FERTILISATION EFFECT ON BIOMASS FORMATION OF PERENNIAL GRASS USED AS ENERGY CROP

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Abstract
Bioenergy production growth rates in the recent years are leading to waste – digestate and wood ash amount increases, which are essential to be managed in the most efficient and safe way. In the formation of plant nutrient recycling these waste products are useful to be included in the energy crop fertilisation plan. In order to study the waste products application options for energy crops – reed canary grass (*Phalaris arundinacea* L.) and festulolium (×*Festulolium pabulare*) fertilisation trials were arranged in 2012 at the Skriveri Latvian University of Agriculture (LLU) Research Institute of Agriculture. In all fertiliser treatments: wood ash; digestate one time per season; digestate two times per season and mineral fertilisers the same doses of the main plant nutrients (N, P, K) were provided, the missing quantities of elements compensating with mineral fertilisers. To obtain the grass biomass, two cutting regimes were used – two-cut and one-cut harvest system. This article summarizes the findings on the productivity of the 1st year of use grassland swards and sward structure data. The productivity of perennial grass biomass was dependent on the type of applied fertilisers, grass species and cutting regime. In the first production year the highest average dry matter yield (7.30 t ha^{-1}) was produced by reed canary grass. The highest DM yields in average for both grass species were obtained by mowing once per season – in autumn at crop senescence (7.01 t ha^{-1}) and in fertilisation treatments of wood ash (WA) – 8.06 t ha^{-1} and mineral fertilisers (MF) – 7.24 t ha^{-1}.
Key words: by-products, energy crop, DM yield, festulolium, reed canary grass.

Introduction

The increase in proportion of alternative energy resources has become more pertinent in the recent decades, which are due to the concern of global warming and efforts to limit it through adoption of EU directives and international commitment for the limitation of fossil energy use and its partial replacement with renewable energy resources.

Biomass is the most common form of renewable energy, widely used in the third world. Energy can be obtained from biomass by direct combustion or fermentation (Prochnow et al., 2009). Lately much attention has been focused on identifying suitable biomass species, which can provide high energy outputs and to replace conventional fossil fuel energy sources (McKendry, 2002). The most promising crops for bioenergy 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; Jasinskas et al., 2008; Sanderson and Adler, 2008). Perennial grasses are environmentally friendly, pest resistant and less demanding in terms of soil conditions compared to other crops (Peeters, 2008). Using grasses as a source of bio-methane negates the need for tillage, and allows for carbon sequestration (Seppala et al., 2009; Murphy et al., 2013). In Latvia is provided suitable soil and climatic conditions for their growth as the amount of rainfall is sufficient, and distribution of precipitation is mostly favourable for high herbaceous biomass yield formation (Rancane et al., 2012). Perennial grasses may compete with maize in respect to the yield and yield stability (Techow et al., 2011).

An anticipated middle-term decrease of grassland use for feed is to be seen alongside an ever growing demand for sustainable energy from renewable energy resources (Wachendorf et al., 2009). Promissing alternative regarding the utilisation of biomass from grassland is using biomass low in digestibility for the generation of biogas (electrical power) and grass pellets for combustion purposes (Blumenstein and Möller, 2011).

Grass is an excellent source of bio-methane; it is a feedstock for anaerobic digestion with a high content of solids, and it has a high specific methane capacity. As a general rule, the specific methane yield of grass silage will increase the earlier the harvesting date, whereas the yield of biomass obtainable per unit grassland area will depend on the attainable growth of the crop (Prochnow et al., 2005; McEniry and O'Kiely, 2013). The increase in fibrious structure leads to a slower rate of degradation and also increases the required hydraulic retention time. However, reed canary grass has been shown to give higher specific methane yields with advancing crop maturity and decrease water content (Lehtomäki et al., 2008).

Reed canary grass (RCG) as a cool-season perennial grass is a promising bio-energy crop and a potential non-wood crop for industrial uses (e.g., papermaking) in Northern Europe (Saijonkari-Pahkala, 2001; Lewandowski et al., 2003; Kukk et al., 2011). RCG can be grown in a wide range of soils and environment and has been used as a pasture and hay crop for many decades, and produce relatively high yields of total biomass (Wrobel et al., 2009; Tahir et al., 2010). Festulolium is a cross between fescue and ryegrass; therefore, it should have the winter-hardiness, persistence and stress tolerance of *Festucas* and the yield quality of *Lolium* (Bardule et al., 2013).

In the process of biomass direct combustion and fermentation waste products are formed – ash and digestate, the amounts of them tend to rise due to the increasing production levels. It is essential to manage their utilisation in the most efficient and safe way, providing the plant nutrient cycling. The ash is rich in potassium (K), calcium (Ca), sulphur (S), phosphorus (P), chlorine (Cl), and silicon (Si) (Insaam et al., 2009). Digestate, the residue from biogas processing, can be used as an organic fertiliser. In addition to energy generation, this route is a realistic choice for recycling plant nutrients, especially phosphorus, which will be a scarce plant production resource in the near future (Cordell et al., 2009).

The objective of this study was to determine the opportunities to use waste products as energy grasses fertilisers and to compare the effect of different type of fertiliser on reed canary grass and festulolium dry matter yield and biomass structure.

Materials and Methods

Experimental plots were established in the July of 2012, it was located in the central part of Latvia at the LLU Research Institute of Agriculture in Skriveri (56°41` N and 25°08` E). The soil of the experimental plot was classified as Endoluvic Epistagnic Phaeozem/ Stagnic Cutanic Albeluvisol (WRB, 2006), fine sandy loam.

Before establishing trials, the experimental area was divided into 40 plots, and from each plot soil samples were taken. The soil samples were prepared for agro-chemical analyses in accordance with LVS ISO 11464 (drying, crushing, sieving). Agrochemical parameters (pH KCl; pH H_2O; $C_{tot.}$, sulphur, organic matter, plant available P and K) were determined. The exchangeable soil acidity was measured in 1*M* KCl suspension potentiometrically (LVS ISO 10390/ NAC). The total carbon and sulphur was analysed using an ELTRA CS 530 element analyzer. The plant available phosphorus and potassium were determined using the Egner-Rheem (DL) method.

Two species of perennial grasses were included in the test: reed canary grass (*Phalaris arundinacea* L.) 'Bamse' and festulolium of tall fescue type (×*Festulolium pabulare*) 'Felina'. Following fertilisation treatments were used: C – control – not fertilised; MF – mineral fertilisers (ammonium nitrate, potassium sulphate and superphosphate); WA – wood ash; D 1 – digestate once per season; D 2 – digestate twice per season.

The fertiliser doses were chosen so that each fertilisation variant would provide for the same amount (kg ha^{-1}) of main plant nutrient elements per year: nitrogen (N); phosphorus (P_2O_5) and potassium (K_2O), accordingly – 100:80:160. The doses were decreased by approximately half in the sowing year (42 kg ha^{-1} N; 32 kg ha^{-1} P_2O_5 and 80 kg ha^{-1} K_2O), applying the correct amount of fertilisers in each variant. The fertilisers were applied manually before the perennial grasses were sown, after that they were incorporated into the soil with a soil tiller.

At the beginning of the vegetation period of the following year, the fertilisers were applied on the soil surface, in D2 variant the annual dose of digestate was split – one half was applied at the beginning of the vegetation period, the other – at the end, after the perennial grasses were cut. The missing amount of the nutrients was compensated using fertilisers in all fertilisation variants.

Perennial grasses were sown using a narrow row spacing with the drill 'Nordsten NS–1025'. Seeding rates: reed canary grass 12 kg ha^{-1} but festulolium 15 kg ha^{-1}. The size of one experimental plot was 43.2 m^2 (9.6 × 4.5 m), the total number of plots was 40. The variants of fertilisers were distributed randomly in 4 replications.

Three weeks after the experimental sowing, plants were sprayed with herbicide MCPA 750 to control dicotyledonous weeds. In September of the sowing year, swards were mowed.

In the 1st year of use the perennial grass sward productivity was established in both, intensive (two-cut harvest system) and extensive (one-cut harvest system – delayed cutting in autumn at crop senescence) mowing types. Both, swards and productive tillers, were measured in length, plants and tillers were counted in a 0.5 m long line, before the calculation of the 1st harvest dry matter yield. A sample sheaf was taken for botanic analysis and the establishment of perennial grass sward structures by cutting the perennial grasses with a sickle. All measurements and calculations were carried out 4 times for each fertilisation type.

Meteorological conditions during the trial years were different. The year 2012 was characterized as a rich with precipitation, the annual rainfall was 928 mm (it is 139% of a long-term average). Precipitation during the vegetation period in 2013 was slightly lower than the long-term average, and its distribution was not favorable for grass growth – hot and dry periods were interrupted by short and heavy rainfalls. Lack of moisture in July and August had a negative impact on the plant development. Precipitation distribution in Skriveri for years 2012 – 2013 compared with long-time average rates is shown in Figure 1.

The experimental data were statistically analysed using a two-way analysis of variance with grass species and fertiliser as factors and dry matter data assessed by using a three-way analysis of variance, with the cutting time as third factor. The differences among means at the 0.05 probability level (Excel for Windows 2003) were detected by LSD.

Results and Discussion

Soil analysis was performed to monitor their changes during the experiment. Some uniformity of soil properties was observed (Table 1). The average soil acidity pH KCl was 5.7 (ranged between 5.5 – 5.9); the average pH H_2O was 6.7 (ranged between 6.5 – 6.9). The average $C_{tot.}$ content was 24.3 g kg^{-1}, and ranged from 22.3 to 27.83 g kg^{-1} within individual plots. The average organic matter (OM) content was 41.9 g kg^{-1}, and ranged from 40.2 to 48.0 41.9 g kg^{-1}, but differences were not significant ($p<0.05$). In the test area plant available nutrients through the plots varied within the following limits: 75.3 – 117.7 mg kg^{-1} P_2O_5, 117.6 – 163.7 mg kg^{-1} K_2O and 13.2 – 44.8 mg kg^{-1} S.

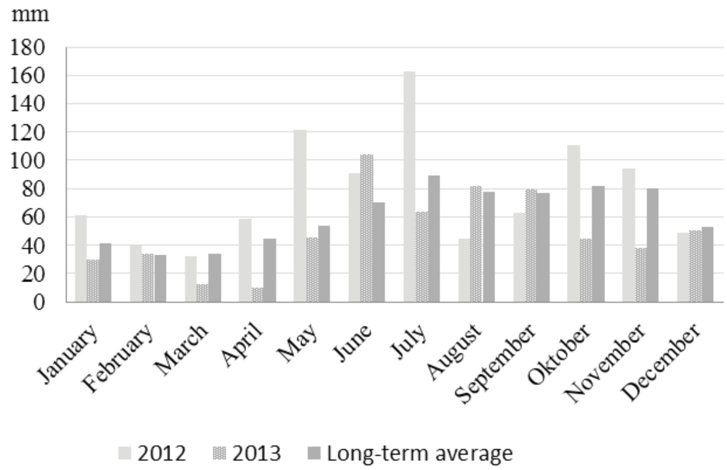

Figure 1. Precipitation over the months in 2012 and 2013 compared with long-term average rates in Skriveri.

Table 1

Soil properties before the experiment

Fertiliser variant	pH KCl	pH H_2O	$C_{tot.}$, g kg^{-1}	OM, g kg^{-1}	P_2O_5, mg kg^{-1}	K_2O, mg kg^{-1}	S, mg kg^{-1}
Reed canary grass							
Control	5.5	6.6	24.6	42.4	96.3	121.8	25.5
Mineral fertilisers	5.8	6.8	27.8	48.0	106.4	143.4	13.2
Wood ash	5.9	6.9	24.6	42.5	91.8	123.4	20.4
Digestate 1×	5.6	6.5	25.4	43.9	75.3	129.4	35.1
Digestate 2×	5.8	6.7	23.5	40.5	117.7	163.7	44.8
Average	5.7	6.7	25.2	43.5	97.5	136.3	27.8
$LSD_{0.05}$	*0.4*	*0.4*	*7.1*	*12.3*	*64.3*	*52.1*	*48.3*
Festulolium							
Control	5.7	6.6	22.5	38.9	102.0	127.5	37.8
Mineral fertilisers	5.7	6.9	24.8	42.7	92.7	122.1	18.3
Wood ash	5.7	6.7	23.3	40.2	82.5	117.6	17.8
Digestate 1×	5.7	6.8	24.0	41.4	89.5	128.7	23.7
Digestate 2×	5.7	6.8	22.3	38.4	105.2	124.7	14.7
Average	5.7	6.7	23.4	40.3	94.4	124.1	22.4
$LSD_{0.05}$	*0.41*	*0.4*	5.5	*9.6*	*70.2*	*47.7*	*33.3*

The statistical analysis shows that there were no significant differences among the mentioned values, all agrochemical parameters ranged within the significance limits ($p<0.05$); thus it can be concluded that the soil was homogeneous before the test set-up, and the natural background of soil will not significantly affect the results of the following experiments.

RCG and festulolium sward length measurements and the counting of plants/productive tillers in the field conditions were carried out to evaluate how fertilisers for the 1st year 1st sward yield affected the growth intensity, plant density and formation of productive tillers. The differences between the number of plants and productive tillers were not significant for different fertilisation variants of single species ($p<0.05$). Between species the RCG swards had the highest plant density, but festulolium swards had more productive tillers (Table 2). RCG has the tendency to tiller intensively in the 1st year of use, especially in sparse swards, just like the ones used in our experiment. The average number of productive tillers for a single RCG plant was 0.7, for festulolium – 2.7.

Results indicate that the average sward length of RCG in the beginning of June was 126.1 cm, which is significantly ($p<0.05$) higher than the average length of festulolium sward 96.1 cm (Table 2). The use of fertilisers for both perennial grass species ensured the growth of sward length. Growth of sward length for festulolium was observed in all fertilisation variants compared to control, the longest swards were in mineral fertiliser (MF) and wood ash (WA) variants, but differences were not significant ($p<0.05$). RCG had a significant growth in all variants. After evaluating the factor interaction effect, it was found that in the wood ash variant it was relatively lower for

Table 2

The field measurements of sward height and density before the mowing of 1st cut

Fertiliser variant (B)	RCG (A)		Festulolium (A)		Height of sward, cm	
	Plants in 0.5 m row	Tillers in 0.5 m row	Plants in 0.5 m row	Tillers in 0.5 m row	RCG (A)	Festulolium (A)
Control	18.3	6.5	26.0	11.0	106.0	85.8
Mineral fertilisers	15.0	16.0	30.3	9.3	140.6	94.4
Wood ash	13.8	13.0	27.0	12.0	138.4	93.3
Digestate 1×	14.8	8.5	32.0	12.3	123.3	89.3
Digestate 2×	15.5	10.5	34.3	11.3	122.2	95.1
$LSD_{AB\ 0.05}$	9.7	9.7	11.4	5.9	9.6	9.6
Average	15.5	10.9	29.9	11.2	126.1	91.6

Table 3

The 1st cut sward structure analysis

Fertiliser variant	Average length of tillers, cm	Productive tillers, %	Number of tillers per m^2	Length of ears, cm
RCG				
Control	102.3	10.2	62.7	5.5
Mineral fertilisers	131.0	22.0	182.3	8.0
Wood ash	135.0	13.0	125.4	8.8
Digestate 1×	122.9	14.1	89.2	6.7
Digestate 2×	119.9	16.7	138.1	6.4
$LSD_{0.05}$	8.6	10.5	94.8	0.9
Festulolium				
Control	72.1	91.7	117.4	14.5
Mineral fertilisers	81.8	83.9	170.8	16.9
Wood ash	80.3	89.3	217.9	16.8
Digestate 1×	78.8	82.3	160.2	16.0
Digestate 2×	83.9	100.0	158.4	17.6
$LSD_{0.05}$	6.8	19.6	52.0	1.9

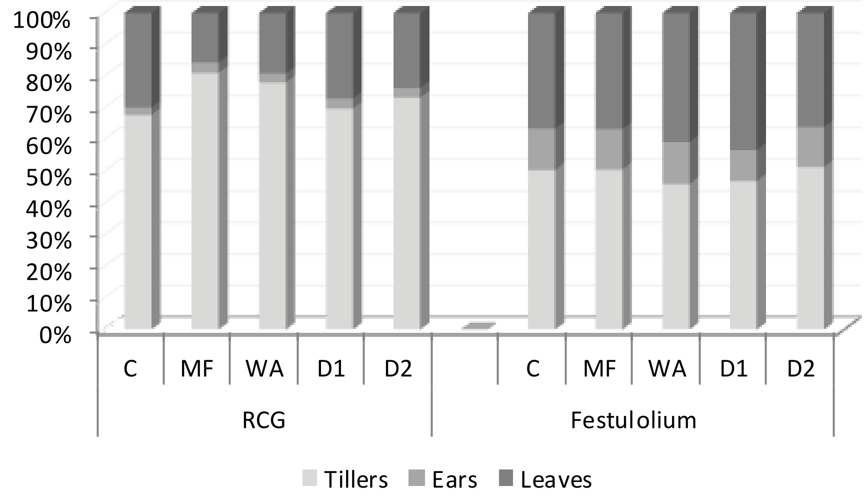

Figure 2. The structure (% from DM yield) of the 1st cut sward of RCG and festulolium.

reed canary grass, but relatively higher for festulolium compared to general tendencies (main effects).

Before the calculation of the 1st cut perennial grasses yield, sward sample sheaves were analysed in order to determine the average length of productive tillers and compare the sward structure in each fertilisation variant. The use of all fertiliser types promoted a significant growth of productive tillers for both, RCG and festololium, ensuring additional length of 17 – 33 cm for RCG and 6 – 11 cm for festulolium productive tillers compared to control. The largest increase in RCG sward height of the first cut was contributed by WA fertiliser use (Table 3).

After evaluating the fertiliser effect on the perennial grass sward development, it can be concluded that for RCG during the 1st year of use, the use of all fertilisers slightly increased the growth of the number of productive tillers in the 1st cut sward, but the number of productive tillers was significantly ($p<0.05$) higher only in MF variant (Table 3). For festulolium different fertilisers made no significant effect on the number of tillers in the 1st cut sward.

For RCG unproductive tillers had the proportionally highest number, which was 55 – 66%, the number of productive tillers on average made up 10 to 20%, whereas undeveloped tillers – 20 to 30%. For festulolium the sward was mostly made up of productive tillers (82 – 100%), there was a very small number of unproductive and undeveloped tillers. Some festulolium samples had no unproductive and/ or undeveloped tillers at all. As a result of using any of the fertilisers, the length of ears was significantly higher ($p<0.05$) for RCG, as well as for festulolium. WA and MF variants had the strongest effect on the ear length of RCG, D1 and D2 fertilisation showed very good results for festulolium (Table 3).

Perennial grass sward analysis allows us to conclude that the development of RCG and festulolium takes place differently during the 1st year of use. In the 1st harvest sward of RCG the tillers made up 70 to 82%, but for festulolium the average number of tillers was only 50% (Figure 2). The number of ears in RCG sward was very small 5 – 9%, while in festulolium sward ears made up 14 –18% of the total mass. The greatest number of leaves (36 – 43%) was in festulolium sward; in RCG sward leaves made up 15 – 30%.

The use of fertilisers allowed both perennial grass species to develop a significantly ($p<0.05$) greater amount of dry matter yield. In two-cut harvest system for RCG 3.9 t ha^{-1} of dry matter was harvested in control variant and up to 8.4 t ha^{-1} in WA variant, which gave the best results in this season. Festulolium had similar tendencies – 2.5 t ha^{-1} of dry matter was harvested in the control variant, and the highest dry matter yield, 4.9 t ha^{-1}, was harvested in the WA variant (Figure 3).

The highest dry matter yields for both species were obtained by harvesting biomass once per season in autumn at crop senescence in comparison with obtained DM yields in the two-cut system: for RCG DM ranged from 6.29 to 9.92 t ha^{-1}; for festulolium – from 3.48 to 7.67 t ha^{-1}, depending on fertilisation treatment. RCG produced a significantly ($p<0.05$) higher dry matter yield when WA was used, while DM yields of festulolium were significantly higher compared with control in all fertilised variants. Using low and medium doses of fertiliser, frequent cutting may not produce the expected yield increase when water supply was as a limiting factor. The number and timing of harvests during the growing season can directly affect the biomass yield and biofuel quality (Tahir et al., 2010). The results of some investigation suggest declining anaerobic degradability (i.e.

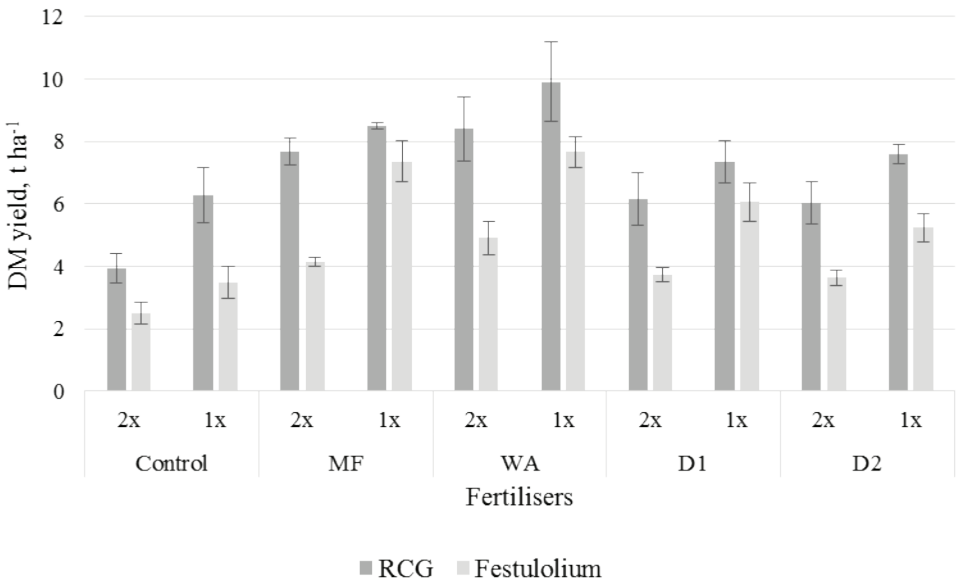

Figure 3. Dry matter yield of RCG and festulolium in intensive (2×) and extensive (1×) cutting regime; error bars indicate the standard errors.

methane production) and improving combustion properties (i.e. mineral composition) of the biomass with increasing sward maturity (Richter et al., 2011). Therefore, one-cut harvest systems provided biomass of better quality for direct combustion than two-cut systems (Kocourkova et al., 2006).

Analysis of variance showed that the influence of all three factors (cutting regime (A), grass species (B) and fertiliser type (C)) on dry matter yields was significant ($p<0.05$). The highest average DM yield (7.01 t ha^{-1}) was achieved by cutting once per season – at crop senescence in comparison with a two-cutting frequency (5.62 t ha^{-1}). The average DM yields of RCG were significantly higher than festulolium, 7.30 t ha^{-1} and 5.33 t ha^{-1}, respectively. In general, the use of all fertiliser variants contributed to a higher DM yield of grasses, in the 1st year of use higher DM yield was produced with WA and MF treatments, 8.06 t ha^{-1} and 7.24 t ha^{-1}, respectively. Interaction between the factors was not significant.

Relatively small yields of festulolium swards can be explained by sward formation in specific climatic conditions. In 2012, extensive amount of rainfall at the beginning of July was followed by a long period of insufficient rainfall. Perennial grasses were sown at the end of July, August was hot and dry, and the total amount of rainfall was lower by almost 50% of the average long-term values. In September, the soil also lacked moisture, and as a result of that festulolium did not germinate well and did not develop a dense sward till wintering. An unusually late spring of the following year delayed intensive tillering of the thinned sward; therefore, a large part of the potential 1st cut yield was lost.

The DM yield of the 2nd cut for both species was adversely affected by an insufficient amount of precipitation and unfavourable distribution of rainfall in the summer. As the grass lacked moisture at the important stages of development, including the early stages of re-growth of aftermath, it was negatively affected by the dry matter yield of intensively mowed grasses. Therefore, a higher total dry matter yield during the growing season was generally obtained from grasses in one-cut harvest system.

Conclusions

The results showed a significant dry matter yield dependence on the grass species, type of applied fertiliser and cutting regime. In the first production year the highest average dry matter yield (7.30 t ha^{-1}) was produced by reed canary grass. The highest average dry matter yields of reed canary grass and festulolium were provided by mowing swards in one-cut harvest system – in autumn at crop senescence (7.01 t ha^{-1}) and in fertilisation treatments with wood ash – 8.06 t ha^{-1} and mineral fertiliser – 7.24 t ha^{-1}.

Reed canary grass and festulolium 1st cut yield formation in the 1st year of use was different: the sward of RCG mostly (70 – 82%) consisted of tillers while the proportion of tillers in festulolium sward averaged only to 50%. Whereas the proportion of ears was higher for festulolium (14 – 18%), in the RCG sward it was only 5 – 9% of the total dry matter yield weight.

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