BIOMASS YIELD AND CHEMICAL COMPOSITION OF PERENNIAL GRASSES FOR ENERGY PRODUCTION

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Abstract. The increase in energy consumption and the security of global energy market make renewable energy a topical issue, for example, the use of biomass for bioenergy, which influences directly the generation of wood ash and digestate – residues of biogas production. These products have high value of plant nutrients, therefore it is important to study their effectiveness. Reed canary grass (RCG) and festulolium fertilisation trials were arranged in 2012. In all fertiliser treatments (wood ash, digestate once per season; digestate twice per season and mineral fertilisers) the same amount of main plant nutrients (N, P, K) was provided; and the missing quantities of elements in ash and digestate were compensated by mineral fertilisers. The dry matter yield (DMY) and chemical composition of biomass in two cutting regimes (one-cut and two-cut harvest system) were assessed. All fertilisers provided a significant increase of DMY; however, better results for both species were ensured by the usage of mineral fertilisers and wood ash. Lower ash content (4.0-5.4 %) and hence more appropriate raw material for combustion can be obtained by mowing RCG once per season late in the autumn. The chemical composition of grass biomass was mostly influenced by the cutting regime and fraction.

Keywords: festulolium, reed canary grass, fertilisation, digestate, wood ash.

Introduction

In each country the increasing segment of renewable energy plays an important economic, environmental, and energy-independence-providing role, therefore each region is looking for the most favourable ways of bioenergy production. The interest in the improvement of efficiency of bioenergy feedstock production in northern countries is focused on perennial grasses, including ×*Festulolium* and reed canary grass (RCG) (*Phalaris arundinacea* L.) as they have many advantages [1; 2]. In most countries RCG is used for pelleting or making briquettes of solid fuels [3; 4]. The changing of agricultural crops from cereals to grasses for bioenergy has resulted in less impact on landscape. Furthermore, grasses is a "traditional agricultural crop" that does not need any special equipment, the same could be used as for hay production that reduces GHG emissions, because grass is perennial – no necessity to plow soil each year what leads to less disturbance of soil.

Grassland management determines not only the yield but also the quality of the harvested biomass. Different pathways for novel uses of grassland biomass have different requirements on the biomass quality [5]. The most relevant parameters of quality among others are the content of N, K, S, Cl and ash in biomass used for burning. High content of the above mentioned elements can lead to problems in the combustion process, such as corrosion or slagging, and to environmentally critical emissions of NO_x, SO_2, HCl or dioxin [6]. The concentration of particular minerals varies depending on the plant species and the plant parts used for burning. The stage of development when harvested and concentration of other minerals also have a significant influence [7]. To avoid problems with biomass quality associated with summer harvests, it is recommended to harvest during the late autumn or spring, following the growing season [8].

The timing of the first cut is important for the biogas yield. It should not be before the vegetation stage "ear emergence". The first cut taken too early reduces the methane yield per hectare [9]. Consequently the intensity of grassland management can be lower when producing feedstock for biogas plants compared with this, when biomass is used for dairy production. A lower cutting frequency also reduces the biomass production costs [10]. Energy and CO_2 balances for power generation in a combined heat and power plant (CHP) using grassland biomass showed the highest net energy yield and CO_2-equivalent reduction with two cuts per year [11].

Late-harvested grass biomass and that from old not-managed grasslands are more suitable for combustion than hay from agriculturally-managed grasslands due to the higher content of lignin and lower content of ash, K and Cl. Thus, extensive grassland management systems with one late cut and low fertilisation are preferable when using grass as solid biofuel. A critical factor is the content of N in biomass as it is responsible for NO_x emissions and losses of N from the ecosystem. Unlike other plant nutrients, for the recycling of N it is not possible to use ash because this element is emitted with combustion gasses [12].

In the transition from fossil to a bio-based economy, it has become an important challenge to recuperate maximally valuable nutrients coming from waste products – digestate and wood ash. The use of them as fertilisers to offset artificial fertilisers is thus of major economic and ecological importance. In digestate organic nutrients are converted and mineralized to more soluble and biologically available forms for plants [13]. The application of digestate as a fertiliser for grasslands could be an effective way to utilize residues from biogas plants, as it can reduce the need of mineral fertilisers and increase the biomass productivity [14]. In some experiments it is observed that the use of bio-digestion waste can stimulate phosphorous and potassium mobilization from the soil, thereby providing a potential path to recycle these valuable, but depleting, nutrients in a sustainable way [15]. Efforts should be made to integrate the approach with beneficial uses of ash derived from biomass, including the potential for recycling of nutrients to the field [16].

The aim of this study was to evaluate the DMY and chemical composition of grass biomass related to grass species, harvest time and different fertilisers used with equal amounts of NPK.

Materials and methods

Two species of perennial grasses were studied in a plot experiment: reed canary grass (RCG) (*Phalaris arundinacea* L.) and festulolium (×*Festulolium pabulare*). The field experiment was established in the central part of Latvia at the LLU Research Institute of Agriculture in Skriveri (56 º41' N, 25 º08' E), 86 m above the sea level. The soil of the experimental plot – *Endoluvic Epistagnic Phaeozem (Loamic)/Stagnic Retisol (Cutanic, Drainic, Loamic)* [17], fine sandy loam.

Five fertilisation treatments were chosen: C – control – not fertilised; MF – mineral fertilisers (ammonium nitrate, potassium sulphate and superphosphate); WA – wood ash; D1 – digestate (once per season); D2 – digestate (twice per season). Two methods of digestate use were compared: 1) giving the full annual amount in the spring at the beginning of vegetation, and 2) one half of digestate at the beginning of vegetation and one half – at the end of vegetation after cutting of grasses. In all treatments equal amount of nitrogen (N); phosphorus (P_2O_5) and potassium (K_2O) was used annually – 100, 80, 160 $kg \cdot ha^{-1}$ accordingly. The amount of nutrients was decreased by approximately one half in the year of grass sowing (42 $kg \cdot ha^{-1}$ N; 32 $kg \cdot ha^{-1}$ P_2O_5 and 80 $kg \cdot ha^{-1}$ K_2O). Every time before treatment the digestate was analysed for the NPK content and the missing amount of nutrients on plots, if necessary, was equalised by using mineral fertilisers.

Pure stands of *Ph. arundinacea* (12 $kg \cdot ha^{-1}$ seed) and ×*Festulolium* (15 $kg \cdot ha^{-1}$ seed) were sown. The size of one experimental plot was 43 m^2, the total number of plots was 40. Plot layout – randomly in 4 replications. In the 1st and 2nd year of use the grasses were cut using two methods: 1) one-cut harvest system where swards were at the stage of crop senescence, and 2) two-cut harvest – at the stage of full panicle emergence.

The chemical composition of the yield was determined by applying the following methods: dry matter – oven drying at the temperature of 105 ºC; ash content – dry combustion (LVS CEN/TS 14775); total carbon – using elemental analyser LECO CR–12 (LVS ISO 106940; total nitrogen Kjeldahl procedure (LVS ISO 11261); total phosphorous – photometrically (LVS EN 14672); potassium, calcium and magnesium – using atom absorption spectroscopy (LVS ISO 11466); total sulphur – S – using elemental analyser ELTRA CS–530.

The experimental data were assessed by using the three factor analysis of variance, the differences among means were detected by LSD at the 0.05 probability level (Excel for Windows 2003).

Results and discussion

The dry matter yield (DMY) of RCG in the first year of use ranged from 4.08 to 8.57 $t \cdot ha^{-1}$ in the two-cut harvest system and from 6.36 to 10.0 t ha^{-1} in the one-cut harvest system depending on the fertiliser treatment (Table 1). The yield level provided of *Festulolium* was relatively lower: it ranged from 2.61 to 5.02 $t \cdot ha^{-1}$ in the two-cut harvest system and from 3.54 to 7.73 $t \cdot ha^{-1}$ in the one-cut harvest system. All fertilisers in the 1st year of use in the two-cut regime provided significantly higher yields for both the species in comparison with the not-fertilised plot.

In the 2nd year of use the DMY of RCG ranged from 4.01 to 8.62 t·ha^{-1} in the two-cut regime and from 4.74 to 6.86 t·ha^{-1} in the one-cut regime. DMY of *Festulolium* was considerably lower due to winter damages after black frost: 1.11-3.65 t·ha^{-1} in the two-cut regime and 1.19-5.66 t·ha^{-1} in the one-cut regime. All types of fertilisers provided a significant increase of DMY in both cutting regimes for both species; yet better results were obtained when using mineral fertilisers (MF) and wood ash (WA).

Table 1

DM yield of *Phalaris arundinacea* and ×*Festulolium* in the 1st and 2nd year of use

Variant	1st year of use (2013), t·ha^{-1}				2nd year of use (2014), t·ha^{-1}			
	two-cut regime			one-cut regime	two-cut regime			one-cut regime
	1st cut	2nd cut	total		1st cut	2nd cut	total	
Phalaris arundinacea								
Control	2.70^{BCDE*}	1.39^{C}	4.08^{BCDE}	6.36^{C}	2.19^{BCDE}	1.82	4.01^{BCDE}	4.74^{BCDE}
MF	5.73^{a}	2.08	7.82^{a}	8.56	6.12^{ade}	2.43	8.54^{ade}	6.77^{a}
WA	5.94^{a}	2.63^{ade}	8.57^{ade}	10.0^{ad}	5.95^{ade}	2.68	8.62^{ade}	6.75^{a}
D1	4.55^{a}	1.77^{C}	6.32^{aC}	7.44^{C}	4.45^{aBC}	2.07	6.52^{aBC}	6.86^{a}
D2	4.49^{a}	1.71^{C}	6.2^{aC}	7.66	3.62^{aBC}	2.12	5.74^{aBC}	7.11^{a}
$LSD_{0.05}$	1.37	0.71	1.96	2.32	1.02	0.79	1.47	1.01
× *Festulolium*								
Control	2.06^{BCDE}	0.54^{BC}	2.61^{BCDE}	3.54^{BCDE}	0.53^{BCDE}	0.58^{BCE}	1.11^{BCDE}	1.19^{BCDE}
MF	3.19^{a}	1.07^{a}	4.26^{a}	7.43^{ae}	2.02^{a}	1.63^{ade}	3.65^{ade}	5.27^{ade}
WA	3.94^{ae}	1.08a	5.02^{ade}	7.73^{ae}	1.91^{a}	1.87^{ade}	3.78^{ade}	5.66^{ade}
D1	3.10^{a}	0.75	3.84^{aC}	6.12^{a}	1.39^{a}	0.88^{BC}	2.27^{aBC}	2.85^{aBC}
D2	2.94^{aC}	0.82	3.76^{aC}	5.31^{aBC}	1.5^{a}	0.99^{aBC}	2.49^{aBC}	2.48^{aBC}
$LSD_{0.05}$	0.81	0.33	0.98	1.63	0.73	0.34	1.01	1.24

*- capital letters indicate the variants with higher result; lowercase- with lower result

Summarizing the results of two years it is possible to see that in general a higher DMY was obtained by using the one-cut regime (Fig. 1). All fertilisers provided the increase of DMY; however, better results for both species were ensured by the usage of MF and WA. Also the use of digestate – both giving the entire dose at once in the spring after the resumption of the vegetation or using one half of digestate at the beginning and one half at the end of vegetation – in general provided a significant increase of DMY in comparison with the control, although it did not provide an equivalent yield increase as it was in WA and MF variants. It can be concluded that in the case of digestate application on the soil surface without immediate incorporation, emissions of ammonium might be relevant [18]. The DM yield was also influenced by species – RCG provided relatively higher DMY in all treatments (Fig. 1).

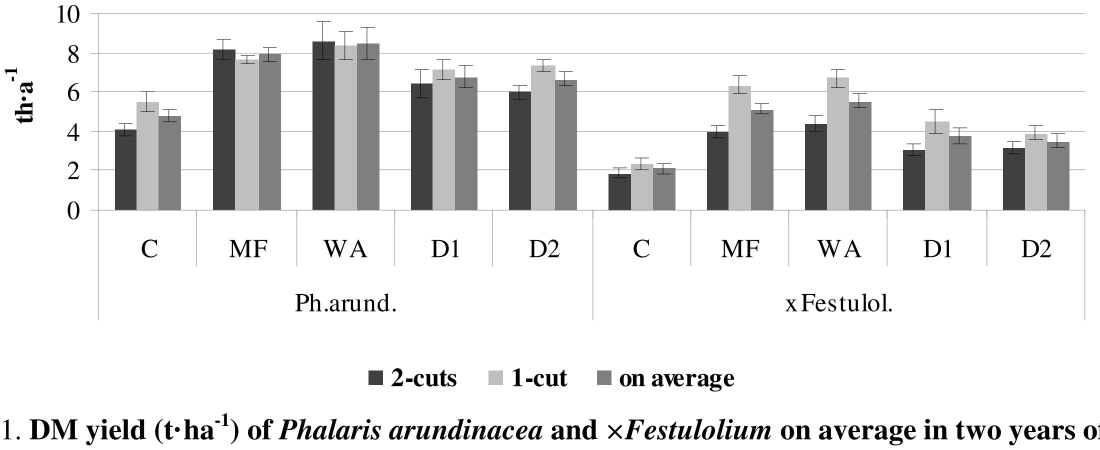

Fig. 1. **DM yield (t·ha^{-1}) of *Phalaris arundinacea* and ×*Festulolium* on average in two years of use**

To decide on the suitability of grass as a raw material for the production of energy it is important to assess the quality of herbaceous biomass. A significant fraction – up to one-fifth – of herbaceous biomass consists of inorganic constituents, commonly referred to as ash that cannot be converted to energy.

The quantity and quality of ash in herbaceous biomass depends on many factors including the species, growing conditions, fertilisation, harvest time, etc. [16]. The ash content in our experiments ranged quite considerably depending on the factors mentioned above: for RCG within: 6.0-6.7 % in the 1st cut; 9.0-11.2 % in the 2nd cut; 4.0-5.4 % in the late harvest (Figure 2). At the same time the ash content in the biomass of *Festulolium*in was slightly higher, it ranged within: 6.9-8.1 % in the 1st cut; 8.3-10.6 % in the 2nd cut; and 5.8-6.5 % in the late harvest. It can be concluded that the most appropriate raw material from grass for combustion was obtained by cutting RCG once per season as late as possible in the autumn. Late harvested, it gave highly lignified and low-ash biomass, which is more suitable for combustion [19; 20].

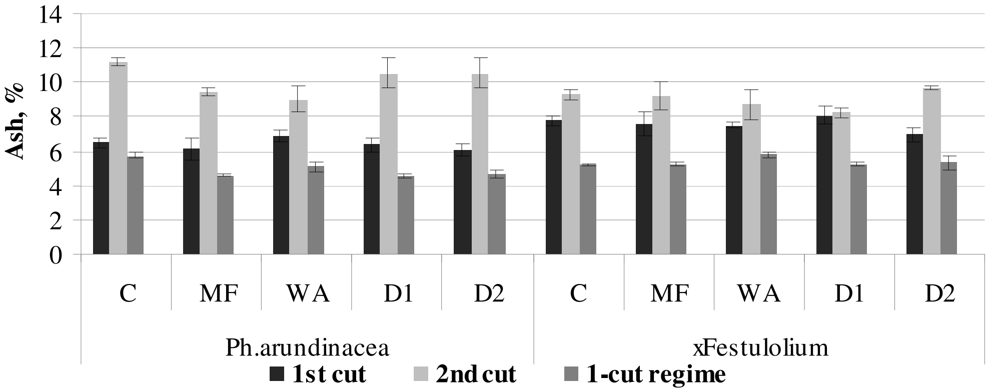

Fig. 2. **Ash content (%) of grass sward using different cutting regimes**

The carbon (C) content in the 1st year of use on average of two cutting regimes ranged within 490.65-510.56 g·kg^{-1}; a relatively higher C content was for RCG swards (Table 2). Nitrogen (N) content varied between 11.14 and 14.86 g·kg^{-1}; a higher content was in WA and MF treatments. Studies show that N content increases with higher N fertiliser doses and early cutting period [11].

Table 2

Chemical content of grass swards as the average of two-cutting regimes

Variant	C, g·kg^{-1}	N, g·kg^{-1}	P, g·kg^{-1}	K, g·kg^{-1}	S, mg·kg^{-1}
Phalaris arundinacea					
C	498.27^{BCE}	11.31^{C}	2.42^{bc}	14.70	1737.8^{Bcde}
MF	510.56^{a}	12.46	2.06^{ADE}	15.66	2229.6^{acde}
WA	509.98^{a}	13.2^{ae}	1.99^{ADE}	14.84	1478.5^{AB}
D1	507.43	12.55	2.37^{bc}	16.35	1309.0^{AB}
D2	509.75^{a}	11.14^{C}	2.31^{bc}	16.55	1406.4^{AB}
x Festulolium					
C	497.72	11.61^{BC}	1,93	17.02^{BD}	1222.9^{B}
MF	498.68	14.86^{ade}	1,86	19.97^{a}	1448.9^{acde}
WA	493.8	14.17^{ade}	1,70	19.34	1157.2^{B}
D1	495.62	12.24^{BC}	1,87	19.99^{a}	1140.9^{B}
D2	490.65	11.64^{BC}	1,80	18.2	1209.5^{B}
$LSD_{0.05}$	*9.29*	*1.73*	*0.24*	*2.40*	*202.3*

*- capital letters indicate the variants with higher result; lowercase- with lower result

In these experiments the content of phosphorus (P) was from 1.70-2.42 g·kg^{-1} with the tendency to be lower in *Festulolium* swards while potassium (K) ranged within 14.70-19.99 g·kg^{-1} with the tendency to be lower in RCG swards. The highest content of sulphur (S) for both species was in MF treatment and in general RCG contained a little more S as *Festulolium* swards (Table 2).

The quality of biomass is mostly dependent on the growing conditions, grass species, cutting frequency and fertilisation [19]. The factor impact analysis by summing both cutting regimes in our experiments is shown in Fig. 3. The ash content was mostly influenced by sward fraction (impact factor – 49.2 %). Culms contained significantly less ash compared to leaves. The cutting period was the second important factor (34.2 %). Considerably smaller it was in the case, when sward was cut once per season late in the autumn. Fertilisation had low impact (3.3 %) and also grass variety (6.2 %) was not very important. RCG contained relatively less ash than *Festulolium* swards.

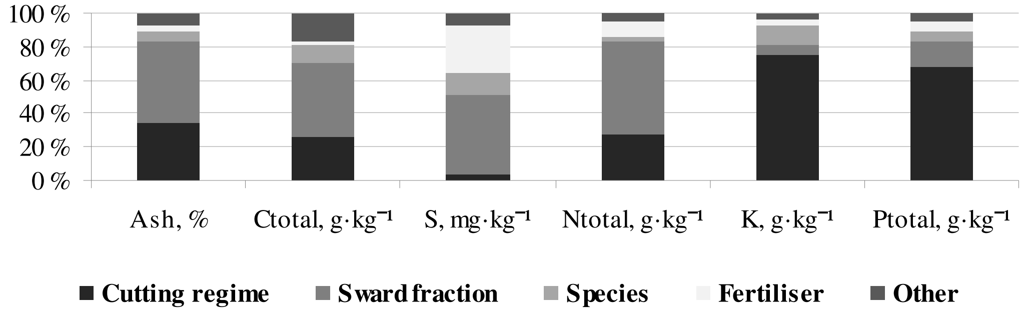

Fig. 3. **Grass biomass composition depending on some factors**

The similar pattern was also for carbon (C) content in biomass – the sward fraction (impact factor – 43.9 %) had dominating influence, more carbon was in the culms. The cutting method was an important (26.3 %) factor for carbon accumulation – it was the highest in the situation when swards were harvested once per season. The fertilisation type and methods practically did not influence this parameter.

Sulphur (S) content was also greatly (47.5 %) influenced by the sward fraction – leaves contained 2 to 3 times more S than culms. The second greatest impact factor was the type of fertiliser (28.9 %) – mineral fertilisers showed the biggest effect on sulphur accumulation probably due to the use of superphosphate. The next highest (12.7 %) influence factor was the type of swards – RCG contained higher sulphur compared to *Festulolium* swards.

Nitrogen (N) content was also greatly (54.9 %) influenced by the sward fraction – leaves contained 2 to 3 times more N than culms; the second important factor was the cutting regime – about two times higher N content was if swards were cut twice per season. For nitrogen the fertilisation effect was important (9.6 %) – on average MF and WA treatment provided higher N content in biomass (13.7 $g \cdot kg^{-1}$) compared to the control plot and D2 treatment (11.5 and 11.4 $g \cdot kg^{-1}$ respectively). The use of mineral fertilisers showed the highest nitrogen accumulation in biomass. Similar results were obtained in the studies conducted in Lithuania, where the swards treated with mineral fertiliser exhibited significantly higher nitrogen concentration compared to those fertilised with digestate [21].

Phosphorous (P) and potassium (K) content in biomass was mainly influenced by the cutting regime (68.0 and 74.5 %). One-time late autumn cutting reduced the PK content in biomass 3 to 4 times. It is a positive feature because high PK content in biofuel is undesirable and also a smaller amount of these plant nutrients are removed from the field. The important factor for K was also the sward type (11.7 %), but for P – grass fraction (15.2 %). Leaves on average contained more P compared to culms, especially when the one-cut method was used. *Festulolium* swards (leaves, culms) contained more K compared to RCG swards. There was a very similar content of K in the leaves and culms for RCG but *Festulolium* leaves contained considerably more K than the culms.

Conclusions

1. On average, the highest dry matter yield was obtained when growing reed canary grass and using the one-cut harvesting method.
2. All types of fertilisers provided an increase of the dry matter yield; however, better results for both grass species were ensured by the usage of mineral fertilisers and wood ash.
3. Lower ash content (4.0-5.4 %) and hence more appropriate raw material from grass for combustion can be obtained by harvesting reed canary grass once per season as late as possible in the autumn. The chemical composition of grass biomass was mostly influenced by the cutting regime and plant fraction.

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