Biomass of grasses and other herbaceous plants for bioenergy use

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Abstract. Biomass supply for different uses, especially for bioenergy production, is becoming increasingly important. Independently of the purposes of biomass use, high yields per unit area and best possible quality need to be achieved. As a result, the selection of appropriate plant species is an important aspect. Cocksfoot (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* Schreb.) and reed canary grass (*Phalaris arundinacea* L.) were investigated on a light loam (*Cambisol*) with a view to assessing the impact of nitrogen (N) and harvest time on biomass yield used for biogas. The biomass yield was influenced by cutting frequency and N fertilizer rate. In the two years of experiment, tall fescue and reed canary grass were most productive. Since traditional grasses (cocksfoot, reed canary grass, *etc*.) generally yield less in a northern climate, it could be attractive some alternative crops. Cocksfoot (*Dactylis glomerata* L.) and other herbaceous crops – *Miscanthus x giganteus*, cup plant (*Silphium perfoliatum* L.), Virginia fanpetals (*Sida hermafrodita* R.), mugwort (*Artemisia vulgaris* L.) *and* absinthe wormwood *(Artemisia dubia* Wall.) were established. The non-traditional herbaceous species were investigated in a small-plot experiment on sand with small stone and gravel admixture (*Eutri-Cambic Arenosol*). Preliminary research results suggest that the biomass yield of some investigated alternative crops is quite promising, particularly absinthe wormwood. Yield data averaged over three years of swards use showed that with and without nitrogen fertilization, absinthe wormwood and Virginia fanpetals out-performed cocksfoot, which is regarded as a traditional grass. Absinthe wormwood and Virginia fanpetals also exhibited the lowest concentration of ash, which is an important indicator of suitability for bioenergy use. Further research on grasses and alternative bioenergy crop management is needed.

Keywords: Biomass, species, yield, nitrogen, chemical composition.

Introduction

Biomass plantations have the potential to become a significant source of renewable energy even if sustainability guidelines for climate mitigation and nature protection constrain the availability of land resources. Perennial crops as renewable energy source are more favoured than annual crops due to the relatively high yields per land unit, and are produced with less impact on the environment (Boehmel *et al*. 2008, Beringer *et al*. 2011). Under warmer climate conditions, more attempts are made to investigate miscanthus and switch grass C_4 type plants which are considered to be more promising as energy crops (Lewandowski and Schmidt 2006, Zub *et al*. 2010). Under more northerly climate conditions more confidence is placed on C_3 plants reed canary grass (*Phalaris arundinacea* L.), tall fescue (*Festuca arundinacea* Schreb.) and others (Jasinskas *et al.* 2008, Hakala *et al.* 2009, Kukk *et al*. 2011, Robbins *et al.* 2012), more attention is being devoted to perennial or natural grassland swards (Prochnow *et al*. 2009, Richter *et al*. 2011).

The yield of dry biomass (DM) of perennial tall grasses in Lithuanian soils average 6–9 t DM/ha and in favourable years may exceed12 t DM/ha (Jasinskas *et al*. 2008, Tilvikienė *et al*. 2009). However, these tall grasses are generally not very productive and their fuel quality does not match that of wood products. Cultivation of Virginia fanpetals (*Sida hermafrodita* R.) under Central-East Europe conditions has indicated a possibility annual harvest yield of 9-17 t DM/ha (Borkowska and Molas 2012). Cup plant (*Silphium perfoliatum* L.) also produces considerable biomass and could be easily cultivated as energy plant (Šiaudinis *et al*. 2012). Preliminary research has showed that *Miscanthus* could also grow in more northern conditions (Kryževičienė *et al*. 2011) as well as other interesting alternative crops (Kryževičienė *et al*. 2010). Independently of the purposes of biomass use, high yield per unit area and the best possible quality need to be achieved. Maximizing the efficiency of biomass production as an energy source requires the evaluation of some of these attractive alternative crops. The present study aimed to establish growth patterns and biomass production of perennial plants differing in origin, type and species as influenced by N supply.

Materials and methods

Field experiments were carried out in Central Lithuania (55º24′N; 23º52′E) on a light loam soil (*Apicalcari-Endohypogleyic Cambisol*). Tall fescue, cocksfoot and reed canary grass were grown in a randomized trial design with four replicates. Biomass yield was measured during 2009-2011. Soil pH was 6.7–7, organic matter content 1.61–1.75%, available P varied from 145 to 224 mg/kg, and K from 128 to 158 mg/kg. Grasses intended for biogas production were cut twice (first cut at flowering) or three times (first cut at heading stage) per season. All swards were fertilized with mineral N fertilizers at rates of 90 (N_{90}) and 180 (N_{180}) kg/ha. For swards cut twice per season, half of the annual N rate was applied in spring and after the first cut whereas for swards cut three times, one-third of the annual N rate was applied in spring and after the first and the second cuts. Biomass dry matter (DM) content was measured after each cut.

The herbaceous plant species were investigated in a small-plot experiment on sand with small stone and gravel admixture [classified as *Eutri-Cambic Arenosol* (*ARb-eu*)] with results obtained over the 2008- 2010 period. Soil pH was 8.0, organic carbon 12.7 g/kg, total N 1.44 g/kg, available P 36-48 mg/kg and K 128-142 mg/kg. Cocksfoot (as control) and other herbaceous crops including: *Miscanthus x gigantheus*, cup plant (*Silphium perfoliatum* L.), Virginia fanpetals (*Sida hermafrodita* R.) and absinthe wormwood *(Artemisia dubia* Wall.) were established. Responses to P and K fertilizers applied at a rate of 60 kg/ha and. N fertileization at three rates (0, 60 and 120 kg/ha) were measured from the second growth season onward. DM yield and the chemical composition of the biomass were determined from plots harvested at the end of each growing season.

The weather conditions had a marked effect on plant development and biomass accumulation. The winter of 2007–2008 was mild and snowless; however, the weather in spring was very changeable and adverse for young plants. The second winter of 2008–2009 was also 1.5ºC milder than usual with up to 5 cm snow cover persisting only in the first 10-day period of January and in February. Overall, the growing season was wet and warm in 2007, dry and warm in 2008, dry spring, later wet and warm in 2009, wet and warm in 2010. The research results were processed by analysis of variance ($P<0.05$).

Results

Total biomass yield measured for the two years of study was significant ($P<0.05$) influenced by the species of perennial grasses, number of cuts and N rate (Table 1). There was a significant ($P<0.05$) interaction between perennial grass species and the number of cuts per season. Over the two years of observations, tall fescue produced the highest ($P<0.05$) yield. Reed canary grass yield was lower ($P<0.05$) than tall fescue, but higher than cocksfoot which produced the lowest DM yield. Yield of all swards varied between years.

The results suggest that tall fescue, cut twice each season, accumulated significantly higher biomass yield, compared to the treatments cut three times per season. Reed canary grass yielded best when cut twice, whereas cocksfoot accumulated higher biomass yield when cut three times per growing season. Application of the additional 90 N kg/ha increased DM yield by 0.2–1.0 DM t/ha for tall fescue, 0.6–2.1 t for cocksfoot and 2.2–2.9 DM t/ha for reed canary grass, the most responsive species to high N fertiliser input.

DM yield of alternative herbaceous species differed depending on the year and fertilizer level (Table 2). Overall, without N fertiliser (N_0), the yield of the alternative species was 23% (cup plant) to 200% (absinthe wormwood) higher ($P<0.05$) than the cocksfoot control (mean 3 year yield, 4.3 t DM/ha). Cocksfoot yield decreased significantly from 2008 to 2010 by 2 t DM/ha/year in the N_0 treatment. However, N application not only increased ($P<0.05$) cocksfoot yield within years, but reduced yield loss ($P<0.05$) trend between years. Application of 60 kg/ha was near optimal for cocksfoot.

Table 1. Dry matter yield of tall fescue, cocksfoot and reed canary grass, DM t/ha

Cuts	N kg/ha	Biomass yield DM t/ha						
		First year of sward use			Second year of sward use			Yield of two years
		2009	2010	Average	2010	2011	Average	
Tall fescue								
2	90	13.7	11.3	12.5	7.6	5.1	6.4	18.9
	180	13.4	13.1	13.3	4.6	6.2	5.4	18.7
3	90	13.5	10.3	11.9	4.2	5.5	4.9	16.8
	180	13.8	11.2	12.5	4.1	6.4	5.3	17.8
Cocksfoot								
2	90	10.7	7.6	9.2	5.1	4.7	4.9	14.1
	180	11.3	9.1	10.2	4.1	5.0	4.6	14.8
3	90	10.4	8.5	9.5	5.1	5.8	5.5	15.0
	180	11.3	10.1	10.7	6.1	6.5	6.3	17.0
Reed canary grass								
2	90	9.1	8.5	8.8	7.4	8.6	8.0	16.8
	180	9.4	10.7	10.1	7.0	10.8	8.9	19.0
3	90	8.3	9.3	8.8	4.8	3.6	4.2	13.0
	180	8.3	11.0	9.7	6.5	5.9	6.2	15.9
LSD (P=0.05)								
Grass species		0.398	0.429	0.323	0.436	0.315	0.309	0.560
Cuts per season		0.281	0.303	0.228	0.308	0.223	0.219	0.396
Nitrogen		0.281	0.303	0.228	0.308	0.223	0.219	0.396

Table 2. The biomass yield and chemical composition of herbaceous plants

Plants	N (kg/ha)	Annual DM yield (t/ha)			Chemical composition (%)			
		2008	2009	2010	ADF	NDF	Lignin	Ash
Sida hermaphrodita L.	0	6.99	11.6	10.5	82.8	73.5	12.7	3.17
	60	9.55	12.4	14.0	80.5	69.3	11.8	4.23
	120	7.32	14.3	8.95	81.1	71.4	12.3	3.86
LSD (*P*=0.05)		2.84	2.85	2.01				
Silphium perfoliatum L.	0	3.39	7.94	4.54	65.1	56.6	13.8	13.1
	60	4.33	13.8	9.83	70.6	63.9	12.9	9.2
	120	3.80	14.2	6.75	73.7	67.7	12.1	7.0
LSD (*P*=0.05)		1.97	0.52	2.02				
Artemisia dubia Wall.	0	10.2	17.5	11.2	70.1	62.7	14.6	4.2
	60	15.6	24.1	13.4	63.4	58.1	14.0	4.2
	120	13.8	27.6	13.4	70.1	64.2	16.4	4.3
LSD (*P*=0.05)		5.37	0.41	1.11				
Miscanthus x giganteus	0	4.62	11.2	4.88	50.7	50.7	8.4	4.9
	60	6.55	11.0	7.22	49.5	49.5	8.2	3.6
	120	6.82	12.2	7.79	57.3	57.3	11.7	2.8
LSD (*P*=0.05)		1.98	2.21	2.37				
Dactylis glomerata L.	0	6.11	4.42	2.36	56.1	32.5	13.1	11.5
	60	6.80	8.05	4.73	61.7	32.6	12.8	9.7
	120	8.29	6.21	7.02	60.5	27.7	8.7	8.4
LSD (*P*=0.05)		0.19	0.57	0.21				

Compared to cocksfoot, the non-traditional species grew and developed well especially when periods of adverse moisture regimes in spring and summer are taken into account. Absinthe wormwood was the best performer in terms of development rate and biomass accumulation during the three years with a DM yield averaged over years and N treatments of 16.3 t /ha/yr, 5.7 t/ha higher than Virginia fanpetals the second best producing species. Absinthe wormwood yield was also quite variably with measured production in 2009 twice that measured in 2008 and 2010 (Table 2). Wormwood responded significantly (P<0.05) to N fertiliser with the highest response recorded in 2009 where N60 increased yield by 6.6 t DM/ha and an additional 3.5 t DM/ha which another 60 kg N/ha (Table 2). Virginia fanpetals performed twice as well as cocksfoot producing an average yield of 12 t DM/ha when fertilised with N_{60}. Cup plant produce a slightly lower average yield as Virginia fanpentals with moderate fertiliser application, but the yield was more variable ranging from 3.4 to 14 t DM/ha. Cup plant over-wintered well in the first and subsequent years and resumed growth very early in the following spring. *Miscanthus x giganteus* varied from 4.6 to 12.2 t DM/ha, and N fertilizer (N_{60}) increased yield (P<0.05) in 2008 and 2010 (Table 2).

When estimating the feasibility of use of all the tested plants for energy needs, plant quality ranks equal in importance to production potential. Calorific capacity which is the key energy indicator of solid fuel is most adversely affected by high ash concentration in biomass. In this study, the lowest (P<0.05) ash concentrations were noted for *Miscanthus*, Virginia fanpetals and absinthe wormwood which were less than half those of cocksfoot and cup plant (Table 2).

While this study has identified absinthe wormwood as potentially the species most suited for bioenergy use, the variation observed due to seasonal conditions and management (in this case fertiliser application) highlights the need for further research to evaluate more comprehensively the feasibility of using non-traditional species as renewable energy sources in Lithuania. It is important to highlight phenotypic variability of these species and to design follow on studies to develop integrated management practices that will provide stability of their biomass production as feedstock for biofuel production and thereby ensure the economic and ecological benefits of their use as alternative crop systems.

Conclusion

The total biomass yield of traditional and non-traditional species monitored in these two studies highlighted the variability due to species, climatic factors and management practices. For example, the highest biomass production of tall fescue and reed canary grass was obtained in the 2 cut system, whereas reed canary grass exhibited the most marked response to higher nitrogen fertilization, compared with other species. Similarly, the DM yields of non-traditional group averaged over three years of use produced by absinthe wormwood and Virginia fanpetals were inconsistent, with and without N fertiliser. To obtain more reliable results further research is needed to help identify factors influencing yield under variable climatic conditions.

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References

Beringer T, Lucht W, Schaphoff S (2011) Bioenergy production potential of global biomass plantations under environmental and agricultural constraints. *GCB Bioenergy* **3,** 299-312.

Boehmel C, Lewandowski I, Claupein W (2008) Comparing annual and perennial energy cropping systems with different management intensities. *Agricultural Systems* **96**, 224–236.

Borkowska H, Molas R (2012) Two extremely different crops, Salix and Sida, as sources of renewable bioenergy. *Biomass and Bioenergy* **36**, 234-240.

Hakala K, Kontturi M, Pahkala K (2009) Field biomass as global energy source. *Agricultural and Food Science* **18**, 347-365.

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

Jasinskas A, Zaltauskas A, Kryzeviciene A (2008) The investigation of growing and using of tall perennial grasses as energy crops. *Biomass and Bioenergy* **32**, 981–987

Kukk L, Roostalu H, Suuster E, Rossner H, Shanskiy M, Astover A (2011) Reed canary grass biomass yield and energy use efficiency in Northen European pedoclimatic conditions. *Biomass and Bioenergy* **35**, 4407-4416

Kryževičienė A, Šarūnaitė L, Stukonis V, Dabkevičius Z, Kadžiulienė Ž (2010) Assessment of perennial mugwort (*Artemisia vulgaris* L. and *Artemisia dubia* Wall.) potential for biofuel production. *Žemės ūkio mokslai* **17** (1-2), 32-40 (in Lithuanian)

Kryževičienė A, Kadžiulienė Ž, Šarūnaitė L, Dabkevičius Z, Tilvikienė V, Šlepetys J (2011) Cultivation of *Miscanthus* × *giganteus* for biofuel and its tolerance of Lithuania's climate plants. *Zemdirbyste-Agriculture* **98** (3), 267-274

Lewandowski I, Schmidt U (2006) Nitrogen, energy and land use efficiencies of miscanthus, reed canary grass and triticale as determined by boundary line approach. *Agriculture, Ecosystems and Environment* **112**, 335-46

Prochnow A, Heiermann M, Plochl M, Linke E.B, Idler C, Amon T, Hobbs SP (2009) Bioenergy from Permanent Grassland – A Review: 1. Biogas. *Bioresource Technology* **100,** 4931–4944.

Ricter F, Fricke T, Wachendorf M (2011) Influence of sward maturity and pre-conditioning temperature on the energy production from grass silage through the integrated generation of solid fuel and biogas from biomass (IFBB):2. Properties of energy carriers and energy yield. *Bioresource Technology* **102**, 4866-4875

Robbins MP, Evans G, Valentine J, Donnison IS, Allison GG (2012) New opportunities for the exploitation of energy crops by thermochemical conversion in Northern Europe and the UK. *Progress in Energy and Combustion Science* **38,** 138-155

Šiaudinis G, Jasinskas A, Šlepetienė A, Karčauskienė D (2012) The evaluation of biomass and energy productivity of common mugwort (*Artemisia vulgaris* L.) and cup plant (*Silphium perfoliatum* L.) in *Albeluvisol. Zemdirbyste-Agriculture* **99** (4), 357-362

Tilvikienė V, Butkutė B, Dabkevičius Z, Kadžiulienė Ž, Kryževičienė A (2009) Nendrinių eraičinų ir paprastųjų šunažolių biomasės kaita plaukėjimo ir žydėjimo tarpsniais. *Zemdirbyste-Agriculture* **96** (2), 138-150 (In Lithuanian)

Zub HW, Arnoult S, Brancourt-Hulmel M (2011) Key traits for biomass production identified in different Miscanthus species at two harvest dates. *Biomass and Bioenergy* **35**, 637-651