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GROSS BETA-RADIOACTIVITY OF LEAVES OF THUJA PYRAMIDALIS IN CONDITIONS OF HYDROPONICS AND SOIL IN ARARAT VALLEY AND DILIJAN FOREST EXPERIMENTAL STATION

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Abstract. *Armenia is affected by the ecological disaster connected with the forest area reduction. It is a mountainous country with a dry subtropical climate and it has a nuclear power plant (NPP), located in the Ararat Valley. All these are not only the basis of the ecological disaster but also make it deeper. For its prevention, it is necessary to restore and expand green zones, and forests. The use of decorative trees and shrubs with the ability to filter the air from radionuclides (RN) is extremely important in green construction. In recent years, the decorative coniferous tree Thuja occidentalis "Pyramidalis" is one of the most demanded landscaping trees in Armenia. The characteristics of gross β-radioactivity of Thuja pyramidalis leaves were studied under outdoor hydroponic and soil cultivation conditions in the territory of the Institute of Hydroponics Problems (IHP) in the Ararat Valley (a zone with a radius of 30 km from the Armenian NPP) (ANPP) and the Dilijan Forest Experiment Station (DFES) (a zone with a radius of 90 km from the ANPP). This has a practical significance because the use of radio-ecologically favorable tree species and shrubs in green construction will have an important ecological significance. The gross β-radioactivity of the leaf samples was determined by radio-chemical methods using a small background UMF-1500 radiometer using sensor CTC-5. According to results, regardless of the growth zone, hydroponic trees exceeded soil ones in the amount of β-radiating technogenic and natural RN by 1.2-1.3 times. Leaves of the Thuja pyramidalis grown in the IHP territory exceeded those grown in DFES in gross β-radioactivity: in hydroponics - 1.6 times, in soil - 1.7 times. Thuja pyramidalis as a radio-ecologically beneficial tree species is proposed to be used for the creation of green zones. This will have important ecological significance as it will reduce the movement of RN in the biosphere.*

Keywords: *Decorative tree, practical offer, technogenic and natural radionuclides, Thuja pyramidalis.*

1. INTRODUCTION

The greenhouse effect is the biggest ecological hazard that the human population is now trying to fight. 25.6% of greenhouse gas emissions are coming from electric power stations. 72% of greenhouse gases come from CO2, of which 34.1% are produced in power plants [1]. Each year the average air temperature is increasing. As the 2023 Global Climate Report from NOAA National Centers for Environmental Information showed, every month of 2023 ranked among the 7 warmest for that month, and in July, August, and September, global temperatures were more than 1.0°C above the long-term average [2]. It is thought that nuclear power has more economic advantages than intermittent renewable sources for generating electrical energy requirements. It will be especially important in 2025-2065 because of a strategy to eliminate all non-carbon capture and storage coal power stations when some 1600 MW of nuclear power would be required and sufficient to cover the base load for the electrical energy supply system [3]. Nuclear power plants may be a source of radiation. Currently, this accounts for only 1% of the sources of radiation exposure of the population [4] but with the increase of the nuclear power plants number, this percentage may increase, too. It is known that ornamental tree species and shrubs can serve as bioindicators for assessing the degree of radionuclides (RN) pollution in an air basin [5,6,7,8].

Technogenic RN ^{90}Sr and ^{137}Cs are two very dangerous fission products that are released during nuclear facility operations and nuclear accidents. Their half-lives are ^{90}Sr, $t_{1/2}$ = 28.8 years and ^{137}Cs, $t_{1/2}$ = 30.2 years, so after the release they can stay in environment very long time. They are highly radiotoxic for the human organism. Therefore, the assessment of ^{137}Cs and ^{90}Sr influence on the environment is highly essential [9].

Urban air temperature is higher than in suburban areas. The high density of buildings and high ratio of impervious surfaces increases the radiation fluxes in cities. Lack of urban vegetation also is a cause of a poor thermal condition in summer in many cities. Park C. et al have calculated the radiation level for Seoul and found that the net radiation of urban ground will increase 2.1 W/m² in the 2050s and 2.7 W/m² in the 2100s. Their modelling showed that the urban vegetation should by increased by 10% to prevent the increase of radiation [10].

Thuja species planted on city streets have a favorable influence on microclimate and noise reduction, help to maintain high air humidity, dampen temperature oscillations, and intercept dust particles, contributing to the improvement of air quality, and the prevention and diminution of environmental pollution [11]. In Armenia, thuja pyramidalis is one of the popular urban trees used in courtyard landscaping [12]. Here we tried to assess the ability of Thuja pyramidalis to accumulate β-emitting

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technogenic and natural RN in the leaves of the plant by measuring gross β-radioactivity.

2. MATERIALS AND METHODS

2.1. Study area and material

The study was done in Ararat Valley, in Yerevan, where the Institute of Hydroponics Problems NAS RA (IHP) is located, and in Dilijan Forest Experimental station (DFES). The distance of Yerevan from the Armenian Nuclear Power Plant (ANPP) is about 30km, and the distance of Dilijan from ANPP is about 90km (Figure 1). The studies were carried out between 2018 and 2023 at the Institute of Hydroponics Problems (IHP) located in the Ararat Valley (city of Yerevan, zone with a 30 km radius from the ANPP) and in the DFES (zone with a 100 km technogenic influence radius from the ANPP).

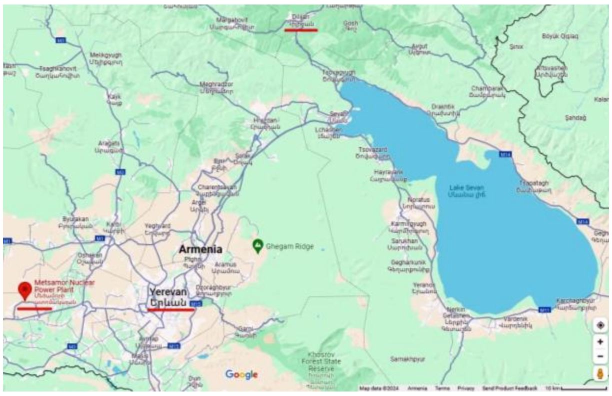

Figure 1. The distance of IHP (Yerevan) and DFES (Dilijan) from the Armenian NPP on a map (map was taken from Google Maps).

Yerevan is located on a plain on the edge of the Ararat Valley at altitudes of 860–1.400 m. It has a dry continental climate. The average annual air temperature in Yerevan is 9.1-12.1 °C. The absolute maximum air temperature is in July (40-43 °C). Annual rainfall in Yerevan is 286–440 mm with the highest share of rainy days in May [13]. The soil of IHP area is rich in phosphorus and potassium, and humus content is 1.5-2.5 % [14].

The DFES is located at an altitude of 1400-1500 m above sea level. The average annual temperature in Dilijan is about 8.10C and the annual precipitation is 660-750 mm. The soil of DFES is brown, the upper layer (0-30 cm) of which has 9.0-9.3% humus. Dilijan's soil is rich in potassium but has very low amounts of nitrogen and phosphorus [15, 16].

For the hydroponic study, volcanic slag with particles in 3-15mm diameter was used as a substrate.

The object of research was Thuja occidentalis “Pyramidalis” imported to Armenia.

In the IHP area, the study was done on Thuja pyramidalis saplings aged from 3 to 6 years and 8 years: soil plants were 4 years old, plants grown in black volcanic slag were 3-6 years and 8 years old, and plants in red volcanic slag were 3 years old. In the DFES area study plants were 8 years old in soil and hydroponic conditions.

The soil plants of IHP were irrigated with artesian water. The hydroponic plants were fed with the nutrient solution proposed by G.S. Davtyan (N=200mg/L, P=65mg/L, K=350mg/L) [17]. To make a nutrient solution the artesian water was used in the IHP area and tap water in DFES.

The study samples (n=3) were taken from the irrigation water (artesian), nutrient solution, Dilijan tap water, upper soil layer (0-30 cm deepness) of IHP and DFES areas, and from the needle leaves of *Thuja pyramidalis* plants grown in studied conditions (3 samples from each variant). Sampling and pre-processing of samples were carried out according to GOST 32161-2013 [18].

2.2. Study method and statistical analysis

The content of the ^{90}Sr and ^{137}Cs and gross β-radioactivity were defined in the ash of samples by the radiochemical methods with the help of a low background radiometer UMF-1500 using sensor CTC-5. Samples were air-dried and were coaled, after being ashed in a muffle furnace at 500°C for 4-5 hours. The error was fluctuated between 5-7%. Controlled technogenic RN (^{90}Sr, ^{137}Cs) were determined in dry sediments of natural waters, nutrient solution, soil, and ash of plant leaves [19].

The results of measurements were statistically analyzed using GraphPad Prism 8.0.1.244 program (t-test). $P < 0.05$ was considered statistically significant.

3. RESULTS

Water samplings showed that artesian and tap water and nutrient solutions have very low amounts of ^{90}Sr and ^{137}Cs compared with the MAC for drinking water (Table 1).

Table 1. The content of 90Sr, 137Cs in nutrition solution, natural waters and soils of IHP territory and DFES

Sample type	**^{90}Sr**	**^{137}Cs**
	Bq/L, Bq/kg*	
Artesian water	0,044 ± 0,002	0,003 ± 0,0001
Tap water of DFES	0.037±0.002	0.002±0.0001
Nutrition solution	0,44 ± 0,030	0,030 ± 0,001
Gray soils*	6,9 ± 0,27*	8,0 ± 0,25*
Forest brown of DFES*	11,9 ± 0,30*	7,0 ± 0,22*
MAC	5,0	11,0

The gross β-radioactivity was measured in the needle leaves of *Thuja pyramidalis* plants of different ages at different vegetation periods for evaluation of their ability to RN accumulation. From Figure 2, it is obvious that hydroponics plants of all ages showed similar vegetation period-dependent changes: gross β-radioactivity was the highest in November, followed by August results, and the lowest results were detected in February. For the soil plants the picture is different: again, the highest result was recorded in November, but the lowest one was in August. Leaves of thuja grown in red volcanic slag exceeded leaves of thuja grown in black volcanic slag in gross β-radioactivity 2.2 times in November (red slag sample – 270±23,1 Bq/kg (mean±SE) and black slag sample – 120±17,3 Bq/kg) and 1.9 times in February (red slag sample – 150±11,6 Bq/kg (mean±SE) and black slag sample – 80±17,3 Bq/kg).

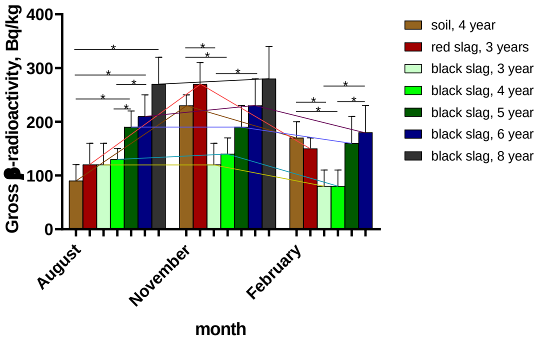

Figure 2. The gross β-radioactivity in needle leaves of Thuja pyramidalis during vegetation in the soil and hydroponics in the area of IHP: * p<0.05.

From Figure 2 it is also obvious that with age gross β- radioactivity levels increased in the leaves of Thuja pyramidalis in hydroponics. The 8-year-old Thuja pyramidalis exceeded the 3-year-old in the gross β-radioactivity of leaves about 2.3 times. It may be because of the RN accumulation ability of Thuja pyramidalis.

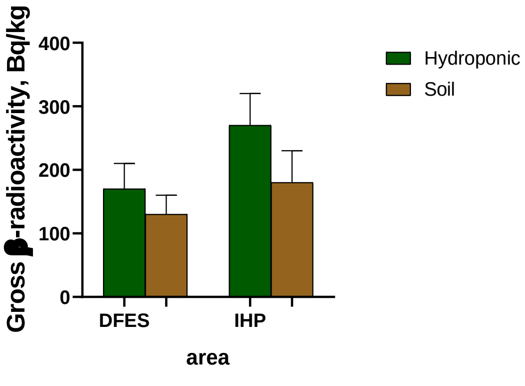

Figure 3. The gross β-radioactivity in needly leaves of 8-year-old plants of Thuja pyramidalis in the soil and hydroponics in the area of IHP and DFES in August.

As shown in Figure 3, in August 8-year-old plants of thuja grown in hydroponic and soil conditions in IHP prevailed over plants of thuja grown in hydroponic and soil conditions of DFES in gross β-radioactivity 1.6 and 1.4 times, respectively. In any case, the differences in the studied variants are not significant (p>0.05), which indicates the similarity of radio-tension of the two studied zones.

In leaves of *Thuja pyramidalis* grown in the soil in the area of IHP, the share of ^{90}Sr and ^{137}Cs in gross β-radioactivity was 8,7 % and 2,9%, respectively. In leaves of *Thuja pyramidalis* grown in the soil in DFES, the same parameters were 8.2% and 5.6%, respectively. For hydroponic plants the same indicators were 5.0% and 2.2% in the area of IHP and 6,2% and 3.0% in DFES (Figure 4).

In soil, the share of other RN in gross β-radioactivity (technogenic:^{89}Sr, ^{134}Cs, ^{141}Ce, etc. and natural: ^{40}K, ^{234}Th, ^{210}Pb, etc.) was 88,4% and 86,2% in the area of IHP and in DFES, respectively, while in hydroponics it was 92,8% in the area of IHP and 90,8% in DFES.

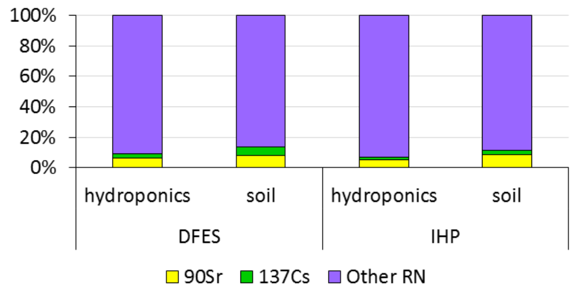

Figure 4. The share of 90Sr, 137Cs, and other RN (except 90Sr, 137Cs) in gross β-radioactivity in needle leaves of Thuja pyramidalis in hydroponics and soil

4. Discussion

Our studies show that in soil culture in the area of IHP, RN penetrated the trees through irrigation water-soil-plant root, and in DFES through soil-plant root, in hydroponics - nutrient solution - substrate - plant root transmission chains [20]. It is not excluded that in the studied radio voltage zones, extra-root penetration of RN into the above-ground organs of trees also occurred from the air basin (atmospheric precipitation, dust, smoke, soot, aerosols) [21]. The character of technogenic RN accumulation in the gray soil in the area of IHP and the brown soil in DFES depends on the influence of many factors (microrelief, soil type, and mechanical composition, hydrophysical and agrochemical properties, etc.). [8, 16, 22, 23]. It can be assumed that RN entered the DFES soil only from the air basin, and the soil in the area of IHP through both the air basin and irrigation water (Table 1). It was found that the content of ^{137}Cs dominates in the soil surrounding the IHP and the content of ^{90}Sr dominates in the soil in DFES. Thus, the soil surrounding the IHP exceeds the DFES soil by a factor of 1.1 in ^{137}Cs content is inferior to it. 1.7 times with ^{90}Sr, content.

In hydroponic plants, the lowest gross β-radioactivity recorded in February may be conditioned by the stop of plants' nutrition with a nutrient solution in the winter period, which brought a decrease of K (^{40}K) in plants.

It can be statistically seen that the accumulation level of β-emitting RN in the leaves of *Thuja pyramidalis* is partly dependent on tree age.

The autumn and winter higher results of gross β-radioactivity of red slag plants compared with same-age black slag plants may be conditioned by the different physicochemical properties (porosity, specific weight, volumetric weight, hygroscopic moisture, water capacity, etc.) of these two substrates. It has been shown that red slag has greater radioactivity and the ability to accumulate radionuclides than black slag [24, 25]. At the same time, red slag is more useful for the growth of thuja, which may be due to the iron oxide content in it [26].

The difference in gross β-radioactivity recorded between thujas grown in the gray soil in the area of IHP (radius of 30 km from the ANPP) and in DFES (radius of 90 km from the ANPP) areas in both hydroponic and soil growth conditions may suggest the different radio intensities of the biosphere in these two areas.

It was revealed that leaves under different cultivation conditions (hydroponics, soil) accumulated different amounts of β-emitting RN. Trees grown in hydroponics exceeded those grown in soil by gross β-radioactivity of leaves: 1.5 times in the area of IHP; and 1.3 times in DFES. Apparently, this is explained by the fact that hydroponics contributes to the improvement of the nutritional and water-aerial regime of plants, which ensures high biological activity of plants [27]. Presumably, the superiority of hydroponic tree leaves in gross β-radioactivity over soil plants is due to the higher content of K (^{40}K) in hydroponic plants compared to soil plants. It is known that the nature radionuclide ^{40}K has 89.33% β-radioactivity, and 10.67% γ-radioactivity [22].

5. Conclusion

Decorative Evergreen conifer *Thuja pyramidalis*, due to its leaf longevity and RN accumulation ability, can be effectively used for greening of cities near NPPs. This will have important ecological significance as it will reduce the movement of RN in the biosphere.

Studies will be continued on other trees and shrubs to find plants that are more capable of accumulating RN.

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