FEASIBILITY OF APPLICATION OF SHORT ROTATION WILLOW TO REMEDIATION OF CONTAMINATED LAND

Alexandre J. Grebenkov, Institute of Power Engineering Problems, Minsk, Belarus
Antonina B. Verzhynskaja, Institute of Power Engineering Problems, Minsk, Belarus
Vladidmir N. Petrushkevich, Institute of Power Engineering Problems, Minsk, Belarus

Abstract

Today, 16 years after Chernobyl Accident, economical and environmental remediation of contaminated farmlands becomes a key problem. One of the options of returning these territories back to be of avail is creation of favorable conditions for safe reuse of contaminated lands by means of culturing the nonfood market oriented products. Relatively high biomass yield of the short rotation willow varieties allows suggesting this crop to be used as a renewable resource of local fuel. The main objective of the present study is to evaluate feasibility of culture of the fast growing willow plantations in contaminated lands. The study includes assessments of environmental constrains and economical effects. A number of field tests of *Salix viminalis* were carried out in Belarus. Two types of soil, peaty and sandy, were examined. In addition to investigation of some parameters important for biomass-to-energy conversion, i.e. growing conditions and yield, the study was focused on accumulation ability of the given variety in extracting radionuclides from contaminated soil. Taking into account the obtained data on the soil-to-plant ^{137}Cs transfer factor for willow wood, this crop may not be applicable as a fuel if its biomass is extracted from the area of contamination of higher than 740 kBq/m^2 (approx. 20 Ci/km^2). Otherwise, this will lead to excess of the exemption limit established for wood fuel and to additional threat to population health. The economical analysis shows that, in Belarus, fuel production from the fast growing willow plantations may be profitable.

Introduction

In Belarus, there are some unproductive pastures and former arable lands totaling about 200 thousand hectares as well as some area of other wastelands, which have no economic value today. In addition, more than 1.8 million hectares of agricultural lands were exposed to radioactive fallout with activity deposition over 37 kBq/m^2 (approx. 1 Ci/km^2) as a result of Chernobyl Accident. Today, 16 years after Chernobyl, economical and environmental remediation of contaminated farmlands becomes a key problem. Almost 270 thousand hectares have been excluded from economic turnover due to high level of contamination, and in this area the regular agricultural technologies formerly applied to food production cannot be used. It is necessary to change crop varieties and gradually introduce in practice some other cultures, which would allow revivifying the contaminated lands and gaining economically useful effects.

The contaminated soil remediation actions envisage either the special technique for soil treatment that mitigates negative effect of radionuclides on food chains, or creation of favorable conditions for safe reuse of contaminated lands by means of culturing some nonfood market oriented products. As to the later, the replacement of food crop species by some profitable technical crops is exercised now. One of the options that could be successfully applied to agricultural practice is culturing the crop varieties, which have biomass yield high enough to be used as a renewable resource of local fuel in contaminated regions. The main objective of the present study is to evaluate feasibility of application of a fast growing willow variety to bioenergy production in contaminated regions and in other wastelands. It is important to identify possible environmental constrains and, therefore, to focus the study on accumulation ability of the given variety in extracting ^{90}Sr and ^{137}Cs from contaminated soil. In addition to this, some parameters relevant to biomass-to-energy conversion, i.e. growing conditions and yield, must be investigated.

Description of Field Study

A number of field tests of *Salix viminalis* were carried out in Belarus (Vandenhove *et al.*, 1999). Two types of soil, peaty and sandy, were examined. In May 1997, four plantations of willow were established at Savichy Research Base and Masany Research Station in Gomel Province within 30-km zone of Chernobyl Power Plant. In each plantation, four willow clones were planted with fourfold replication. The clones are Rapp, Orm and Jorr (*Salix viminalis*), and Bjorn (*S. viminalis* x *S. schwerinii*). The general parameters of the plantations are presented in Table 1.

Table 1. Parameters of Willow Plantations

Location	Landscape and soil type	Area (ha)	Density (cuttings/ha)	Contamination (kBq/m^2)	
				^{137}Cs	^{90}Sr
Savichy, Field #1	Poorly drained dry meadow. Soddy-podzolic sandy on glacial sand superseded with loose sand	0.26	18000	1427±94	167±14
Savichy, Field #2	Lowland. Peaty-marsh on medium-thick well decomposed sedge-reed-woody peat	0.30	18000	12876±2275	1368±122
Masany, Field #3	Former arable land. Soddy-podzolic, sandy-loam based on alluvial gleic shallow-grainy sand	0.12	18000	-	-
Masany, Field #4	Wetland. Peat bog of lowland type	0.10	18000	2857±365	2659±1120

It has to be noted that growth of the willow plantations established on the both sandy fields was not successful. Willow in Masany sandy soil died almost all within the first growing season. In Savichy sandy soil, the plantation was a bit more successful and has survived with mortality rate of about 40%. During the first cutting-back, willow biomass and soil matter was sampled to determine radionuclides content and principal nutrient concentration. Before measurements, eight soil samples from each test field were taken with 25-cm cores, homogenized, oven-dried and sieved. Stems and leaves of a willow plant (10 samples per each variety plot) were sampled separately, oven-dried, ground, homogenized, and two samples from the homogenized mixture were taken for further measurements.

The permanent and time dependent soil characteristics were defined with atomic-absorption analysis. To provide elemental analysis of the samples the ICP PLASMA spectroscope was used. Exchangeable forms of the measured nutrients and radionuclides were extracted with 1N acetous ammonia. Content of ^{137}Cs in the samples was measured using a Ge(Li) detector system with a NaI(Tl) annulus. Two spectrometers were used, i.e. ADCAM-300 and NOKIA LP-4900. Content of ^{90}Sr in the soil samples was determined by means of radiochemical method. The probe is formed from the samples ashed with HCl acid solution of 6M during 6 hours at 600°C followed by washing in ammonia solution at pH=8. Strontium is extracted in a form of carbonates. For plant matter, the probe is formed by ashing with concentrated HCl acid solution until forming oxalates during 7-20 hours at 500-600°C followed by transferring oxalates into their oxides at 700°C and cleaning against other radionuclides. The daughter isotope, ^{90}Y is extracted in a form of its oxalate and counted after 14 days. The chemical yield of ^{90}Sr is determined by an atomic adsorption spectrometer, while ^{90}Y is measured by weighing. Measurements of the targets were provided by Beta-spectrometer CANBERRA-2400.

The plantations were under observation during four years, i.e. one year before and three years after cutting-back. The mortality rate was evaluated by counting the total number of dead plants among living plants. In order to determine the growth parameters of willow biomass, the representative samples were taken monthly during the growing season every year. The biomass dry weight was measured after drying the willow stem samples during 24 hour at 105°C.

Results and Discussion

Radionuclide Accumulation Factor

The average values of specific activity of two soils at Savichy fields and content of exchangeable forms of ^{137}Cs and ^{90}Sr as well as content of cations are presented in Table 2.

Table 2. Content of Cations and Radionuclides in Soils of Savichy Fields

Soil type	Cations, mg-eq/100g			Exchangeable forms, Bq/kg		Total radionuclide content, Bq/kg	
	K	Ca	Mg	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr
Sandy (field #1)	0.0388 (±0.0075)	0.890 (±0.101)	0.02	108.25 (±3.40)	399.5 (±5.5)	4030 (±242)	472.5 (±10.7)
Peaty (field #2)	0.155 (±0.062)	11.13 (±0.22)	1.18 (±0.16)	2985 (±359)	10550 (±790)	139350 (±26510)	14810 (±1010)

In our example, the peaty soil (field #2) contained approx. 12 times as much of exchangeable forms of Ca and 4 times as much of that of K compared to the sandy soil (field #1). Under this condition, for the peaty soil, equilibrium between the nature analogues (K – Cs, Ca – Sr) is shifted towards calcium and potassium. As a result, the ratio of exchangeable forms of radionuclides to their total content is lower for the peaty soil (see Fig. 1 for ^{137}Cs and Fig. 2 for ^{90}Sr. The blank boxes refer to sandy soil).

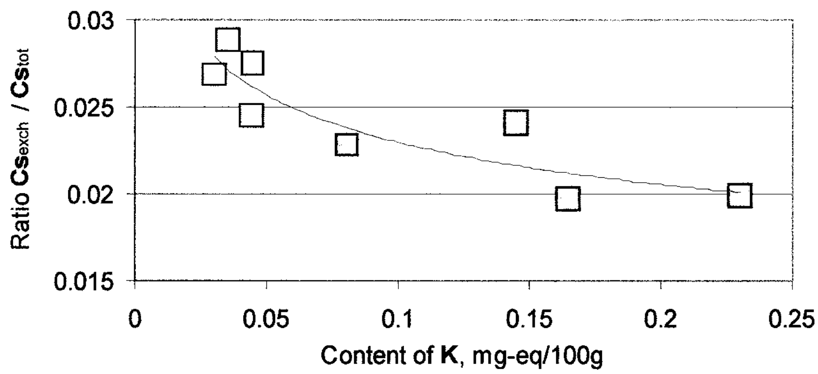

Figure 1. Effect of Potassium on Concentration of Exchangeable Forms of ^{134}Cs

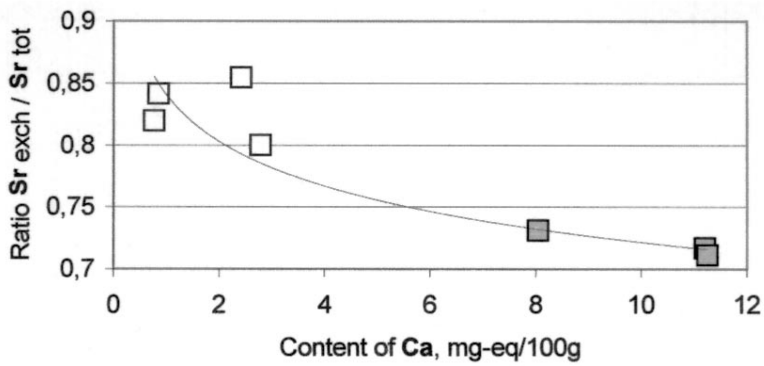

Figure 2. Effect of Calcium on Concentration of Exchangeable Forms of ^{90}Sr

The same pattern of correlation between the content of exchangeable forms of radionuclides in soil and the soil cation exchange capacity was revealed for Masany field. Since the exchangeable forms of the given radionuclides are biologically easy assimilable, the noted difference results in the fact that extraction of ^{137}Cs and ^{90}Sr from sandy soil is more intensive (Fig. 3). The data obtained also confirm that there is no significant difference of accumulation coefficient between different clones of willow. In the given paper, the accumulation coefficient is defined as a ratio of radionuclide specific activity in willow tissue to that in soil.

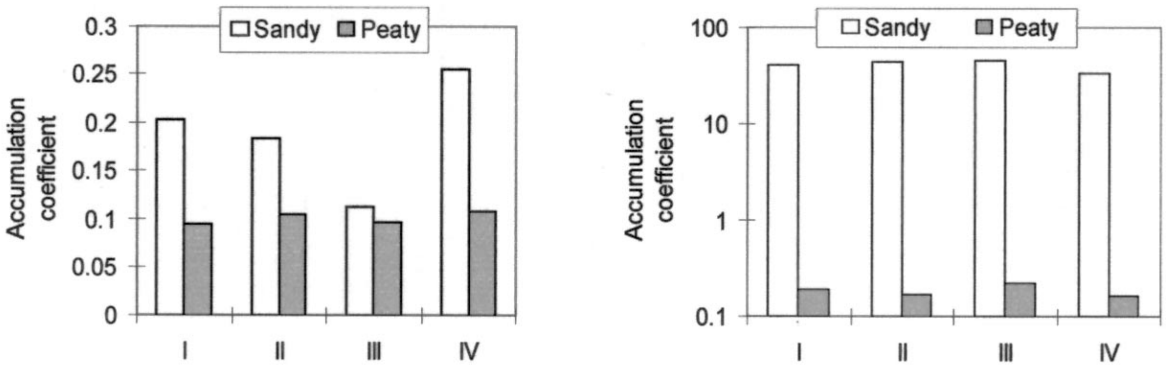

Figure 3. Accumulation Coefficient of ^{137}Cs (left picture) and ^{90}Sr (right picture) in Savichy

The results of specific activity measurements carried out at Masany field (Table 3) allow evaluating the accumulation coefficient both for willow stem and leaves. In all plots of Masany field, the ^{137}Cs accumulation coefficient for leaves is about sixfold higher than that for stem. As to ^{90}Sr, the accumulation coefficient for leaves is by a factor of 1.5-3.5 higher compared to that for stem. Like in Savichy, we did not reveal any significant difference of accumulation coefficient between different clones of willow.

Table 3. Content of Radionuclides in Soils and Willow of Masany Fields

Soil type	^{137}Cs specific activity, Bq/kg			^{90}Sr specific activity, Bq/kg		
	Soil	Leaves	Stem	Soil	Leaves	Stem
Peaty (field #4)	30920±3950	3566±808	598.8±215.2	28780±12120	5856±1400	1998±784

The investigated correlation between soil properties and the rate of extraction of radionuclides by fast growing willow species provides more data for sound decision on applicability of phytoremediation to radioactively contaminated area. For example, in view of relatively high ^{137}Cs transfer factor for willow wood, ranging from 0.2 10^{-3} through 1.5 10^{-3} m^2/kg, willow chips may not be applicable as a fuel if wood is extracted from the area of contamination of higher than 740 kBq/m^2. Otherwise, it will lead to excess of exemption limit (740 Bq/kg) established for wood fuel and to additional threat to population health.

Biomass Yield

The highest mortality rate was found in sandy soils, especially in Massany field due to very low water reserve. The most successful growth was obtained in peaty soil in both Savichy and Masany fields where the mortality rate did not exceed 30%. The final harvest from all peaty fields gave about 34 tons (odw) per hectare.

The evolution of stem biomass averaged for Savichy and Masany fields is shown in Fig. 4. The potential yield should be higher (ca. 40-50 t/ha) and the actual relatively low biomass growth resulted from lack of weed control and some animal intrusion. Nevertheless, it is expected that the further extension of plantations and improve management practice in Belarus may lead to more successful results.

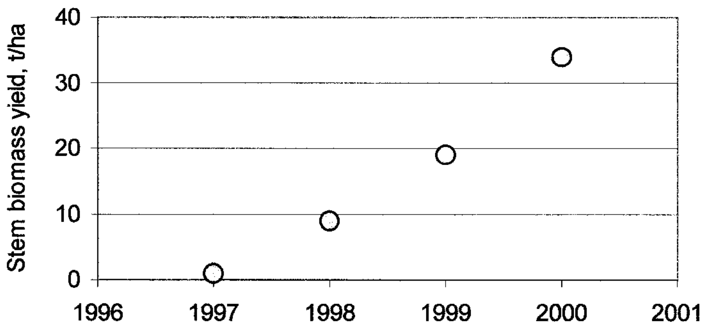

Figure 4. Evolution of Stem Biomass in Peaty Soil

Economical Assessments

In order to provide the actual data for feasibility study and economical evaluation of the large-scale application of short rotation willow in Belarus, we recently planted the same varieties in a demonstration field of about 10 ha.

The lump-sum costs including the cost of establishing this plantation and the cost of future stubbing is about 485 $US/ha. This value as well as the maintenance costs and other data reduced to 1 ha are presented in Table 4. Taking into account discounting, we evaluated a prime cost of fuel produced from willow biomass in Belarus conditions to be about 25 $US per ton of coal equivalent (tce). The results of least cost analysis are shown in Fig. 5, assuming that biomass annual production is 8 tce per hectare. From this analysis, the payback period after establishing the willow plantation is expected to be about 5.5 years.

Table 4. Some economical parameters of willow biomass production (reduced to 1 ha)

Annual biomass yield, tce	8
Reduced capital outlays, $US	331
Running costs, $US/year	105
Rate of use, %	100
Fuel market price, $US/tce	60
Plantation life, year	25
Cutting cycle, year	3
Bank interest, %	0
Internal rate of return, %	77
Net present value, $US	5635

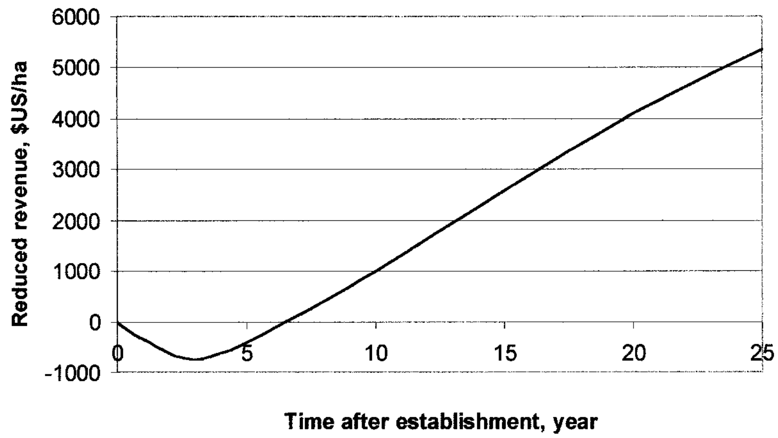

Figure 5. Results of Least Cost Analysis

Conclusion

In the agricultural lands contaminated as a result of Chernobyl Accident, normal production of the crops involved in human food chains is questionable. The nonfood market oriented crops have to be used to make the abandoned lands profitable. One of the possible options is culturing the fast growing willow varieties, which biomass can be used as a renewable fuel. The feasibility of this idea was evaluated in the presented study.

The investigated correlation between the soil properties and the rate of extraction of radionuclides by the identified crops provides data for possible environmental constraint. Willow chips may not be applicable as a fuel if wood is extracted from the area of contamination of higher than 740 kBq/m^2. Otherwise, it will lead to excess of exemption limit established for wood fuel and to additional threat to population health. The results of analysis based on actual field tests of short rotation willow plantations in Belarus shows that bioenergy production from the identified crop variety grown in affected regions is economically sound and may be profitable. Preliminary calculation of trailing expenditures for heat generation by a boiler of 0.45MW shows that about 10 $US can be gained as a boot for each 1 Gcal produced.

The study was supported by Committee on Energy Efficiency, Belarus and RECOVER Project of the European Commission (DG-XII).

References

1. Vandenhove, H., A. Gommers, Y. Thiry, F. Goor, J.M. Jossart, E. Holm, T. Gävfert, J. Roed, A. Grebenkov, S. Timofeyev, and S. Firsakova, (1999), "Evaluation of short rotation coppice as remediation option for contaminated farmland", The NATO Advanced Research Workshop on Contaminated Forests: Recent Developments in Risk Identification and Future Perspectives, NATO Science Series, Environmental Security, Vol. 58, I. Linkov and R. Schell Eds. (Kluwer Academic Publishers, USA, Massachusetts, 1999) pp. 377-384