Study of knotweed (*Reynoutria*) as possible phytomass resource for energy and industrial utilization

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Abstract

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This paper deals with the *Reynoutria* × *bohemica* and *Reynoutria japonica* under conditions of the Czech Republic. It evaluates the impact of soil, weather conditions and various terms of harvest (autumn, spring) on the yield, dry matter content, phytomass loss, ash content, and basic elements content change in plants. Heavy metals content was determined in soil where plants were grown and consequently in plants themselves. The average yield of dry matter at the fully closed stands of *Reynoutria japonica* were 9.06 t/ha in autumn, *Reynoutria* × *bohemica* from 13.23 to 21.41 t/ha, according to the site. The yield losses within the winter period were found on average 42% for *Reynoutria japonica* and 34% for *Reynoutria* × *bohemica*. The moisture decrease of *Reynoutria japonica* was found from 68% in the autumn to 24% in the spring, and of *Reynoutria* × *bohemica* from 67% to 23%, respectively. Decreased content of nitrogen, phosphorus, potassium, calcium, and magnesium in the knotweed phytomass was found during the latter (spring) harvest periods in comparison with the earlier harvest periods. Decreased elements content in phytomass during the latter harvest period (spring) increases the phytomass quality as a fuel from both aspects – technical and emissions generation. The ash content in plants varied according to the site, on average from 3.12% in Ruzyně to 4.6% in Chomutov. None of the heavy metals monitored in knotweed plants reached the maximum admissible values determined for the food or feed purposes in the Czech Republic. From the results of combustion experiments, it is evident that *Reynoutria* × *bohemica* is a good fuel. Energy sorrel shows the extreme CO concentration in flue gases in comparison with other monitored fuels. According to the ČSN EN 12809 (2001) standard it does not meet even the third class of requirements. On the contrary, knotweed and wood bark fulfill the requirements for the first class. The surprising fact is that both of these fuels show the lower level of CO emissions, than the wooden briquettes. Concentrations of nitrogen oxids are comparable with biofuels, except of wood, and probably are related to the nitrogen content in heating material.

Keywords: *Reynoutria*; yields of phytomass; terms of harvest; nutrients content; heavy metals uptake; combustion

The knotweed species belong among the most effective crops in the Central Europe as regards the phytomass yield. Knotweeds are not the original species in the Czech Republic. They were introduced in Europe from the Asian temperate zone. From the knotweed species the *Reynoutria sachalinensis* (F. Schmidt) Nakai, and *Reynoutria japonica* Houtt are represented within the Czech flora. The hybrid of the mentioned species is known as the *Reynoutria* × *bohemica* Chrtek and Chrtkova. The individual species resolution was presented for example in Mandák and Pyšek (1997). From

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Table 1. Average yields of above-ground phytomass d.m. of *Reynoutria* × *bohemica* harvested in autumn at different sites (average of years 1996–2002)

Site	Ruzyně	Lukavec	Chomutov
Yield (t/ha)	19.78	13.23	21.41

the reported species the *Reynoutria sachalinensis* reaches the higher growth and phytomass yields. All of the Japanese knotweed (*Reynoutria japonica*) plants in Europe are female (Kidd 2000). Due to their escaping, aggressivity and rapid uncontrolled propagation the knotweeds are considered the invasion weed in many European countries (Bailey et al. 1994) including the Czech Republic. This fact causes inconvenience in obtaining the permission for their growing. In our trials *Reynoutria japonica* and *Reynoutria* × *bohemica* were investigated from the point of view of possible utilization for energy purposes.

Objectives

Monitoring of the species and site effect on the above-ground phytomass yield. Determination of the harvest time effect on water content in the harvested material, phytomass loss within the winter period. Basic nutrients content in the crops and heavy metals uptake by the crops.

MATERIALS AND METHODS

Yield experiment

The yield experiments with *Reynoutria* × *bohemica* were carried out at three sites (Ruzyně, Lukavec, Chomutov), with *Reynoutria japonica* in Ruzyně with two terms of harvest (autumn, spring). At the crop stand establishment, 2 seedlings/m^2 were planted. The plots of size 3 × 5 m were not fertilized all the time from stand establishment till the end of experiment.

Comparison of emission parameters of biofuels

The selected biofuels were tested in pure form in combustion installations, in which their emission parameters were determined. These fuels were used in the form of briquettes in hearth stoves. The measurement was carried out at hearth stove, type SK-2, manufacturer RETAP, limited liability company, in Bahniště. For the emission measurement the apparatus of the MADUR company, type GA-60 was used. This measuring instrument is equipped with a probe serving to flue gases sampling, which is placed directly in the smoke flue; the measured values are displayed in real time by means of electrochemical inverters. These values are stored continuously in selected intervals in data memory. It enables their fur-

Table 2. Dry matter yields of *Reynoutria japonica* above-ground phytomass in autumn and spring (t/ha) and moisture of harvested phytomass (%) at the Ruzyně site

Year	Autumn		Spring		Difference in the yield autumn–spring (%)
	yield	moisture	yield	moisture	
1995 (establishment)	1.524	68.9	1.220	35.8	19.9
1996	6.107	67.1	3.763	21.6	38.4
1997	5.476	60.3	2.719	20.7	50.3
1998	5.485	70.7	2.808	23.7	48.8
1999	15.893	61.5	6.106	21.5	61.6
2000	7.982	71.5	6.113	20.4	23.4
2001	11.158	68.3	6.776	23.0	39.3
2002	8.360	73.5	6.866	28.7	17.9
Average 1995–2002	7.774	67.7	4.546	24.4	41.7
Average 1997–2002	9.059	67.6	5.231	23.0	42.3

Seedlings number at the stand establishment 2 seedlings/m^2

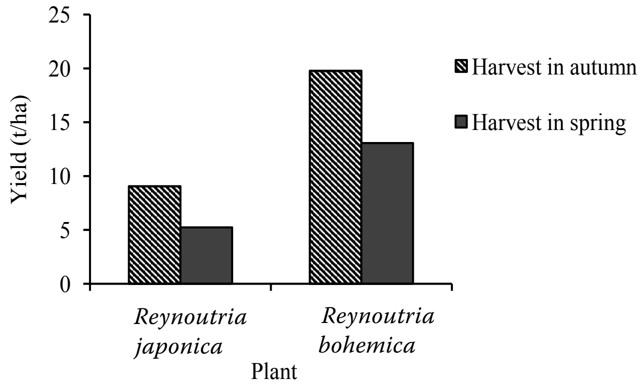

Fig. 1. Losses of phytomass d.m. during winter period (average of years 1996–2002)

ther electronical processing. We used the apparatus equipped with inverters destined for concentration measurement of the following substances: CO, CO_2, SO_2, O_2, NO, HCl (ppm), air surplus *n*, etc. and also by sensors for measurement of ambient temperature T_{ok} and temperature of flue gases T_{pl} (°C). The other parameters are calculated. The obtained values are consequently converted to specific concentrations (mg/m^3). During the measurements the interval of data storage into data memory was set to 1 min. The most important value for our objectives is CO concentration.

RESULTS AND DISCUSSION

From the yield aspect, it is suitable to grow the *Reynoutria* × *bohemica* or *Reynoutria sachalinensis* species. The knotweed phytomass yields depend considerably on the climate conditions course in individual years and on the given sites (Tables 1–3).

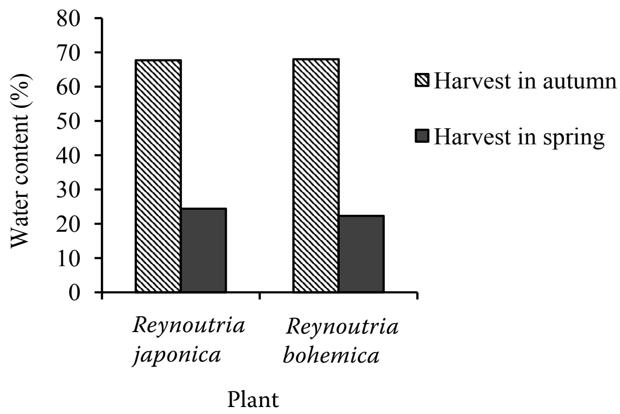

Fig. 2. Losses of water content (%) during winter period (average of years 1996–2002)

In the investigation years the found average yields of the *Reynoutria* × *bohemica* were 13.2 t/ha in Lukavec, 19.78 t/ha in Ruzyně, and 21.41 t/ha in Chomutov (Table 1) at autumn harvest period.

The *Reynoutria japonica* reached the average yield of 9.06 t/ha of the phytomass dry matter (d.m.) in autumn (Table 2). In England the above-ground phytomass yields and underground matter of *Reynoutria japonica* were investigated during the autumn harvest (Brock 1994); the average yield of the air-dried phytomass was 9.365 t/ha and the rhizomes and roots yields to the depth of 25 cm were 14.677 t/ha. Horn and Prach (1994) presented similar yields of *Reynoutria japonica* d.m. yield (9.03 t/ha) to those we obtained in our trials. In the Blatnická dolina valley, Slovakia, the above-ground biomass yield of *Reynoutria japonica* was about 21 t/ha at the density of 12 shoots/m^2 (Eliáš 1998).

The time sequences of knotweed phytomass d.m. yields from the Ruzyně site are presented (Tables 2 and 3). The yields of both knotweed species were very low in the first year of the trials establishment. Nevertheless, in the second year *Reynoutria japonica* yield in the autumn was over 6 t/ha of the above-ground phytomass d.m., while *Reynoutria* × *bohemica* reached the yield over 10 t/ha. Since the third year after the trial establishment these two crops reached the stable high yields of the above-ground phytomass. *Reynoutria* × *bohemica* produced higher yield (24.2 t/ha d.m.) in a field trial in Germany (Pude, Franken 2001).

The losses during the winter period caused by the leaves and shoot falling and breaking were 42% of *Reynoutria japonica* and 34.5% of *Reynoutria* × *bohemica* (Tables 2 and 3; Fig. 1).

Also moisture of the harvested material was different when the autumn and spring harvest periods were compared. *Reynoutria japonica* average moisture in autumn was 68%, while in spring it was only 24%. Similarly, *Reynoutria* × *bohemica* average moisture in autumn was 67%, while in spring it was only 23% (Tables 2 and 3; Fig. 2). For energy proposes the after-winter harvest period (February, March) seems more suitable because it does not need the eventual subsequent drying.

The elements content in the crops is one of the most important factors partly for determination of the nutrients taking by the yields, partly from the phytomass combustion point of view. Knotweeds were considered for the energy purpose, and also nitrogen and other elements content in the crop were determined from the aspect of the emis-

Table 3. Dry matter yields of *Reynoutria x bohemica* above-ground phytomass in autumn and spring (t/ha) and moisture of harvested phytomass (%) at the Ruzyně site

Year	Autumn		Spring		Difference in the yield autumn–spring (%)
	yield	moisture	yield	moisture	
1994 (establishment)	2.616	60.4	0.745	17.6	71.5
1995	10.126	68.6	6.841	30.8	33.4
1996	13.292	68.1	10.155	32.3	23.6
1997	28.000	65.0	14.774	16.6	47.2
1998	14.220	72.9	9.403	18.0	33.9
1999	24.360	62.6	12.628	20.5	48.2
2000	16.867	65.7	11.368	18.8	32.6
2001	21.281	63.9	15.430	23.2	27.5
2002	20.432	77.7	17.741	26.5	13.2
Average 1994–2002	16.799	67.2	11.009	22.7	34.5
Average 1996–2002	19.779	68.0	13.071	22.3	34.0

sions generating. Also in later (spring) knotweed harvest period the reduced nitrogen, phosphorus, potassium, calcium, and magnesium contents were found compared with the earlier harvest period (Figs 3 and 4). The reduced content of elements in the phytomass during later harvest period (spring) increased the phytomass quality as a fuel in both aspects – technical and emissions generating.

Knotweed dry phytomass is a fuel with high heating value (combustible heat of whole overground plant d.m. is 18.402 MJ/kg) and low ash content. The heating value of phytomass depends on its moisture. The heating value of knotweed with moisture of 25% is 14.563 MJ/kg, but at 60% moisture the heating value is only 7.809 MJ/kg. An average ash content in the plant ranged from 3.12% in Ruzyně to 4.6% in Chomutov (Table 4). The influence of the soil type on ash content in the plants was also confirmed for example by Burvall (1997).

From the presented results, it is evident that none of the monitored heavy metals in knotweed plants reached the maximum admissible values de-

Table 4. The heavy metals content in soil and crops (mg/kg) in monitored sites (extraction by 2M HNO solution at soil to extractor ratio 1:10)

Site	Crop/soil	Ash %	Heavy metals content in crop/soil (mg/kg)							
			Cd	Pb	Cr	Ni	Co	Zn	As	Cu
Ruzyně	*Reynoutria × bohemica*	3.12	0.225	8.05	0.215	1.45	0.9	28.9	0.242	5.05
Lukavec	*Reynoutria × bohemica*	3.97	0.23	2.9	–	0.9	1.3	7.8	–	0.01
Chomutov	*Reynoutria × bohemica*	4.60	0.12	7.07	0.13	2.73	0.70	46.0	0.163	0.01
Ruzyně	*Reynoutria japonica*	3.15	0.16	6.1	0.15	1.2	0.9	23.1	0.215	3.7
Ruzyně	Orthic luvisol	–	0.25	29.0	2.8	4.7	3.2	22.0	4.4	13.6
Lukavec	Vertic cambisol	–	0.21	20.4	11.6	8.6	6.4	31.6	6.9	13.2
Chomutov	Stagno-gleyic cambisol	–	0.22	24.2	6.0	14.3	10.6	54.6	19.2	16.1
CR standard*	All soils except light soil**		1	70	40	25	25	100	4.5	50

*maximum admissible values; **light soils are the sandy-clay soils according to the analytical methods of Prof. Novák – Metodology of crops nutrition No. 1/1990, edited by the Institute of Scientific-Technical Information in Agriculture, Prague

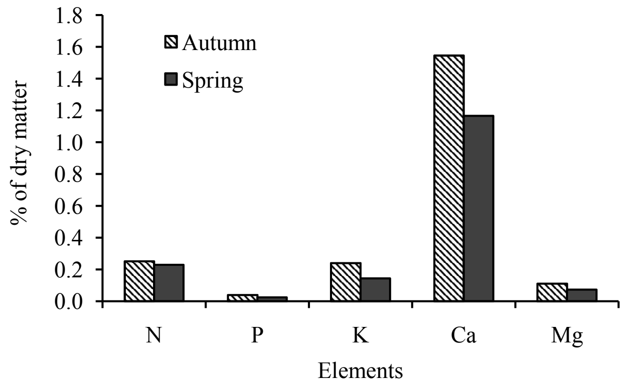

Fig. 3. Content of main nutrients in *Reynoutria japonica* in different harvest terms

termined for the food or feed purposes at any site (Table 4). The found heavy metals contents in the soil at given sites (Table 4) did not exceed the maximum admissible values according to the decree No. 13/94 valid for the Czech Republic. Therefore, there is no presumption that also the monitored crops will contain the increased amount of some of the investigated heavy metals.

Accumulation of heavy metals in cell walls of *Reynoutria japonica* roots from metalliferous habitats was observed by Nishizono et al. (1989). About 90% of the metal ions were located in the cell wall fraction of roots of plants grown in either metalliferous and non-metalliferous habitat.

Almost identical composition of knotweed biomass is observed in Bernik et al. (2007) and Lisovski et al. (2008).

Table 5. Parameters of hearth stove SK-2

Type	Dimensions (mm)	Power (kW)	Efficiency (–)	Weight (kg)
SK-2	1,490 × 680 × 460	8	max. 0.9	320

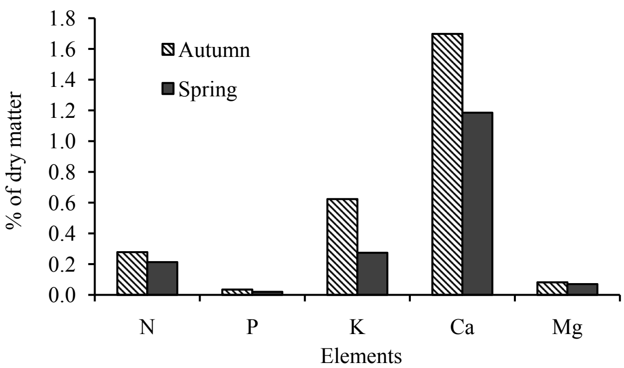

Fig. 4. Content of main nutrients in *Reinoutria* × *bohemica* in different harvest terms

Fig. 5. Hearth stove SK-2

Comparison of emission parameters of biofuels

The selected biofuels were tested in pure form in combustion installations, in which their emission parameters were determined. Samples of *Reynoutria* × *bohemica* used for combustion were obtained from the autumn term of harvest. These fuels were used in the form of briquettes in hearth stoves. The measurement was carried out at hearth stove, type SK-2, manufacturer RETAP, limited liability company, in Bahniště, which can be seen in Fig. 5. Table 5 shows the parameters of this stove.

The first measurement was carried out at briquettes produced from pure wood. This measurement serves for determination of parameters, which can be reached during combustion in given device and further also for comparison with other fuels.

All other measured fuels, especially energy crops, were modified before combustion in the following way:

– crushing in high-speed vertical crusher, average of sieve mesh 10 mm
– pressing in hydraulic briquetting press, average of briquette 65 mm

List of measured fuels:

– giant knotweed (measuring time 45 min)
– wood bark of coniferous trees (measuring time 30 min)
– energy sorrel (measuring time 60 min)

Table 6. Emission parameters of biofuels in the form of heating briquettes

	T_{ok}	T_{pl}	O_2	n from O_2	CO_2	n from CO_2	CO	CO (13% O_2)	NO	NO (13% O_2)	HCl	HCl (13% O_2)	NO_x	NO_x (13% O_2)
	(°C)		(%)	(–)	(%)	(–)	(mg/m^3)							
Wood	17.00	391.500	14.713	3.468	5.780	3.926	2,313.580	3,271.540	31.470	38.650	39.030	47.930	48.250	59.260
Giant knotweed	17.67	485.024	10.636	2.279	10.250	2.240	3,088.600	2,580.300	127.154	98.374	157.689	122.000	194.950	150.822
Wood bark of coniferous trees	17.00	417.900	14.720	3.490	5.760	3.780	1,161.580	1,686.040	88.870	110.240	110.220	136.710	136.300	169.010
Sorrel	14.33	429.820	15.850	4.340	4.996	4.525	6,872.080	11,005.900	77.890	119.742	96.600	148.500	119.420	183.580

T_{ok} – ambient temperature (temperature is higher, than there is in reality, because the sampling probe is heated); T_{pl} – temperature of flue gases; n from O_2 – air surplus calculated from O_2; n from CO_2 – air surplus calculated from CO_2; 13% O_2 – values calculated for 13% oxygen

The results are summarized in Table 6. The values of NO and SO_2, concentrations are not mentioned, because they were in all cases at zero level.

Fig. 6 shows the average values of CO and NO_x emissions for given measurements, calculated for 13% oxygen concentration in flue gases.

From the results of combustion experiments it is evident that *Reynoutria* × *bohemica* is good fuel. Energy sorrel shows the extreme CO concentration in flue gases in comparison with other monitored fuels. According to the ČSN EN 12809 (2001) standard it does not meet even the third class of requirements. On the contrary, knotweed and wood bark fulfill the requirements for the first class. The surprising fact is that both of these fuels show the lower level of CO emissions than the wooden briquettes. Concentrations of nitrogen oxides are comparable with biofuels, except of wood, and probably are related to the nitrogen content in heating material. Very similar results were reported by Hutla et al. (2005).

CONCLUSIONS

Knotweeds are crops giving stable high phytomass yield. In the form of fuel, knotweeds are comparable with dry wooden chips and, after the treatment, also with wooden briquettes or pellets because of their similar mechanical and heating properties. Recently, with regard to the high yield of phytomass d.m. from unit of area and other utilization possibilities, knotweeds are considered suitable crops (at certain more strict growing rules maintenance) as an alternative source of renewable energy and other substance usable in pharmaceutical and other industrial production, despite knotweeds are one of the most intractable weeds. From this focus, knotweeds are not only the rejected weeds, but important crops with a wide spectrum of utilization.

From the energy crops, which can be cultivated at the present time, the energy sorrel and reed canarygrass have the greatest production potential and thereby perspective of further development. In line with the facts mentioned in other research documents it can be stated that emission parameters of a fuel consisting of pure sorrel need not fulfill the requirements for use in some combustion facilities. It is also the reason for future testing of some combinations of fuels, in which, however, the energy sorrel will be an essential component. There is also the possibility to produce biofuels with brown coal additives. However, it can be difficult to place these

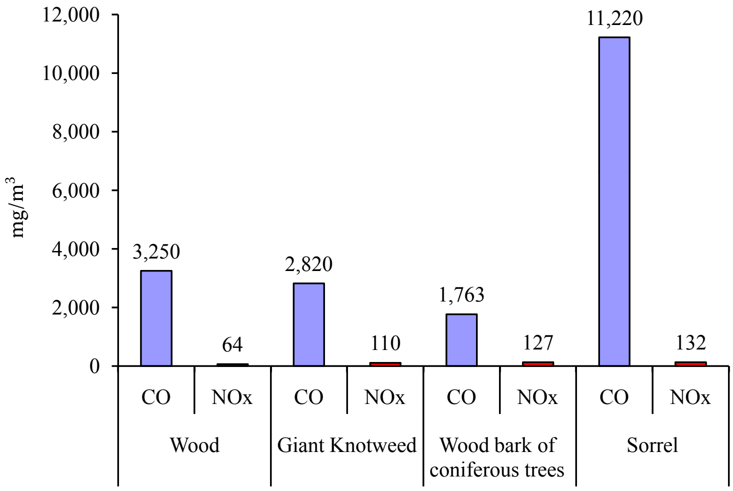

Fig. 6. Average values of CO and NO_x concentrations calculated for 13% O_2 at combustion of biofuels in the form of briquettes

products on the market. Naturally, the knowledge concerning their properties, mainly emission parameters, can be very interesting.

The open question is a possibility to grow other perspective energy crop – knotweed (*Reynoutria*). This crop can be grown also at the present time and after changes in the system of subsidies even with state assistance, which was not possible up to 2003. However, it would be very important to apply such cultivation technologies that could eliminate its uncontrolled spread outside of a given plot.

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