The Potential of a Model Catchment Area for Growing Energy Riparian Stands

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Abstract: In Central Europe, there is a several centuries long tradition of the flood-protection regulation of watercourses by means of biological engineering measures. Various species of willows show ideal conditions for this way of use. They tolerate water table fluctuation as well as temporary flooding. Through drawing nutrients which are to a considerable rate washed down to a water course from the surrounding agricultural land willows contribute to the treatment of surface waters. From the point of view of economy, however, bank protection by willows is very expensive and the use of wicker is rather limited. Only the use of wood for energy purposes provides a chance to change this unfavourable situation. With the present cost of energies obtaining energy wood can at least partly cover costs for the maintenance of banks protected and reinforced by biological measures. Total adjustment of costs is not necessary because flood protection is partly covered from all-society sources. Efforts for the energy use of wicker obtained from biologically reinforced banks date back before the year 2000 when the economic stimulation to replace fossil fuels by woody biomass did not exist in the Czech Republic due to cost deformation of fossil fuels. Present (and quite certainly also future) costs of heat and electric energy make an intention to use wicker for energy purposes absolutely realistic.

The production potential of natural stands of white willow was studied in communities developed due to primary succession. Their development is monitored since oecesis in 1996. The development of population density, height and girth of trees are determined on research plots. The biomass of stems, branches, annual rings and leaves is determined on the basis of samples taken destructively corresponding to the mean of particular diameter classes. Subsequently, the conversion of values of the biomass production was carried out per the area unit or per the watercourse length unit.

The Odra river basin was selected as a model basin. Forest site survey and mapping were carried out there. On the basis of the survey suitable sections of watercourses were determined fulfilling ecological requirements of white willow. By means of their quantification, the calculation was carried out of the energy potential of riparian stands in the model catchment area.

The study results in assessing the realistic potential of wicker used for energy purposes which can be obtained without any demand on forest or agricultural land. Thus, on the example of a model basin managed by a state organization its energy potential is presented not yet used including technological procedures. Ecological benefits of the biological protection of river banks as compared with technocracy procedures used so far are not also negligible.

Keywords: *Salix alba* L., dry matter, potential, Odra river, catchment area

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INTRODUCTION

In Czech lands, torrent training develops traditionally using close-to-nature methods of bank protection since the beginning of the 19th century. One of the methods is living riprap when streambanks are stabilized by stones of local origin and cuttings of shrubby willows are planted into gaps between stones. After flushing, these willows hide visually contours of a technical work because torrent training is the technical work beyond dispute. An advantage of the combination of a technical and biological protection of banks consists in the stabilization of streambanks by roots of willows and, above all, during the increased water level shrubby willows "lie down" due to the water pressure to the stream bed and prevent (by their roots and branches) the erosion of stones reinforcing the river bank. At this bio-technical treatment, there is no need of massive protection using concrete as it would be necessary by reason of hydraulic resistance at purely technical measures. Thus, the bio-technical protection of torrents represents also a unique ecotone and line element of ecological stability. It was demonstrated in recent decades when biological stabilization of banks restricted effectively the distribution of invasive *Reynoutria*. However, a necessity to maintain stands of shrubby willows is a disadvantage of the bio-technical protection of torrents. These stands have to be regularly cut down in an interval of max. 3 years not to overgrow and to keep their decumbent character at higher levels of water. If shrubby willows overgrow to an arborescent form they "extend" for light above the watercourse, cause ruptures of banks, break and close the watercourse flow profile. Because maintaining the flow profile is a flood control priority managers of watercourses abandon the requirement of bio-technical measures due to work difficulty and costs of their maintenance and replace them by technical measures, which are relatively maintenance-free but effect as an inorganic element in the natural environment.

METHODS AND MATERIALS

Geobiocoenological mapping of the Odra river basin and the analysis of results
Geobiocoenological mapping is a reconstruction mapping depicting in principle segments of potential natural vegetation or its geobiocoenoses, namely on the level of geobiocoene type groups. Groups of geobiocoene types are associated types of geobiocoenes with similar permanent ecological conditions. Types of geobiocoenoses are associated into groups on the basis of phytocoenological similarity of natural forest biocoenoses in the stage of maturity. Groups of geobiocoene types occur within so much homogenous ecological conditions (climatic, trophic and hydric) that they are characterized by a certain species composition and spatial structure of biocoenoses, productivity and dynamics of their development. Thus, it is possible to relate them to a certain functional potential and optimum possibility of using corresponding to natural conditions (Zlatník 1973, 1976a).

The aim of field mapping was to differentiate groups of geobiocoene types along watercourses as frameworks of permanent ecological conditions. The mapping was carried out in a "riparian zone", which was specified as a double-sided belt along a watercourse including the river bed and adjacent plots in the floodplain and on neighbouring slopes usually up to 50 m from the river bed margin.

The list of mapped groups of geobiocoene types is as follows:
Alni glutinosae-saliceta = AlS / (2)3-3BC5b(a) / in depressions with waterlogged gleys in wide floodplains
Alneta = Al / (2)3-3BC5ab / in depressions with waterlogged gleys in wide floodplains along watercourses

Saliceta albae = Sa / (2)3B-C5a / on gravel-sand deposits in a stream bed
Saliceta fragilis = Sf / (2)3-3B-C5a, 4-5B-C5a / on gravel-sand deposits in a stream bed
Querci roboris-fraxineta = QFr / (2)3-3BC-C(4)5a / on heavy-textured soils (fluvisols) in wide floodplains with groundwater table up to 150 cm
Ulmi-fraxineta populi = UFrp / (2)3-3BC-C(4)5a / on arenaceous fluvisols in wide floodplains with groundwater table up to 150 cm
Ulmi-fraxineta carpini = UFrc / 3BC-C(3)-4 / on fluvisols in wide floodplains with groundwater table below 150 cm
Fraxini-alneta = FrAl / 3BC-C(4)5a, 4-5BC-C(4)5a / on fluvisols in floodplains in bottoms of valleys of uplands and highlands with groundwater table usually up to 1 (1.5) m
Fraxini-alneta aceris = FrAlac / 3BC(4)5a, / 4-5BC4(5a) / on elevated parts of floodplains in bottoms of valleys of uplands and highlands with groundwater table below 150 cm
Contact GTG = GTG outside floodplains (in case they intervene into a riparian zone).

Explanatory notes:
vegetation zones: 3. oak/beech, 4. beech/oak, 5. fir/beech
trophic series and inter-series: B-mesotrophic, BC-mesotrophic-nitrophilous, C- nitrophilous
hydric series: 3-normal, 4-waterlogged, 5a-wet, flowing water, 5b-wet, stagnant water

In the course of field surveys, groups of geobiocoene types (GTG) were mapped as frameworks of permanent ecological conditions (Zlatník 1976b, Buček, Lacina 1999). Segments of the riparian zone landscape were included in GTG on the basis of bioindication by vegetation (particularly in more natural parts) and on the basis of differences in soil conditions particularly the groundwater table and soil texture.

In the GIS TopoL environment, lengths of particular segments were added (according to river km) occupied by the relevant group of geobiocoene types within vegetation zones.

Area under study
The preparation of geobiocoenological maps of the riparian zone of watercourses was carried out along all important watercourses in the Odra river basin (in total 75 watercourses) administered by the Povodí Odry Co. The Povodí Odry basin occupies an area of 10 288 km^2 (Vlček at al. 1984) in the Czech Republic. The total length of mapped parts of watercourses amounts to 1 256.627 km (Buček, Štykar et al. 1999, 2000, 2001).

The natural model of productivity
As input data for evaluating the production potential of the Odra river basin results were used of monitoring the succession of white willow communities in the region of Nové Mlýny reservoirs. The Nové Mlýny reservoirs are situated on the confluence of the Dyje, Svratka and Jihlava rivers about 40 km south of Brno in the Czech Republic. Spontaneous succession started in 1996 when the reservoir level was decreased by 85 cm in connection with the construction of a biocorridor (habitat corridor) through the central Nové Mlýny reservoir. On several tens of hectares of exposed banks and deposits, the rare natural succession of communities of a "soft-wooded" floodplain started. Since 1996, the dynamics of succession processes was monitored in 40 research plots (Buček, Maděra, Packová 2001). In the majority of plots of an area of 25 to 1000 m^2, population density, tree height and girth at breast height (gbh) were monitored. In selected plots, production analysis was carried out with an objective to determine the dry weight of above-ground biomass in stems, branches, annual shoots and leaves. The content of energy in the dry matter (DM) of these organs was also determined. Research plots were mostly situated into closed stands, however, some plots also into

relatively narrow riparian stands. During the research, 19 sample trees were analysed using a destructive method and gbh and height were measured in more than 2000 trees. Allometric relationships were used to calculate quantities, which were not measured in some plots. Plots were also classified according to the kind of a substrate and according to the distance from the bank line:

1) Narrow riparian stands on stony bases of dams
2) Narrow riparian stands on clayey sediments
3) Wide closed stands on clayey sediments:
   (a) at a distance of 0-10 m from the bank line
   (b) at a distance of 10-25 m from the bank line
   (c) at a distance of 25-40 m from the bank line

For the model of the Odra river basin only parameters for narrow riparian stands on stony bases of dams and on clayey sediments in a 5-m zone along the watercourse will be used. From determined data, correlations were calculated between the age of a succession stage and growth or production characteristics, which were subsequently used to model the potential production of the watershed biomass.

The Odra river basin situated in the area of the highest precipitation amounts in our republic is, at the same time, a basin with the highest density of watercourses of a torrent character and also a basin where flood control protection of the industrial agglomeration of Ostrava and mines is a dominant requirement.

Methods of the technical implementation of the bio-technical stabilization of banks will be adopted from the study of feasibility for the Odra river basin (Simanov, 1994). Quantification of woody biomass utilizable for energy purposes will be adopted from a production analysis (Buček, Maděra, Packová, 2004).
The calorific value of particular components of woody biomass of willow will be tested in the laboratory in the course of a production analysis.
Only woody biomass will be included into the calculation of the actual energy potential of the bio-technical stabilization of banks (annual shoots, branches, stems) because the wicker harvest will be carried out after leaf-fall. Leaves will remain for natural decomposition at sites and will not be used for energy purposes.
Methodological approach is based on a fact that the bio-technical stabilization of banks is not a riparian stand but from the viewpoint of the Forest Law, Building Law and Nature Conservation Law is part of a construction. For the calculation of a production potential a zone 6 m from the bank line will be used. According to the CR legislation (Water Act) it refers to "land along a watercourse", which can be used by the watercourse manager or the manager is in capacity to remove or plant trees and shrubs on this land (note: 10 m holds only for watercourses fulfilling the function of a waterway, however, it does not refer to torrents). Because planting of willows into stone packing is carried out only 1 m from the bank line (level) the calculation of potential will be based on a 5-m zone along both sides of a watercourse.
The actual potential will be related only to those parts of a watercourse, which exceed the width of 5 m in the stream bed because in narrower streams, the bio-technical stabilization of banks by willow is not used by reason of too fast closing the stream by vegetation and the loss of a safe flow profile.

In the calculation of a real potential, those parts of the stream will be subtracted where an accompanying road does not occur. It will not be possible to use the wicker there and thus, it will be burnt in place not to be flushed away to the stream during spring thawing and create obstacles in the stream.

Objectives of the paper

The main objective of the paper was to demonstrate possibilities of using osiers obtained at the maintenance of the bio-technical stabilization of torrents for energy purposes. To attain this objective following partial objectives were formulated:

- to test through the method of geobiocoenological mapping the biological acceptability of using willows for the bio-technical stabilization of banks of torrents in the Odra river basin
- on the basis of geobiocoenological mapping and using production analyses from another region of the Czech Republic to quantify the production potential of the bio-technical stabilization of stream banks
- to assess possibilities of the rationalization of maintenance of the bio-technical stabilization of stream banks
- to assess possibilities of using material obtained from the maintenance of the bio-technical stabilization of banks as energy wood
- to formulate recommendations for the catchment area manager
- to formulate other objectives of basic and application research

RESULTS AND DISCUSSION

With respect to the occurrence of white willow in natural and close-to-nature geobiocoenoses up to the 3rd vegetation zone inclusive, the quantification of sites was carried out for transition from the 2nd to the 3rd vegetation zone (marked (2)3. vs) and for the 3rd vegetation zone. For the purpose of comparisons with sites where studies of the biomass growth were carried out groups of geobiocoene types were aggregated into two groups, namely: (1) representing moister parts of floodplains, and (2) occupying relatively drier parts of floodplains. Group 1 consists of GTG (geobiocoene type group) AlS, Al, Sa, Sf, QFr, UFrp and FrAl and Group 2 consists of UFrc and FrAlac. The quantification of sites took into account the occurrence of segments of geobiocoenoses in wide river (ravine) floodplains and in narrow stream (valley) floodplains (Table 1).

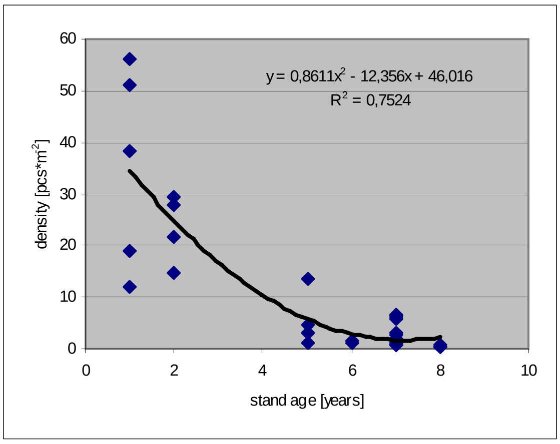
Table 1. Quantification of sites (summary)

[in km]	Moister biotops	Drier biotops	Total
Wide river alluvium (2)3.vz	30.21	54.177	87.408
Wide river alluvium 3.vz	241.853	479.793	745.831
Narrow brook alluvium	334.245	564.474	932.144
Total	606.308	1 098.44	1 765.38

The potential condition of vegetation informs on possibilities to create biomass from the viewpoint of the complex of factors of the abiotic environment, particularly climatic conditions, soil moisture regime and nutrient availability.

Population density

During oecesis, the population density of willow seedlings was very high reaching 121 to 561 thousand plants/ha. In connection with the growth of trees self-thinning and gradual lowering the density occurred, which decreased to a value about 10 000 trees/ha during 4-5 years (Figure 1). Stands on the bank line where the growth of trees is negatively affected by the high level of groundwater show somewhat higher density. Trees of inferior growth show lower competition for light and thus, there is lower mortality in these locations.



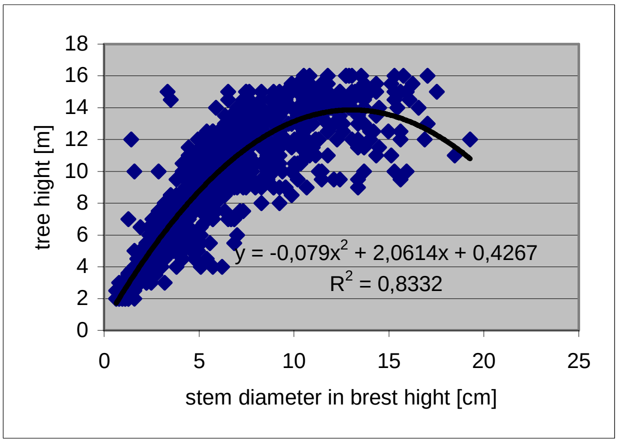
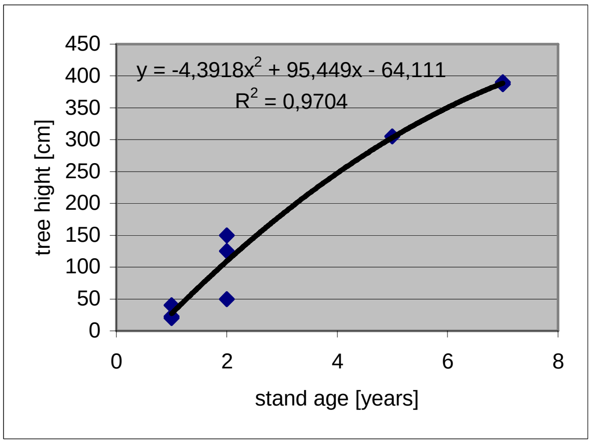


Figure 1. Relationship between the population density of white willow and the age of a succession stage (left)

Figure 2. Relationship between the diameter at breast height (dbh) and the tree height (right)

Tree height

In plots where the height was not measured it was calculated using a correlation equation according to the dependence expressed in Figure 2. Moreover, dependences were expressed between the stand age and the height of an average tree in particular types of plots. These correlations hold for the stand age in an interval of 21 to 7 years (Figures 3 and 4).



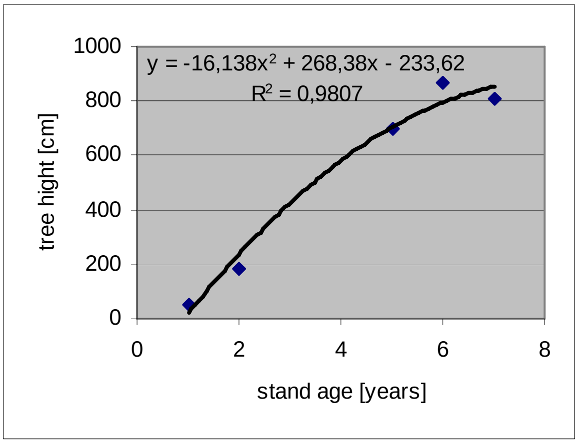


Figure 3. Relationship between the average tree height and stand age in research plots on stony bases of lateral dams (left)

Figure 4. Relationship between the average tree height and stand age in research plots in narrow riparian stands on clayey sediments near stream banks (right)

Diameter at breast height (dbh)

In plots where dbh was not measured it was calculated using a correlation equation expressed in Figure 5. Moreover, dependences were expressed between the stand age and the average tree dbh in particular types of plots. These correlations hold for the stand age in an interval from 1 to 7 years (Figures 6 and 7).

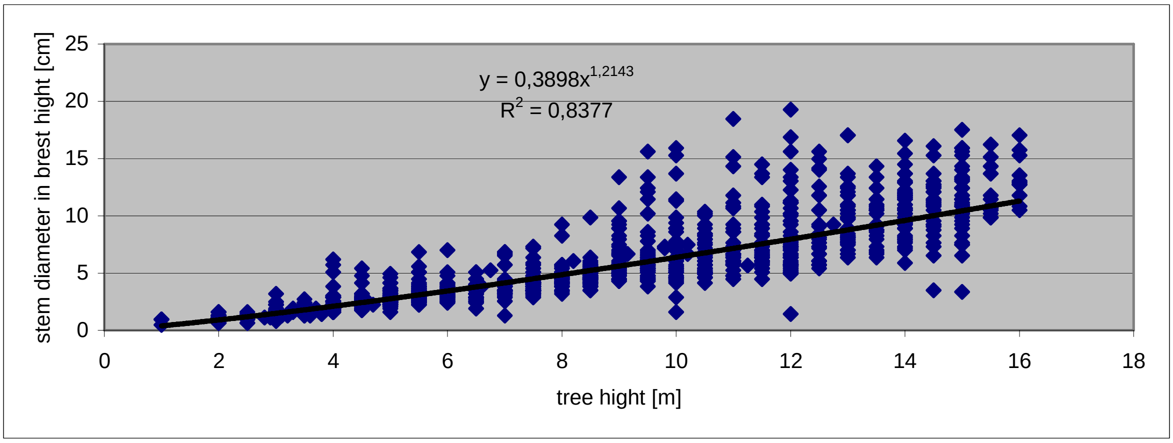
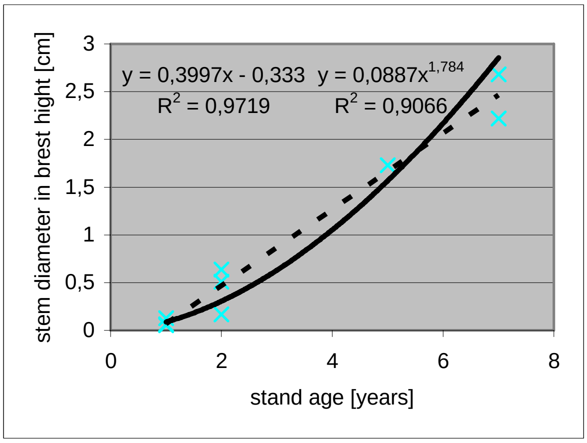


Figure 5. Relationship between the tree height and dbh



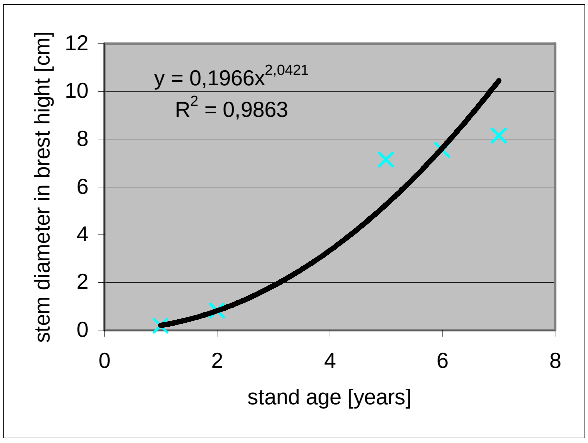


Figure 6. Relationship between the average dbh and stand age in research plots on stony bases of lateral dams (left)

Figure 7. Relationship between the average dbh and stand age in research plots in narrow riparian stands on clayey sediments near banks (right)

Stem volume

In plots where the stem volume of sample trees was not determined by a destructive method the stem volume of an average tree was calculated by a correlation equation in Figure 8. The stem volume of an average tree was then converted per ha by means of the known tree density in the research plot. Relationship between the stand age and stem volume converted per ha in particular types of plots is shown in Figures 9 and 10. These correlations hold for the stand age in an interval of 1-7 years.

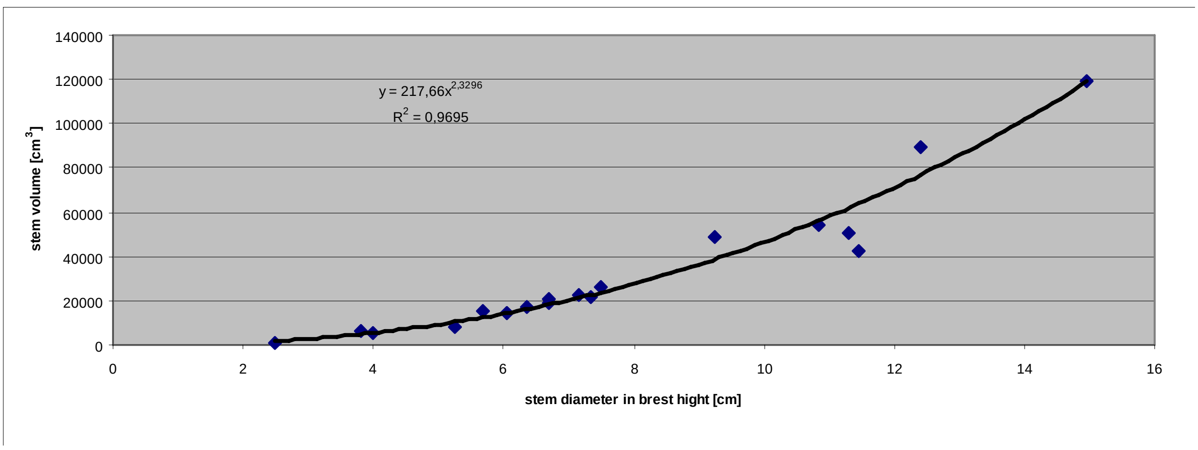
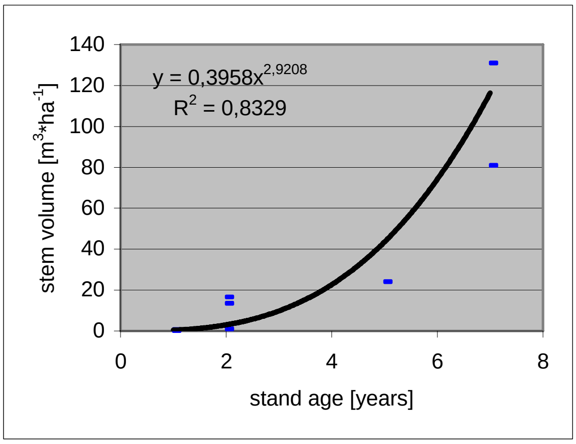


Figure 8. Relationship between the dbh and the stem volume of sample trees



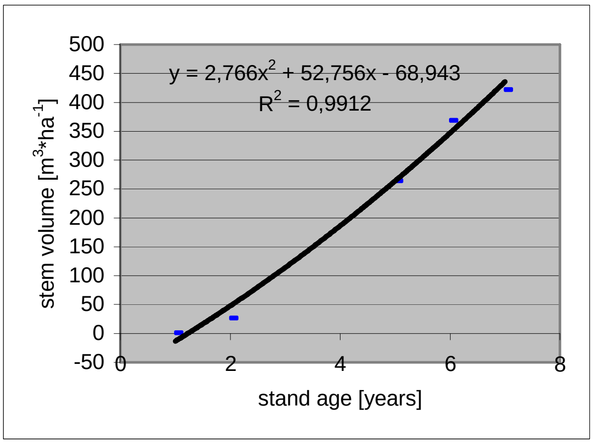
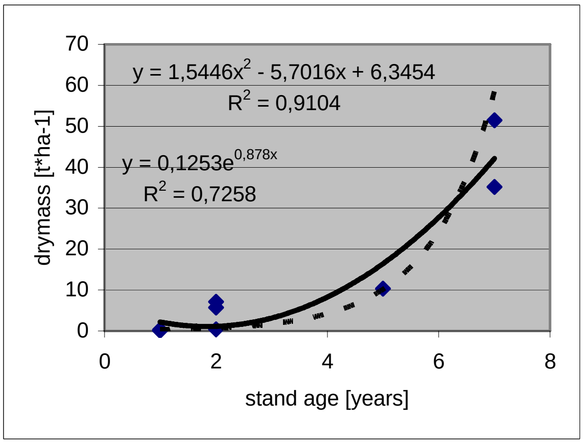


Figure 9. Relationship between the stem volume and stand age in research plots on stony bases of lateral dams (left)

Figure 10. Relationship between the stem volume and stand age in research plots in narrow riparian stands on clayey sediments near banks (right)

Dry matter (DM)

Relationship between the stand age and the DM weight of the above-ground biomass converted per ha in particular types of plots is shown in Figures 11 and 12. These correlations hold for the stand age in an interval of 1-7 years.



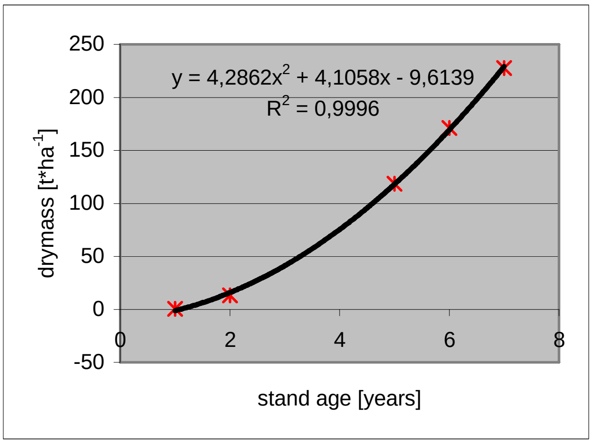


Figure 11. Relationship between the DM weight of the above-ground biomass and the stand age in research plots on stony bases of lateral dams (left)

Figure 12. Relationship between the DM weight of the above-ground biomass and the stand age in research plots in narrow riparian stands on clayey sediments near banks (right)

Assessing the possibility of the rationalization of maintenence of the bio-technical stabilization of banks

In the Czech Republic, there are no other available means of mechanization for harvesting shrubby willows on narrow strips (5 m) and on slopes adjacent to the water level than brush-cutters. The maintenance of this type of stabilization by cutting off willows has to be carried out in time because otherwise willows lose their flexibility, which is necessary in case of possible flood flows. The stump diameter of 5 cm can be considered to be a limiting diameter when willow is able at all to bend due to the effect of flowing water. Because standard brush-cutters (power category “profi”) can be used for cutting stems up to a diameter of 6 cm by a single application and stems of greater diameter have to be cut “in two parts”, the stage of a stand at the stump diameter 6 cm is the ultimate one when the cutting has to be carried out. Measurements carried out at the production analysis show that from the viewpoint of technical feasibility the utmost interval could be four-year. However, it holds only from the viewpoint of the willow diameter attained, which can be used only in wide watercourses, water reservoirs and plantations of energy willows. In narrow watercourses, where the closure of a flow profile threatens the stand height is a decisive factor for timely cutting the willow stems. Thus, growth conditions and locality will decide more on the time of cutting off than age. Thus, on the ground of maintaining ideal flow conditions it is desirable (according to results of measurements within a production analysis) to cut off willows in the bio-technical stabilization every 2 years. It has been also proved by practical experience in the Odra river basin.

The aim of cutting off willows is not their mere disposal but such cutting, which creates ideal conditions for a coppice system. Thus, cutting off willows should be always carried out after the perfect lignification of shoots after the growing season. The cut has to be smooth for the bark on stumps not to be torn (risk of mildews, fungi and insect attack). It can be achieved only when using circular saw blades with special teeth (Cobra Blade). Cutting off using brush cutters does not make possible to lead a cut less than 10 cm above the soil surface on stony ground. Thus, regeneration from stumps is sabre-shaped, which virtually forbids to use harvested withes for wicker-work.

The transport of osier to an accompanying road can be carried out only manually. If the wicker will be deposited outside the flooded area it can be kept there till its drying. It cannot remain in the flooded area not to be flushed away to a watercourse and thus create an obstacle in case of a flood wave. In such cases, it will be necessary to transport wicker up to the place of processing. It is possible to carry out chipping only after drying because osier is so flexible under conditions of natural moisture that fractions of extra-large dimensions go through standard chippers.

Quantification of the production potential of the bio-technical stabilization of banks

Based on dependences obtained potential production of DM was determined for the whole length of the stream on various substrates: on stony bases of dams and on clayey sediments (Tables 2 and 3).

Table 2. Potential production of dry matter on stony bases of banks in t for the whole length of the water course 1 765.38 km in a zone 1 to 5 m wide at the stand age 1 – 7 years

Width of bank [m]→	1	2	3	4	5
Age [years] ↓					
1	386.33642	772.6728314	1159.00925	1545.34566	1931.68208
2	197.82882	395.657638	593.486457	791.315276	989.144095
3	554.68334	1109.366677	1664.05002	2218.73335	2773.41669
4	1456.9	2913.799949	4370.69992	5827.5999	7284.49987
5	2904.4787	5808.957454	8713.43618	11617.9149	14522.3936
6	4897.4196	9794.839191	14692.2588	19589.6784	24487.098
7	7435.7226	14871.44516	22307.1677	29742.8903	37178.6129

Table 3. Potential production of dry matter in narrow riparian stands on clayey sediments in t for the whole length of the water course 1 765.38 km in a zone 1 to 5 m wide at the stand age 1 – 7 years

Width of bank [m]→	1	2	3	4	5
Age [years] ↓					
1	-	-	-	-	-
2	2779.1542	5558.308376	8337.46256	11116.6168	13895.7709
3	7287.3774	14574.75489	21862.1323	29149.5098	36436.8872

4	13308.958	26617.91526	39926.8729	53235.8305	66544.7881
5	20843.895	41687.78947	62531.6842	83375.5789	104219.474
6	29892.189	59784.37753	89676.5663	119568.755	149460.944
7	40453.84	80907.67943	121361.519	161815.359	202269.199

Assessing the possibility of using materials from the maintenance of bio-technical stabilization of banks as energy wood

The Czech Republic falls behind the majority of EU countries in the use of wood as the source of energy. However, demand for energy wood steadily increases and its cheap sources (bark, sawdust, saw-mill residues) have been already depleted. Thus, interest is concentrated on more expensive sources (logging residues, wood from cleaning and thinning operations). Although the present situation in the CR can be termed as the period of market formation with energy wood demand for the source is a reality.

Volume weight of willow is 271.128 kg/m^3 absolute DM (Bozděch, Černák, 1986) and calorific value determined in the laboratory at production analyses differs according to the specific part of a plant. Annual shoots contain the higher content of bark (showing also higher calorific value than stemwood with respect to the higher content of volatile oils). Because the proportion of stemwood and the proportion of wood in annual shoots differs according to the age or diameter of willow trees the converted calorific value per the unit of wood volume is also different.

Data concerning the energy potential of willow are given in tables:

Table 4. *Salix alba*, age 6 years, area 1000 m^2

	Diameter class (cm)	Avereage breast-height diameter (cm)	Average height (m)	Number of trees in class	Mass of dry matter in g of 1 sample				All trees in class	
					annual shoot	branch	trunk	sum	kg	m^3
1	0.5 – 3.9	2.387	3.00	477	10.360	92.441	460.417	563.218	268.655	0.991
2	4.0 – 7.3	5.666	11.25	340	130.599	459.762	5141.172	5731.533	1948.721	7.187
3	7.4 – 10.7	9.072	15.25	164	376,177	1539.392	16939.10	18854.669	3092.166	11.405
4	10. 8 -14.1	12.414	13.50	93	988.579	3009.917	30807.31	34805.806	3236.940	11.939
5	14.2– 17.5	15.120	12.50	21	1816.69	6687.489	41163.38	49667.557	1043.019	3.847
				1095					9589.501	35.369

Note: Since it is assumed that chipping of willows is carried out after leaf fall the weight of leaves is not included in the table

Table 5. Calculation of calorific value, *Salix alba*, age 6 years

	Diameter class (cm)	Number of trees in class	Heating capacity of dry matter in MJ/kg		Mass of dry matter in g of 1 sample		Total heating capacity of dry matter in MJ/kg		Weighted heating capacity
			annual shoot	branches and trunks	annual shoot	branches and trunks	annual shoot	branches and trunks	MJ/kg
1	0.5 – 3.9	477	18.800	17.9170	10.360	552.858	92.904	4724.951	17.9332
2	4.0 – 7.3	340	18.503	17.8097	130.599	5600.934	821.601	33915.324	17.8255
3	7,4 – 10.7	164	18.796	17.8620	376.177	18478.492	1159.582	54130.303	17.8806
4	10.8– 14.1	93	18.708	17.2678	988.579	33817.227	1719.973	54307.267	17.3087
5	14.2– 17.5	21	18.309	18.2710	1816.688	47850.869	698.500	18359.947	18.2724
		1095					4492.560	165437.780	17.7205

According to our research results the highest diameter class shows weighted calorific value, however, this finding would be utilizable in practice only in using willow as the tree species of energy plantations.

With respect to the requirement to cut off willow in bio-technical stabilization of riparian banks every second year, there is an important finding that the second highest weighted calorific value (17.9332 MJ/kg) occurs just in the lowest diameter class

The production of DM (without leaves) per ha per year is 16 t, including leaves 16.5 t. This value is very favourable exceeding the majority of species which are grown for energy purposes in Central Europe.

CONCLUSION

Based on results of our research we recommend the watershed manager to use arborescent willow *Salix alba* for the bio-technical stabilization of riparian banks. It refers to an indigenous species which is characterized by fast growth in juvenile stages and high stump sprouting. At regular cutting down white willow is of shrubby growth habit with flexible shoots, which prostrate themselves in case of flood waves providing thus erosion control protection to riparian banks (Šimíček 1992).

We recommend to test (in a semi-industrial scale) the recommended technology of using osier for energy purposes (energy chips) with the consistent evaluation of labour input, costs and yield and thus to prove theoretical calculations obtained on the basis of production analyses in another model region.

In the Czech Republic, there are over 91 000 km watercourses and over 25 000 various water reservoirs. Hydraulic engineering using biological stabilization of riparian banks or the prospective utilization of temporarily flooded areas by suitable willows can represent the indispensable source of energy wood with respect to the engagement of the Czech Republic to increase the proportion of using energy from renewable resources. Moreover, yields for the dendromass can at least partly cover costs for the maintenance of bio-technical stabilization of riparian banks.

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