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Biomass yield and chemical composition of *Phalaris arundinacea* L. using different rates of fermentation residue as fertiliser

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Abstract. Using biomass of various crops for bioenergy production is a common practice all over the world. Grasses, including reed canary grass (*Phalaris arundinacea* L.), as bioenergy crops have many advantages. Therefore it is important to look for the most effective technology to produce high biomass grass yields taking into consideration the quality parameters important for this purpose, and at the same time providing sustainable plant nutrient recycling schemes. The use of fermentation residue (FR) from biogas plants as fertiliser could be environmentally and economically cost-effective, as this by-product contain considerable amount of plant nutrients. However, there is little research on the efficiency of FR use for grassland. In our experiments we evaluated the effect of FR used at different rates (from N0 to N150 kg ha^{-1}) and different treatment techniques (once/ twice/ or three times per season) on the productivity of RCG under two-cut and single-cut harvest regime. The data of three ley years (2012–2015) show that annual dry matter yields ranged from: 3.93–11.44 t ha^{-1} in two-cut and 5.89–13.94 t ha^{-1} in single-cut regime. The highest dry matter yield was obtained using FR at: 60 kg ha^{-1} N using the entire amount in a single application at the beginning of the season; 120 and 150 kg ha^{-1} N split for three applications. The chemical composition of reed canary grass biomass was mostly influenced by harvest regime: late harvest at single-cut regime ensured more appropriate sward quality for bioenergy production with a higher carbon and lower ash, nitrogen, potassium and phosphorus content.

Key words: dry matter yield; fermentation residue, fertilisation, *Phalaris arundinacea* L.

INTRODUCTION

Perennial grasses may provide a renewable source of biomass for energy production. Energy produced from biomass plays an important role in the current EU strategy to deal with climate change and to meet increasing energy demands (Ericsson & Nilsson, 2006). Grass can produce significant amount of biomass, and methane produced from grass has a good energy balance (input – output energy). Moreover, grass cultivation does not involve significant habitat destruction, land use change, application of new farming practices or annual soil tillage (Smyth, B.M. et al., 2009; Bardule et al., 2013; Rancane et al., 2014a).

Biomass from grass is a renewable energy resource with significant potential; it is a feedstock for anaerobic digestion in order to generate biogas and biomethane or for combustion in adapted heating plants (Thumm et al., 2014; Rancane et al., 2015). In the regions of northern latitudes higher energy potential is achieved from the production of cool season (C3) perennial grasses, such as reed canary grass (*Phalaris arundinacea* L.) (Carlson, 1996; Heinsoo et al., 2011). This species produces high biomass yields in cool climates and wetlands (Wrobel et al., 2008; Rancane et al., 2016). In natural grass stands most commonly it occurs in the vicinity of water. Although it tolerates an abundance or shortfall of moisture, high yields are achieved in years with higher rainfall (Strasil, 2012).

Grassland management determines not only the yield but also the quality of the harvested biomass. Different uses of grassland biomass have different quality requirements. Fuel constituents beside C, H and O are undesirable since they are potential pollutants and may increase deposit formation, corrosion, and ash (Nussbaumer, 2003; Bakker & Elbersen, 2005). Nitrogen content is a critical factor, as this is responsible for NOx emissions and N losses from the ecosystem. Unlike other plant nutrients, N is not recycled to the soil by ash (Tonn et al., 2010). Generally, the nitrogen content in biomass increases with higher N fertiliser doses and early cutting (Thumm et al., 2014). High content of ash, nitrogen, sulphur, potassium and chlorine can lead to problems in the combustion process, such as corrosion or slagging, and to environmentally critical emissions (Lewandowski & Kircherer, 1997; Nussbaumer, 2003).

One of the key factors impacting quality of grass biomass as feedstock for combustion is harvesting time (Pociene & Kadziuliene, 2016). It could strongly affect biomass chemical composition, as it has a significant influence on concentration of ash and minerals (Hadders & Olsson, 1997). Late-harvested grass biomass has a higher lignin content and lower ash, K and Cl content (Bakker & Elbersen, 2005). Therefore, late-harvested, highly lignified and low-ash biomass is more suitable for combustion (Prochnow et al., 2009; Iqbal & Lewandowski, 2014).

Fermentation of biomass produces fermentation residue or digestate. Degradation of organic compounds during the fermentation process leads to an increased ammonium content and therefore a higher proportion of plant available nitrogen in the fermentation residue (Makadi et al., 2012; Möller & Müller, 2012). It could be an excellent organic fertiliser what may have a positive effect on crop yields and long-term soil fertility. Fermentation residue contains a relatively high percentage of readily available nutrients which can be directly applied in liquid form to plants both for basal and top-dressing (Mikled et al., 2002). The application of this by-product as a fertiliser for grasslands could be an effective way to utilize residues from biogas plants (Alburquerque et al., 2012). It contributes to the reduction of artificial fertiliser needs, thereby providing both economic and ecological importance (Rancane et al., 2015).

However, liquid fertilisers including fermentation residue that is not used efficiently for plant production could be a source of pollution for groundwater, surface waters and the atmosphere (Nyord et al., 2008). NH_3 emission is considered a risk to the environment (Schulze et al., 1989; Hutchings et al., 2001). Therefore despite the fact that fermentation residue contains many important plant nutrients, studies are needed on the recommended rates of use and treatment regime in order to prevent potential risks and ensure the highest possible efficiency.

The aim of this study was to evaluate the differences in dry matter yield and chemical composition of reed canary grass under two harvest regimes using different rates in different regimes of fermentation residue.

MATERIALS AND METHODS

The field experiment was conducted from 2012 to 2015 in the central part of Latvia at the LLU Institute of Agriculture in Skriveri (56°37' N, 25°07' E). Small plots (1 m^2) of reed canary grass (RCG) were established in the sod-podzolic sandy loam soil (Eutric Retisol – WRB 2015) with pH KCl 6.4 (LVS ISO 10390/NAC), organic carbon – 25.1 g kg^{-1} (LVS ISO 10694), plant available phosphorus (P_2O_5) 81.7 mg kg^{-1} (spectrophotometrically in 0.2 M HCl extract – LVS 398), plant available potassium (K_2O) 91.7 mg kg^{-1} (in extract of 1.0M CH3COONH4 using flame atomic-absorption spectrometer) and sulphur (S) 29.2 mg kg^{-1} (using ELTRA CS 530 element analyser).

RCG 15 kg ha^{-1} was sowed with a small seed drill on August 17, 2012. Before sowing, borders of each plot were delimited with plastic plates up to the depth of 20 cm. Different amounts of FR were evenly dispersed on soil surface and after mixed with the soil using hand tiller; in the following years FR was used on the surface.

The liquid fraction of separated FR from a biogas plant was applied, and dry matter content ranged from 4.4 to 5.4%, with an average organic matter content of 3.7%. Prior to treatments, the chemical composition of FR was determined using modified Kjeldahl method (reference method for determination of total N). The content of main plant nutrients ranged between 2.7 to 5.1 g L^{-1} N; 0.4 to 0.77 g L^{-1} P_2O_5; 3.3 to 3.7 g L^{-1} K_2O.

Seven fertiliser treatments were compared, with 1–3 FR application times per growing season. The following fertiliser rates were used: FR 0 kg N ha^{-1}; FR 30 kg N ha^{-1}; FR 60 kg N ha^{-1}; FR 60 (30 + 30) kg N ha^{-1}; FR 90 (30 + 30 + 30) kg N ha^{-1}; FR 120 (40 + 40 + 40) kg N ha^{-1}; FR 150 (50 + 50 + 50) kg N ha^{-1}. The experiment was established as a randomised block design with four replicates.

The meteorological conditions and distribution of rainfall during the experimental years were monitored, average annual precipitation amounts at the study site were: 698 mm or 102% from long-term average in 2013; 807 mm (118%) in 2014; and 549 mm (80%) in 2015. Artificial watering was not used.

RCG was harvested by manually cut using two harvest regimes: two-cut and single-cut regime. Cutting height was 3–4 cm from the ground level. Half of each plot (0.5 m^2) was mowed once or twice per season. The 1^{st} cut was done at the full heading of RCG, and the 2^{nd} cut occurred in September. The single cut occurred in late September or early October. For determination of sward structure the samples from each harvest were divided into tillers, leaves and panicles.

The chemical composition of RCG sward was analysed 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); total phosphorous – photometrically (LVS EN 14672); potassium – using atomic absorption spectroscopy (LVS ISO 11466).

Experimental data were evaluated using analysis of variance (ANOVA) ($P > 0.05$). The test of statistically significant differences (*LSD* 0.05) and the Fisher criterion (*F*-test) were used for the analyses of data obtained.

RESULTS AND DISCUSSION

Biomass productivity is the main parameter which determines the suitability of crop cultivation for energy production. The dry matter yield (DMY) of RCG varies considerably depending on cultivation condition (Heinsoo et al., 2011; Kołodziej et al., 2016). During the three years of this project, DMY of RCG ranged considerably depending on the rate of fertiliser, ley year and harvest regime.

The DMY in a two-cut regime ranged from: 7.07 to 11.44 in the 1st ley year, 3.93 to 8.99 in the 2nd ley year, and 3.98 to 7.68 in the 3rd ley year (Fig. 1). Using two-cut regime significantly higher DMY of RCG in all treatments were obtained in the 1st year of use. Although in the 3rd year of use were obtained lower dry matter yields, they did not differ significantly between 2nd and 3rd year.

Yield reduction in the 2nd and 3rd year of use was mostly influenced by partial disappearance of RCG plants from the sward due to various reasons, particularly with the two-cut regime. It had a negative impact on total DMY.

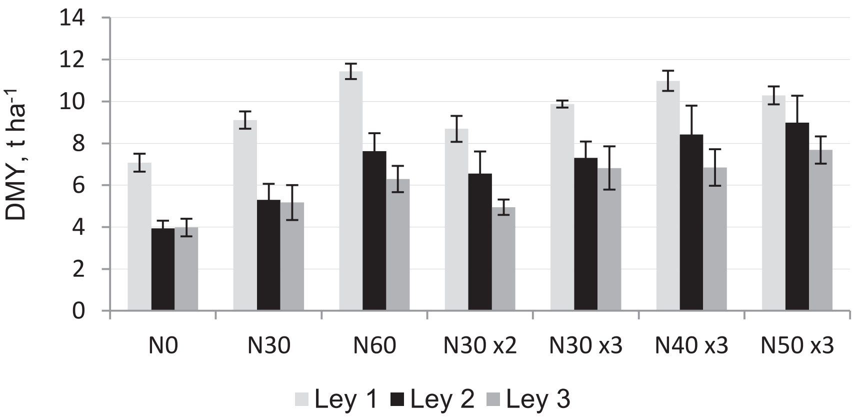

Figure 1. Total DMY of RCG in two-cut regime (error bars indicate standard error).

Using a two-cut regime, the proportion of DMY for 1st cut is usually over 60% of total yield. In our trials the following pattern was observed in the 1st and in the 3rd ley years. However, in the 2nd ley year ratio of the 1st and 2nd cut was different – the DMY of the 2nd cut was atypically slightly greater than 1st cut (Table 1). This may be the result of hard overwintering conditions with a long black frost period in previous winter and late spring as well which delayed RCG re-growth in spring, reducing 1st cut and hence the total DMY.

Table 1. The DMY of 1st and 2nd cut of RCG using two-cut regime in three ley years (2013–2015)

Variant	DMY of RCG – 1st cut			DMY of RCG – 2nd cut		
	Ley 1	Ley 2	Ley 3	Ley 1	Ley 2	Ley 3
N0	4.69 ± 0.38*	1.88 ± 0.14	2.54 ± 0.23	2.38 ± 0.16	2.05 ± 0.29	1.44 ± 0.23
N30	6.81 ± 0.23	2.89 ± 0.42	3.51 ± 0.43	2.3 ± 0.23	2.42 ± 0.47	1.67 ± 0.42
N60	8.37 ± 0.28	4.19 ± 0.24	4.44 ± 0.48	3.07 ± 0.32	3.42 ± 0.79	1.85 ± 0.17
N30 × 2	5.61 ± 0.32	3.52 ± 0.42	3.38 ± 0.22	3.08 ± 0.31	3.04 ± 0.88	1.57 ± 0.22
N30 × 3	6.76 ± 0.27	4.26 ± 0.38	4.78 ± 0.65	3.12 ± 0.26	3.06 ± 0.50	2.04 ± 0.44
N40 × 3	7.71 ± 0.29	4.89 ± 0.61	4.51 ± 0.43	3.27 ± 0.42	3.53 ± 0.81	2.34 ± 0.47
N50 × 3	7.15 ± 0.34	5.53 ± 0.57	5.2 ± 0.54	3.13 ± 0.32	3.46 ± 0.72	2.48 ± 0.28
$LSD_{0.05}$	*0.77*	*1.17*	*0.98*	*0.48*	*1.09*	*0.63*

*– standard error.

The DMY in a single-cut regime ranged from 5.82 to 10.69 in the 1st ley year, 6.48 to 13.94 in the 2nd ley year, and 5.89 to 12.06 in the 3rd ley year (Fig. 2). Although using single-cut regime there was a trend to be higher DMY in the 2nd year of use, the differences were not significant ($P > 0.05$).

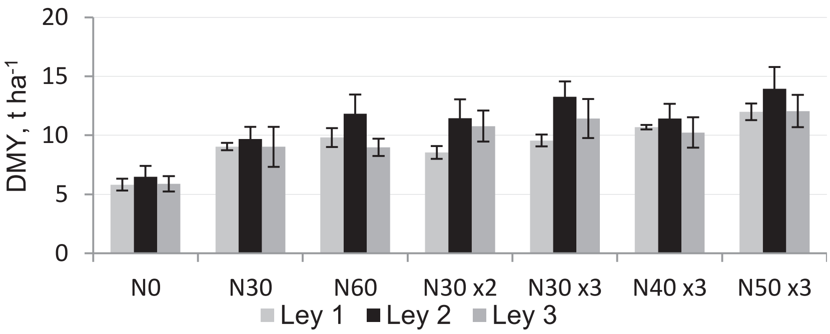

Figure 2. DMY of RCG in a single-cut regime (error bars indicate standard error).

Assessment of DMY among fertiliser treatments on average over three-year period shows that in general DMY significantly ($P < 0.05$) correlated with the rate of fertiliser: $r = 0.81$ for 1st cut; $r = 0.51$ for 2nd cut; $r = 0.75$ for total DMY using two-cut regime, and $r = 0.72$ for DMY using single-cut regime. However, the yield increase was not proportional to the level of fertiliser. Relatively good results in both harvest regimes were provided by the treatment of FR N 60 kg ha^{-1} using the entire amount in a single application at the beginning of the season.

DMY data collected over the period of three years led to the conclusion that higher effect was not achieved by split applications of fertiliser, but by the rate of fertiliser used immediately after growth initiated in the spring. Obviously the most intensive growth and, consequently, more efficient use of fertilisers take place at this time. In early spring soil moisture usually is higher, whereas the air temperatures lower, which limits volatile compounds emissions from the FR. It should be taken into account when choosing an application rates and treatment because ammonia (NH_3) volatilisation following the liquid ammoniacal fertilisers to agricultural land is a significant source of atmospheric NH_3, which not only poses a risk to the environment, but also results in a loss of plant available nitrogen (Nyord et al., 2008).

DMY was influenced inconsistently by harvest regime, it varied over the ley years. Almost no differences between mowing regimes were found in the 1st ley year. All in all the average DMY was nearly equal: 9.36 and 9.64 t ha^{-1} for two-cut and single-cut regimes, respectively. In the 2nd and 3rd ley years significantly higher DMY in all fertiliser treatments were harvested using a single-cut regime. This may be explained by the ability of RCG to remove plant nutrients from above-ground parts to the rhizomes in autumn (Wrobel et al., 2008), thus ensuring more rapid re-growth in spring and prolonging period of growth, which generally results in higher biomass production. Late harvesting is preferable for RCG, it is confirmed by our previous research (Rancane et al., 2014b; Rancane et al., 2015) and by data of other authors as well (Xiong et al., 2009; Cherney & Verma, 2013).

For determination of sward structure the biomass of each harvest was divided into culms, leaves and panicles. Results showed that in the 1st year, the highest proportion of culms was in the 1st cut (71.3–75.9%), whereas the lowest proportion of culms was in the 2nd cut (34.7–48.5%) (Fig. 3). Proportion of culms in the swards of late harvest using single-cut ranged from 58.7 to 66.4%. Proportion of leaves in swards was inversely proportional to the content of culms – the highest proportion of leaves was found in the 2nd cut (Fig. 4).

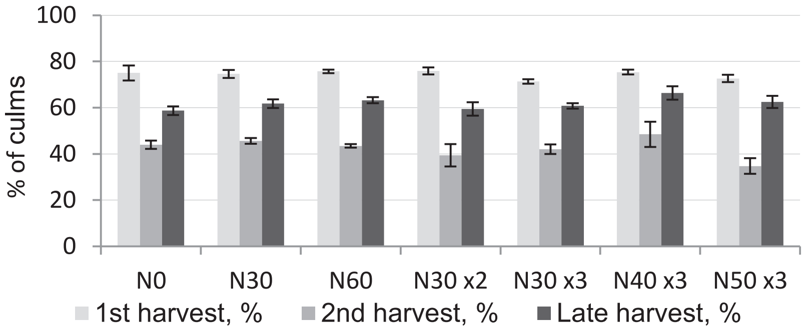

Figure 3. The proportion (%) of culms in swards of different harvests in the 1st ley year (error bars indicate standard error).

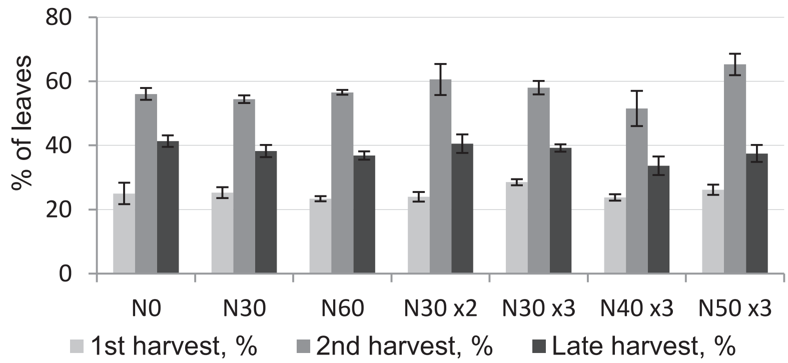

Figure 4. The proportion (%) of leaves in swards of different harvests in the 1st ley year (error bars indicate standard error).

Ash content of RCG ranged from 6.21 to 6.77 % on average (Table 2). There were not any substantial differences in ash content among fertiliser treatments. Fertiliser treatment did not significantly affect the content of carbon (C), nitrogen (N) and potassium (K) as well, parameters ranged between 469.7–480.0 g kg^{-1} for C, 13.4–15.2 g kg^{-1} for N, and 15.5–17.4 g kg^{-1} for K.

Table 2. The chemical content of RCG using different rates of FR and harvest regime

Factor	Ash content, %	C, g kg^{-1}	N, g kg^{-1}	K, g kg^{-1}	P, g kg^{-1}
Fertiliser (B)	*0.8/2.6**	*0.8/2.6*	*1.2/2.6*	*1.1/2.6*	*3.6/2.6*
N0	6.75	475.52	14.27	15.77	2.47
N30	6.21	480.04	15.11	16.79	2.27
N60	6.83	471.44	13.41	15.87	2.10
N30 × 2	6.77	475.78	13.98	17.40	2.29
N30 × 3	6.56	476.58	14.78	16.43	2.22
N40 × 3	6.53	474.99	15.18	16.95	2.26
N50 × 3	6.38	469.87	13.67	15.52	2.05
$LSD_{0.05}$	*0.73*	*11.04*	*1.89*	*1.99*	*0.21*
Harvest regime (A)	*22.4/3.5*	*8.3/3.5*	*108.6/3.5*	*448.4/3.5*	*143.8/3.5*
1st cut	6.63	477.92	16.58	26.21	2.42
2nd cut	7.31	466.84	17.15	15.32	2.69
Single-cut	5.79	479.90	9.31	7.64	1.60
$LSD_{0.05}$	*0.47*	*7.23*	*1.24*	*1.30*	*0.14*

*Fisher criterion (*F/F0.05*).

Significant differences ($P < 0.05$) between fertilised and non-fertilised treatments were found in terms of phosphorus (P) content. The highest P (2.47 g kg^{-1}) was in non-fertilised swards, while in fertilised swards P were significantly lower, ranging from 2.05 to 2.29 g kg^{-1}. This may be a positive outcome, as higher P content does not provide higher energy outcome and there is not necessity to remove P from field.

Chemical composition of swards was significantly influenced by harvest regime: there were found significant differences in terms of all parameters. Perennial grasses harvested at booting stage or full maturity accumulate different amounts of biomass with different composition (Kandel et al., 2013; Kołodziej et al., 2016). The highest ash and P content was found in swards of the 2nd cut. Significantly lower both parameters were in swards of the single-cut. Previous studies confirm that using later harvest times significantly reduces N, P, K content in biomass of RCG (Strasil, 2012; Rancane et al., 2015). This is favourable for the combustion process itself and also with respect to the environment.

Carbon (C) content was significantly higher in the swards of the single-cut and in the 1st cut as well, because the swards of both cuts had a higher proportion of culms. Swards with a high culm content consists of highly lignified biomass. High content of carbon in lignin leads to higher heating value (Wrobel et al., 2008; Prochnow et al., 2009).

Nitrogen (9.31 g kg^{-1}) and K (7.64 g kg^{-1}) content was significantly lower in the single-cut. It can be evaluated as a positive trend if biomass is intended to be used for bioenergy production, especially for combustion. Extensive grassland management systems with one late cut and low fertilisation are preferable when using grass as a solid biofuel due to higher content of lignin and lower content of ash and potassium in late harvested biomass (Thumm et al., 2014).

CONCLUSIONS

Fermentation residue used as fertiliser ensures a significant (*P < 0.05*) increase of biomass production of RCG. The DMY significantly (*P < 0.05*) correlated with the rate of fertiliser – higher rates ensured higher DMY. The best results in both harvest regimes were provided by following rates of FR: N 60 kg ha^{-1} using the entire amount in a single application at the beginning of the season; and N 120 and 150 kg ha^{-1} split for three applications.

FR treatment did not significantly (*P > 0.05*) affect the content of ash, carbon (C), nitrogen (N) and potassium (K). The chemical composition of RCG swards was mostly influenced by the harvest regime: late harvest using single-cut ensured more appropriate quality for combustion with higher C content and reduced amount of ash, N, K and P.

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