EKOLOGIJA. 2006. Nr. 2. P. 66–71

Herbaceous plants as a renewable source of bioenergy

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The study was designed to investigate the feasibility of cultivating perennial grasses as energy crops and their effect on soil agroecological potencial. Field experiments with different grasses were conducted at the Lithuanian Institute of Agriculture during the period 2000–2004. Perennial grasses *Phalaroides arundinacea* L. and *Bromopsis inermis* Leysser. were grown pure and in mixtures with legumes *Melilotus officinalis*, *Lupinus polyphyllus* and *Galega orientalis* on a light gleyic loam soil (Cambisol) with a humus content of ca. to 2%. Pure swards of grasses were either fertilized with nitrogen or not. Mixtures did not receive any N. The swards were cut once per season when their biomass was used for combustion, and twice per season when their biomass was used for biogas. Dry matter yield of grasses in pure stands ranged from 6.4 to 9.3 t ha^{-1}. Under normal weather conditions, grass-legume mixtures without nitrogen (N) fertilization were higher yielding than N-fertilized (60+60 kg N ha^{-1}) grass in pure swards, but the mixtures were lower yielding in the years with inadequate rainfall. In all cases, mixtures had an important ecological advantage over N-fertilized grass swards. The swards had a positive soil conservation effect and maintained the soil fertility potential.

The energy potential of perennial grasses in both cases of biomass utilisation varied according to DM yield variation and totalled up to 153 $GJha^{-1}$. Our experimental evidence suggests that the tested swards sown on less fertile soils, which amount to over 0.5 million ha in Lithuania, would be able to produce up to 4 million tons of biomass for energy production annually.

Key words: perennial grasses, biomass, energy potential

INTRODUCTION

The use of local resources, i.e. the biomass of perennial grasses, for biofuel production is one of the ways to facilitate the implementation of the environmental protection and energy saving programme. Swards are not demanding in terms of soil, therefore for energy purposes it is expedient to establish them on less productive or abandoned land.

In the US and Europe, the initial task for biomass research with perennial grasses was to identify the grasses that best fulfil the demands of bioenergy production, namely high biomass yields and appropriate biomass characteristics (Wright, 1990; Nordberg, Edstrom, 1997; McLaughlin et al., 1998; Hallam et al., 2001; Karpenstein-Macham, 2001; Lewandowski et al., 2003; Venturi, Venturi, 2003). After evaluating 35 potential herbaceous crops in the US and 20 in Europe it was concluded that native perennial rhizomatous grasses, switchgrass, miscanthus, reed canary grass and giant reed showed the greatest potential as bioenergy crops (McLaughlin et al., 1999; Nilsson and Hansson, 2001; Lewandowski et al., 2003; Askew, 2005). Reed canary grass has a C_3 photosynthetic pathway and is native to Europe and consequently to Lithuania. Grasses display the following advantages: they are indigenous plants already adapted to the site conditions, have a wide genetic variability, and the biomass has a good combustion quality (Börjesson, 1999; Olsson, 2003; Lewandowski et al., 2003).

Lithuanian research evidence also suggests that perennial grasses are higher yielding, moreover, they can yield for 7–10 years without being reseeded, protect hilly soils from erosion and maintain soil fertility (LIA, 2000). This advantage of perennial grasses on hilly and less fertile soils, which amount to over 0.5 million ha in Lithuania, is of special importance since such soils are not suited for intensive agriculture.

Data on the calorific value and other characteristics of grasses biomass for biofuel have been comprehensively analysed and discussed in Kryzeviciene et al. (2004).

Data on the characteristics of biomass for biogas production are analysed and discussed in Navickas et al. (2003). The energy potential was up to 153 GJ ha^{-1}, and it was up to 19 times higher than the energy input for biofuel production. The aim of the present study was to investigate perennial grasses as bioenergy crops, their cultivation feasibility without nitrogen fertilization, i.e. in mixtures with legumes, and to estimate the effect of energy swards on soil. Such mixtures were tested in Lithuania for the first time.

MATERIALS AND METHODS

The trials were set up in 2000 in a field adjacent to the Dotnuva sand quarry.

The pre-crop was amaranth, prior to which the field had not been used for several years. The soil was characterized as Endocalcari–Endohypogleyic Cambisols, light loam. The soil pH varied from 5.2 to 7.0, humus content was low – 1.5–1.9 %, available P_2O_5 150 mg kg^{-1} and K_2O 169 mg kg^{-1}. Eight swards differing in species composition were tested. Four of the swards included reed canary grass (*Phalaroides arundinacea*), sown pure and in mixtures (2-component) with 3 legumes: sweet clover (*Melilotus officinalis),* perennial lupine (*Lupinus polyphyllus)* and goat's rue *(Galega orientalis)*, the other four swards included awnless brome grass (*Bromopsis inermis*), sown pure and in mixtures with legumes. The plots without grasses were laid out next to the grasses and were equalled to abandoned land and used for estimating soil characteristics (treatment 1–1). The harvested plot size was 10 m^2, the plots were arranged in one row and replicated four times.

Stands of perennial grasses were established following the same recommendations as for forage swards establishment. The biomass of swards cut once per season was used for combustion, and that of swards cut twice per season was used for biogas production.

The pure grass swards (treatment 1) were fertilized with nitrogen (120 kg N ha^{-1}) in two equal applications in spring and after the cut and not fertilised (treatment 5), where biomass was not cut but left to rot. The mixtures received no nitrogen fertilization. On the day of cutting the harvested biomass was weighed and sampled for dry matter (DM) content determination. The naturally field–dried biomass was chopped and burned in the form of chops in an experimental boiler with a hearth furnace at the Institute of Agricultural Engineering LUA (Žaltauskas, Rutkauskas, 2003). The energy potential of swards for combustion was calculated according to the herbage DM yield and calorific value of biomass fuel. The energy potential of swards for biogas was calculated according to the herbage DM yield and biogas yield extracted from biomass on laboratory scale digesters at the Lithuanian University of Agriculture (LUA) (Navickas et al., 2003).

The effect of different swards on soil was estimated by analysing soil chemical composition, biochemical interaction process (allelopathy) and soil weed contamination.

Soil samples were collected from the 0–20 cm layer in four replications of each treatment in the autumn of the sowing year and the third harvest year. Soil pH_{KCL} was analysed by the potentiometric method, mobile P_2O_5 and K_2O by AL, humus percentage by the Tyurin methods.

Weed seed in soil was determined by washing soil samples, allelopathic activity was estimated on the basis of radish seed germination test according to A. Grodzinsky's technique (Grodzinsky, Grodzinsky, 1973). The weather conditions that influenced sward yield were normal in 2001 and in 2002, but in 2003 they were adverse due to lasting droughts. The results of DM yield and of allelopathic effects were statistically evaluated by using ANOVA procedures.

RESULTS

Sward species composition and the weather conditions had some effect on the annual DM yield, legumes had a positive impact on the yield of mixtures.

Table 1. **Dry matter yield (DM) of swards of different species for combustion**

Treatment number (grass species and their mixtures with legumes)	DM yield t ha^{-1} in I–III years			
	2001[1]	2002[2]	2003[2]	mean
Bromopsis inermis Leysser:				
1. Pure grass, N_{60+60}	7.8	5.5	5.8	6.4
2. Mixture with *Melilotus officinalis*	6.5	3.2	2.8	4.2
3. Mixture with *Lupinus polyphyllus*	7.3	3.2	4.2	4.9
4. Mixture with *Galega orientalis*	6.3	4.1	5.0	5.1
$LSD_{0.05}$	0.38	0.42	0.49	0.25
Phalaroides arundinacea L.:				
1. Pure grass, N_{60+60}	7.5	6.1	7.0	6.9
2. Mixture with *Melilotus officinalis*	7.8	4.2	3.2	5.1
3. Mixture with *Lupinus polyphyllus*	8.4	5.0	6.4	6.6
4. Mixture with *Galega orientalis*	8.4	5.5	7.0	7.0
$LSD_{0.05}$	0.49	0.26	0.59	0.27

Weather conditions during growing periods (April–October): [1] normal, [2] unfavourable.

Table 2. **Dry matter yield of biomass of swards of different species for biogas**

Treatment number (grass species and their mixtures)	DM yield t ha^{-1}					
	Experiment 1 (Exp-1)			Experiment 2 (Exp-2)		
	1st cut June	2nd cut September	Total	1st cut July	2nd cut September	Total
Phalaroides arundinacea L.						
1. Pure grass, N_{60+60}	5.9	3.4	9.3	6.9	2.5	9.3
2. Mixture with *M. officinalis*	4.0	1.9	5.9	5.1	1.2	6.3
3. Mixture with *L. olyphyllus*	4.4	2.0	6.4	5.9	1.5	7.4
4. Mixture with *G. orientalis*	4.8	2.2	7.0	7.0	2.1	9.1
$LSD_{0.05}$	0.27	0.09	0.28	0.27	0.06	0.35
Bromopsis inermis Leysser.						
1. Pure grass, N_{60+60}	6.1	2.2	8.3	6.4	1.4	7.8
2. Mxture with *M. officinalis*	4.2	1.0	5.2	4.1	0.6	4.8
3. Mixture with *L.polyphyllus*	4.6	1.6	6.3	4.9	0.7	5.6
4. Mixture with *G. orientalis*	4.7	1.7	6.4	5.2	1.2	6.3
$LSD_{0.05}$	0.43	0.63	0.76	0.43	0.11	0.44

Biomass for combustion

The data of DM yield of biomass of swards with one cut are presented in Table 1. The average DM yield ranged between 4.2 and 7 t ha^{-1}. In 2001 the DM yield of the two grass species in pure stands (with N) were similar and amounted to 7.5–7.8 t ha^{-1}.

Much higher yielding than these grasses were mixtures composed of *Ph. arundinacea – G. orientalis* and *Ph. arundinacea – L. polyphyllus* (8.4 t ha^{-1}). In the same trials, in unfavourable years (2002) pure grasses were markedly more productive than the mixtures. It is likely that the rapid effect of nitrogen fertilizers alleviated the negative effect of drought on grass growth.

In 2003, despite the moisture shortage, the DM yield differences of swards differing in composition declined or disappeared; pure *Ph. arundinacea* and its mixtures with *G. orientalis* gave the same DM yield (7 t ha^{-1}).

These results were attributed to the fact that in the mixtures of the third harvest year the share of *G. orientalis* was already high and it was able to supply the sward with biological nitrogen. Mean results from the three harvest years suggest that the swards of *Ph. arundinacea* were higher yielding than *B. inermis* swards, especially in mixtures. In all of the experimental years the productivity of these swards was lower compared with 1997–1999 (Kryževičienė et al., 2001). During this period, which was favourable for herbage growth, the biomass yield of swards amounted to 12 t ha^{-1}.

The energy potential of perennial grasses was up to 153 GJ ha^{-1}. The highest energy potential was shown by pure *Ph. arundinacea* and its mixtures with *G. orientalis* (Kryzeviciene et al., 2004). The energy generated was up to 5–19 times greater than the energy input for biofuel production.

Biomass for biogas

DM yield of the 1st cut of pure swards when taken in June (Exp-1), was 5.9–6.1 t ha^{-1}, and it was higher than that of mixtures, the difference amounting to 1.1 t ha^{-1} (Table 2). The early-cut swards had more chances to produce a more abundant aftermath or the second yield (to 3.4 t ha^{-1}). When the first cut was taken later in July (Exp-2), the DM yield of pure sward (with N) and of mixture with *G. orientalis* was similar (nearly 7 t ha^{-1}). The total DM yield for mixture with *G. orientalis* in Exp-2 was basically the same as that for pure grass sward with N (over 9 t ha^{-1}). Analysis of the annual yield indicates that the timing of the first cut exerted a lesser effect on pure grass sward since its growth and yield stability were maintained by nitrogen fertilisation; the yield difference of the swards cut at different dates was as low as 0.5 t ha^{-1}. The averaged results from three years (two cuts) suggest that swards of *Ph. arundinacea* were higher yielding than *B. inermis* in most cases. Biogas yield from aftermath herbage mass was significantly higher than that from the 1st cut. The highest total energy yield (130–138 GJ ha^{-1} per year) was obtained from pure sward of *Ph. arundinacea* and especially from its mixture with *G. orientalis*.

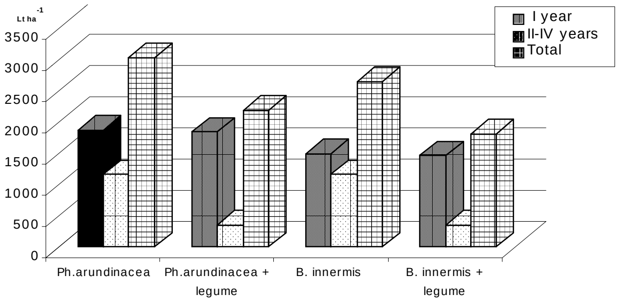

Figure. Cultivation costs of perennial grasses and legumes in the I–IV years

Table 3. **Variation of weed incidence in energy swards over the period from 2000 to 2004**

Treatment and composition of swards	Number of weed plants m^{-2} 2000–2004	Number of weed seed in soil (0–20 cm) m^{-2}			
		2000		2003	
		Number	Emerged %*	Number	Emerged %*
1–1.Plots without grasses	199–160	19 684	27.5	18 960	6.7
1. Pure *Ph. arundinacea*, N_{60+60}	139–0.5	11 172	40.5	10 640	7.5
2. Mixture with *M. officinalis*	150–1.1	17 556	22.7	12 502	4.3
3. Mixture with *L. polyphyllus*	141–1.0	14 630	23.6	13 300	4.0
4. Mixture with *G. orientalis*	144–0.3	16 758	23.8	14 098	1.9
5. Pure *Ph. arundinacea*, N_0 (biomass rotted naturally)	130–0.5	15 960	24.4	13 566	2.0

*Germinated naturally in pots outdoors.

Table 4. **Allelopathic effects of swards on soil, using *Raphanus sativus* L. as test plant**

Treatment and composition of swards	Germination of garden radish in soil under different swards % (laboratory germination of garden radish was 98%)					
	Phalaris arundinacea			*Bromopsis inermis*		
	2000	2003		2000	2003	
	%	%	% to control	%	%	% to control
1–1. Plots without grasses	42	43	88	42	43	88
1–2. Sand (control)	49	49	100	49	49	100
1. Pure grass, N_{60+60}	57	58	117	49	65	124
2. Mixture with *M. officinalis*, N_0	57	60	105	46	60	120
3. Mixture with *L. polyphylus*, N_0	57	60	105	53	62	124
4. Mixture with *G. orientalis*, N_0	58	61	126	51	67	125
5. Pure grass, N_0 (biomass rotted naturally)	57	60	122	53	64	121
$LSD_{0.05}$	1.2	0.9	1.22	1.3	0.82	1.17

Changes in soil agrochemical composition

In the course of the study, agrochemical soil indicators changed inappreciably. PH_{KCL} changed by 0.2–0.4, humus increase was more marked in mixtures and in the swards where biomass was left to rot, whereas the contents of phosphorus and potassium in them during the four years even slightly increased. In treatment 1–1, reduced PK and especially N were utilised by weeds, whereas in mixtures N content significantly increased (from 0.140 to 0.156%).

Crop and soil contamination with weeds

In the sowing year, there were found over 20 weed species in the swards, of which the most prevalent ones were *Tripleurospermum inodorum, Amaranthus retroflexus, Atriplex patula, Chenopodium album, Galeopsis tetrahit, Lamium purpureum, Stellaria media, Thlaspi arvense, Capsella bursa – pastoris.* The total number of weeds varied from 130 to 199 plants m^{-2} (Table 3). The number of weeds in the crops of energy grasses declined every year and in the fourth year there were found only sporadic weeds of which *Tripleurospermum inodorum* was the most abundant. Most of the weeds tended to disappear shortly after emergence due to the competition with tall–growing grasses. Analysis of seed bank data showed that in the sowing year there were found up to 19.7 thousand weed seed m^{-2} in the soil, of which from 3.4 to 5.3 thousand were viable. After four years the number of weed seed declined to 5 thousand, of which only 2–8% were viable. Literature sources also indicate that in the communities of cultivated swards the number of weeds in the soil, and especially their viability, rapidly declines (Rice, 1989).

Allelopathic effects of swards on the soil

Garden radish (*Raphanus sativus* L.) is considered by the researchers of allelopathy to be very sensitive to soil. As a result, it is often used as a biotest for measuring soil activity. It was found that during four years of grass growth, different soil activity had formed on the background (rhizosphere) of each sward, which determined the seed germination of the test plant. Seed germination was assayed according to Grodzinsky, i. e. when 50% (k = 50%) viable seeds had emerged in control (sand). Recording of germination at k = 50% enabled to estimate the mode of action (inhibitory, neutral and stimulating) of the study soil. Both at the beginning and end of the study, the poorest germination was recorded in the soil of plots without grasses (treatment 1–1, 42–43%) (Table 4).

The negative allelopathic effect on the soil of this treatment was caused by weeds. The greatest stimulating effect on radish germination was exerted by the soil under mixtures with *G. orientalis*. The effect of rotten herbage biomass was also positive. Summarised data suggest that all swards had a positive effect on soil activity and at the same time on radish germination in this soil, which was by 17 to 26% higher than in the control on sand and by 38% higher than in the plots without grasses.

Economic assessment of cultivation of energy swards

Bearing in mind that the productivity of properly established and managed swards does not decline for seven years of use (Kryževičienė, Žemaitis, 1996), the costs were calculated using the tariffs for mechanised agriservice operations developed by the LR Ministry of Agriculture Labour Economics and Training Service (Tariffs for Mechanised Agriservice Operations, 2003, p. 30–36). During the experimental period (four years of crops' age) the greatest costs (up to 1900 Lt ha^{-1}) were incurred in the sowing year (or year I) of swards (Fig.). The costs of the sowing year could be markedly reduced by sowing grasses with an early barley variety as a cover crop. The costs for crop management in each harvest year ranged from 118 to 387 Lt ha^{-1}; the greatest costs were incurred for the growing of pure grass swards. The use of nitrogen fertiliser was responsible for the difference in the costs. Summarised data of calculations suggest that the costs for the swards of different species composition over the four years of use were different: under an intensive farming system pure grass crops have to be fertilised with nitrogen fertilisers, which involves extra costs amounting to over 800 Lt ha^{-1}, compared with the costs for mixtures. Besides saving costs, mixtures with legumes provided ecological fuel and protected the soil from weed propagation and accumulation of toxic substances and tended to increase humus content in the soil. Further research is needed for economic assessment of these positive effects.

CONCLUSIONS

1. Species composition of swards and growing conditions had the some effect on the DM yield of perennial grasses when grown on light soils with low humus content (up to 2%).

2. The DM yield of the grasses in pure stands ranged from 6.4 to 6.9 t ha^{-1} when the swards were cut once per season and the biomass was used for combustion, and the yield amounted to 9.3 t ha^{-1} when the swards were cut twice per season and the biomass was used for biogas.

3. In favourable years the DM yield of grass-legume mixtures was higher than or similar to that of pure grasses fertilized with N_{60+60}, but the mixtures were lower yielding in the years with inadequate rainfall.

4. The energy potential of perennial grasses in both cases of biomass utilisation varied according to DM yield variation and totalled up to 153 GJ ha^{-1}.

5. Legumes in mixed swards were very important in terms of economy and ecology since they were able to fully or partly replace nitrogen fertilizer by biological nitrogen and at the same time produce ecological biomass for biofuel.

6. The swards had a positive soil conservation effect and maintained soil productivity potential.

ACKNOWLEDGEMENTS

Part of the present research work was done according to the programme "Conversion and Use of Solar Energy". The research was supported by the Lithuanian State Science and Studies Foundation. The author thanks Dr. A. Žaltauskas and Dr. A. Jasinskas (LAII) and Dr. K. Navickas (LUA) for the co-operation in the study area.

Received 8 November 2005
Accepted 10 January 2006

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Aldona Kryževičienė

DAUGIAMETĖS ŽOLĖS – ATSINAUJINANČIOS ENERGIJOS ŠALTINIS

S a n t r a u k a

Straipsnyje pateikti daugiamečių žolynų, galinčių teikti vietinę žaliavą (biomasę) energijai gaminti ir dirvų agroekologiniam potencialui išsaugoti, tyrimų rezultatai.

Lauko bandymuose, atliktuose 2000–2004 m. Lietuvos žemdirbystės institute Dotnuvoje, žolės augo lengvo priemolio giliau karbonatiniame, sekliai glėjiškame rudžemyje (*Endocalcari–Endohypogleyic Cambisols*), kuriame humuso buvo tik 2%. Tirti skirtingos rūšinės sudėties žolynai: grynų varpinių šakniastiebinių žolių – nendrinių dryžučių (*Phalaroides arundinacea* L.) ir beginklių dirsių (*Bromopsis inermis* Leyser.) ir jų dvinariai mišiniai su ankštinėmis žolėmis. Azoto trąšomis buvo tręšti tik gryni varpiniai žolynai. Per vegetaciją vieną kartą pjautų žolynų biomasė buvo naudota kurui, 2 kartus pjautų žolynų – dujų gamybai.

Gauti tyrimų duomenys parodė, kad žolynų derlingumui įtakos turėjo jų rūšinė sudėtis bei meteorologinės sąlygos. Palankiomis žolėms augti sąlygomis žolynų rūšinė sudėtis mažai veikė biomasės derlių, vidutiniais trejų derliaus metų duomenimis (iš kurių dveji buvo nepalankūs žolėms), biomasės derlius, atsižvelgiant į pjūties laiką, kito nuo 6 iki 9 t ha^{-1} sausųjų medžiagų. Nendrinių dryžučių žolynai, ir gryni, ir jų mišiniai su daugiamečiais lubinais bei rytiniais ožiarūčiais, buvo derlingesni už beginklių dirsuolių žolynus. Abiem biomasės naudojimo atvejais žolynų energetinį potencialą lėmė jų derlingumas. Minėtų derlingiausių žolynų energetinis potencialas, naudojant biomasę kurui, buvo iki 120 GJ ha^{-1}, naudojant dujų gamybai – iki 138 GJ ha^{-1}. Palankiais metais šių žolynų energetinis potencialas siekė iki 153 GJ ha^{-1}.

Raktažodžiai: daugiametės žolės, biomasė, energetinis potencialas