory scale anaerobic digesters of 20 litres. Digesters were operating automatically and data of temperature and alkalinity of substrate, biogas productivity and composition were recorded by a programmable logic controller and stored in the computer database. Experiments were performed in mesophilic (39 ± 0.5ºC) temperatures. The volume of produced biogas was measured by biogas drum type flowmeter and collected in gasholder (Tedlar® bag). The collected biogas was analysed by "Schmack SSM 6000".

The anaerobic digestion was made in batch type mode in order to determine energy potential of biomass. The biomass anaerobic digestion was evaluated according to volume of produced biogas during the time interval dt, biogas productivity from biomass dry mater B_{DM}, energy value of biomass obtained at anaerobic conversion e_{DM}. Biogas productivity from biomass dry matter is calculated by the equation (Navickas et al., 2007):

$$B_{DM} = b_{dt}/m, \qquad (1),$$

where: b_{dt} – volume of produced biogas during the time interval dt, l; m – mass of the sample, kg.

Energy value of biomass dry mater (DM) obtained at anaerobic digestion e_{DM} is determined by the equation:

$$e_{DM} = B_{DM} \cdot e_b, \qquad (2),$$

where: e_b – energy value of biogas which depends on methane concentration in biogas, MJ l^{-1}.

Energy value of biogas is determined by the equation:

$$e_b = 0.0353 \cdot C_M / 100, \qquad (3),$$

where: C_M – methane concentration in biogas, %.

Difference was considered significant for probability below 0.05 ($P < 0.05$).

Results and discussion

One of the parameters in evaluating biomass suitability as the substrate for biogas is biomass yield (Amon et al., 2007; Lakaniemi et al., 2011). In our research, the annual biomass yield of differently managed grasses was determined (Fig. 1). At the first cut, all swards produced significantly higher biomass yield from heading to flowering stages: biomass yield of tall fescue at flowering stage was 38%, cocksfoot – 30–35%, reed canary grass – 14–18% higher compared to swards, harvested at heading stage. In the second cut, tall fescue and cocksfoot swards, cut for the first time at heading stage, produced higher biomass yield compared to those cut for the first time at flowering stage. The biomass yield of reed canary grass was similar in both cases. In previous research it was noticed, that timing of the first cut is of vital importance for the annual biomass yield: first cut at early heading stage significantly reduces biomass yield (Amon et al., 2007), but in the first year of grass use we did not observe any significant influence of timing of the first cut on annual biomass yield. This could be influenced by the weather conditions. After the drought, which lasted from the resumption of vegetation to heading of most grasses, rainy weather occurred and grasses, cut at flowering stage produced higher biomass yield than usual.

In our research, tall fescue produced significantly higher annual biomass yield compared to cocksfoot and reed canary grass. These results agree with previous experiments held in Lithuania with tall fescue for forage (Brencienė, 1995). Tall fescue swards which were cut four times per season and which were fertilized with N_{90} yielded 13.68 ± 0.436 t ha^{-1} and those fertilized with N_{180} – 13.37 ± 0.978 t ha^{-1}. The yield of swards, cut three times was 13.52 ± 0.376 t ha^{-1} and 13.84 ± 0.502 t ha^{-1}, respectively. The difference between the treatments was not significant.

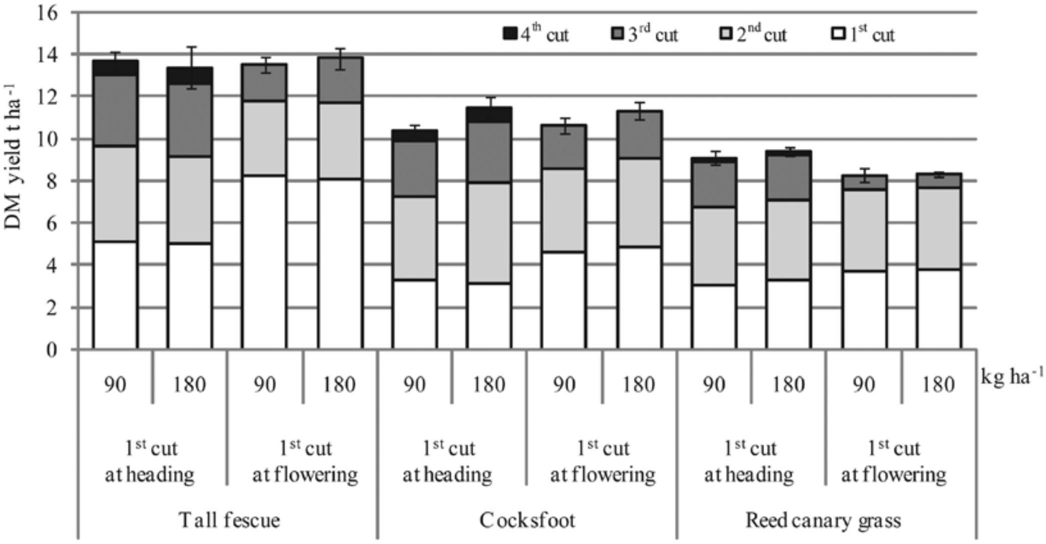

Figure 1. The influence of mineral nitrogen fertilizer and cutting frequency on annual DM yield of tall fescue, cocksfoot and reed canary grass swards

In our research, with the same rate of fertilization (N_{90}) cocksfoot produced 10.39 ± 0.259 t ha^{-1} biomass in four-cut system and 10.66 ± 0.368 t ha^{-1} biomass in three-cut system. Higher nitrogen fertilizer rate had a positive effect on biomass yield; it increased to 11.47 ± 0.488 t ha^{-1} in four-cut system and to 11.31 ± 0.396 t ha^{-1} in three-cut system. In previous study it was found that $N_{240\text{-}360}$ fertilized cocksfoot could be harvested four times per vegetation season (Ruzgas, Kadžiulis, 1989). The results of the first year of sward use confirmed that lower rates of nitrogen fertilizer N_{90} and N_{180} did not have significantly higher effect on biomass yield of grasses in both four-cut and three-cut systems.

The lowest biomass yield was accumulated by reed canary grass. The swards produced dry matter yield at heading and flowering stages respectively: fertilized with N_{90} 8.27–9.10 t ha^{-1}, N_{180} fertilized swards produced 8.33–9.41 t ha^{-1} of dry matter. Lewandowski and Schmidt (2006) proved that biomass yield of reed canary grass increased with increasing N supply from 0 to 150 kg ha^{-1}. They got the highest difference in biomass yield in the swards, fertilized with N_{100} and N_{150}. In our research, there were no significant differences in productivity between the swards fertilized with N_{90} and N_{180}.

Many grasses have very good re-growth ability. Usually, the biomass quality of aftermath is better compared to the first cut taken later. This suggests that for the optimization of biomass for biogas quality and for the increase of energy value a few-cut decision of grass management should be chosen. However, different grass species have different sensitivity to cutting frequency. More than two cuts decrease the dry matter and dry organic matter yield of reed canary grass, which is a very popular grass for bioenergy (Geber, 2002). The data of our study (Fig. 1) show that maturity stage at first cut had little effect on annual biomass yield of grasses. We did not get any significant difference in annual biomass yield of tall fescue, cocksfoot and reed canary grass cut three or four times. For some grasses more than two cuts are needed for the optimization of the anaerobic process, but increased frequency of cuts does not always give significantly higher effect on the process. Researchers found out, that annual biogas productivity in three-cut and four-cut systems is similar (Amon et al., 2007). Nevertheless, in the review article Prochnow et al. (2009) reported that there were greater differences in feedstock for biogas production between growing regions than between management systems. This shows that the selection of crops should be done in all climatic regions, because growth and quality are mostly influenced by climate conditions during the vegetation period.

In our study, biomass quality was specified as energy value. The specific methane yield varied significantly between grass species. The variation of energy value of tall fescue ranged from 10.87 to 14.67 MJ kg^{-1} DM (Fig. 2). The influence of tall fescue growth stage on energy value was most evident in the first cut. At the same rate of fertilization (N_{90}) the cutting of herbage at later maturity had a negative influence on the energy value, it decreased from 14.67 MJ kg^{-1} DM at heading to 10.87 MJ kg^{-1} DM at flowering stage. The effect of growth stage at higher fertilization (N_{180}) was lower – reduction of energy value from heading to flowering stages was only 1.48 MJ kg^{-1} DM. The biomass yield from the second and the third cuts of N_{180} fertilized swards did not differ significantly compared to N_{90} fertilized swards. The fertilization with higher nitrogen rate had a positive effect only on cocksfoot biomass yield of swards, which were harvested for the first time at heading stage.

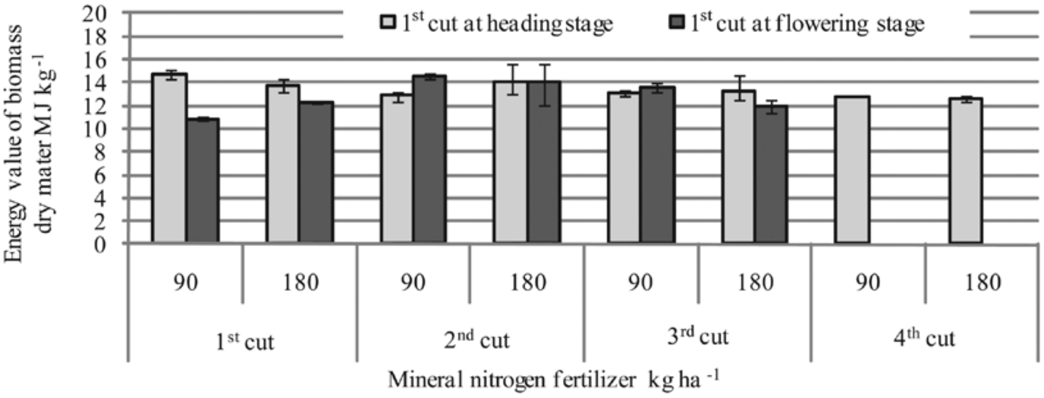

Figure 2. The impact of nitrogen fertilization and cutting frequency on energy value of tall fescue biomass

Similar tendency as in tall fescue biomass was found in energy value of cocksfoot biomass (Fig. 3). The highest energy value was in the first cut in the swards, harvested at heading stage: it varied from 15.49 to 16.10 MJ kg^{-1} DM in differently fertilized swards. A delay in the first cut increased the energy potential of biomass in the second cut, but it had a negative effect on the rest of the cuts. Fertilization significantly influenced biomass yield of swards in the second cut. The higher nitrogen rate had a negative effect on energy value. The energy value decreased from 15.91 MJ kg^{-1} DM in swards fertilized with N_{90} to 13.31 MJ kg^{-1} DM in swards fertilized with N_{180}.

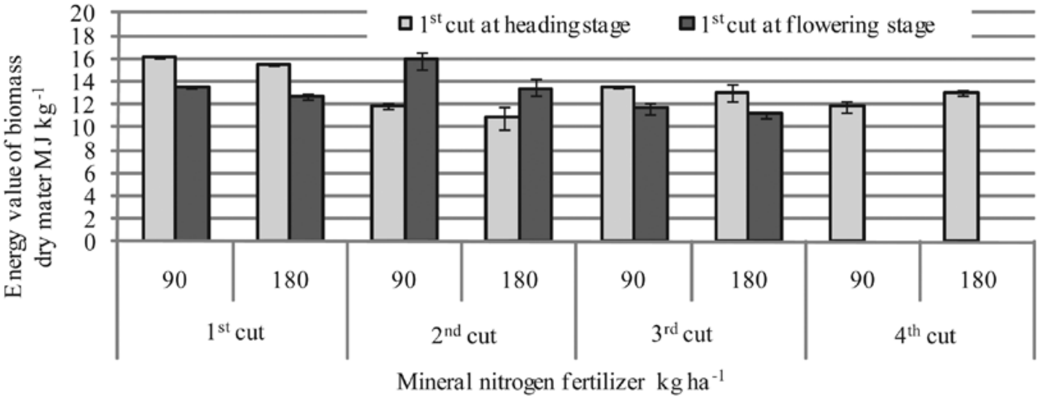

Figure 3. The impact of nitrogen fertilization and cutting frequency on energy value of cocksfoot biomass

The variation of the results of cocksfoot at all cuts was higher compared to tall fescue. The highest energy value of cocksfoot biomass was 16.10 MJ kg^{-1} DM and the lowest 10.92 MJ kg^{-1} DM.

The energy productivity of reed canary grass was the lowest compared to tall fescue and reed canary grass (Fig. 4). Like in other grasses, the highest effect of maturity stage on energy value of biomass was measured in the first cut. The energy value of biomass of swards fertilized with N_{90} and N_{180} decreased respectively from 13.79 and 14.33 MJ kg^{-1} DM at heading to 10.89 and 10.54 MJ kg^{-1} DM at flowering stages. The difference varied from 2.90 to 3.79 MJ kg^{-1} DM depending on fertilization.

As it was mentioned before, specific biogas production and energy value of biomass unit do not represent the total biomass energy potential of plot area (Amon et al., 2007). In our research, all grasses produced biogas with the highest energy value in the first cut at heading stage, but the biomass yield of tall fescue and cocksfoot was significantly lower, which resulted in a higher total energy value per plot area in swards cut for the first time at flowering stage (Fig. 5). This agrees with the results that at early and very late stages the biogas productivity is very low and delaying of the first cut has a positive effect on energy value (Amon et al., 2007). The total energy value of tall fescue varied from 164.6 to 186.1 GJ ha^{-1}, of cocksfoot from 141.4 to 149.5 GJ ha^{-1} and of reed canary grass from 89.7 to 114.1 GJ ha^{-1}. The tendency of results of different grass species obtained in this study were within the same range as those previously reported (Mähnert et al., 2005; Lehtomäki et al., 2008; Seppälä et al., 2009).

Seppälä et al. (2009) indicated, that the energy value of biomass at the first cut is higher, compared to the second cut. In our research the energy value of tall fescue at the first cut was 20–48% higher, compared to the second cut. Other grasses showed different results and in some cases cocksfoot and reed canary grass gave even higher energy value per plot area in the second cut compared to the first cut. The reduction of energy value during the third and the fourth cuts was obvious.

The total energy value was mostly influenced by grass species and growing technology. Tall fescue and reed canary grass had higher energy potential when swards had been cut for the first time at heading stage, compared to those, cut for the first time at flowering stage. There was no significant effect of fertilization on biomass energy potential. The results of our research confirm the findings obtained by Seppälä et al. (2009), where tall fescue and cocksfoot were selected as better biosubstrate for biogas production, compared to reed canary grass.

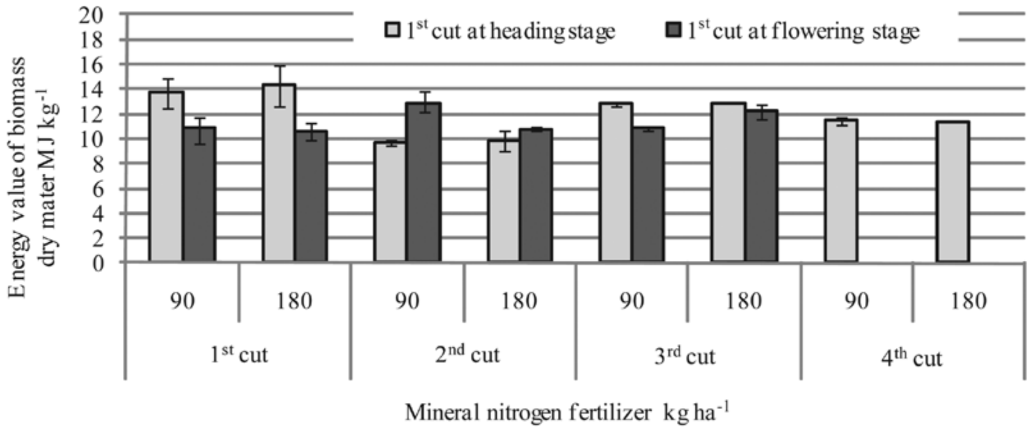

Figure 4. The impact of nitrogen fertilization and cutting frequency on energy value of reed canary grass biomass

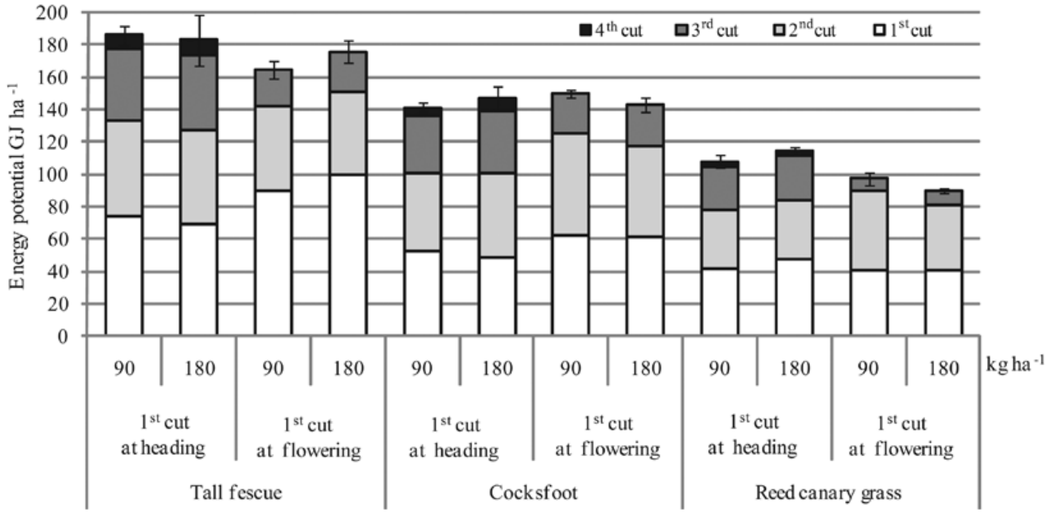

Figure 5. The impact of nitrogen fertilization and cutting frequency on annual energy value per hectare of tall fescue, cocksfoot and reed canary grass

Conclusions

1. Tall fescue produced higher DM yield compared to cocksfoot and reed canary grass. The variation of DM yield of tall fescue ranged from 13.37 to 13.84 t ha^{-1}, of cocksfoot from 10.39 to 11.47 t ha^{-1} and of reed canary grass from 8.27 to 9.41 t ha^{-1}.

2. There was no significant difference in productivity of tall fescue and reed canary grass fertilized with N_{90} and N_{180}; however, cocksfoot, cut for the first time at heading stage, produced a significant higher biomass yield.

3. The three-cut and four-cut systems did not influence the total DM yield, but had a significant effect on energy value of grasses. The variation of energy value of tall fescue ranged from 10.87 to 14.67 MJ kg^{-1} DM, of cocksfoot from 10.92 to 16.10 MJ kg^{-1} DM, and of reed canary grass from 9.68 to 14.33 MJ kg^{-1} DM.

4. The total energy potential of all swards whose first cut had been taken at heading stage was higher compared to those whose first cut was taken at flowering stage.

5. The total energy value of tall fescue varied from 164.6 to 186.1 GJ ha^{-1}, of cocksfoot from 141.4 to 149.5 GJ ha^{-1} and of reed canary grass from 89.7 to 114.1 GJ ha^{-1}. This variation was caused by maturity stage of the first-cut and mineral fertilization rates.

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Daugiamečių žolių biomasės derlius ir dujų išeiga

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Santrauka

Straipsnyje pateikti biomasės ir biodujų gamybos iš daugiamečių žolių nendrinio eraičino (*Festuca arundinacea* Schreb.), paprastosios šunažolės (*Dactylis glomerata* L.) ir nendrinio dryžučio (*Phalaris arundinacea* L.) tyrimų rezultatai. Tyrimų tikslas – įvertinti pirmosios pjūties laiko įtaką biomasės derliui ir biodujų išeigai, naudojant antrųjų auginimo metų žolynus. Daugiametės žolės augintos giliau karbonatingame sekliai glėjiškame rudžemyje (RDg4-k2). Vegetacijos sezono metu nuo balandžio iki spalio mėn. vidutinė oro temperatūra buvo 13,5° C 2008 m. ir 12,9° C 2009 m., kritulių kiekis – atitinkamai 336 ir 509 mm. Pjauta keturis kartus, patręšus 90 ir 180 kg ha^{-1} mineralinių azoto trąšų. Tyrimų rezultatai parodė ryškius biomasės derliaus skirtumus tarp žolių rūšių. Tręšimas N_{90} ir N_{180} neturėjo esminės įtakos nendrinių eraičinų ir nendrinių dryžučių produktyvumui, tačiau paprastosios šunažolės, pirmą kartą nupjautos plaukėjimo tarpsniu ir patręštos N_{180}, sukaupė iš esmės didesnį biomasės derlių, lyginant su N_{90} tręštais žolynais. Nendrinių eraičinų sausųjų medžiagų (SM) derlingumas varijavo nuo 13,37 iki 13,84 t ha^{-1}, paprastųjų šunažolių – nuo 10,39 iki 11,47 t ha^{-1}, nendrinių dryžučių – nuo 8,27 iki 9,41 t ha^{-1}. Biodujų savitoji išeiga ir energinė vertė iš sausosios masės vieneto kito priklausomai nuo žolių rūšies ir subrendimo. Nendrinių eraičinų biomasėje ji kito nuo 10,87 iki 14,67 MJ kg^{-1} SM, paprastųjų šunažolių – nuo 10,92 iki 16,10 MJ kg^{-1} SM, nendrinių dryžučių – nuo 9,68 iki 14,33 MJ kg^{-1} SM. Didžiausia biodujų išeiga iš ploto vieneto gauta į biodujas perdirbus nendrinius eraičinus, pjautus keturis kartus per metus, ji buvo 186,1 GJ ha^{-1}. Tyrimų metu nustatyta, kad biodujų gamybai mažiausiai tinkamas yra nendrinis dryžutis.

Reikšminiai žodžiai: biodujos, biodujų išeiga, energinis potencialas, daugiametės žolės.