ABSTRACT: One of the key environmental problems in Belarus is effective use of agricultural lands contaminated by radionuclide due to the Chernobyl disaster. The alternative method to traditional agricultural crops is fast growing willow cultivation. It is possible to use biomass of willow as renewable energy source. The goal of our investigation was the estimation of environmental aspects of willow wood production on polluted areas. The field study experiments (2007—2010) were conducted at Krichev district of Mogilev region in eastern Belarus. This region characterized by high level of Cs-137 contamination as well as high level of heavy metals pollution. In the first stage of experiments, the concentration of cesium-137 in different parts of willow biomass had been measured and transfer factor calculated. The measuring had been done for leaves, roots, and wood. To control cesium-137 accumulation in willow biomass we apply different types (nitrogen N, phosphorus P and potassium K) and dose of fertilizer. The experiments show that potassium mineral fertilizer is the key factor for radionuclide accumulation control. The optimal dose of potassium is 90 kg per hectare. On the base of experimental results the model of cesium-137 accumulation in the wood for a 21 year has been developed. In accordance with calculation to the end of willow cultivation (21 year) concentration of cesium-137 in wood will not be higher than permitted even with the level of cesium-137 contamination in the soil 1480 kBq/m² (maximum 140 kBq/m² with permitted level for firewood is 740 Bq/kg.). The concentration of cesium-137 in the roots increases gradually and get maximum in 21 year (3000 kBq/m²).

Our results confirm that in the sum about 0.8 million hectares of radionuclide polluted arable lands partly excluded from agricultural practice in Belarus could be used for willow biomass production.

KEY WORDS: biomass, fertilizer, potassium, radionuclide-contaminated soils, willow

INTRODUCTION

The Republic of Belarus does not have an adequate potential of its own fossil fuels supplying and nowadays we use about 5% of Belarus demand of energy at the cost of local renewable recourses. The National State Program was approved in order to increase this input to 25% until 2012. The most pers-
pective resources of renewable energy in Belarus are bioenergy, wind, and hydroenergy. Belarus has about 9.5 million hectares of forests, 5.7 million hectares of arable lands, and 3 million hectares of pastures. Part of lands may be used for biomass production on the base of cultivation of fast-growing crops like willow. The yield of willow biomass crops may achieve 10—15 tons of dried wood or 5—6 toe per hectare. The potential area for willow biomass production in Belarus is estimated in 0.5 millions hectare. It means the annual energy potential of willow biomass systems in Belarus is 2.5—3 millions toe.

Willow biomass cropping systems simultaneously produce not only power and economic, but also environmental and social benefits. These include reduced SO$_2$ and NO$_x$ emission, less extraction of additional CO$_2$ to the atmosphere, reduced soil erosion, and pollution from non-point source of agricultural lands, and enhanced agricultural landscape diversity. Willow plants may be successfully grown on different types of lands and have the potential in reclamation of degraded and polluted soils.

Because of the Chernobyl disaster the area of radionuclide contaminated agricultural soils in Belarus is about 1.3 million ha, including 0.8 million ha of arable lands. The optimal system of cultivation of this type of soils on contaminated area is a serious problem, because traditional crops such as grass and cereals may accumulate extra radionuclide (Abagyan et al., 1996). The willow does not accumulate a lot of radionuclide and it can be used as wood for bioenergy purpose.

There are some publications concerning cultivation of willow on radioactive polluted soils.

The experiments in Palesse district, a typical rural area located close to Chernobyl, were fulfilled for modeling of SRC biomass production and estimations of Cs-137 soil-to-wood transfer. The results shown that from the radio-ecological viewpoint, and according to the local legislation, the SRC biomass produced on loamy sand, sandy loam and loamy soils is suitable for firewood. SRC biomass from the highly productive peaty soils (39.4% of the land area of Palesse) may also be used but only if its conversion into heat or electricity is carefully managed (Goor et al., 2001).

Gommers, A., and others (2000) get the same conclusion in experiments with radiocesium uptake by one-year-old willows planted as short rotation coppice (Gommers et al., 2000). Radicesium uptake and distribution were measured in a willow (Salix viminalis L. var. Orm) short rotation coppice (SRC) stand. This system allows production of energy from the harvested biomass. Even at this high soil contamination level, radicesium concentrations in wood do not exceed appreciably the naturally occurring K-40 content in the wood (135 Bq/kg).

The Norway scientists compare the accumulation of radionuclide by different types of trees. The results showed that willow accumulate radionuclide not as intensive as birch or alder (Brittain and Bjoernstad, 1996).

These publications confirm that it is possible to get comparatively clean biomass of willow on radionuclide-polluted areas. The problem is the development of adequate technology of willow production for polluted soils and esti-
mation of pollutants accumulation in the wood for future period. The goal of our investigation is the estimation of cesium-137 in willow biomass to model opportunity of wood utilization as a bioenergy.

**MATERIALS AND METHODS**

The field study experiments (2007—2010) were conducted at Krichev district of Mogilev region in eastern Belarus, close to the Russian border. This region characterized by high level of Cs-137 contamination as well as high level of heavy metals pollution. The radioactive contamination in the region has been conditioned by precipitating from clouds after the Chernobyl accident. As a result, local cesium “spots” appeared. The level of contamination in the place of our experiment varied from 185 to 370 kBq/m² (Figure 1).

The soils of experimental plot were sandy and sandy loams with single grain structure. It was excluded from agricultural practice after Chernobyl disaster. Available water capacity was moderate to high.

The practical experiment included some variants with different dose of fertilizer application:
1. Control (C).
2. Variant N₃₀P₆₀K₉₀ (V-2)
3. Variant K₃₀ (V-3)
4. Variant K₆₀ (V-4)
5. Variant N₃₀ (V-5)
6. Variant N₆₀ (V-6)
7. Variant K₉₀ (V-7)
8. Variant K₁₂₀ (V-8)
9. Variant K₉₀ (V-9)
10. Variant K₁₅₀ (V-10)

The different rates of potassium fertilizer were used, as it is chemical analog of cesium. In accordance with our hypothesis, the additional application of potassium enables to decrease the level of accumulation cesium in willow biomass.

The different rates of nitrogen fertilizer in experiment should let us find optimal balance of the element. From one side the rates of nitrogen should be optimal for willow growing but not so high for extra weed development from another side.

The experimental design was randomized by complete blocks of four treatment replicated four or five times. Each elementary plot was 7 m long by 7.2 m wide (50 m²) and contained 4 double rows of plants.

RESULTS AND DISCUSSION

In the first stage of our experiments, the concentration of cesium-137 in different parts of willow biomass had been measured and transfer factor calculated (Table 1). The measuring had been done for leaves, roots, and wood. The same experiments fulfilled because of different ways of utilisations these components. The leaves go back to the soil every year, wood is using for energy in every 3 year and roots leave in the soils as far as plantation of willow used. We admitted it for 21 year.

To control cesium-137 accumulation in willow biomass we apply different types (nitrogen N, phosphorus P and potassium K) and dose of fertilizer.

Tab. 1. — The transfer factor of cesium-137 from soil to willow biomass

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Transfer factor for roots 10⁻⁵ m²/kg</th>
<th>Transfer factor for wood 10⁻⁵ m²/kg</th>
<th>Transfer factor for leaves 10⁻⁵ m²/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (C)</td>
<td>93.925</td>
<td>3.175</td>
<td>5.110</td>
</tr>
<tr>
<td>N₃₀P₆₀K₉₀</td>
<td>33.712</td>
<td>1.315</td>
<td>2.999</td>
</tr>
<tr>
<td>K₃₀</td>
<td>56.425</td>
<td>2.875</td>
<td>5.088</td>
</tr>
<tr>
<td>K₆₀</td>
<td>39.325</td>
<td>1.5</td>
<td>4.105</td>
</tr>
<tr>
<td>K₉₀</td>
<td>20.425</td>
<td>0.9</td>
<td>3.163</td>
</tr>
<tr>
<td>N₆₀</td>
<td>54.375</td>
<td>2.6775</td>
<td>4.782</td>
</tr>
<tr>
<td>N₈₀</td>
<td>55.911</td>
<td>2.8</td>
<td>5.139</td>
</tr>
</tbody>
</table>
The highest rates of transferring took place in roots. The transfer factor for leaves was approximately twice as compared to wood.

Our experiments also shown that accumulation of cesium-137 in willow biomass mostly depends on potassium application. This dependence has linear character for roots and wood but not for leaves.

It is obviously that potassium mineral fertilizer is the key factor for radio-nuclide accumulation controlling and for cesium-137 modeling in willow biomass. The application of doze potassium above 90 kg per hectare (120—150 kg/ha) not delayed accumulation of cesium-137.

It was admitted that for modeling of cesium-137 accumulations for long time it is necessary to identify following factors:

- the level of cesium-137 contamination of the soil
- the period of cesium-137 half life
- yield of willow wood
- transfer factor

On the base of these factors the model of cesium-137 accumulation in the wood for a 21 year has been developed. The level of soil contamination by cesium-137 was choosing as for experimental plots (Figure 2). The 3 year is the period between harvesting time for biomass in willow in accordance with technology.

![Graph showing the dynamic of level of cesium-137 in the wood in depend on fertilizer application. The level of cesium-137 contamination in the soil is 294 kBq/m².](image)

Fig. 2. — The dynamic of cesium-137 level in wood depending on fertilizer application; the level of cesium-137 contamination in the soil is 294 kBq/m².
The results of modeling identify that for this level of the soil contamination cesium-137 activity in wood was several times lower than Belarus permitted level for firewood (740 Bq/kg).

The following task was confirming by opportunity of willow wood production at the soils with higher level of radionuclide contamination. The results of modeling for soils contaminations from 185 to 1480 kBq/m² presented in the Figure 3.

It was found that it was possible to get normatively “clean” wood even without additional fertilizer application for the level of cesium-137 contamination of the soil as high as 1480 kBq/m². The application of the 90 kg of potassium let us decrease of cesium-137 activity in the wood in 3 times.

As it was shown, earlier the roots accumulate biomass more actively than wood. As a result, to the end of willow plantation existing (21 year) the level of cesium-137 in biomass of root will be higher than permitted level for firewood. The application of 90 kg of potassium decrease of cesium accumulation more than in 4 times. Results of the modeling are shown on the Figure 4.

The future problem will be roots utilization. It is possible to use two directions. The first is to recultivate the plantation in 12—15 year, not after 21. It will be possible to use part of roots as firewood. The alternative way is to leave it in the soil to plough the plot and do new plantation willow or other perennial crop. The optimal decision may be adopted after economy and ecology calculation.

Fig. 3. — The dynamic of cesium-137 level in wood without fertilizer application
CONCLUSION

It was confirmed that potassium application might control accumulation of cesium-137 to biomass. It is possible to get relatively “clean” biomass especially with application additional rates of K fertilizer on the site with the extra level of cesium-137 contamination. The optimal dose of K for delaying of cesium-137 accumulation to the willow biomass is 90 kg/ha. The higher dose of potassium application not stimulate and adequate accumulation of cesium-137.

There are some difference in accumulation of cesium-137 in wood, leaves, and roots. The level of cesium in wood biomass after three years of willow cultivation varied from 5 (with high rates of fertilizer application) to 25 (control plants) Bq/kg with the level of cesium-137 contamination in the soil 294 kBq/m². In Republic of Belarus, the permitted level for firewood is 740 Bq/kg. On the base of field experiments the model of cesium-137 accumulation for long time has been developed. In accordance with calculation to the end of willow cultivation for firewood (21 year) concentration of cesium-137 in wood will not be higher than permitted even with the level of cesium-137 contamination in the soil 1480 kBq/m² (maximum 140 kBq/m²).

The concentration of cesium-137 in the roots increases gradually and get maximum in 21 year (3000 kBq/m²). The future problem will be roots utilization because it is not possible to use root’s residues as energy biomass. We believe that two directions may be admitted. The first one is to recultivate the plantation in 12—15 year, not after 21. It will be possible to use part of roots as firewood this way. The alternative decision is to leave it in the soil to
plough the plot and do new plantation willow or other perennial crop. The optimal decision may be adopted after economy and ecology calculation.

The accumulation of cesium-137 in the leaves was not as active as in other parts of biomass.

REFERENCES


млъштима са онтаминациом од 1480 kBq/m² (највише 140 kBq/m², а дозвољени ниво је 740 kBq/m²). Концентрација Cs-137 у корену расла би и достигла максимум током 21. године (3000 kBq/m²).

Резултати су потврдили да би се око 0.8 милиона хектара пољопривредног земљишта загађеног радионуклидима, које се не користи за пољопривредну производњу, могло користити за гајење врба, као извора обновљиве енергије.