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The efficiency of nitrogen fertilizer on the dry matter yield of tall fescue and festulolium grown as feedstock for combustion

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Abstract. Grass biomass grows during one vegetation season and can be cultivated and consumed at the place of breeding. Grass biomass can be used not only in traditional feed, but, recently, also for energy production (biogas, solid fuels). The most important economic indicator for any crop is its productivity. The study found that it is important to use nitrogen fertilizer to increase the productivity of tall fescue and festulolium. A significant increase ($p < 0.05$) in the yield of tall fescue was observed starting from the nitrogen norm of 60 kg ha^{-1} N. Further increase in nitrogen fertilizer norm provides a significant increase in dry mater yield of tall fescue (reaching 8.64 t ha^{-1}) and festulolium (reaching 8.11 t ha^{-1}) at 180 kg ha^{-1} N. The analysis of linear regression coefficients of polynomials showed that the highest nitrogen efficiency in the first year of the use of tall fescue was achieved at the norm of 180 kg ha^{-1} N, but for festulolium – at the norm of 120 kg ha^{-1} N. In the following years of tall fescue use, the highest efficiency of nitrogen norms differed: in the 2nd and 4th year of use – at 60 kg ha^{-1} N, in the 3rd year of use – at 30 kg ha^{-1} N, and in the 5th year of use – at 120 kg ha^{-1} N. In contrast, for festulolium, in the 2nd year of use, the highest nitrogen efficiency was reached at the norm of 30 kg ha^{-1} N, and in the 3rd–5th year of use – at the norm of 60 kg ha^{-1} N.

Key words: tall fescue, festulolium, nitrogen fertilizer, dry matter yield, solid fuels.

INTRODUCTION

Grass biomass grows during one vegetation season and can be cultivated and consumed at the place of breeding. Grass biomass can be used not only in traditional feed, but, recently, also for energy production (biogas, solid fuels). The most important economic indicator for any crop is its productivity.

Many countries in Europe and other regions are dependent on fossil energy sources. In order to maintain a sufficient amount of energy supplies for future generations and less reliance on imports, there is a necessity to find a proper alternative to fossil fuels (Scholz & Ellerbrock, 2002; Lewandowski et al., 2003; Tonn et al., 2010; Heinsoo et al., 2011; Nilsson et al., 2015).

The growing of grass for the production of fuel has been a well-accepted technology in Europe but not in the Baltic States. Energy crops have been reported to be potential solid biofuels in Northern Europe (Kaķītis et al., 2009; Tilvikiene et al., 2016; Adamovics et al., 2017a).

The burning of grass pellets as a biofuel is economical, energy-efficient, environmentally friendly and sustainable (Tara et al., 2016).

The biofuels made from perennial grasses and other cellulosic biomasses could meet renewable fuel goals in the Baltic States, with little impact on food production and reducing the fossil fuel use and greenhouse gas emissions.

Nitrogen fertilizers play an important role in optimizing the grasses life processes, increasing the productivity, and improving the harvest quality. Nitrogen fertilizer significantly increases the yield and quality of grasses if the soil contains low levels of organic matter and nitrogen supply (Prochnow et al., 2009; Adamovics et al., 2017a). The dependence of terrestrial biomass yield on fertilizers is not unequivocal as several studies yield different results. Some studies have shown a linear dependence between nitrogen fertilizer rates and biomass increases (Landström et al., 1996; Scholz & Ellerbrock, 2002; Lemus et al., 2008; Mulkey et al., 2008; Adamovics et al., 2017b) while other nitrogen fertilizer norms do not affect biomass productivity and nitrogen content (Lewandowski & Kicherer, 1997).

The objective of the current study was to assess the influence of nitrogen fertilizer on the dry matter yield of grasses grown in five harvesting years as feedstock for the combustion and energy yield of perennial energy crops - festulolium and tall fescue.

MATERIALS AND METHODS

Field trials were conducted at the 'Peterlauki' Study and Research Farm (56°53' N, 23°71' E) of the Latvia University of Life Sciences and Technologies in 2011. The study was conducted from 2012 to 2016.

Soil characteristics: sod calcareous soil LUVISOLS (according to the FAO classification); granulometric composition: heavy dusty sand clay. Soil agrochemical parameters: pH_{KCL} 6.7 (LVS ISO 10390: 2006), organic matter content 21 g kg^{-1} (by Tyurin method; LV ST ZM 80-91), phosphorus content 52 mg kg^{-1} P_2O_5, and potassium content 128 mg kg^{-1} K_2O (according to the Egner-Rhym method; LV ST ZM 82-97).

Before grasses, summer barley was grown for the last two years. The study was carried out on festulolium (× *Festulolium* Asch. & Graebn.) cultivar 'Vetra' and tall fescue (*Festuca arundinaceae* Schreb.) cultivar 'Fawn'. After harvesting barley, the soil was ploughed 22 cm deep in October. In the spring, when the soil reached physical-mechanical readiness, it was first broken off (27.04.2011) and then cultivated (9.05.2011). The experimental plot was sown using the seed-drill 'Hēge-80' on 10 May 2011. Seed rate of 1000 germinating seeds per 1 m^2 was: for festulolium – 9.5 kg ha^{-1}, and for tall fescue – 17.0 kg ha^{-1}.

The fertilizers applied included: P80K120 kg ha^{-1} – main fertilizer (F), and six levels of additional nitrogen fertilizers: F + 30, F + 60, F + 90, F + 120, F + 150, and F + 180 kg ha^{-1} N. In the year of grass sowing, mineral fertilizers were not used but, instead, were applied in the spring of the years of grass use. On the field, fertilizers were applied by hand.

The harvested plot size was 10 m^2, with a 2-m wide column between grass species. The experiment was laid out in a randomized complete block design with three replicates. During the experiment, once in summer, weeding was carried out during the wake of grasses. Herbicides were not used in planting. The grasses harvesting time was the first cut at the end of July (the biomass after the first cut in July was harvested for the second time in mid-September, but the biomass yield of the second cut was not included in this assessment).

The total biomass yield was calculated using fresh weight and moisture content. The sample moisture level was measured after oven drying at 105 °C for 12 h.

Ash melting temperature was identified in the Waste and Fuel Research and Testing Laboratory 'Virsma' Ltd. using the methods of the standard ISO 540 LVS NE 15370-1. During the pellet manufacturing process, grass biomass was ground to fine powder with the electric mill 'ЭМ-3А УХЛ 4.2' in a laboratory of LLU. The obtained grass powder was formed into pellets using the hand press 'IKA WERKE'. The highest calorific value (Qa) was determined according to the standard ISO 1928 LVS EN 14918. The highest calorific value of germ and wood biomass was used to calculate the amount of energy produced. The energy value of pellets was calculated using the following formula (Kaķītis, Smits, Belicka, 2009):

$$Q_{kop} = Q_a \cdot M_s \qquad (1)$$

where Q_{kop} – total amount of energy obtained from 1 ha, MJ ha^{-1}; Q_a – highest calorific value of biomass dry matter, MJ kg^{-1}; M_s – dry mass of the biomass of 1 hectare, kg ha^{-1}.

The average data of the experimental sites were statistically analysed using the three-way analysis of variance with 'grass species', 'fertiliser', and 'year of sward use' as factors, and the difference among means was detected by LSD at the $p < 0.05$ probability level (Excel for Windows, 2003).

Characteristics of meteorological conditions. For the period from 01/01/2011 to 31/12/2016, the data about the air temperature and rainfall were obtained from the automatic Meteorological station at the 'Peterlauki' Study and Research Farm of the Latvia University of Life Sciences and Technologies. For the comparison of annual meteorological data, the long-term average temperature and precipitation data (norm) were used from the Jelgava Meteorological station (Figs 1–2).

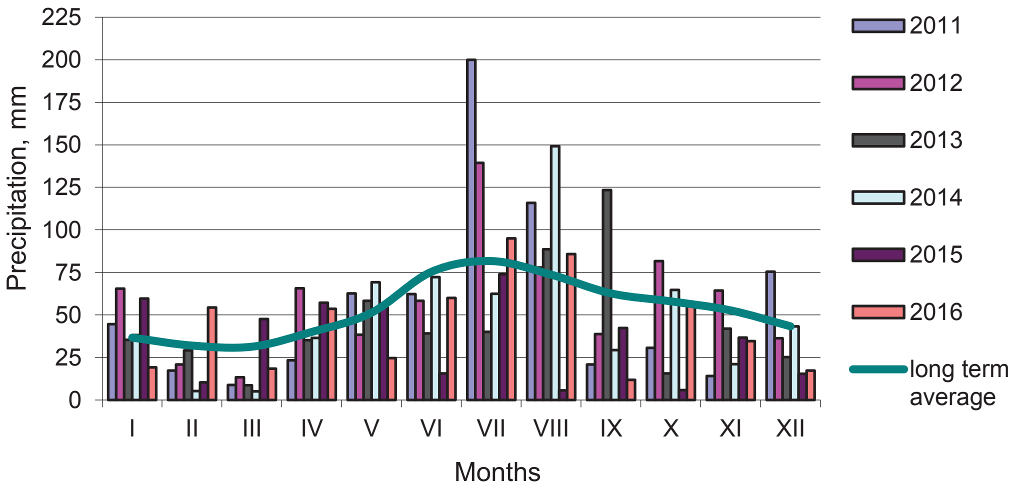

Figure 1. The average accumulated precipitation in 2011–2016.

Climatic conditions affect grass hibernation and growing of grassland and determine the size of the crop. The length of the wintering period varied from 128 days in 2013/2014 to 173 days in 2012/2013. During the five-year period, only two winters had a negative average air temperature. The coldest winter was in 2012/2013, when the average temperature dropped to -2.5 °C, whereas the warmest winters were in 2014/2015 and 2015/2016, when the average temperature in wintertime reached or exceeded +1.0 °C.

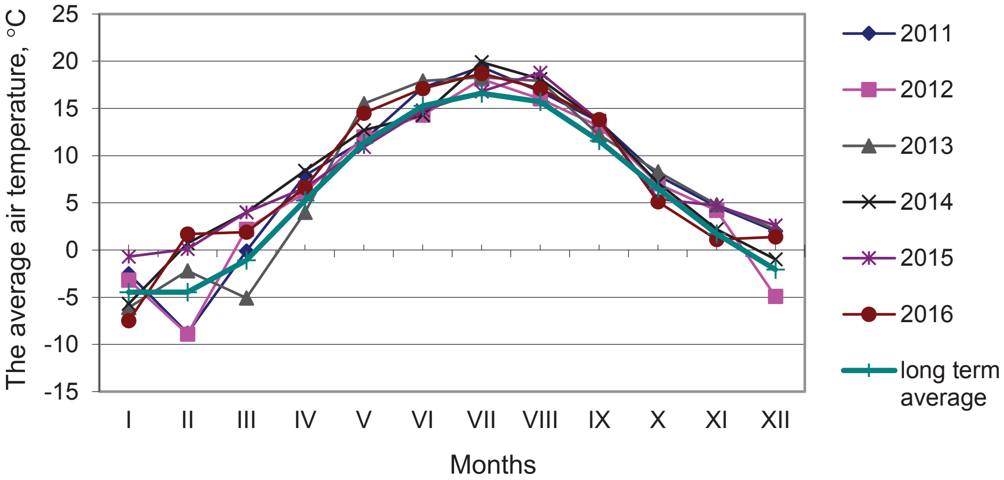

Figure 2. The average air temperature in 2011–2016.

In the vegetation period, the amount of precipitation corresponded to the norm in 2011, 2012 and 2014, when it was consistent with the average amount observed on a long-term basis; however, in 2013, 2015 and 2016, it was significantly lower than the norm.

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RESULTS AND DISCUSSION

The dry matter yield in the first year of festulolium use varied from 4.33 t ha^{-1} (N0P80K120) to 8.96 t ha^{-1} (N180P80K120), but for tall fescue – from 5.01 t ha^{-1} (N0P80K120) to 9.38 t ha^{-1} (N180P80K120) (Fig. 3). Compared to festulolium, tall fescue was more productive from the first to fourth year of use, as well as in variants where no nitrogen fertilizers were used; in other years of grass use, festulolium was more productive.

The results showed that tall fescue and festulolium were responsive to nitrogen fertilizers and the increase in nitrogen content also significantly increased the yield of dry matter.

The dry matter yield of tall fescue increased with the increase in nitrogen fertilizer norm: from 5.48 t ha^{-1} at 30 kg ha^{-1} N to 8.32 t ha^{-1} at 180 kg ha^{-1} N. On average, over the five years of the experiment, as a result of nitrogen fertilizer use, the dry matter yield increased from 22% (nitrogen norm 30 kg ha^{-1} N) to 81% (nitrogen norm 180 kg ha^{-1} N). In the variant with the lowest nitrogen norm (30 kg ha^{-1} N), the dry matter yield of festulolium increased significantly during all years of grassland use. On average, the increase in dry matter yield obtained over the five years was 0.86 t ha^{-1} (+22%), and the yields in different years varied from 0.70 t ha^{-1} (+14%) to 1.50 t ha^{-1} (+33%). The average dry matter yield of festulolium at nitrogen fertilizer norm of 60 kg ha^{-1} N, was 6.91 t ha^{-1} (from 5.70 t ha^{-1} to 7.86 t ha^{-1}), with further increase in yield to 8.54 t ha^{-1} (from 8.11 t ha^{-1} to 8.96 t ha^{-1}) at 180 kg ha^{-1} N (Fig. 3).

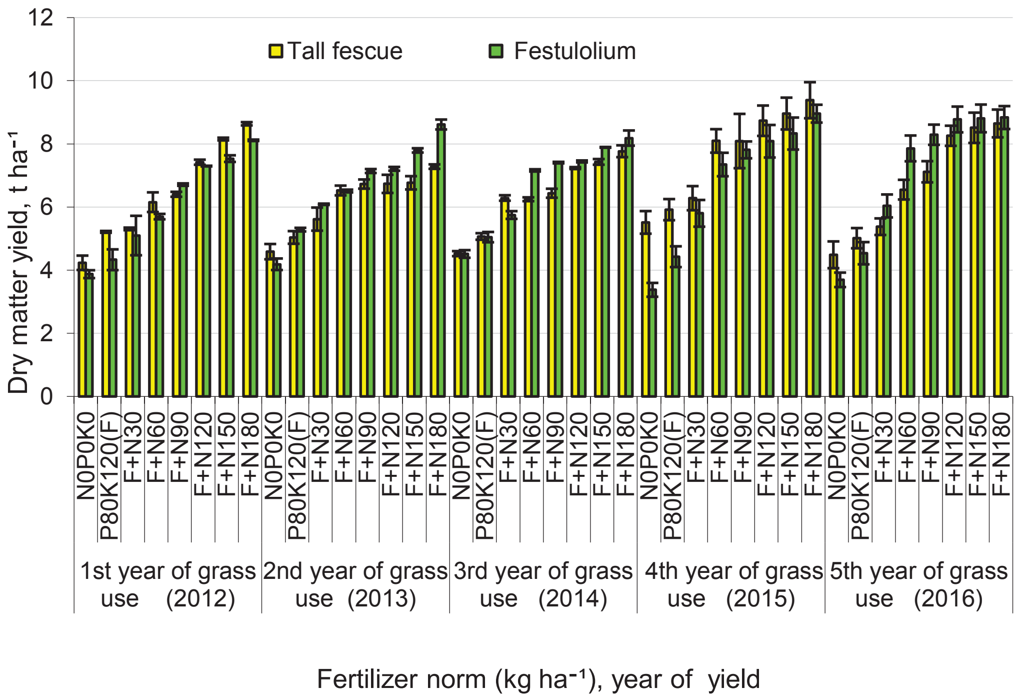


Figure 3. The effect of nitrogen fertilizer on the yield of tall fescue and festulolium.

In assessing the effect of nitrogen fertilizer on the production of high yields, tall fescue and festulolium revealed that significant increases in dry matter yields varied between the years of use. Agrometeorological conditions in the growing year had a significant ($p < 0.001$) effect on tall fescue and festulolium.

In the first year of nitrogen fertilizer use, a significant increase in dry matter yield of tall fescue ($p < 0.05$) was observed at the nitrogen norm of 60 kg ha^{-1} N, when the dry matter yield reached 6.15 t ha^{-1}, and a further increase in nitrogen norm contributed to a significant increase in dry matter yields up to the nitrogen norm of 180 kg ha^{-1} N, when the dry matter yield reached 8.64 t ha^{-1}. Similarly, the dry matter yield ($p < 0.05$) of festulolium increased with the increase in nitrogen fertilizer norm, reaching 8.11 t ha^{-1} of dry matter at 180 kg ha^{-1} N. In the following years, the development of a denser sward of festulolium resulted in the dry matter yield of more than 8.0 t ha^{-1} by applying lower nitrogen rates than those required for the first year of use.

In the second year of tall fescue use, a significant increase ($p < 0.05$) in dry matter yield was achieved at the nitrogen norm of 30 kg ha^{-1} N, and the increase in nitrogen norm continued to provide a significant yield increase of up to 60 kg ha^{-1} N; however, a further increase in nitrogen norm did not result in significant increase in dry matter yield. Also, in the third year of tall fescue use, a significant increase in dry matter yield was gained at the nitrogen norms of 30, 120, and 180 kg ha^{-1} N. In the fourth year of grassland use, a significant yield increase ($p < 0.05$) was detected at the nitrogen norms of 60, 120, and 180 kg ha^{-1} N. In the fifth year of grassland use, a significant increase in dry matter yield was obtained applying nitrogen norms of 60 and 120 kg ha^{-1} N.

From the agronomic point of view, in the first year of tall fescue use, it is necessary to use high nitrogen norms (> 150 kg ha^{-1} N) to exceed the 8.0 t ha^{-1} yield of dry matter. With the age of grassland, when tall fescue becomes stronger and denser, in order to produce a dry matter yield of over 8.0 t ha^{-1}, it is necessary to use 120 kg ha^{-1} N and more.

The linear distribution of polynomials was determined to study the effects of factors such as the year of use, the effect of increasing the nitrogen fertilizer rates, and the importance of increasing nitrogen fertilizer rates. By using linear regression coefficients (Fig. 4), it was found that in the first year of tall fescue use, the highest nitrogen efficiency was achieved with the nitrogen norm of 180 kg ha^{-1} N, in the second and fourth year – with the nitrogen norm of 60 kg ha^{-1} N, in the third year – with the nitrogen norm of 30 kg ha^{-1} N, and in the fifth year – with the nitrogen norm of 120 kg ha^{-1} N.

The estimation of linear coefficients confirmed variations in the significance of the previously established and described growth of dry matter yields. In its turn, the highest efficiency of increasing nitrogen norms in the first year of festulolium use was achieved with the nitrogen norm of 120 kg ha^{-1} N, in the second year – with 30 kg ha^{-1} N, and from the third to fifth year of use – with 60 kg ha^{-1} N.

Linear regression coefficients show that for high yielding of tall fescue (1^{st} year of use) and older grasses (5^{th} year of use), high nitrogen norms (180 kg ha^{-1} N) should be applied (Figs 5 and 6). From 1 kg of N, a dry matter yield of 0.0205 t is produced. In the second and fourth year of tall fescue use, the highest dry matter yields – 0.0248 and 0.0363 t of 1 kg N respectively – were provided by 60 kg ha^{-1} N nitrogen fertilizer, while in the third year of use, the nitrogen fertilizer norm was 30 kg ha^{-1} N, i.e., 0.0407 t of dry matter yield were obtained from 1 kg N. In the second, third and fourth year of tall fescue use, when the highest efficiency of nitrogen fertilizer was detected with nitrogen norms of 30 and 60 kg ha^{-1} N, the use of elevated norms was less effective. The yield of tall fescue in the second year of its use from 1 kg N decreased by 80%, in the third year – by 73%, and in the fourth year – by 68%.

Festulolium

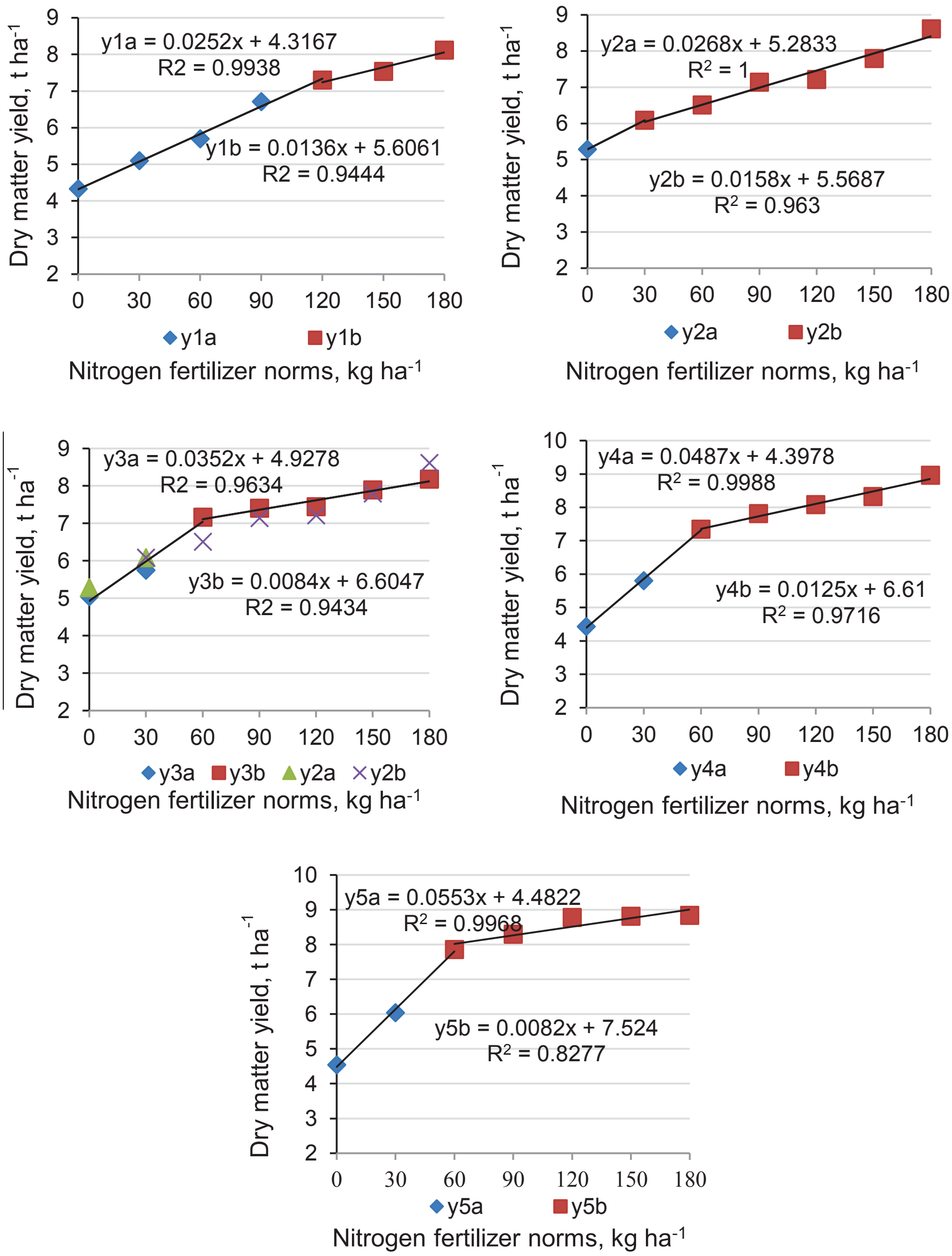
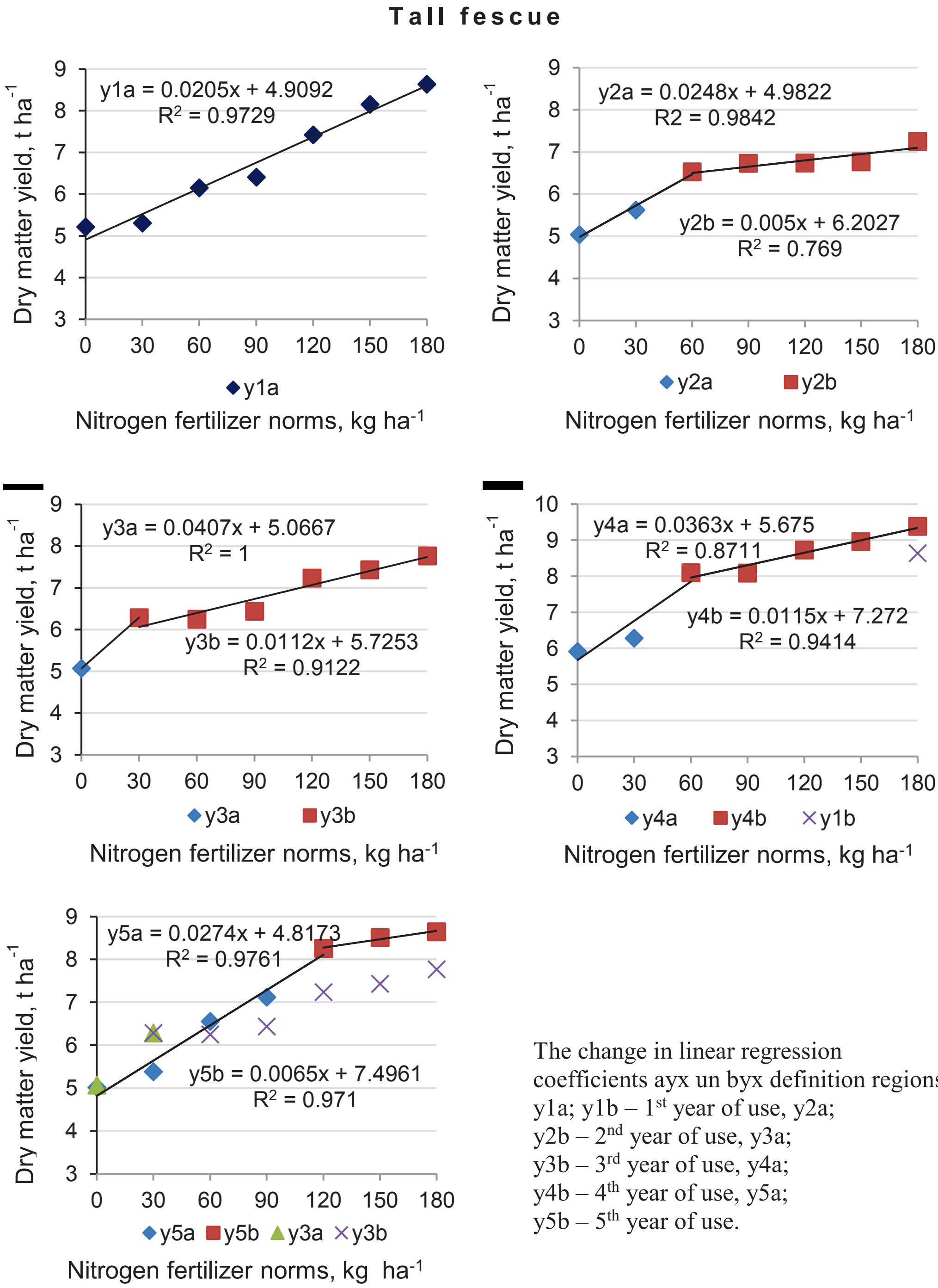


Figure 4 (Continues)



The change in linear regression coefficients ayx un byx definition regions: y1a; y1b – 1st year of use, y2a; y2b – 2nd year of use, y3a; y3b – 3rd year of use, y4a; y4b – 4th year of use, y5a; y5b – 5th year of use.

Figure 4. The efficiency of increasing nitrogen fertilizer norms in the years of festulolium and tall fescue use.

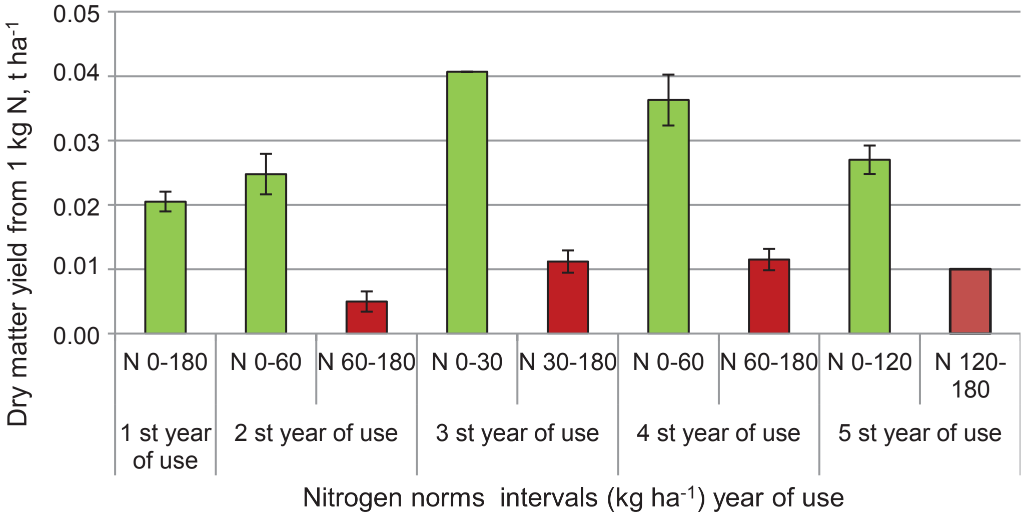


Figure 5. Nitrogen fertilizer efficiency depending on the intervals of nitrogen fertilizer norms for tall fescue.

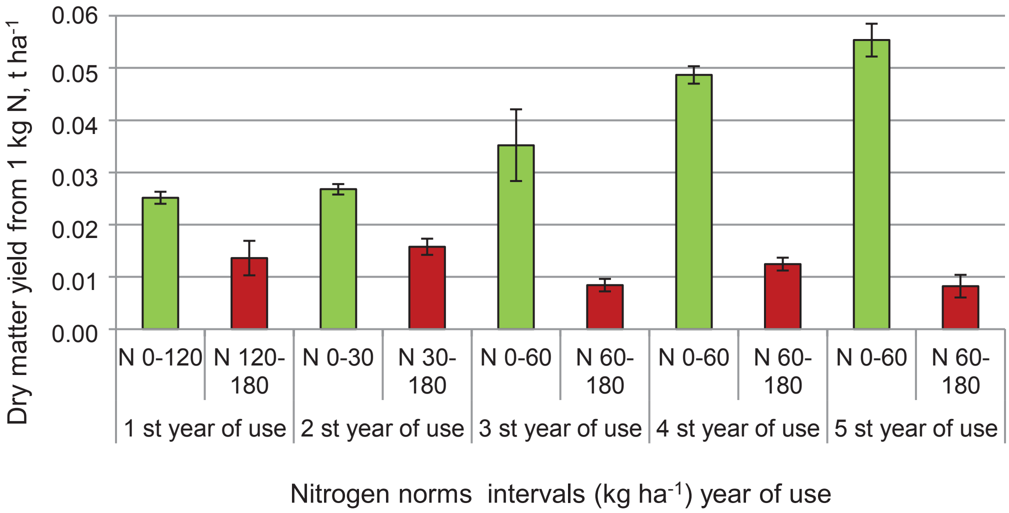


Figure 6. Nitrogen fertilizer efficiency depending on the intervals of nitrogen fertilizer norms for festulolium.

Throughout all years of the experiment, the dry matter yield of festulolium increased concurrently with nitrogen fertilizer norm: in the first year of use, 120–180 kg ha^{-1} N provided the highest fertilizer efficiency; in the second year – accordingly 30–180 kg ha^{-1} N; and from the third to fifth year of use, the most efficient norm was 60–180 kg ha^{-1} N. However, compared to the first two years, nitrogen efficiency decreased. In the first year of use, the reduction was 46%, in the second year – 41%, and in the third, fourth, and fifth year of use, the reduction in dry matter yield was 76%, 74%, and 85%, respectively.

Ash is one of the key indicators characterising the quality of fuel. A too high content of ash and non-combustible minerals (also of sand) causes problems with the automation of combustion process, resulting in the reduction of an effective fuel combustion ratio (Prochnow et al., 2009). Ash content in grass biomass is notably higher than in timber (Volynets & Dahman, 2011; Platače & Adamovičs, 2014).

In this research, ash content in the studied energy grasses was high, reaching on average 7.7%; moreover, nitrogen fertilizers did not have major impact on it. The highest ash content was found in festulolium treated with fertilizer F+30 – 8.6%, and in tall fescue treated with P80K120 (F–background) – 7.9%.

Ash melting temperature has four phases: DT – the initial point of deformation when the sharp peak is rounding; ST – softening temperature, when the ash cone deforms to such extent that the height of the structure reduces to the size of its diameter; HT – the point of the formation of hemisphere, or the cone collapses and becomes dome-shaped; FT – flow temperature, when the liquid ash dissipates along the surface (Kakitis et al., 2009).

At all four ash melting phases, the birch biomass pellets had the temperature above 1,400 °C, but the temperature of grass biomass pellets varied within 1,020–1,200 °C. When burning grass biomass pellets with low ash melting temperature (< 1,000 °C), special attention should be paid to a correct combustion regime. The presence of alkali metals, phosphorus, silicon and calcium is a key determinant of ash melting temperature (Magasiner et al., 2002; Maciejewska et al., 2006); therefore, grass (tall fescue, festulolium) biomass ash melting temperature is lower (1,020–1,270 °C) at all phases, whereas birch biomass temperature is higher and reaches 1,460–1,500 °C.

From the grasses included in the study, the highest calorific value of the first-cut biomass varied from 15.20 MJ kg^{-1} for festulolium to 16.90 MJ kg^{-1} for tall fescue (Table 1).

Table 1. Gross calorific value (*Q*) for different grass species, MJ kg^{-1}

Reed canary grass	Festulolium	Tall fescue	Average	Sx
16.40	16.50	15.20	15.85	± 0.32

Nitrogen fertilizers contributed not only to the increase in dry matter yield but also to the amount of energy produced. On average, the amount of energy from 1 ha of all nitrogen standard variants varied from 103.9 GJ ha^{-1} for tall fescue to 126.4 GJ ha^{-1} for festulolium. The largest amount of energy received from 1 ha was detected in the variant with a nitrogen norm of 180 kg ha^{-1} N: from 142.6 GJ ha^{-1} for tall fescue to 147.8 GJ ha^{-1} for festulolium.

CONCLUSIONS

1. The grass species and nitrogen fertilization significantly affected the biomass yield of both grasses. The highest dry matter yields of tall fescue (8.96 t ha^{-1}) and festulolium (8.32 t ha^{-1}) were produced when nitrogen fertilizer was applied. Dry matter yields from nitrogen fertilizer levels increased from 10% to 59% for tall fescue, and from 22% to 81% for festulolium.

2. Linear regression coefficients of the polynomial distribution showed that the highest efficiency of nitrogen fertilizer varied over the years of the use of the grasses. The highest nitrogen efficiency for tall fescue was achieved with the norm of 30 kg ha^{-1} N in the 3rd year of use, with the norm of 60 kg ha^{-1} N in the 2nd and 4th year of use, with

the norm of 120 kg ha^{-1} N in the 5^{th} year of use, and with the norm of 180 kg ha^{-1} N in the 1^{st} year of use; whereas for festulolium, the highest nitrogen efficiency was achieved with the norm of 30 kg ha^{-1} N in the 2^{nd} year of use, with the norm of 60 kg ha^{-1} N in the 3^{rd} to 5^{th} year of use, and with the norm of 120 kg ha^{-1} N in the 1^{st} year of use.

3. At all four ash melting phases, the burning temperature of grass biomass pellets varied within 1,020–1,200 °C.

4. From the first cut, the average calorific value of grass biomass was 15.85 MJ kg^{-1}, and the amount of energy produced was 145.29 GJ ha^{-1}.

REFERENCES

Adamovics, A., Gutmane, I. & Adamovica, O. 2017a. The influence of nitrogen fertilisation on the yields and quality of multicomponent sown meadows. *Grassland Science in Europe* **22**, 289–291.

Adamovics, A., Platace, R., Gulbe, I. & Ivanovs, S. 2017b. Influence of fertilizers on chemical content of energy grass biomass. *16th International scientific conference "Engineering for rural development*": proceedings, Latvia, Latvia University of Agriculture, Faculty of Engineering, Latvian Academy of Agricultural and Forestry Sciences. Jelgava, 2017. Vol. **16**, pp. 98–102.

Heinsoo, K., Hein, K., Melts, I., Holm, B. & Ivask, M. 2011. Reed canary grass yield and fuel quality in Estonian farmers' fields. *Biomass and Bioenergy* **35**, 617–625. http://dx.doi.org/10.1016/j.biombioe.2010.10.022

Kaķītis, A., Šmits, M. & Belicka, I. 2009. Suitability of crop varieties for energy production. In: *Engineering for Rural Development. Proceedings of the 8th International Scientific Conference,* May 28–29, 2009. Jelgava, pp. 188–193.

Landström, S., Lomakka, L. & Andersson, L. 1996. Harvest in spring improves yield and quality of reed canary grass as bioenergy crop. *Biomass and Bioenergy* **11**, 333–341.

Lemus, R., Brummer, E.C., Burras, C.L., Moore, K.J., Barker, M.F. & Molstad, N.E. 2008. Effects of nitrogen fertilization on biomass yield and quality in large fields of established switchgrass in southern Iowa, USA. *Biomass and Bioenergy* **32**, 1187–1194.

Lewandowski, I. & Kicherer, A. 1997. Combustion quality of biomass: practical relevance and experiments to modify the biomass quality of *Miscanthus x giganteus*. *European Journal of Agronomy* **6**, pp 163–177.

Lewandowski, I., Scurlock, J.M.O., Lindvall, E. & Christou, M. 2003. The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe. *Biomass and Bioenergy* **25**, 335–361. http://dx.doi.org/10.1016/S0961-9534(03)00030-8

Maciejewska & A., Veringa & H., Sanders & J. & Peteves & S.D. 2006. Co-firing of biomass with coal: constraints and role of biomass pre-treatment. Luxemburg: Office for Official Publications of the European Communities, 100 pp.

Magasiner, N., van Alphen, M., Inkson, M. & Misplon, B. 2002. Characterising Fuels for Biomass – Coal Fired Cogeneration. *International Sugar Journal* **104**(1242), 251–267.

Mulkey, V.R., Owens, V.N. & Lee, D.K. 2008. Management of warm-season grass mixtures for biomass production in South Dakota, USA. *Bioresource Technology* **99**, 609–617.

Nilsson, D., Rosenqvist, H. & Bernesson, S. 2015. Profitability of the production of energy grasses on marginal agricultural land in Sweden. *Biomass and Bioenergy* **83**, 159–168. http://dx.doi.org/10.1016/j.biombioe.2015.09.007

Platače, R. & Adamovičs, A. 2014. The evaluation of ash content in grass biomass used for energy production. *WIT Transactions on Ecology and the Environment* **190**(2), 1057–1065.

Prochnow, A., Heiermann, M., Plöchl, M., Amon, T. & Hobbs, P.J. 2009. Bioenergy from permanent grassland – A review: 2. Combustion. *Bioresource Technology* **100**, 4945–4954.

Scholz, V. & Ellerbrock, R. 2002. The growth productivity and environmental impact of the cultivation of energy crops on sandy soils in Germany. *Biomass and Bioenergy* **23**, 81–92.

Tara, W. Hudiburg, WeiWei, Wang, Madhu, Khanna, Stephen, P. Long,, Puneet Dwivedi, William, J. Parton, Melannie, Hartman & Evan, H. DeLucia. 2016. Impacts of a 32-billion-gallon bioenergy landscape on land and fossil fuel use in the US. *Nature Energy* **1**, doi:10.1038/nenergy.2015.5

Tilvikiene, V., Kadziuliene, Z., Dabkevicius, Z., Venslauskas, K. & Navickas, K. 2016. Feasibility of tall fescue, cocksfoot and reed canary grass for anaerobic digestion: Analysis of productivity and energy potential. *Industrial Crops and Products* **84**, 87–96. http://dx.doi.org/10.1016/j.indcrop.2016.01.033

Tonn, B., Thumm, U. & Claupein, W. 2010. Semi-natural grassland biomass for combustion: influence of botanical composition, harvest date and site conditions on fuel composition. *Grass and Forage Science* **65**, 383–397. http://dx.doi.org/10.1111/j.1365-2494.2010.00758.x

Volynets, B. & Dahman, Y. 2011. Assessment of pretreatments and enzymatic hydrolysis of wheat straw as a sugar source for bioprocess industry. *International Journal of Energy and Environment* **2**, 427–446.