Agronomy Research **14**(1), 198–210, 2016

The evaluation of biomass yield and quality of *Phalaris arundinacea* and *Festulolium* fertilised with bio-energy waste products

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Abstract. Tall growing perennial grasses such as *Phalaris arundinacea* and *Festulolium* can be used as an alternative source for bioenergy production in northern latitudes as they can be grown in less cultivated areas and can be potentially used as a dual purpose crop (bioenergy and forage). The aim of studies was to investigate the effectiveness of using bioenergy waste products – fermentation residues (digestate) and wood ash as fertilisers for perennial grasses. The field experiment was conducted in the central part of Latvia (56°42' N and 25°08' E) from 2013 to 2015. For all fertiliser treatments (wood ash, digestate once per season; digestate twice per season and mineral fertilisers) the same amount of plant nutrients (N, P, K) was applied annually: N (100), P_2O_5 (80), K_2O (160); and the missing quantities of elements in ash and digestate were compensated by mineral fertilisers. Dry matter yield (DMY) in two harvest regimes (single cut and two cut) and chemical composition (ash content; total C and N) of grass biomass partitioning among tillers, leaves and panicles were estimated.
Biomass yield in the three years of use varied considerably depending on the fertiliser, harvest regime and species, ranging up to 10.0 Mg ha^{-1} for RCG and 7.73 Mg ha^{-1} for festulolium. All fertilisers provided a significant increase of DMY, however, better results for both species were obtained using wood ash and mineral fertilisers. The harvest regime and species affected directly the quality of biomass, single cut of RCG contained significantly less ash and more carbon. There were significant differences between sward fractions – culms in comparison with leaves contained less ash and nitrogen, and more carbon, what are desirable features for solid fuel.

Key words: perennial grasses, dry matter yield, chemical composition, fermentation residues, wood ash.

INTRODUCTION

Biomass is an abundant and renewable source of energy and its use for that purpose would diversify the energy supply and reduce dependency on fossil fuels. Furthermore biomass production may create additional jobs for the local economy in rural areas (Rancane et al., 2014b). Biomass yield and quality are the indicators which determine possible energy yield of biomass per unit and an optional species of plants for energy conversion (Pociene et al, 2013).

One of the most suitable sources for bioenergy in agriculture is perennial grasses (Ceotto, 2008; Bardule et al., 2013; Rancane et al., 2014a). Perennial grasses may provide a renewable source of biomass for energy production since they have many advantages including reduced cost of establishment and cultivation; relatively high yield potential on land not suitable for annual crops; soil and water conservation; increased carbon sequestration; and wildlife habitat conservation (McLaughlin et. al., 2002). Besides contributing to the reduction of anthropogenic carbon dioxide (CO_2) emissions, these alternative biomass materials show other ecological benefits. They prevent soil erosion and require limited soil management and a low demand for nutrient inputs (Fournel et al., 2015).

In addition to the traditional perennial grasses use for forage, they can be source of biofuel for direct burning to generate electricity or for fermentation to ethanol. Different requirements of biomass quality are for biogas production and solid fuels, but there is one, which is common for all bioenergy sources, namely biomass yield (Prochnow et al., 2009a). In addition, low moisture content, low levels of ash and alkali metals, and high fiber content are the desirable features of a crop to be used as a source of bioenergy (Tahir et al., 2011).

To be a potential perennial energy crop, a perennial species should be native, have high biomass yield potential, be harvested with typical farm equipment, and exhibit positive environmental attributes. In the regions of Northern Canada, Europe and Russia higher energy potential is achieved from the production of cold season (C3) perennial grasses, such as reed canary grass (*Phalaris arundinacea* L.) and tall fescue (*Festuca arundinacea* Schreb.) (Carlson, 1996; Samson et al., 2005).

Reed canary grass (RCG) is a perennial, heterogamous and stolonate grass from the *Poaceae* family. RCG produces high biomass yield in cool climates and wetlands. The number and timing of harvests during a growing season directly affected biomass yield and biofuel quality (Tahir et al., 2011). The suitability of reed canary grass as a source for energy or cellulose production also has been confirmed by many authors (Nixon & Bullard, 1997; Pahkala & Mela, 1997, Pedersen, 1997; Saijonkari-Pahkala, 2001; Lewandowski et al., 2003).

Festulolium is the hybrid perennial grass developed by crossing *Festuca pratensis* or *Festuca arundinacea* with *Lolium perenne* or *Lolium multiflorum*. This enables combining the best properties of the two types of grass: high dry matter yield, resistance to cold, drought tolerance and persistence, rapid establishment, good spring growth, good digestibility and high sugar content (Gutmane & Adamovics, 2006; Bardule et al., 2013). The individual festulolium varieties contain various combinations of these qualities, but all are substantially higher yielding than their parent lines. In our research was included *Festulolium pabulare* 'Felina' – hybrid of tall fescue type (*Festuca arundinacea* × *Lolium multiflorum*) and reed canary grass 'Bamse'. In addition to their use for direct burning or co-generation (producing electricity and heat), both species, when still green, can be used as fodder and for the production of biogas.

If biomass is used for combustion, quantitative parameters are relevant together with several indicators of the quality. The ash content of biomass is very important because when ash concentration is increased by 1%, the calorific value is reduced by 0.2 MJ kg^{-1} (Jenkins et al., 1998). Ash contributes to dust emissions and some operational problems such as fouling, slagging and corrosion. In small scale appliances, they may disturb the combustion process, reduce efficiency and lead to unwanted shutdowns and higher levels of compounds from an incomplete combustion including carbon monoxide (CO) (Obernberger et al., 2006; Tissari et al., 2011; Verma et al., 2011). The major components of ash are silica and potassium (Samson et al., 1999). Compared to wood, agricultural materials usually contain less carbon and have higher contents in ash and elements such as nitrogen, sulphur, chlorine, potassium and silicon. Carbon impact the higher heating value (Werther et al., 2000; Obernberger et al., 2006; Vassiliev et al., 2010). High amounts of N, S and Cl in energy crops increase the emissions of nitrogen oxides (NOx), sulfur dioxide (SO_2) and hydrogen chloride (HCl), respectively (Obernberger et al., 2006; Van Loo & Koppejan, 2008).

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 fertiliser is thus of major economic and ecological importance (Rancane et al., 2015). The application of digestate as a fertiliser for grasslands could be an effective way to utilize residues from biogas plants (Alburquerque et al., 2012). 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 (Bakker R.R & Elbersen, 2005).

The aim of this study were to evaluate biomass yield and quality of reed canary grass and festulolium as potential bioenergy crops related to grass species, harvest time and different fertilisers used with equal amounts of NPK.

MATERIALS AND METHODS

Two species of cool season perennial grasses were studied in a field experiment: reed canary grass (RCG) (*Phalaris arundinacea* L.) and festulolium (×*Festulolium pabulare*) from 2013 to 2015. The experiment was established in the central part of Latvia at the LLU Institute of Agriculture in Skriveri (56°41' N, 25°08' E), 86 m above the sea level. The soil pH KCl was 5.7 (LVS ISO 10390/NAC), total carbon – 24.3 g kg^{-1} (LVS ISO 10694), plant available phosphorus (P_2O_5) 95 mg kg^{-1} (in 0.2 M HCl extract spectrophotometrically – LVS 398), potassium (K_2O) 130 mg kg^{-1} (in 1.0 M CH_3COONH_4 extract using atomic-absorption spectrometer) and sulphur (S) 25 mg kg^{-1} (using ELTRA CS 530 element analyser). The soil of the experimental field was classified as *Endoluvic Epistagnic Phaeozem (Loamic)/Stagnic Retisol (Cutanic, Drainic, Loamic)*, fine sandy loam (WRB 2014).

Five fertilisation treatments of grasses were compated: C – control – not fertilised; MF – mineral fertilisers (ammonium nitrate, potassium sulphate and superphosphate); WA – wood ash; D1 – fermentation residues or digestate used once per season; D2 – fermentation residues or digestate used twice per season. In the sowing year before the establishment of experiment all fertilisers were incorporated in the soil; in subsequent crop years they were used to the surface of the swards. 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. For all fertiliser treatments the same amount of plant nutrients: nitrogen (N); phosphorus (P_2O_5) and potassium (K_2O) was applied annually – 100, 80, 160 kg ha^{-1} accordingly. The amount of nutrients was decreased approximately by one half in the year of grass sowing (2012): 42 kg ha^{-1} N; 32 kg ha^{-1} P_2O_5 and 80 kg ha^{-1} K_2O. Every time before treatment fermentation residues and wood ash were analysed for NPK content and the missing quantities of elements on each plot, if necessary, were equalised by using mineral fertilisers – ammonium nitrate, potassium sulphate or superphosphate. Stabilized wood ash from the boiler house with average main plant nutrient content of NPK g kg^{-1} (0.5:11:32) was used. The neutralization value of wood ash was 47–53%. In treatment of grass swards the liquid fraction of separated fermentation residues with DM content from 4.4 to 5.4% and an average OM content 3.7% was used. The chemical content ranged between: 2.7 and 5.1 g L^{-1} N; 0.4 and 0.77 g L^{-1} P_2O_5; 3.3 and 3.7 g L^{-1} K_2O.

Pure stands of RCG (12 kg ha^{-1} seed) and *Festulolium* (15 kg ha^{-1} seed) were sown by drill. The experiment was designed as a randomized complete block with four replicates. Two harvest regimes for determination of dry matter yield were used: 1) one-cut per season or single harvest was taken in autumn at the stage of crop senescence (end of September – beginning of October), and 2) two-cut per season: first cut was taken at the full panicle emergence, the second – in autumn simultaneously with the single cut.

The meteorological conditions and distribution of rainfalls during experimental years were different, the average annual precipitation amount at the study site was: 698 mm or 102% from long-term average in 2013; 807 mm (118%) in 2014; and 549 mm (80%) in 2015. The monthly distribution of precipitation is shown in Fig. 1.

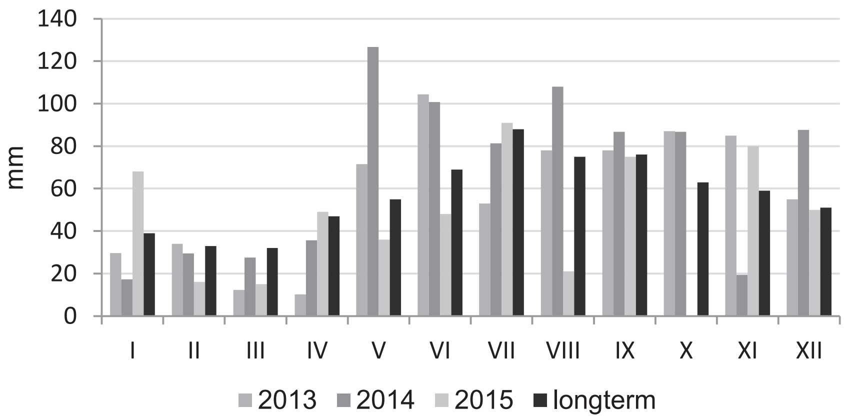

Figure 1. The monthly distribution of precipitation, 2013–2015, and long-term average.

For determination of sward structure the samples from each harvest were partitioned among tillers, leaves and panicles. The chemical composition of grasses was determined by using the following methods: dry matter – oven drying at the temperature of 105 °C; 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).

The experimental data were processed by analysis of variance ($p < 0.05$), the differences among means were detected by LSD at the 0.05 probability level (Excel for Windows 2003). To determine the factor's influence multifactor analyze was used. Sums of squared deviations were calculated and interactions in equal shares were divided on the main factors.

RESULTS AND DISCUSSION

The dry matter yield (DMY) of grasses varied quite considerably depending on the fertiliser, harvest regime, species and year. In the first year of sward use the DMY of reed canary grass (RCG) ranged from 4.08 to 8.57 Mg ha^{-1} in two-harvest regime and from 6.36 to 10.00 Mg ha^{-1} in one-harvest regime (Fig. 2). Dry matter yields in all fertilised variants were significantly (*P > 0.05*) higher compared with control; the best results were provided by MF and WA fertiliser options, where DMY level was significantly higher than in options with digestate use once or twice per season (D1 and D2). It would be explained by a partial nitrogen losses using surface application of digestate. It is known that injection of liquid fertilisers directly into the soil significantly reduces NH_3 emissions (Ismail et al., 1991; Sigunga et al., 2002) compared with surface application, because gaseous NH_3 is bound to soil colloids and soil water (McDowell & Smith, 1958; Stanley & Smith, 1956).

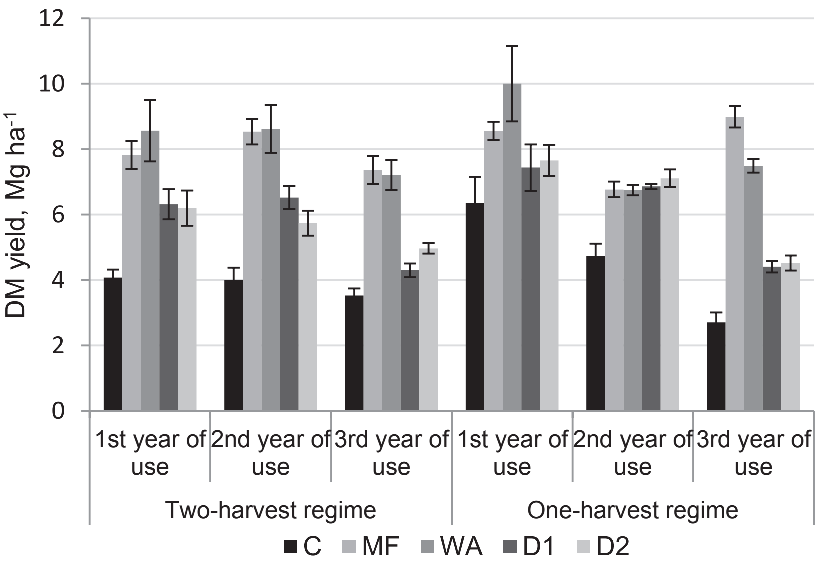

Figure 2. The DMY (Mg ha^{-1}) of reed canary grass, using two-harvest regimes.

In the 2nd year of sward use the biomass yield of RCG and fertiliser efficiency in two-harvest regime was similar to the first year: it ranged from 4.01 Mg ha^{-1} without use of fertilisers to 8.62 and 8.54 Mg ha^{-1} in WA and MF variants, respectively. However in one-harvest regime DMY was more similar among all fertilised variants, there were significant differences (*P > 0.05*) only between control variant and all fertilised variants, but DM yields among them did not differ significantly.

In the 3rd year of sward use DMY of RCG in general was slightly behind the yield level of the first two years with the exception of MF option in one-harvest regime.

The DM yields of festulolium in the 1st year of sward use ranged from 2.61 to 5.02 Mg ha^{-1} in two-harvest regime; and from 3.54 to 7.73 Mg ha^{-1} in one-harvest regime (Fig. 3). In the 2nd year of sward use DM yields of festulolium were slightly lower: from 1.11 to 3.78 Mg ha^{-1} in two-harvest regime and from 1.19 to 5.66 Mg ha^{-1} in one-harvest regime. In the 3rd year of sward use DM yield level did not differ significantly between harvest regimes: DMY ranged from 2.55 to 7.29 Mg ha^{-1} in two-harvest regime and from 2.57 to 7.86 Mg ha^{-1} in one-harvest regime. Similar to the RCG, the highest yields of festulolium were provided by using mineral fertilisers and wood ash, as well as digestate ensured significant increase of DMY compared with control variant.

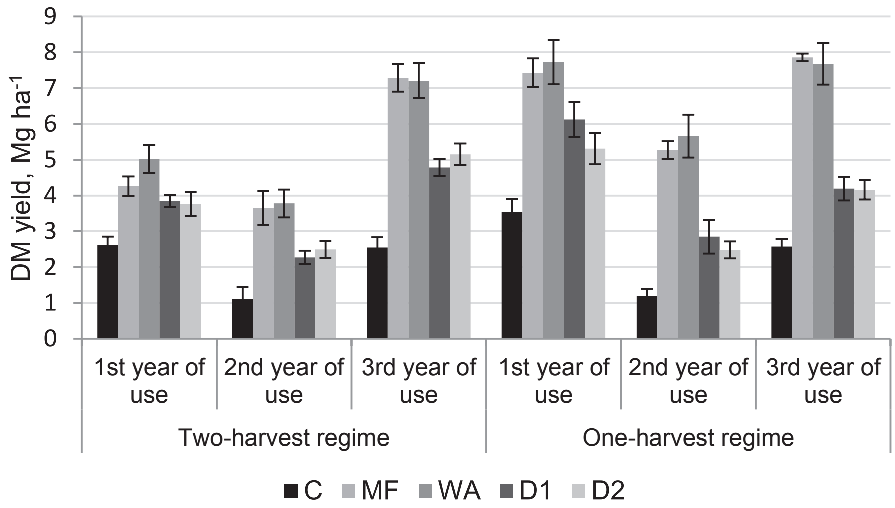

Figure 3. The DMY (Mg ha^{-1}) of festulolium, using two-harvest regimes.

In general, the biomass yields of RCG in a three-year period were relatively stable with a slight tendency to decrease – from 6.7/8.0 Mg ha^{-1} (two-harvest/one-harvest regime) on average in the 1st year of use to 5.5/5.6 Mg ha^{-1} (two-harvest/one-harvest regime) on average in the 3rd year of use. DMY of festulolium declined more in the 2nd year of use. One of the factors influencing the biomass yield of perennial grasses was meterological conditions during the experimental period. The yield reduction of RCG in the 3rd year of use was mostly influenced by unequal rainfall distribution (Fig. 1), there was insufficient rainfall in May, June and August. The decline in yield of festuloliums in the 2nd year of use can be explained by long-term black frost period in the previous winter. Festulolium in such circumstances was less winter-hardy, part of plants died. Festulolium has very high forage quality and good summer production, but has greatest value in multiple-species mixtures because of its relatively low cold tolerance.

One of indirect indicators of sward productivity is plant length; there exists a strong correlation between the length of grass and biomass yield. In our trials it was confirmed by measurements of plant length before the first mowing of sward in two-harvest regime (Fig. 4). The tallest swards were in WA and MF variants, and a higher dry matter yield was also obtained.

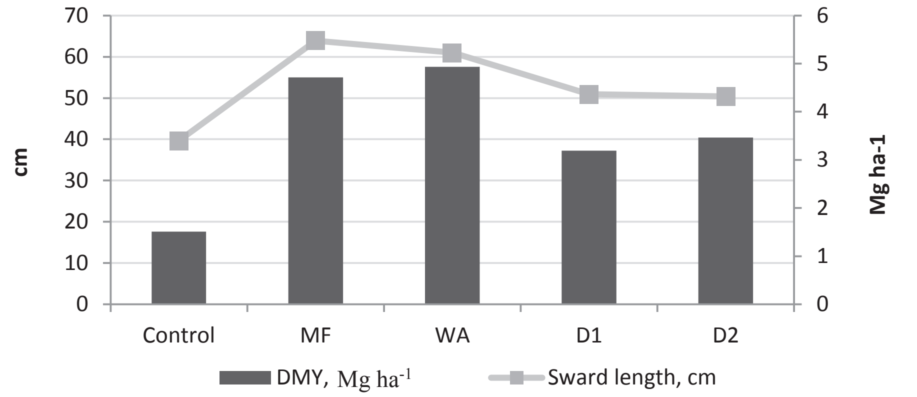

Figure 4. Correlation of festulolium plant length and DM yield of the 1st cut.

The sward of each harvest was evaluated by partitioning of grass biomass among tillers, leaves and panicles. The highest content of leaves was in the sward of the 2nd mowing for both species, particularly high percentage of leaves in the 2nd cut was for festulolium (Fig. 5), as this species has a feature to form only few culms in the aftermath, it mostly consisted from leaves. In our experiment the percentage of leaves in the 2nd cut of festulolium was 90% on average.

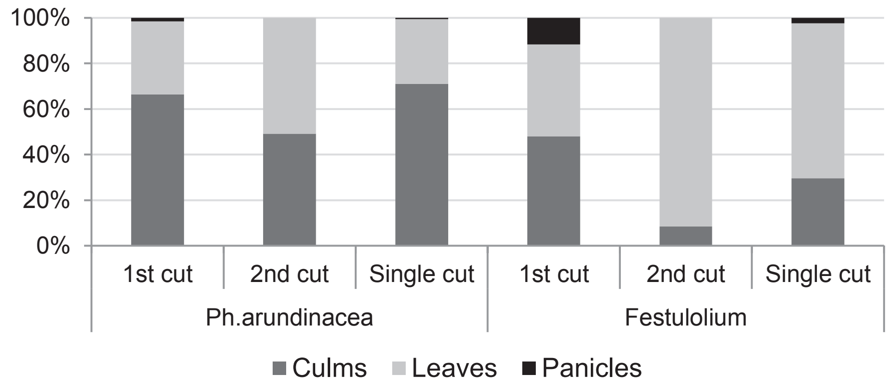

Figure 5. Grass sward structure on average in all fertiliser options.

Whereas the swards of RCG were more abundant in culms, it was particularly pronounced within one-harvest regime, when mowing was done in late autumn at crop senescence. The content of culms was 73% on average. Slightly smaller percentage of culms was in RCG sward of the 1st mowing, it contained 66% of culms on average. The ratio of leaves and culms in the 2nd cut of RCG sward was almost equal – it contained 49% of culms and 51% of leaves on average.

The analysis of grass structure by fertilisation variants show that the higher culms percentage is for more productive swards. Thus MF and WA fertiliser variants, which provided the highest DM yields, ensured greater percentage of culms, too. Considering that in general the culms contain relatively less ash and more carbon (C) it could be concluded that swards with higher percentage of culms have higher heat output and less residue of ash, so they are more suitable for solid fuel production.

Higher content of panicles was in the first mowing for both species: 1.6% for RCG and 11.7% for festulolium. Neither RCG nor festulolium develop any panicles in the aftermath. The small proportion of panicles in the sward of one-harvest regime was due to the fact that the seed was already scattered out in late autumn and therefore panicles had become much lighter.

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 (Rancane et al., 2015).

For each fraction of the swards of the first and single cut the chemical composition was determined. The distribution and composition of ash varies among different plant fractions. Ash levels usually are lowest in grass stems and highest in leaves (Lanning & Eleuterius, 1989). The analysis showed that in our trial the ash content of culms was approximately 1.5 times lower in comparison with leaves (Table 1). Whereas most of the 2nd mowing grass consists of leaves, the ash content of it was significantly higher compared to the 1st cut, and especially to the single cut.

Chemical composition was different also between grass species: swards of festulolium contained greater amount of ash. It could be explained by a higher percentage of leaves in the sward. Furthermore festulolium leaves were richer in ash if compared to RCG, the difference was approximately 1.4%: 9.5 and 7.9% in the 1st cut; 7.1 and 6.0% in single cut, respectively. There was no significant difference between ash content in culms of RCG and festulolium.

Ash is an inorganic constituent of plant biomass and it cannot be converted to energy, therefore biomass with less content of ash is preferred. On average single cut of both species contained considerably less ash compared with the 1st cut: approximate reduction was 25% in leaves and 35% in culms. Harvesting biomass with higher stem content can reduce the plant's ash concentration, thus improving the biomass quality for combustion. Several studies (Burvall, 1997; Hadders et al., 1997; Prochnow et al., 2009a; Heinsoo et al., 2011) revealed that fuel quality is improved with delayed harvest, because of a 20–80% reduction of the concentrations of most elements that lead to environmentally harmful emissions or ash-related problems during combustion.

The higher carbon (C) content leads to a higher heating value. The carbon content of biomass is around 45%, while coal contains 60% or greater (Demirbas, 2004). The carbon (C) content of our swards on average in all treatments for both species varied around 476 g kg^{-1} for leaves and around 494 g kg^{-1} for culms of the 1st cut (Table 1). A slightly higher C content was for single cut: around 487 g kg^{-1} for leaves and 532 g kg^{-1} for culms on average. Obviously the carbon content in the culms was higher than in the leaves in general, it was notably expressed in festulolium.

Fuel-bound nitrogen is responsible for most nitrogen oxide (NO_x) emissions produced from biomass combustion. The fuel nitrogen content is responsible for nitrogen oxide formation and should not exceed 0.6% w/w in dry matter (DM) (Obernberger et al., 2006). Lower nitrogen content in the fuel should lead to lower NO_x emissions. The nitrogen (N) content in leaves was 2–3 times higher compared to culms, it varied around 25 g kg^{-1} in leaves and around 9 g kg^{-1} in culms on average of both species in the 1st cut.

Table 1. Chemical composition of the 1st and single cut leaves and culms; and the 2nd cut swards

Species	Fertiliser variant	1st cut		Single cut		2nd cut
		Leaves	Culms	Leaves	Culms	Sward
Ash content, %						
Phalaris arundin.	Control	7.76	5.93	6.75	4.86	11.19
	MF	8.10	5.57	6.47	3.07	9.48
	WA	8.09	6.35	6.88	3.68	9.01
	D1	8.06	5.73	5.33	4.23	10.52
	D2	7.72	5.49	4.75	4.18	10.52
Festulolium	Control	9.20	5.61	7.59	3.77	10.59
	MF	9.51	6.89	7.02	3.65	9.22
	WA	9.88	6.72	7.30	4.21	8.70
	D1	9.80	6.99	7.24	3.34	8.27
	D2	8.95	6.15	6.48	4.01	9.64
On average		8.71	6.14	6.58	3.90	9.71
$LSD_{0.05}$		1.41	1.41	1.41	1.41	2.51
Carbon content, g kg^{-1}						
Phalaris arundin.	Control	480.60	487.10	498.27	515.25	497.61
	MF	490.45	492.11	506.89	538.18	508.10
	WA	497.68	497.37	498.45	526.49	511.90
	D1	482.84	495.49	505.22	535.85	501.35
	D2	494.62	491.65	497.87	537.12	508.79
Festulolium	Control	460.60	499.34	477.62	528.79	501.13
	MF	458.61	505.28	470.31	543.29	510.51
	WA	474.82	492.36	467.34	528.15	503.32
	D1	467.15	491.55	473.27	539.08	504.55
	D2	456.28	487.34	477.63	526.44	493.88
On average		476.37	493.96	487.29	531.86	504.11
$LSD_{0.05}$		23.54	23.54	23.54	23.54	13.53
Nitrogen content, g kg^{-1}						
Phalaris arundin.	Control	22.33	8.53	11.51	5.10	13.88
	MF	29.20	9.93	17.61	5.68	14.97
	WA	35.68	13.52	15.53	5.33	13.43
	D1	25.83	9.64	10.16	6.87	15.32
	D2	23.15	8.85	10.48	3.46	15.26
Festulolium	Control	14.76	7.19	12.77	3.65	12.02
	MF	25.54	13.24	15.08	5.11	13.15
	WA	28.91	9.08	13.70	5.33	11.96
	D1	23.35	6.91	12.06	3.30	11.74
	D2	18.63	5.27	11.51	4.17	13.19
On average		24.74	9.22	13.04	4.80	13.49
$LSD_{0.05}$		4.41	4.41	4.41	4.41	1.52

In single cut the nitrogen content was almost two times lower – around 13 g kg^{-1} in leaves and around 5 g kg^{-1} in culms, on average. All fertilised variants contained significantly ($P > 0.05$) more nitrogen compared to control, particularly MF and WA. Obviously it was due to mineral N fertiliser use that facilitated the highest nitrogen accumulation in biomass. It is also confirmed by studies results elsewhere which show that N content increases with higher N fertiliser doses and early cutting period (Nilsson et al., 2011). In the studies in Lithuania with *Dactylis glomerata* the swards treated with mineral fertiliser exhibited significantly higher nitrogen concentration compared to those fertilised with digestate (Tilvikiene et al., 2014).

The quality of biomass is mostly dependent on growing conditions, grass species, cutting frequency and fertilisation (Prochnow et al., 2009b). The factor impact analysis by summing both cutting regimes in our experiments is summarized in Table 2. The ash content was mostly influenced by sward fraction (impact factor – 49.2%) and harvest regime (34.2%). In the culms of single cut there was lower ash content for both species, what is a positive feature for combustion material.

Table 2. The influence of various factors on the chemical composition of the herbaceous biomass

Factors	Factor influence (%) on the content of		
	ash	carbon	nitrogen
Harvest regime	34.2	26.3	27.9
Sward fraction	49.2	43.9	54.9
Species	6.1	10.3	2.4
Fertiliser	3.3	2.8	9.6
Other (environment etc.)	7.2	16.7	5.2

The similar pattern was also for carbon and nitrogen content – it was mostly influenced by sward fraction (43.9 and 54.9%, respectively) and harvest regime (26.3 and 27.9%, respectively). Leaves contained 2 to 3 times more nitrogen than culms; and swards of two-harvest regime had almost two times higher N content. But contrary to ash and nitrogen, more carbon was accumulated in the culms of a single cut. The content of nitrogen was greatly influenced by fertilisers applied (impact factor 9.6%), the highest nitrogen content was in MF and WA variants.

CONCLUSIONS

DM yield ranged over the years between harvest regimes, but summarising the data of three years significant differences were not found. Relatively higher biomass yield was provided by reed canary grass.

All types of fertilisers provided an increase of dry matter yield; however better results for both grass species were ensured by the usage of mineral fertilisers and wood ash.

The harvest regime and species affected directly the quality of biomass. The single cut of reed canary grass contained significantly less ash and more carbon, therefore more appropriate raw material for solid fuel could be obtained by harvesting reed canary grass once per season as late as possible in the autumn.

There were significant differences between sward fractions – culms contained less ash and nitrogen, and they had significantly higher carbon content than leaves. It can be concluded that more suitable for solid fuel are swards with the higher proportion of culms, which provides greater heat output and less atmospheric pollution.

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