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Perennial grasses as a source of bioenergy in Lithuania

A. Kryževičienė[1], A. Jasinskas[2] and A. Gulbinas[2]

[1] Lithuanian Institute of Agriculture, Instituto al.1, LT-58344 Akademija,
Kėdainiai reg., Lithuania; e-mail: akryzeviciene@lzi.lt
[2] Institute of Agricultural Engineering Lithuanian University of Agriculture,
Raudondvaris, LT-54132 Kaunas reg., Lithuania; e-mail: aljas@mei.lt

Abstract. The study was designed to investigate the feasibility of cultivating perennial grasses as energy crops and their effect on soil agroecological potential. Field experiments with different grasses were conducted at the Lithuanian Institute of Agriculture from 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 soil fertility potential.

The energy potential of perennial grasses in both cases of biomass utilization varied according to DM yield variation and totaled up to 153 GJ ha^{-1}; energy input for biofuel production amounted to 8.0 – 19.2 GJ ha^{-1}. Our experimental evidence suggests that the tested swards sown on less fertile soil, amounting to over 0.5 million ha in Lithuania, would be able to produce to 4 million tons of biomass for energy production annually.

Key words: perennial grasses, biomass, biofuel, energy potential, energy input

INTRODUCTION

The use of local resources, i.e. biomass of perennial grasses for biofuel production, is one way to facilitate 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 those grasses that best fulfill 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, 20001; Lewandowski et al. 2003; Venturi P. & Venturi G. 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

& Hansson, 2001; Lewandowski et al. 2003; Askew, 2005). Reed canary grass has a C_3 photosynthetic pathway and is native to Europe and to Lithuania. Grasses display the following advantages: they are indigenous plants, already adapted to site conditions, have wide genetic variability, and the biomass has 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, accounting for over 0.5 million ha in Lithuania, is of special importance since such soils are not suited for intensive agriculture.

The data on calorific value and other characteristics of grasses biomass for biofuel are comprehensively analysed and discussed in Kryzeviciene et al. (2004). The data on 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 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 the field adjacent to the Dotnuvos 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 – Epihypogleyic Cambisol, light loam. 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 tested 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 the equivalent of 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.

The stands of perennial grasses were established following the same recommendations as for forage swards. The biomass of swards cut once per season was used for combustion; that 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 cutting 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 the experimental boiler with a hearth furnace at the Institute of Agricultural Engineering LUA (Žaltauskas & Rutkauskas, 2003). Energy potential of swards for combustion was calculated according to the herbage DM yield and calorific value of biomass fuel. 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 after completion of analyses of soil chemical composition, biochemical interaction process (allelopathy) and soil weed contamination.

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

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

Energy efficiency of biofuel production and utilization depends on energy balance (Scholz & Berg, 1998). Energy evaluation of the technologies intended for herbage cultivation, harvesting and preparation as fuel was conducted according to the standard methodology which can be used in Lithuania and Germany (Methodological recommendations…, 1989; Scholz & Berg, 1998; Jasinskas, 2003).

While estimating technological operations of plant cultivation, harvesting and preparation as biofuel the following energy evaluation parameters were calculated: direct energy input (fuel used, electric power, heat), indirect energy input (fertilizers, herbicides, seeds, etc.), machinery energy consumption, human labour energy input. By summing up these parameters we get the total energy input (MJ ha^{-1}) for biofuel preparation. More detailed methodology of energy inputs calculation with indication of the main specific energy equivalents for fertilisers, seeds, etc. are written in the article of Jasinskas et al. (2008).

RESULTS AND DISCUSSIONS

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.

Biomass for combustion.

The data of DM yield of biomass of swards with one cut are presented in Table 1. Average DM stands (with N) was similar and amounted to 7.5–7.8 t ha^{-1}.

Mixtures composed of *Ph. arundinacea – G. orientalis* and *Ph. arundinacea – L. polyphyllus*, 8.4 t ha^{-1} produced much higher yields. 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.

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

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 the swards in 1997–1999 (Kryzevicienė 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 to153 GJ ha^{-1}. The highest energy potential was from pure *Ph. arundinacea* and its mixtures with *G. orientalis* (Kryzeviciene et al., 2004). The energy generated was 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 was higher than that of mixtures: the difference amounted to 1.1 t ha^{-1} (Table 2).

The early-cut swards had more chances to produce a more abundant aftermath than 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}. Averaged results from three years, 2nd cut, 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*.

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. polyphyllus*	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. Mixture 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

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. In addition, phosphorus and potassium content during the four years slightly increased. In treatment 1-1 the 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 over 20 weed species were found in the swards. The most prevalent were the following: *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; in the fourth year only sporadic weeds were found: *Tripleurospermum inodorum* was the most abundant. Most of the weeds tended to disappear shortly after emergence due to the competition with tall-growing grasses.

The analysis of seed bank data showed that in the sowing year up to 19.7 thousand weed seeds m^{-2} were found in the soil: 3.4–.3 thousand were viable. After four years the number of weed seeds declined to 5 thousand: 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).

Table 3. Variation of weed incidence in energy swards from 2000–2004.

Treatment and composition of swards	Number of weed plants m^{-2}	Number of weed seed in soil (0-20 cm) m^{-2}			
	2000–2004	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	17556	22.7	12502	4.3
3. Mixture with *L. polyphyllus*	141-1.0	14630	23.6	13300	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

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 4 years of grass growth, different soil activity had formed on the background (rhizosphere) of each sward, which determined 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 estimating the mode of action (inhibitory, neutral and stimulating) of the investigated 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).

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			*Bromus inermis*		
	2000	2003		2000	2003	
	Percent	Percent	% to control	Percent	Percent	% 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 *Ph. arundinacea,* 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. polyphyllus,* N_0	57	60	105	53	62	124
4. Mixture with *G. orientalis*, N_0	58	61	126	51	67	125
5. Pure *Ph. arundinacea*, 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

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; at the same time, on radish germination in this soil, it was from 17 to 26% higher than in the control on sand and up to 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's 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 I year) of swards (Fig. 1).

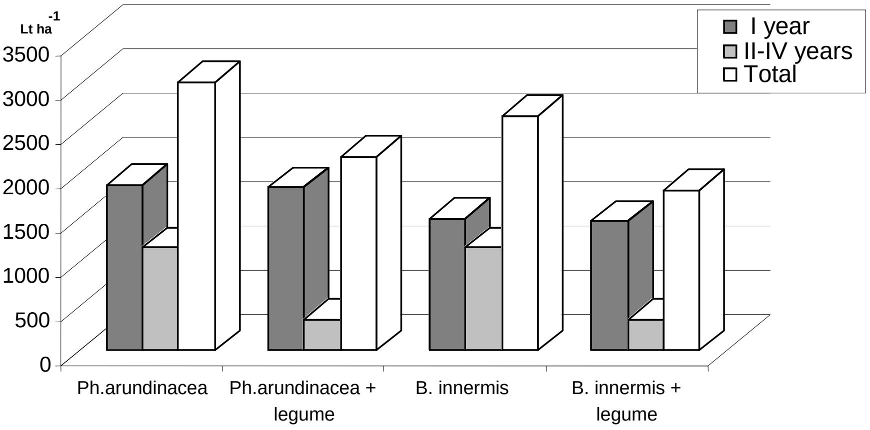

Fig. 1. Cultivation costs of perennial grasses and legumes in the I–IV years.

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 118-387 Lt ha^{-1}, and 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.

Summarized data of calculations suggest that the costs for the swards of different species composition over the four years of use were different: under intensive farming systems pure grass crops have to be fertilised with nitrogen fertilisers, which involves extra costs amounting to more than 800 Lt ha^{-1}, compared with the costs for mixtures.

Table 5. Energy input for pure grass swards (with N) cultivation and harvesting.

Indicator and unit of measurement	Energy input for cultivation		Energy input for harvesting	Total energy input	
	Sowing year	Harvest year	Sowing and harvest year	Sowing year	Harvest year
Direct energy input, MJ ha^{-1}	1009.9	1069.7	2828.3	3838.2	3898.0
Indirect energy input (fertiliser, seed), MJ ha^{-1}	8315.0	13835.0	-	8315.0	13835.0
Machinery energy consumption, MJ ha^{-1}	424.0	445.9	984.7	1408.7	1430.6
Human labour input, MJ ha^{-1}	4.5	4.8	17.1	21.6	21.9
Total energy input, MJ ha^{-1}	9753.4	15355.4	3830.1	13583.5	19185.5

Table 6. Energy input for grass/legume mixtures cultivation and harvesting.

Indicator and unit of measurement	Energy input for cultivation	Energy input for harvesting	Total energy input
Direct energy input, MJ ha^{-1}	950.1	2828.3	3778.4
Indirect energy input (fertiliser, seed), MJ ha^{-1}	2795.0	-	2795.0
Machinery energy consumption, MJ ha^{-1}	402.2	984.7	1386.9
Human labour input, MJ ha^{-1}	4.2	17.1	21.3
Total energy input, MJ ha^{-1}	4151.5	3830.1	7981.6

Besides saving costs, mixtures with legumes provided ecological fuel, 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.

While calculating energy input for biofuel preparation from tall-growing perennial grasses we estimated energy input for swards establishment, cultivation and harvesting. Sward establishment and cultivation energy input consist of pre-sowing soil preparation, sowing and sward fertilisation. Harvesting energy input consists of herbage mowing, swathing, turning, drying, gathering of the dried biomass, baling, loading of bales and transportation to the storage place.

Total energy input was calculated having estimated machinery energy consumption; human labour input is presented in Tables 5 and 6.

Total energy input for pure grass swards (with N) cultivation and harvesting of sowing (first growing) year amounted to 13.6 GJ ha^{-1}, and of first harvest (second growing) year reached 19.2 GJ ha^{-1}. Total energy input for grass/legume mixtures cultivation and harvesting of sowing and harvest year was considerably less – they reached 8.0 GJ ha^{-1}. Indirect energy input amount accounts for the largest share (over 80%) of the total energy input. The energy potential was from 95 GJ ha^{-1} to 153 GJ ha^{-1} and is 5 – 19 times higher than the energy input for biofuel production.

CONCLUSIONS

1. The DM yield of the grasses in pure stands ranged from 6.4-6.9 t ha^{-1} when the swards were cut once per season and biomass was used for combustion; the yield amounted to 9.3 t ha^{-1} when the swards were cut twice per season and biomass was used for biogas.
2. 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.
3. 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. The swards had a positive soil conservation effect and maintained soil productivity potential.
4. The energy potential of tall-growing perennial grasses and their mixtures with legumes in the years favourable for their growth was 123–153 GJ ha^{-1}. The energy potential of pure reed canary grass swards (with N) was 115–130 GJ ha^{-1}, and that of the mixtures with goat's rue and perennial lupine (without N) - 95–153 GJ ha^{-1}.
5. Total energy input for pure grass swards (with N) cultivation and harvesting of a sowing year amounted to 13.6 GJ ha^{-1}, and of the first harvest (second growing) year reached up to 19.2 GJ ha^{-1}. Total energy input for grass/legume mixtures cultivation and harvesting of sowing and harvest year was considerably less – they reached 8.0 GJ ha^{-1}. The energy potential is 5–19 times higher than the energy input for biofuel production.

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