Evaluation of reed canary grass (*Phalaris arundinacea* L.) grown for energy use

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Abstract

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Field experiments with reed canary grass were conducted during 1996–2000 at four different sites (Ruzyně, Troubsko, Lukavec and Chomutov in the Czech Republic). In the period 2001–2009 the experiments were run at Ruzyně and Lukavec. During vegetation the following indicators were monitored: the course of weather in individual years at given sites and infestation of stands by pests and diseases. Furthermore, we monitored the effects of N application rates, year, site, as well as the effect of harvest time on yields of harvested biomass, moisture content, elements content, and energy content. The content of heavy metals in soils and subsequently in plants was also monitored. The zoning methodology was created for reed canary grass. The highest average dry matter yield of reed canary grass harvested in late autumn was achieved for comparable periods during 1996–2000 at Ruzyně (8.33 t/ha), and the lowest at Chomutov (6.80 t/ha). The greatest effect of N fertilization on yields was recorded at Ruzyně, where the N2 rate (80 kg/ha) increased the yield on average by 28.6% in comparison with the non-fertilized variants. Average loss of biomass over winter was 23.0%.

Keywords: reed canary grass; yield, N fertilization; energy content; heavy metals; zoning

One of the alternative crops being considered for extensive cultivation for industrial and energy use is reed canary grass (*Phalaris arundinacea* L., syn.: *Baldingera arundinacea* L. Dumort.). It is a perennial, heterogamous and stolonate grass from the Poaceae family. The species is indigenous to the Czech Republic.

In natural grass stands, reed canary grass most commonly occurs in the vicinity of water. Its spread even into high mountains points to resistance to harsh climatic conditions. It can grow in all soils (with higher fertilization even in poor soils) and it tolerates an abundance or shortfall of moisture. High yields are achieved, however, in years with higher rainfall and in soils where the ground water level is around 30–40 cm. Reed canary grass is a perennial species, but after sowing it develops more slowly than other commonly grown grasses.

In addition to its use for direct burning or cogeneration (producing electricity and heat), reed canary grass can be used when still green as fodder (fresh forage, hay, silage), and possibly for the production of biogas.

Reed canary grass is being newly adopted as an energy source also in the Baltic countries, where it is preferred to fast-growing trees (Hovi 1994). In Sweden, it is planned for reed canary grass to serve as a resource for pulp production (lignin content is around 14%, cellulose content is 30–36%) or as a potential energy source. The suitability of reed canary grass as a source for energy or cellulose production also has been confirmed e.g. by Kozlowski et

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al. (1996), Nixon and Bullard (1997), Pahkala and Mela (1997), Pedersen (1997), Frydrych et al. (2001), Saijonkari-Pahkala (2001), Strašil (2008) and others.

The Crop Research Institute in Prague-Ruzyně, in cooperation with other organizations, began research some years ago on the cultivation of non-traditional industrial and energy crops. The research is aimed at screening (i.e. finding suitable species, or possibly varieties) and testing plants from the viewpoint of their suitability for industrial and energy use. The aims of the experiments with reed canary grass were to evaluate its yield and the suitability of the crop for energy use, in particularly for combustion purposes (to generate heat and electricity). Here are present results from field trials conducted over the course of several years at various ecologically distinct sites.

MATERIAL AND METHODS

Experiments with reed canary grass were established at selected sites in 1994. This article reports results from 1996–2000, i.e. from fully integrated and mature stands. Field experiments took place in that period at four different sites (Ruzyně, Troubsko, Lukavec and Chomutov in the Czech Republic) in three repetitions on small plots of 5 × 2.5 m, i.e. 12.5 m^2. Soil and climate characteristics for individual sites are given in Table 1. Since 2001, experiments with reed canary grass have continued at two sites only, Ruzyně and Lukavec. The experiments at Ruzyně were conducted at the same field until 2002. From 2003, experiments with reed canary grass were established at a different field of the site where they have been conducted until today. Experiments at Lukavec were conducted at the same field until 2006. That means the reed canary grass was at the same site for 13 years. From 2007, the experiments in Lukavec were also established at a different field. We chose the Motterwitzer variety for use in the trials.

Fertilization in field trials was as follows: prior to establishing the trials, P and K fertilizer was applied in autumn at the rate of 60 kg/ha P_2O_5 in superphosphate and 60 kg/ha in potassium chloride. In the following years PK fertilizer was not applied. Reed canary grass was always established in early spring as monoculture. The seeding rate was 20 kg/ha of seed. Three levels of N fertilization were applied in the experiments (N0 – without N fertilization, N1 – 40 kg/ha N, and N2 – 80 kg/ha N in two applications). N fertilizer was applied every year in spring (end of March) from the second year after the spring harvest of reed canary grass. In the case of the N2 rate, the N fertilization was divided into halves. The first nitrogen application was made at the end of March and the second in mid-May. Ammonium sulphate was applied in spring and calcium ammonium nitrate was applied during vegetation.

Harvest of reed canary grass was made for the entire monitored period. A single autumn harvest

Table 1. Characteristics of experimental sites

Parameter	Experimental site			
	Prague-Ruzyně	Lukavec	Troubsko	Chomutov
Latitude	50°04'	49°37'	49°12'	50°26'
Longitude	14°26'	15°03'	16°37'	13°23'
Altitude (m)	350	620	270	363
Soil texture	clay-loam	sandy-loam	loam	sandy-loam
Great soil group	orthic luvisol	orthic cambisol	luvic chernozem	stagno-gleyic cambisol
Average annual air temperature (°C)	8.2	6.9	8.4	7.6
Average annual precipitation sum (mm)	477	657	547	514
Agrochemical properties of topsoil:				
Humus content (%)	3.00	3.03	3.44	2.58
pH (KCl)	5.57	5.43	5.94	5.03
P content (Mehlich II, mg/kg of soil)	124.9	131.0	112.0	16.6
K content (Mehlich II, mg/kg of soil)	126.0	166.0	199.7	44.9

was taken initially, and since 2001 another cutting was taken also in the following spring. During 2007–2009, apart from the autumn and spring cuttings, two cuttings were made in summer and autumn.

The following indicators were monitored during vegetation: the course of weather in individual years at given sites, health condition, and degree of infestation by pests and diseases. We studied the effects of the N fertilizations, year, site and timing of harvest on yields of harvested biomass, moisture content, elements content, and energy content.

The monitored indicators also include ash and energy content. Energy content was determined by Parr 1356 calorimeter (PARR Instrument Company, Moline, USA) in accordance with the Czech national standard ČSN 44 1352 (1928), excluding ash.

Ash content was determined in accordance with the technical standard ČSN EN 14775 (2010).

Moisture content was determined by drying samples in a dryer HS 202A (LABsystem Praha, Prague, Czech Republic) at 90°C to a constant weight. The 90°C temperature was chosen so that the volatile substances did not vaporize from the dried sample.

Content of individual elements in soils and plants was determined in compliance with the ČSN ISO 11 885 (2009). Plants and soils were decomposed in an MLS-1200 Mega microwave decomposing device from MILESTONE s.r.l. (Sorisole, Italy). The 10-position rotor (low-pressure decomposition) was used for plants and the 6-position rotor (medium-pressure decomposition) was used for soils. Measurement was performed using a Thermo Jarrell Ash inductively coupled plasma – optical emission spectrometer from Trace Scan (Franklin, USA).

Comparison of heavy metals content in soils was in accordance with Regulation No. 13/1994 Coll. Soils and plants were mineralized according to the methodology. Decomposition of soils was carried out using *aqua regia*, and plants were decomposed by H_2SO_4 mineralization. Elements in prepared samples of soils and plants were subsequently determined on an atomic absorbance spectrometer (Thermo Jarrell Ash, Franklin, USA). Content of heavy metals in plants was compared to limit values reported for forage crops according to Neuberg (1990).

Results were statistically processed using the method of analysis of variance (ANOVA) and multivariate comparison (least significant difference).

Two main sources were used to create the zoning methodology: results of field testing of reed canary grass on more sites and the Czech agricultural land valuation or more precisely its main soil-climatic units (HPKJ in Czech). Each unit comprises sites with similar climatic and soil conditions for agricultural (plant) production. HPKJ are expressed in 3-numeric code that stands for: (1) Climatic region (KR with 10 classes) and (2)–(3) Main soil units (HPJ with 64 classes). Results of the crop's field testing were related to HPKJ units to create groups of land suitability types for reed canary grass.

RESULTS AND DISCUSSION

Monitoring during vegetation

During the monitored period no significant occurrence of diseases or pests was detected in reed canary grass at any of the sites. In the first year after establishing the grass stands, one cutting (two cuttings in Lukavec) was made to remove weeds at all sites with the exception of Ruzyně. These were sufficient to maintain the stands nearly weed-free in the following years.

Yields from single autumn harvest

Average biomass dry matter yields of the reed canary grass from single autumn harvest at individual sites are presented in Tables 2 and 3.

Table 2 presents results from 1996–2009, i.e. for fully integrated and mature stands. In 2002, the reed canary grass stand in Ruzyně was eliminated and in 2003 was established at a different place. A similar situation was in Lukavec, where the stand of reed canary grass was eliminated in 2006 and established at a different place in 2007. It is clear from the results that the biomass yields of reed canary grass greatly depend on the course of weather conditions in individual years and on given sites. In Ruzyně, for example, biomass yields from a single autumn harvest varied on average between 3.9 t/ha of dry matter in 2003 and 12.9 t/ha in 2002. The low yield in 2003 was caused in particular by the fact that a new stand of reed canary grass was established at a different place in that year. It is known that yields of most grasses, and in particular of reed canary grass, are not highest in the year when established. Higher yields have been achieved since the second year. Similarly significant yield variation is evident also at other sites (Table 3).

Table 2. Year and N fertilization effects on dry matter yields of reed canary grass (t/ha) harvested in late autumn at Ruzyně and Lukavec sites

Year	N0		N1		N2		N average	
	Ruzyně	Lukavec	Ruzyně	Lukavec	Ruzyně	Lukavec	Ruzyně	Lukavec
1996	10.8	3.7	10.5	5.7	14.6	6.7	12.0	5.4
1997	4.7	6.9	5.8	7.8	6.8	8.0	6.3	7.6
1998	5.3	11.5	6.4	14.3	6.0	15.6	6.0	13.8
1999	11.1	3.6	11.8	7.8	13.1	9.4	11.7	6.9
2000	4.3	3.4	4.2	3.9	8.6	4.4	5.7	3.9
2001	9.7	5.9	10.6	6.8	10.6	7.7	10.3	6.8
2002	11.3	8.3	13.9	9.1	13.5	10.3	12.9	9.2
2003	3.4	9.1	3.9	10.5	4.4	13.9	3.9	11.3
2004	3.9	11.3	6.5	11.9	8.0	14.6	6.1	12.6
2005	6.4	5.9	7.6	6.1	9.1	6.8	7.7	6.2
2006	8.35	8.6	13.0	8.9	14.7	9.0	12.0	8.9
2007	3.4	5.5	4.4	5.7	7.2	6.4	5.0	5.9
2008	5.3	7.2	5.1	8.6	7.0	8.7	5.8	8.2
2009	5.9	5.9	7.3	6.5	8.5	7.1	7.2	6.5
Average 1996–2000	7.23	5.8	7.74	7.9	9.81	8.8	8.33	7.5
Average 1996–2000 (%)	100	100	106.5	126.6	126.3	134.1	113.2	122.3
Average 1996–2009	6.64	7.07	7.83	8.13	9.30	9.02	7.95	8.08
Average 1996–2009 (%)	100	100	115.2	113.0	128.6	121.6	116.5	112.5

dosage of N fertilizers: N0 – without N fertilization, N1 – 40 kg/ha, N2 – 80 kg/ha

Yields of reed canary grass biomass during the monitored period were significantly affected by site, weather and N fertilization (Tables 4 and 5). Only in comparing the two sites Ruzyně and Lukavec there was no determination of significant influence by site (Table 5). Yields variation depends upon the course of the weather and in particularly on the distribution of rainfall and temperatures during vegetation in individual years and at given sites. Katterer et al. (1998) state, for example, that a relatively cold May limited growth and caused reed canary grass yields to decrease compared with other years. The highest range of average yields between 1996 and 2000 was recorded in Lukavec (3.9 to 13.8 t/ha – Table 2), the lowest in Troubsko (7.0 to 9.5 t/ha – Table 3).

Table 3. Year and N fertilization effects on dry matter yields of reed canary grass (t/ha) harvested in late autumn at Troubsko and Chomutov (Chom.) sites

Year	N0		N1		N2		N average	
	Troubsko	Chom.	Troubsko	Chom.	Troubsko	Chom.	Troubsko	Chom.
1996*	7.20	4.30	7.50	4.00	8.60	7.10	7.80	5.10
1997	7.80	5.30	8.20	4.70	8.80	8.00	8.30	6.00
1998	8.90	4.40	9.30	5.00	10.10	7.80	9.50	5.70
1999	8.37	10.0	9.57	11.40	9.71	10.40	9.22	10.60
2000	6.10	5.60	6.20	6.8	8.70	7.60	7.00	6.70
Average 1996–2000	7.67	5.90	8.15	6.40	9.18	8.20	8.36	6.80
Average 1996–2000 (%)	100	100	105.9	107.1	116.4	126.9	108.3	113.2

dosage of N fertilizers: N0 – without N fertilization, N1 – 40 kg/ha, N2 – 80 kg/ha; *crop established in the year 1994

Table 4. ANOVA results for yields of reed canary grass harvested in autumn during 1996–2000 at four sites in experiments with different N fertilization

Source of variation	Sum of squares	df	Mean square	Stat *F*	Significance
Main effects	251.295	9	27.922	28.980	0.0000**
Site	38.057	3	12.686	13.166	0.0000**
Year	147.124	4	36.781	38.175	0.0000**
N-fertilization	66.114	2	33.057	34.309	0.0000**
Two way interaction	280.918	26	10.805	11.214	0.0000**
Site × Year	265.856	12	22.155	22.994	0.0000**
Site × N fertilization	4.753	6	0.792	0.822	0.5638
Year × N fertilization	10.308	8	1.288	1.337	0.2732
Error	23.124	24	0.963		

**statistically significant effect ($P < 0.01$)

Table 5. ANOVA results for yields of reed canary grass harvested in autumn during 1996–2009 at Ruzyně and Lukavec sites in experiments with different N fertilization

Source of variation	Sum of squares	df	Mean square	Stat *F*	Significance
Main effects	351.399	16	21.962	17.755	0.0000**
Site	0.142	1	0.142	0.115	0.7377
Year	271.768	13	20.905	16.900	0.0000**
N-fertilization	79.489	2	39.745	32.130	0.0000**
Two-way interaction	432.620	41	10.552	8.530	0.0000**
Site × Year	409.225	13	31.479	25.448	0.0000**
Site × N fertilization	1.758	2	0.879	0.710	0.5007
Year × N fertilization	21.637	26	0.832	0.673	0.8408

**statistically significant effect ($P < 0.01$)

The highest average yield in comparable periods was achieved at Ruzyně (8.33 t/ha), and the lowest at Chomutov (6.81 t/ha). On average for all sites during 1996–2000, the average biomass dry matter yield was 7.77 t/ha. For the period 1996–2009 average dry matter yield at Ruzyně was 7.95 t/ha, and similar yield of 8.08 t/ha was achieved at Lukavec (Table 2). Statistical comparison of individual sites is provided in Tables 4 and 5.

The average yields achieved were not the highest in comparison with those of some other perennial energy crops, such as knotweed or Chinese silver grass (Miscanthus sinensis). It is important, however, to compare the economics of growing reed canary grass versus other energy crops. Strašil (2000) calculated that the overall costs without subsidies to produce 1 tonne of reed canary grass dry matter to be an average 1,200 CZK. Usťak and Peterová

Table 6. Comparison between dry matter yields of reed canary grass (t/ha) obtained after harvesting in two terms (in summer and autumn) and in one term in autumn at Ruzyně and Lukavec sites (average values)

Year	Ruzyně				Lukavec			
	1st term	2nd term	sum	autumn	1st term	2nd term	sum	autumn
2008	8.32	1.94	10.26	8.90	6.31	2.28	8.59	8.10
2009	7.28	2.59	9.87	6.66	4.60	2.62	7.22	8.71
Average	7.80	2.27	10.07	7.78	5.46	2.45	7.91	8.41

(2006) determined that the technological costs for growing reed canary grass over a ten-year growth period ranged according to the intensity of growing from 715 to 762 CZK per 1 tonne, Frydrych et al. (2001) reported that costs for growing energy grasses per 1 tonne of dry matter are 1,400 CZK in the first and second cropping years and 1,265 CZK in the third and fourth cropping years. These indicated costs are lower in comparison with, for example, those for Uteusch's sorrel, sorghum, or miscanthus, where Kavka et al. (2006) reported that technological costs per 1 t of dry matter of these products, depending upon the intensity of their growing, are from 404 to 1,030 CZK, from 1,425 to 1,851 CZK, and from 1,354 to 2,376 CZK, respectively. For another comparison, Moudrý and Pokorný (1998) reported that costs per 1 t of cereal straw as fuel are around 700 CZK and costs per 1 t of biomass of whole cereal plants average 1,200 CZK.

Effect of N fertilization on yields

Reed canary grass reacted positively to increasing N application rates by increasing biomass yields. Already at the lower N1 annual rate of 40 kg/ha applied in spring, average biomass yields were increased at all sites across years. On average, across years and sites, the rate of 40 kg/ha (N1) increased reed canary grass biomass dry matter yields by 8.6% (0.81 t/ha). Also, subsequent N fertilization at the rate of an additional 40 kg/ha in ammonium nitrate during vegetation (N2) further significantly increased average biomass yields by 23.6% (2.11 t/ha) compared with non-fertilized plots (Tables 4 and 5). The highest yield increases due to N fertilization were recorded during the monitored period at Ruzyně and Lukavec (Table 2), where the N1 rate increased yields on average by 15.2 and 13.0% and the N2 rate by 28.6 and 21.6% in comparison with non-fertilized plots. At Chomutov, we also recorded an increase in average yields at the N2 rate by 26.9% in comparison with non-fertilized plots (Table 3).

N fertilization also had a positive effect on the status of the reed canary grass stand. If N fertilization was not applied, the stand was thinning (loss of plants) on non-fertilized plots, especially in later years, which manifested itself in decreased yields. Plots that were N fertilized every year were in good condition even after several years.

When we compare one autumn harvest and the two harvests shown in Table 6, higher dry matter yields were recorded in individual years and on average at Ruzyně for the sum of two harvest times by an average of 2.29 t/ha (22.7%). The situation was similar at Lukavec, except for in 2009, when one autumn harvest had higher yields compared to the two harvest times.

In a comparison with neighbouring countries, reed canary grass achieves yields of 4.5 to 9.0 t/ha converted to dry matter, and dry matter losses through winter range from 25 to 40% (Nixon, Bullard 1997; Strašil et al. 2005). Yates et al. (2001) state that maximum dry matter yields of reed canary grass achieved in Great Britain are 11.5 t/ha.

Harvest date and moisture content

From the energy and economic viewpoints, harvest date is also important. Generally, the greatest increase of biomass in most plants is at the time of flowering or shortly past flowering. Thereafter, biomass is gradually lost. In the first harvest period the moisture content in biomass in most energy plants is 60–80%. From an energy viewpoint, biomass that is this moist only can be used for biogas production. If it is to be used for purposes of direct boiler combustion or for producing pellets or briquettes, it must be dried directly on the field if the weather is good, or artificially in drying plants. In these cases, other costs must be incurred for these operations, chiefly drying by hot air.

During late-autumn harvest, the moisture content continues to be relatively high (in a range of 30–70%) in most perennial energy plants, including reed canary grass. Yield is not much lower compared with the first harvest period.

Differences in biomass yields (in dry matter) and moisture of reed canary grass at different harvest times are shown in Table 7. Without being dried, biomass of reed canary grass is not suitable for immediate burning even at the end of November. At the reported time, we found the average moisture content to be around 50%. There are two possibilities to get rid of the excessive water by winter: either to desiccate the stand in autumn or harvest and dry it artificially. If soil, climate and snow conditions permit, the stand may also be harvested over the winter season, or can be harvested until spring, until the time before stand starts rising again.

First frosts will dry the stand so that it can be harvested and directly combusted. Moisture below 20% at the spring harvest time is suitable for

Table 7. Reed canary grass yields of fresh matter (t/ha), dry matter (t/ha) and dry matter content of phytomass (%) obtained at two sites in various terms of harvest (average 2006–2009)

Site	1st term*			2nd term**			3rd term***		
	yield		dry matter content (%)	yield		dry matter content (%)	yield		dry matter content (%)
	fresh matter	dry matter		fresh matter	dry matter		fresh matter	dry matter	
Ruzyně	17.04	5.98	35.1	14.74	8.36	56.7	7.21	6.29	87.2
Lukavec	24.77	7.48	30.2	14.11	7.80	55.3	5.37	4.54	84.6
Average	20.91	6.73	32.7	14.43	8.08	56.0	6.29	5.42	85.9

*harvest in heading time (half of June), **harvest in autumn (beginning of November), ***harvest early in spring (half of March following year)

direct pressing into briquettes or pellets, storage, or immediate burning. Reed canary grass's average 23.0% loss of biomass (Table 7) over the winter period is not high in comparison with some energy crops. For example, loss of biomass over the winter period was reported to be 37.5% in knotweed and 35.1% in *Miscanthus* (Kára et al. 2004). The loss is compensated by the moisture reduction. A stand of reed canary grass usually does not lodge over winter, which makes harvest possible without significant losses of biomass.

Looking at yields abroad, for example in Sweden, Landstrom et al. (1996) reported that average dry matter yields for 5 years of growing (starting from the second year) with N fertilization at the rate of 100 kg/ha N were 9 t/ha at the end of the vegetation season and 7.5 t/ha in spring. Dry matter losses over the winter period were reported to be around 25%.

Spring harvest is recommended also because at later harvest times the contents of potassium, chlorine, nitrogen and sulphur in the biomass of reed canary grass and other crops decrease compared to early harvest times. The amount of nutrients contained in plants is almost halved in spring compared to plants harvested in August, for example. A reason for this is the translocation of nutrients to the root part and its leaching from plants during winter (Katterer, Andren 1999; Partala et al. 2001). A comparison of the element content in reed canary grass at different harvest times per 1 kg of air-dried material according to our observations is given in Table 8. The dry matter content of this material varied across years, sites and varieties from 91.0 to 92.5%. The fact that postponing harvest decreases the element content in reed canary grass is also confirmed by Yates et al. (2001).

At late harvest times (March), for example, the temperature of ash sintering when burning reed canary grass biomass increases and lower emissions of SO_x and NO_x are recorded compared to earlier harvest times (July–September) (Kára et al. 2004). The fact that biomass of reed canary grass from spring harvest has better combustion parameters was also confirmed by Landstrom et al. (1996), Hadders and Olsson R. (1997), Hutla et al. (2005).

Another advantage of harvest after winter is that in autumn some stems in certain populations of reed canary grass have the tendency to form green branches from the axil on leaf sheaths, which causes an undesirable increase of moisture content.

For reed canary grass considered for biogas production, three to four cuttings per year are recommended (Jo, Lee 1997; Geber 2002). For reed canary grass intended for burning one harvest per year is most prevalent. In our experiments, we har-

Table 8. Element content (g/kg of dry matter) in plants of reed canary grass in various terms of harvest (average 2006–2009)

Term of harvest	Element content (g/kg) in dry matter				
	N	P	K	Ca	Mg
1st term	13.55	2.33	10.54	7.02	1.89
2nd term	9.95	1.70	5.69	4.01	1.19
3rd term	9.23	1.43	1.43	2.45	0.55
Average	10.91	1.82	5.89	4.49	1.21

Table 9. Values of combustion heat of reed canary grass biomass (kJ/g) at different terms of harvest and at different moisture contents of harvested material (average values)

Indicator	Term of harvest	Energy value
Combustion heat of dry matter	1st term*	17.74
Combustion heat of dry matter	2nd term**	17.30
Combustion heat of dry matter	3rd term***	17.80
Average terms of harvest		17.61
Combustion heat of dry matter (fertilization N0)	1st term*	17.51
Combustion heat of dry matter (fertilization N2)	2nd term**	17.97
Combustion heat of matter with moisture content of 50%	3rd term***	9.90
Combustion heat of matter with moisture content of 20%	3rd term***	14.59

*harvest in heading time (half of June), **harvest in autumn (beginning of November), ***harvest early in spring (half of March following year), N fertilization: N0 – without fertilization, N2 – 80 (kg/ha)

vested reed canary grass intended for combustion also in June when the plant was in bloom. Yields from summer harvest are shown in Table 7. This harvest time has an advantage in that the biomass of reed canary grass can be dried at low cost in the field in direct sun. A disadvantage is that plants continue to grow through the end of vegetation during summer, and this must be harvested or mulched in autumn. Harvest or mulching in autumn are necessary in terms of pests, a new stand tillering in spring and to make any trouble during the subsequent harvest.

Energy content of biomass

For combustion purposes, energy content of the combusted material is an important factor. Therefore, the energy content and fuel value of reed canary grass biomass at different harvest times were established. Table 9 presents average values for 2001–2005. Average energy value of the biomass dry matter, at 17.6 kJ/g, is similar to values for brown coal used for heating in households. Combustible heat strongly depends on moisture content of the biomass. If moisture is 50%, it is only 9.9 kJ/g. In the case of moisture up to 20%, it is suitable for direct combustion in most low-output boilers and the combustible heat of reed canary grass is 14.6 kJ/g, which corresponds to poorer quality brown coal that is used in Czech thermal power plants. Moreover, the table shows that the various harvest times and levels of N fertilization do not significantly affect the energy content of the harvested reed canary grass biomass.

Effect of site and N fertilization on the content of ash and heavy metals

Table 10 shows the following when comparing soils from different sites: according to the 1989 Criteria of the Central Institute for Supervising and Testing in Agriculture (Neuberg et al. 1990) and extraction according to Mehlich II, the soil phosphorous content at the Chomutov site is low, while it is high at other sites. The potassium content is low at the Chomutov site, adequate at Ruzyně, and good at

Table 10. Content of heavy metals in soils (mg/kg) in experimental sites in average during 1994–1996 and maximal admitted value according to Regulation No. 13/1994 Coll

Site	Cd	Pb	Cr	Ni	Co	Zn	Cu	As
Prague-Ruzyně	0.3	29.0	2.8	4.7	3.2	22.0	13.6	4.4
Lukavec	0.2	16.9	6.7	2.5	4.5	19.6	6.0	0.8
Chomutov	0.2	22.9	4.2	10.9	8.6	34.8	13.0	10.9
Maximal admitted values (decomposition of *aqua regia*)								
Light soils	0.4	100	100	60	25	130	60	30
Other soils	1.0	140	200	80	50	200	100	30

the other sites. Based on the evaluation criteria, the soil reaction at the Chomutov site is strongly acid, at Ruzyně and Lukavec it is acid, and at Troubsko it is slightly acid.

Ash and energy contents depend on many factors. These also vary by the type of raw material. Ash content in plant biomass depends, as well, upon the age of the plant. Young plants typically contain less ash than do older plants. For example, ash contents in young plants of timothy or cereals in bloom are 2.0 and 1.5%, respectively, while older timothy plants contain 5.9% ash and cereal straw after harvest 4.5% ash (Čvančara 1962). In our experiments, we observed how the ash content, or more precisely, nutrients content, is affected by site and N fertilization. Average values from autumn harvest are presented in Table 11.

Table 11 clearly shows the effect of site on ash content. It was found that on average the ash content in plants increases depending on the type of soil, from lighter soil in Lukavec (4.5%) to heavier soil with higher representation of clay particles in Ruzyně (7.8%). We found the average ash content in reed canary grass to be 5.7% (Table 11). Comparison of ash content with other plants is made, for example, in the work of Strašil (2007). Similarly, Burvall (1997) found that when reed canary grass was grown in thick clay soils, the ash content was 10.1% while plants grown in humus soils had ash content of just 2.2%.

Furthermore, N fertilization was found to decrease the ash content at all sites on average by 8.6% (Table 11) compared with unfertilized plots. The ash content in reed canary grass is slightly higher than in the woody material (0.5–3.0%), but it is much lower than in black or brown coal (around 25.0%) Pastorek et al. (2004).

Heavy metals content in soils was monitored at the selected sites and subsequently in plants of reed canary grass. The content of heavy metals in soils at given sites, including max. permissible values according to Regulation No. 13/1994 Coll., are presented as averages for the period 1994–1996 in Table 10. Based on the results, we can conclude: Soils in which the selected crops were grown do not exceed maximum permissible values according to Regulation No. 13/1994 Coll. for any of the monitored heavy metals at any site, nor are they even close to such levels (Table 10). Thus, there is not a high probability that the monitored plants will contain a sharply increased amount of some of the monitored heavy metals.

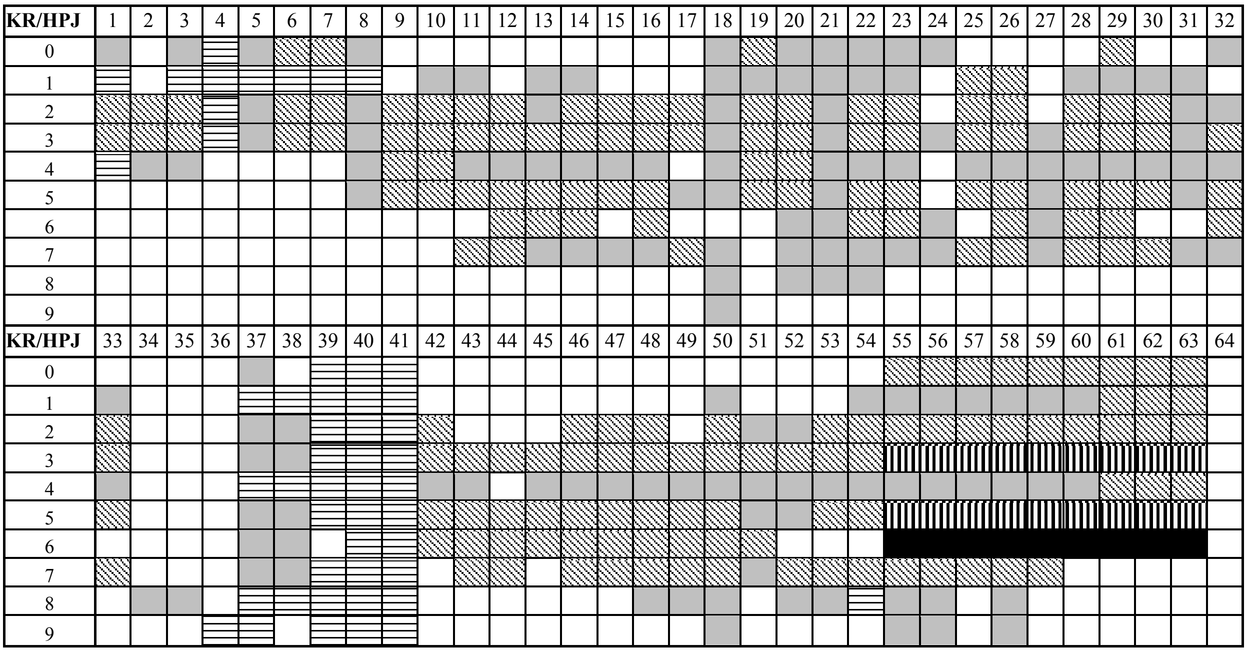
In general, soils at the Lukavec site show the lowest values of the monitored heavy metals in comparison with other sites, excluding chromium and cobalt. The highest contents of most of the moni-

Table 11. Heavy metals content according to the amount of N fertilization (mg/kg) in reed canary grass from selected experimental sites on average during period 1994–1996 and their maximal admitted values in coarse fodder

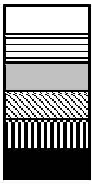
Site	N rate	Ash (%)	Cd	Pb	Ni	Co	Zn	Cu	As
	N0	8.02	0.24	0.32	0.92	0.36	31.7	4.5	1.008
Ruzyně	N2	7.54	0.22	0.33	0.67	0.76	14.7	3.2	1.098
	Average	7.78	0.29	0.57	0.72	0.80	24.7	4.07	1.136
	N0	4.85	0.17	3.20	0.90	1.40	53.6	6.7	–
Lukavec	N2	4.08	0.18	3.10	0.40	0.90	41.2	5.3	–
	Average	4.47	0.18	3.15	0.65	1.15	47.4	6.0	–
	N0	4.95	0.20	7.40	1.60	0.50	33.5	2.8	0.133
Chomutov	N2	4.49	0.25	6.10	1.40	0.30	25.9	4.3	0.204
	Average	4.72	0.22	7.17	1.40	0.43	30.1	3.57	0.172
	N0	5.94	0.20	3.64	1.14	0.75	39.6	4.70	0.571
Sites average	N2	5.37	0.24	3.22	1.04	0.53	20.3	3.75	0.651
	Average	5.66	0.28	2.64	0.91	0.85	29.2	4.31	0.842
Proposed limit values of heavy metals for dried forage*									
			1.0	15.0	15.0	6.0	500	100	–

*according to Neuberg et al. (1990); N fertilization in mineral fertilizers (kg/ha): N0 – 0, N2 – 80

Table 12. Table of preliminary zoning of agricultural land for reed canary grass in the Czech Republic within climatic regions (KR) and main soil units (HPJ) of the Czech agricultural land valuation



Expected autumn yields of dry biomass in five land suitability types for reed canary grass



not existing HPJ
unsuitable sites (autumn yield below 5.0 t (DM)/ha/year)
from 5.0 to 7.0 t/ha
from 7.0 to 9.0 t/ha
from 9.0 to 11.0 t/ha
very suitable and optimal sites (autumn yield over 11.0 t/ha)

tored heavy metals were found in the soil from Chomutov.

Analyses also showed (Table 11) that none of the monitored heavy metals in reed canary grass reaches maximum permissible values proposed for food or fodder purposes (Neuberg 1990). A comparison of heavy metals in reed canary grass and other plants is described in the work by Kára et al. (2004).

We also examined how the nitrogen application rates used influence plants' uptake of heavy metals from soil. From average values of heavy metal contents in plants found at individual sites or summarized for all sites, it can be concluded, derived that under the given conditions no effect of N fertilization on the content of the monitored heavy metals in the reed canary grass biomass was observed.

Preliminary zoning

Preliminary agricultural land suitability types for reed canary grass are shown in Table 12, which also includes expected yields of dry biomass during autumn harvests for conditions of the Czech Republic. Given yields are achievable under average climatic conditions and if reed canary grass is grown in accordance with recommended methodologies. Both results may be corrected according to the results of current field testing.

CONCLUSION

In the case of harvest once a year in autumn, the average of biomass yields of reed canary grass converted to dry matter was around 8.0 t/ha. On the basis of the results obtained, it can be stated that reed canary grass performs well in humid conditions and that it responds well to nitrogen fertilization in poorer soils.

If a stand is well-established, reed canary grass will sustain at one site for a number of years with no reduction in biomass yields. In addition, a dense system of rhizomes and roots stabilizes the soil and a virtually year-round soil cover prevents erosion. Growing reed canary grass improves the soil's physical, chemical and biological features, including increasing organic component. Moreover, the soil can be returned without great difficulty to its original use for production of food crops.

In comparing the different harvest times, the spring harvest can be recommended. The average 23% loss of biomass over the winter period is compensated by the reduction in moisture, since in the autumn we had harvested phytomass dry.

A stand of reed canary grass does not usually lodge over winter, which makes harvest possible without any large biomass losses. Spring harvest is recommended also because at later harvest times the contents of potassium, chlorine, nitrogen and sulphur in biomass of reed canary grass and other crops decrease compared to early harvest times. This is favourable for the combustion process itself and also with respect to the environment.

When compared with certain tufted grasses in particular, reed canary grass, as a rhizomatous grass, appears to be more suited to early spring harvest in terms of energy use, as it does not lodge over winter, its leaves grow from the stalks and it does not create ground-level bunches (which means that reed canary grass stands dry faster).

Introduction of reed canary grass is advantageous for the low costs of establishing stands, minimal or no required use of herbicides or pesticides, and other low direct costs. An indisputable advantage is that in its cultivation and harvest common agricultural machinery is used. Moreover, in the Czech Republic it can be grown while applying appropriate agronomic practices in almost all climatic conditions, from lowlands to highlands.

The zoning methodology were created for reed canary grass. The zoning can now be used in the strategic planning to determine ecologically or economically suitable sites or some environmentally conflicting areas for biomass production using this new energy crop.

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