UDC 504.064.4:633. 282:620.952

Agroecological efficiency of elements of technique of cultivation of Miscánthus at radiological contamination of soils

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The purpose. To study accumulation of 137Cs and 90Sr in biomass and lysimetric waters and to determine agroecological efficiency of elements of technique of growing Misc nthus large on the soils contaminated with radioactive substances. **Methods.** Lysimetric, biomorphological, radiometric, statistical, comparative-calculation. **Results.** Data on accumulation of radioisotopes in biomass of Misc nthus large and lysimetric waters are cited. It is established that the level of accumulation of radioactive nuclides in plants of Misc nthus on the low-purity soils depends on elements of technique of growing, radioisotope and its density in soil. It is established that in alternatives where biopower crop was cultivated on soils contaminated with radioactive nuclides, accumulation in biomass of 137Cs made 14,7 – 18,6, 90Sr — 0,46 – 0,54 Bq/kg, in lysimetric waters — 4,36 – 4,57 and 0,28 – 0,65 Bq/l accordingly. Importation of fertilizers together with defecate and treatment of Misc nthus rhizomes before planting with microbial preparation Polimiksobakterin together with BioMAG promoted 28% increase of yield of dry biomass as compared to control. **Conclusions.** Application of fertilizers in a complex with chalking, inoculation of Misc nthus rhizomes with microbial preparation Polimiksobakterin and pre-sowing treatment with organomineral fertilizer BioMAG promoted essential increase of yield of dry biomass, decrease of 137Cs and 90Sr in biomass and lysimetric waters. Accumulation of these radioisotopes in Misc nthus biomass at growing on soils contaminated by radioactive nuclides did not exceed allowable level, and application of elements of technique promoted lowering content of 137Cs on 12 – 21%, 90Sr — on 9 – 15% as compared to control alternatives. At use of fertilizer complex «mineral fertilizer + defecate + Polimiksobakterin + BioMAG» they gained the least accumulation coefficients in Misc nthus biomass (137Cs — 0,07, 90Sr — 0,05), and in lysimetric waters (137Cs — 0,02, 90Sr — 0,03).

Key words: *137Cs, 90Sr, agrotechnical methods, migration of radioactive nuclides, productivity of biomass, lysimetric device.*

DOI: https://doi.org/10.31073/agrovisnyk201909-09

Problems in the regulation of biological processes in soils are very relevant in the context of modern agriculture. The existence of modern civilization is characterized by irrational use of natural resources and increased man-caused and man-made impact on the environment. One of the negative consequences of human activity is the radioactive contamination of the lands due to the Chornobyl disaster.

Total area of radioactive contaminated soils in Ukraine is 5345,4 hectares or 4,8% of the total area [1]; of these, 22 districts are located in the Region of Chernihiv. At present, according to the results of studies of the Chernihiv branch of the State Institution "Institute for Soil Protection of Ukraine" on stationary control sites, the average value of soil pollution density of ^{137}Cs exceeds the pre-disaster level 12 times, ^{90}Sr – 5 times. Among the contaminated agricultural areas, the largest amount is found in sod-podzolic soils (43.6 %), characterized by low fertility, high acidity and high mobility of radionuclides [2].

In the time elapsed after the Chornobyl disaster, the situation has improved due to a series of countermeasures to reduce the consequences of the accident, the physical decay of radionuclides, and their washout by atmospheric precipitation. Compared to the data of the first radioecological survey, the area of lands contaminated with ^{137}Cs amounted to over 1 Ci/km^2 decreased by 22 thousand hectares, and ^{90}Sr to over 0,15 Ci/km^2 –by 10 thousand hectares [3].

In the Chernihiv Region as of 2012, the area of lands contaminated with ^{137}Cs to over 1 Ci/km^2 was 44 thousand hectares, or 2,4% of the area, and with ^{90}Sr to over 0.02 Ci/km^2 –1624 thousand hectares, or 88% of the area [4]. The accumulation of radionuclides in crop production depends on the density of soil contamination (Ci/km^2), soil texture, content of biogenic elements in soil, and transition factor. That is why, upon agricultural production in radiation contaminated areas, it is important to apply, first of all, such agrotechnical and agrochemical measures to reduce the level of contamination of products, which do not require significant funds and changes in existing technologies for growing crops. The most common and most available among the anti-radionuclide measures are agrochemical, namely: liming, application of high doses of phosphorus-potassium and organic fertilizers, and the use of microfertilizers [5].

With application of mineral fertilizers on sod-podzolic soil in proportion of $N_{60}P_{90}K_{120}$, the contamination of production with ^{137}Cs is reduced by 1.5 –2 times. The application of lime is effective in the proportion providing neutralization of acidity in soil solution at a rate of 1,5 of $CaCO_3$ norm. In the fields, where the predicted ^{137}Cs activity in production exceeds acceptable level 2006, liming should be carried out according to the standards of hydrolytic acidity, fertilizer should be applied 50–80 t/ha, mineral fertilizers should be used in proportion of $N_{60}P_{90}K_{120,}$ which by their combined use reduce contamination with ^{137}Cs by 2,5 - 4 times [6].

In contaminated areas, it is impossible to grow crops for food and feed cultures are restricted. Such areas require reclamation. Plant cultivation for industrial and energy needs may be helpful. This way of reclamation will contribute to reducing the level of contamination of the territory. Separate researchers propose to grow a giant sword grass (*Miscanthus x giganteus J.M. Greef & Deuter ex Hodkinson and Renvoize*) [7, 8] on radioactively contaminated lands, which during the vegetation requires a minimum amount of mineral fertilizers due to the active development of the root system, which can penetrate deeply and use nutrients from deeper horizons of the soil [9]. In addition, nutrients that accumulate in rhizomes are used repeatedly in a new vegetative period [10].

Sword grass plants accumulate a small amount of radioactive isotope ^{137}Cs. According to the calculations of the factors of transition of ^{137}Cs from the soil to sword grass plants, it can be argued that their values are within the range of 0.22-0.10 (Bq/kg/kBq/m^2), which are close to the values of the factor of transition of ^{137}Cs in grain crops (winter wheat, rye, barley) [11]. Therefore, it remains crucial to monitor soil, agricultural and groundwater contamination levels with ^{137}Cs and ^{90}Sr in order to broaden scientific knowledge and develop proposals for the restoration of radioactively contaminated lands for future agricultural use. The main purpose of these studies is to create such growing conditions that will facilitate a safe crop. Thus, has been first established transition factors of ^{137}Cs and ^{90}Sr for radioactively contaminated soils in the systems of Soil-Plant and Soil-Lysimetric Waters for growing giant sword grass. The effective elements of sword grass cultivation technology that contribute to reducing the negative effects of radioactive contamination in sod-podzolic soils and reduce the accumulation of radioactive ^{137}Cs and ^{90}Sr isotopes in sword grass biomass and lysimetric waters have been identified.

The development of modern technologies that would contribute to the further restoration of the fertility and soil safety of sod-podzolic type, as well as the reduction of the accumulation of radioactive isotopes of ^{90}Sr and ^{137}Cs in the biomass of the sword grass is extremely important.

The purpose — to study the accumulation of ^{137}Cs and ^{90}Sr in biomass and lysimetric waters and carry out agroecological efficiency assessment of the technology elements of cultivating the giant sword grass on radiation contaminated soils.

Materials and methods. The study was conducted (2016-2018) in a stationary lysimetric plant at the Department of Scientific Support of Agroindustrial Production (Village of Progress) of the Institute of Agricultural Microbiology and Agroindustrial Manufacture of the National Academy of Agrarian Sciences. By design lysimeters are concrete, by type —earth-filled with 5-layer waterproofing. Soil filling was carried out starting from the parent material, taking into account the thickness of each genetic horizon in its natural location. Soil layer of one cell is 155 cm, its weight — 10,5 tons. Sowing area of the lysimetric cell is 3.8 m^2.

The scheme of the experiment included four variants: 1. Control (conditionally clean soil); 2. Soil contaminated with radionuclides; 3. Soil contaminated with radionuclides + NPK + BioMAG + Polimiksobakteryn; 4. Equivalent to var. 3 + defecate. Agrochemical soil analyzes were conducted according to generally accepted methods [12]. The activity of ^{137}Cs in soil, plants and lysimetric waters was determined according to the conventional method using a pulse analyzer SEG 0,5. To determine the content of ^{90}Sr in soil samples method [13] was used, and in plant samples - method [14].

Soil in variant 1 is sod-podzolic sandy loam. The plow layer is characterized by a content of: humus – 1.15 %; easily hydrolysable nitrogen – 60 mg; mobile phosphorus – 190 mg; exchangeable potassium –

60 mg per kg of soil; pH_{sal} – 5.5. In variants 2-4, the plow layer of soil was replaced with soil contaminated with radionuclides (from the territory of the Pakul Village Council of the Region of Chernihiv, which belongs to the 3rd zone of radioactive contamination). The soil is sod-podzolic, clay, sandy loam, which is characterized by a content of: humus – 1.21 %; easily hydrolysable nitrogen – 68 mg; mobile phosphorus – 142 mg; exchangeable potassium – 76 mg per kg of soil; pH_{sal} – 5.7.

BioMAG is an organomineral, ecologically safe sapropel-based fertilizer of a new generation, includes biologically active substances and a set of trace and macronutrients.

Polimiksobakteryn is a microbial preparation based on a phosphate-mobilizing bacterium *Paenibacillus polymyxa* KB. The mechanism of action of the preparation is associated with the ability of bacteria to produce organic acids and phosphatase, which helps to dissolve the poorly soluble mineral and organic phosphates of soil and fertilizers, which activates the process of assimilating phosphorus by plants. In addition, bacteria produce phytohormonal substances that stimulate the growth and development of plants [15].

Defecate is a waste of sugar production. Content of $CaCO_3$ – 60-85 % on dry basis.

Weather conditions were characterized by an increase in average daily temperature of 1.6-3.4°C compared with long-time average annual data and a moisture deficit of 40% of long-time average annual rate (142 mm).

Results. To determine the levels of radionuclide accumulation in biomass and lysimetric waters, the soil of the lysimetric plant (variant 1) and the soil from the contaminated area (variants 2, 3 and 4) were analyzed for the content of radionuclides according to the agronomic techniques.

According to the results of soil analysis of the lysimetric plant, density of contamination with radionuclide ^{137}Cs amounted to 0.89 Ci/km^2 and at the same time with ^{90}Sr – 0.019 Ci/km^2. According to the current legislation, the territories contaminated with ^{137}Cs to 1 Ci/km^2 and ^{90}Sr to 0.02 Ci/km^2 are considered to be conditionally clean, where agricultural production is possible without restrictions. Consequently, the soil of a stationary lysimetric device is conditionally clean.

The density of soil contamination from the polluted area by the radionuclide ^{137}Cs was 3.00 Ci/km^2 and by ^{90}Sr – 0.08 Ci/km^2. In accordance with the current legislation, territories contaminated with ^{137}Cs from 1 to 5 Ci/km^2 and ^{90}Sr from 0.02 to 0.15 Ci/km^2 belong to the fourth zone of radioactively contaminated territories with preferential economic conditions.

It is known that penetration of radionuclides from the soil to plants primarily depends on their concentration in the soil and the specific characteristics of crops. With the increase of their content in the soil, their accumulation in the economically valuable part of plants increases [16].

In our studies, in variants where sword grass was grown on soils contaminated with radionuclides, radioactive ^{137}Cs accumulation in biomass was observed in the range of 14.7-18.6 Bq/kg (Table 1). It should be noted that in all experimental variants the content of ^{137}Cs did not exceed the permissible level for grain of cereal crops (PL – 50 Bq/kg) [17].

1. Content of ^{137}Cs in soil, plants and lysimetric waters depending on the agrotechnical approaches under cultivating sword grass (2016-2018)

No.	Variants of experiment	^{137}Cs, Bq/kg			System: soil-plant		System: soil-lysimetric water	
		soil	plants	lysimetric water	AF	UF	AF	UF
1	Control (conditionally clean soil)	72,2±5,7	4,9±0,42	2,67±0,16	0.07	0.23	0.04	0.10
2	Radionuclide contaminated soil	242,3±6,8	18,6±0,90	4,57±0,11	0.08	0.26	0.02	0.06
3	Contaminated soil + NPK + Polimiksobakteryn + BioMAG	228,9±20,3	16,4±1,31	4,50±0,14	0.07	0.24	0.02	0.07

4	Contaminated soil + NPK + defecate + Polimiksobakteryn + BioMAG	204,0±8,3	14,7±1,14	4,36±0,15	0.07	0.24	0.02	0.07

Accumulation of radionuclide in sword grass plants on contaminated soil was the smallest in variant 4 (mineral fertilizers + defecate + Polimiksobakteryn + BioMAG) and it was 14.7 Bq/kg, which is 3.9 Bq/kg less than the parameters of variant 2, accumulation factor (AF) – 0.07, uptake factor (UF) – 0.24. The control variant (conditionally clean soil) showed the lowest parameter of radionuclide content in the soil – 72.2 Bq/kg and in plants – 4.9 Bq/kg. However, the conversion factor was somewhat lower compared to variants 2-4 and it was 0.23 versus 0.23-0.26.

The content of ^{137}Cs in lysimetric waters in variants with contaminated soil was almost identical and it was at the level of 4.36-4.57 Bq/L. The highest AF and UF were in the variant with conditionally clean soil, 0.04 and 0.10, respectively. On the contaminated soil, regardless of the studied methods, AF was the same and amounted to 0.02, and UF was within the range of 0.06-0.07.

On average, over the years of studies, in variants where the bioenergy culture was grown on contaminated soil, the accumulation of radioactive strontium-90 in biomass was observed in the range of 0.46-0.54 Bq/kg (Table 2), which did not exceed the acceptable level of radioactive strontium for grain cereals – 20 Bq/kg [17].

2. Content of ^{90}Sr in soil, plants and lysimetric waters depending on the agrotechnical approaches under cultivating sword grass (2016-2018)

No.	Variant	^{90}Sr, Bq/kg			System: soil-plant		System: soil-lysimetric water	
		soil	plants	lysimetric water	AF	UF	AF	UF
1	Control (conditionally clean soil)	2,21±0,09	0,09±0,01	0,07±0,01	0.04	0.13	0.03	0.10
2	Radionuclide contaminated soil	10,64±0,66	0,54±0,01	0,65±0,01	0.05	0.17	0.06	0.19
3	Contaminated soil + NPK + Polimiksobakteryn + BioMAG	9,69±0,66	0,49±0,02	0,52±0,01	0.05	0.16	0.05	0.15
4	Contaminated soil + NPK + defecate + Polimiksobakteryn + BioMAG	9,22±0,37	0,46±0,01	0,28±0,01	0.05	0.15	0.03	0.10

The accumulation of radionuclide ^{90}Sr in sword grass plants on the contaminated soil was the smallest in the case where mineral fertilizers were combined with liming and under treatment of sword grass rhizomes with the microbial preparation Polimiksobakteryn and organomineral fertilizer BioMAG, which was 0.46 Bq/kg, i. e., 0.08 Bq/kg less than the parameter in variant 2, the accumulation factor (AF) was 0.05, and the uptake factor (UF) – 0.15, respectively.

In the control variant (conditionally clean soil), the least parameter of the content of ^{90}Sr was observed in the soil - 2.2 Bq/kg, and in plants - 0.09 Bq/kg, and in infiltrate – 0.07 Bq/L. However, transition factor at the same time was somewhat lower in comparison with variants 2-4 and amounted to 0.13 in the soil-plant system and 0.10 in soil-lysimetric water system.

The content of radionuclide ^{90}Sr in lysimetric waters in variants 2-4 was within the range of 0.28-0.65 Bq/L. The highest AF and UF, 0.06 and 0.19, respectively, were in the variant 2, where sword grass was grown on contaminated soils. When applied on contaminated radionuclides soils, mineral fertilizers combined with liming and treating sword grass rhizomes by the microbial preparation Polimiksobakteryn and organomineral fertilizer BioMAG, accumulation factor decreased by 50 %, uptake factor – by 47 % compared to variant 2.

On average, in the stationary lysimetric plant over the years of study, the maximum yield of biomass of the sword grass was obtained in the variant, where before fertilization mineral fertilizers were added together with the defecate, and the rhizomes were treated with Polimiksobakteryn combined with BioMAG – 27.1 t/ha, which is higher than the control parameter by 26 % (Table 3). Accordingly, in the same variant the highest yield of dry matter was obtained – 9.96 t/ha, solid biofuel output – 10.96 t/ha, and energy output – 175.3 GJ.

On average, for three years, the yield of biomass in the variant where mineral fertilizers were added to the contaminated radionuclides soil together with the defecate, and the rhizomes were treated with Polimiksobakteryn combined with BioMAG, exceeded the yield in variant 2 (soil contaminated with radionuclides) by 4.1 t/ha (18 %), yield of dry matter – by 1.58 t/ha (19 %), output of solid fuels – by 1.75 t/ha, and energy output – by 27.9 GJ.

3. Influence of agrotechnical approaches on the productivity of sword grass plants

No.	Variants of the experiment	Yield of biomass by years, t/ha			Yield of dry matter (average)		Solid fuel output, t/ha	Energy output, GJ
		2016	2017	2018	t/ha	increment ,%		
1	Control (conditionally clean soil)	7,53±0,76	22,0±1,53	35,1±1,34	7.78	100	8.56	136.9
2	Radionuclide contaminated soil	7,92±0,46	23,3±1,18	37,7±1,73	8.38	108	9.21	147.4
3	Contaminated soil + NPK + Polimiksobakteryn + BioMAG	8,14±0,49	24,5±1,78	40,4±1,03	9.05	116	9.95	159.2
4	Contaminated soil + NPK + defecate + Polimiksobakteryn + BioMAG	8,76±0,75	27,2±1,21	45,3±1,27	9.96	128	10.96	175.3

Comparing the yield of biomass in variants 1 and 2, it can be noted that the yield in variant 2 was higher by 1.5 t/ha, dry matter yield – by 0.6 t/ha, yield of solid biofuels – by 0.65 t/ha, and energy output – by 10.5 GJ compared to control (conditionally clean soil).

Conclusions

Under the cultivation of sword grass in conditions of radioactive contaminated sod-podzolic soils, it was established that the content of radioactive elements in the biomass of the sword grass on such soils was within the following range: for ^{137}Cs – 14.7-18.6 Bq/kg, ^{90}Sr – 0.46-0.54 Bq/kg (lower than MPC). The use of mineral nutrition in complex with liming, inoculation of rhizomes with the microbial preparation Polimiksobakteryn and pre-treatment with organomineral fertilizer BioMAG has provided a decrease in radioactive elements income to biomass by 21 % and 15 %, respectively, compared to the biomass yields obtained on contaminated soil. With the use of the fertilizing complex "mineral fertilizers + defecate + Polimiksobakteryn ^{137}Cs was 0.07 and ^{90}Sr – 0.05, the accumulation factor of radionuclides in lysimetric waters was 0.02 and 0.03, respectively. The application of these agronomic measures has provided the formation of a dry biomass yield at the level of 9.96 t/ha that is higher by 28 % compared with control.

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