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HYDROPONICAL GROWTH AND RADIONUCLIDE ACCUMULATION SPECIFICITIES OF *THUJA OCCIDENTALIS* IN ARARAT VALLEY AND DILIJAN FOREST ZONE CONDITIONS

Kh. Mayrapetyan, A. Hakobjanyan*, L. Ghalachyan, A. Karapetyan, A. Ghahramanyan, S. Eloyan, A. Yeghiazaryan, A. Tadevosyan

Institute of Hydroponics Problems, NAS RA, Yerevan, Armenia

Abstract. *The aim of this study was to evaluate the hydroponic growth technology of Thuja pyramidalis as an accelerated sapling cultivation method and the ability of this plant to accumulate radionuclides that are nowadays big ecological problems for the settlements, which are near to the nuclear power stations. Our results show that hydroponic growth technology provides on average 1.3-1.4 times yearly increase of height of overground part, root and foliage perimeter. Already third years old saplings have about 30 cm height, 11 mm cingulum diameter, 46 cm foliage perimeter and 23 cm root length and may be transplanted into the soil in their final places. In hydroponic conditions of Ararat Valley saplings of this tree showed an increase of the ability to absorb total β–radioactivity with age. Eight years aged plant's total β-radioactivity level is two times higher from the three years aged one. In absorbed radioactivity the 90 Sr is about 6.5-9.5 % and 137 Cs is about 2.7-3.4 %. Other RN include technogenic (^{89}Sr, ^{134}Cs, ^{141}Ce, etc.) and natural (^{40}K, ^{234}Th, ^{210}Pb, etc.) ones and is about 87.3-91.4 %. From our results it may be proposed that Thuja occidentalis 'Pyramidalis Compacta' may be effectively used in the greenings of cities near to NPPs and hydroponic growth technology may be used to receive its saplings in a short time period.*

Keywords: *β-radioactivity, city greening, ^{134}Cs hydroponic growth, radionuclide accumulation, ^{89}Sr, thuja*

1. Introduction

Thuja occidentalis is native to Eastern North America [1]. It is a slow-growing tree, the maximum height of which reaches 25 to 40 feet. It prefers wet and rich soil, but may grow also in sandy and acidic, slightly alkaline soils [2].

Thuja is characterized with yellowish male flowers on branchlets near the base of the shoot and pinkish female flowers at the tips of short terminal branchlets. Final rip cones are oblong (8-13mm) and have cinnamon brown color [3]. The fresh leaves contain 0.6% essential oil (from which 65% is thujone and 8% is isothujone), 2.11% water-soluble minerals, and 1.31% tannic agents [4].

Thuja occidentalis L. is a valuable tree in the ecology of urban ecosystems as a biofilter and a producer of phytoncides [5]. It shows high stability in the air polluted with smoke and dust, thus it can also decorate industrial areas [6].

Thuja occidentalis leaves have an antibacterial activity and are used in folk medicine [7]. The medicinal importance of plants is due to the great diversity of bioactive molecules. *Thuja occidentalis* L. has a wide range of pharmacological activities, like antifungal, antiviral, immunostimulant, and radioprotector [1].

Thuja occidentalis L. is cultivated as an ornamental tree, that is used in cities greenings. There are many cultivated variants. One of them is *Thuja occidentalis 'Pyramidalis Compacta'* (*Thuja pyramidalis*), which is introduced into Armenia. Nowadays it is used a lot in city greenings and in gardens.

Today's energy big demand makes nuclear power plants one of the indispensable solutions and energy sources on the planet. But it is a fraught danger of environmental radioactive pollution especially in a close distance. In forests affected by the Fukushima Daiichi Nuclear Power Plant (NPP) accident, trees were contaminated with ^{137}Cs that entered into trees mostly (>99%) through its surface uptake trapped by needles and bark during the fallout. For example, foliated cedar trees received 30% of ^{137}Cs through bark; the remaining uptake occurred through needles. Because of that the removal of the forest floor organic layer will not reduce the tree contamination for a long term [8]. It is necessary to monitor the environment near NPP periodically for population, environment and food safety and cover soil near NPP with forest of trees resistant to radiation or with high ability to accumulate radionuclides.

In this study we estimate hydroponic growth technology of *Thuja pyramidalis* and its ability to accumulate radionuclides for further use in city greenings especially in places near to NPP.

2. Materials and methods

2.1. Study area

The study was done in Ararat Valley, in Yerevan (where is the Institute of Hydroponics Problems (IHP) NAS RA) and Dilijan forest zone (where is the Dilijan forest experimental station (DFES) of the Institute of Hydroponics Problems). Ararat Valley is in the south-

* ahakobjanian@gmail.com

west of Armenia, 850-900m above sea level and the average annual temperature is 11.0-11.8 o C, average annual precipitation amount is 200-300mm. The soil is semi-desert, gray carbonate; humus content is 1.5-2.5 %. It is rich in phosphorus and potassium. DFES was chosen as a background control zone on which the ANPP has no influence. DFES is in the north-east of Armenia, 1400-1500m above sea level and the average annual precipitation amount is 660-850mm. In brown forest soils humus content was 9.0-9.3 %, the soil is rich in potassium and poor in nitrogen and phosphorus [9; 10].

2.2. Study material

Saplings of *Thuja pyramidalis* were grown from the seeds. In Ararat Valley Thuja's 2 years aged saplings were transferred into hydroponic black slag substrate and in Dilijan Forest Experimental Station (DFES) into hydroponic red slag substrate for further outdoor hydroponic growth by classical hydroponic way. Both substrates consist of particles with 3-15mm diameter. Some saplings were transferred into soil in DFES to be used as controls. Hydroponic plants were nourished with the Davtyan's nutrition solution [11], made on the base of artesian water. The growth of plants was evaluated by the help of biometric measurements (plant height, cingulum thickness, root length, etc.) of 2-6 year saplings, using ruler. In each studied group 6-10 saplings were included for the biometric measurements.

2.3. Study of radioactivity and statistical analysis

Gross β-radioactivity and proportion of controlled technogenic radionuclides (RN) ^{90}Sr ($T_{1/2}$ = 28.6 years) and ^{137}Cs ($T_{1/2}$ = 30.1 years) in it were determined in the samples using small UMF-1500 background radiometer. For this ^{90}Sr and ^{137}Cs were extracted from the samples by the radiochemical method. ^{90}Sr was determined according to yttrium [12].

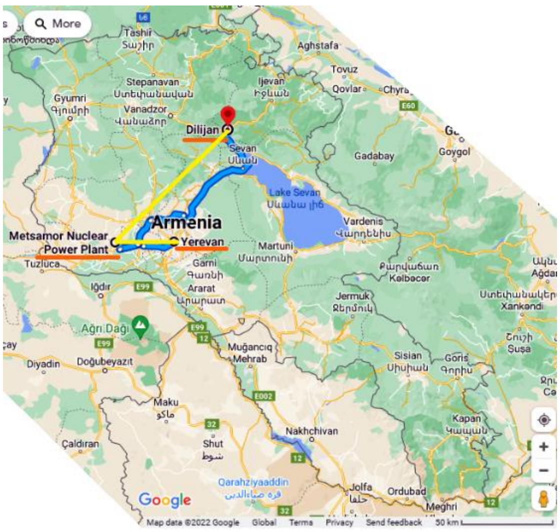

Figure 1. The map of Armenia taken from Google maps. Yellow lines show the distance of Yerevan and Dilijan from ANPP.

Yerevan is within a 30km radius and DFES is within a 90km radius of the Armenian Nuclear Power Point (ANPP) (Fig. 1). The study was done with three repetitions for each sample. The statistical analysis was done using GraphPad Prism5 and Excel. $p<0.05$ was considered statistically significant.

3. Results and discussion

3.1. Biometric study results of hydroponic growth

According to received data the height of saplings of *Thuja pyramidalis* showed the highest growth rate in the second year (2.7 times growth) growing from 11.2cm to 30.3cm. Later yearly growth rate was approximately stable (1.3-1.4 times growth) (Fig. 2). On the sixth year the average height of the plant was about 84.7cm. In DFES hydroponic conditions the height of the same age plant was 61.3cm, which indicates that Ararat Valley conditions are more suitable for the *Thuja pyramidalis* growth.

Cingulum thickness increase was the highest during the third and sixth years (2.3-2.4 times) (Fig. 3). Compared with the soil growth of Thuja in Canada, to which it is native, mentioned by C. Laoruche et al. (mean height increment = 14.8 cm/year, mean root collar diameter increment = 3.0 mm/year) [13] hydroponic growth shows more effective results.

From the Figure 3b it is obvious that with age plants start their increase in a cingulum diameter compared with height growth rate. There is a positive correlation recorded between height and cingulum diameter at two years aged saplings (Pearson $r=0.5183$, $p=0.001$).

Thuja pyramidalis has a branching property. 3 to 5 years old saplings have on average 2 main trunks and only in 6th year there is activation in the process of trunk generation increasing their average number to 4. Secondary branches amount is about 3 during 3rd and 4th year of plant life and 4th in 5th year plant. During 6th year, the amount of the secondary branches is about 6 (Table 1).

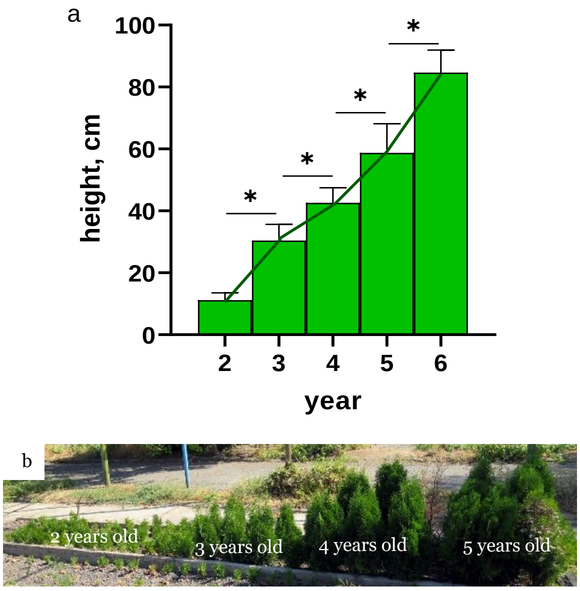

Figure 2. a. Height of *Thuja pyramidalis* saplings from the 2nd to 6th year of growth and b. view of the 2,3, 4 and 5 yeas aged *Thuja pyramidalis* in hydroponic conditions of Ararat Valley (* - $p<0.05$ (t-test)).

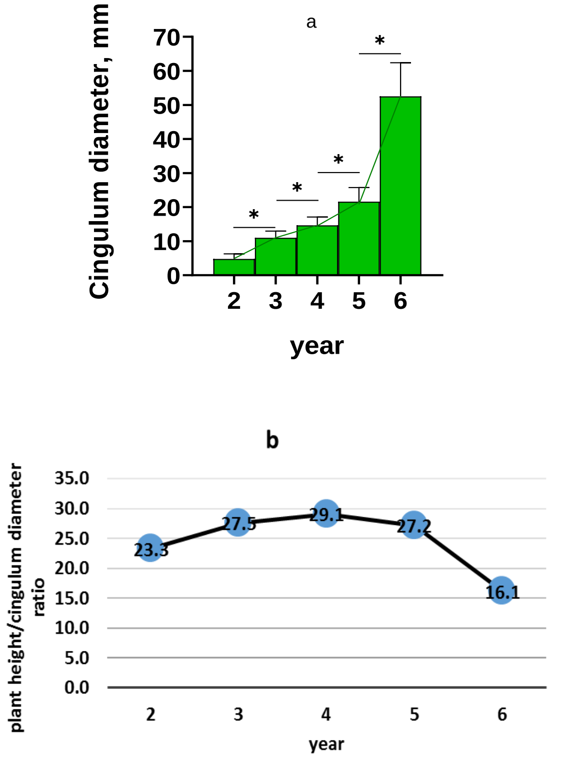

Figure 3. Cingulum diameter (a) and plant height/cingulum diameter ratio (b) of *Thuja pyramidalis* saplings from the 2nd to 6th year of growth (* - p<0.05 (t-test)).

Table 1. Number of main trunks and secondary branches, as well as foliage perimeter/root length ratio of different year aged saplings of *Thuja pyramidalis*.

	3rd year	4th year	5th year	6th year
Main trunk	2	2	2	4
Secondary branches	3	3	4	6
Foliage perimeter/root length ratio	2.0	2.5	2.5	2.6

Yearly growth of the perimeter of sapling's foliage is stable and is about 1.3-1.4 times (Fig. 4) and during four year of growth (from 3rd to 6th year) it increased from 46.3cm to 117.5cm.

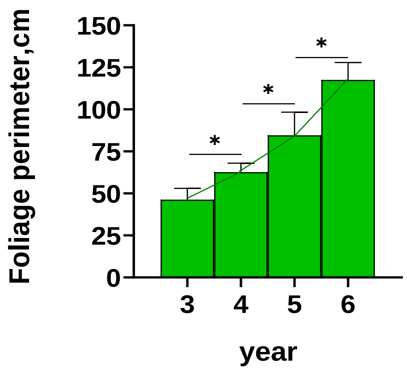

Figure 4. Foliage perimeter of *Thuja pyramidalis* saplings from the 3rd to 6th year of growth (* - p<0.05 (t-test)).

Root length increase of *Thuja pyramidalis* is the highest during 5th-6th years (1.3 times) (Fig. 5). At the same time foliage perimeter/root length ratio increases with the age of the plant showing that with the age and root elongation thickening of foliage becomes more intense. With the age the ratio of the trunk height to root length is also increased (Fig. 6) Positive correlation between the trunk height and root length was found in two and four years aged saplings (Pearson $r=0.7177$, $p=0.029$ and Pearson $r=0.8275$, $p=0.042$, respectively).

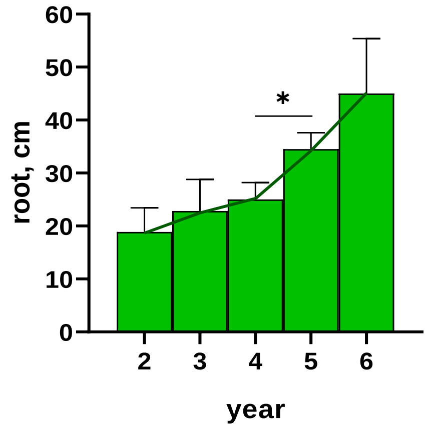

Figure 5. Root length of *Thuja pyramidalis* saplings from the 2nd to 6th year of growth (* - p<0.05 (t-test)).

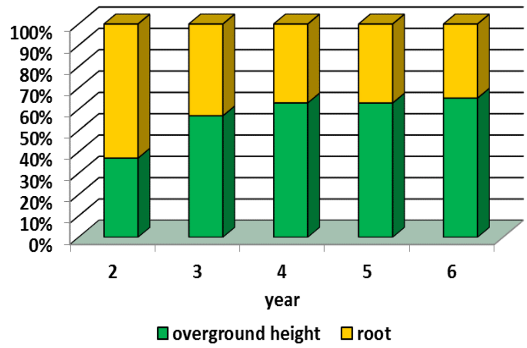

Figure 6. Overground height/root length ratio of *Thuja pyramidalis* saplings from the 2nd to 6th year of growth.

3.2. The ability to absorb total β–radioactivity

The content of ^{90}Sr and ^{137}Cs in the artesian water (irrigation water) of HPI was higher (1.2 and 1.5 times) than the tap water of DFES (Table 2).

The soil cover of the Ararat valley is mainly represented by gray soil, and the soil cover of the DFES is represented by brown soil. In both areas, the nature of man-made RN accumulation in the soils is determined by simultaneous influence of many factors (micro-relief, vegetation density, plant species composition, soil type and mechanical composition, water-physical and agrochemical properties, etc.) [9]. It can be assumed that RN penetrated into the soil of DFES only from the air basin (precipitations, dust, smoke, aerosols), and into the soil of the surrounding area of the IHP, not only from the air basin, but also through irrigation water (Table 2). It was found that the content of ^{137}Cs prevailed in the soil of the Ararat valley, and the content of ^{90}Sr prevailed in the soil of the DFES: the soil surrounding the IHP exceeded soil of the DFES by 1.1 times in ^{137}Cs content, and was inferior it by 1.6 times in the ^{90}Sr content. This indicates that soil contamination with radionuclides is caused not only by the proximity of NPP, and radionuclide contamination can also be dangerous for places remote from NPP.

In hydroponic conditions of Ararat Valley saplings of *Thuja pyramidalis* showed increase of the ability to absorb total β–radioactivity with the age (Table 3). In Ararat Valley leaves of 8 years old trees accumulate 2 times more RN, than 3 years old ones. It may be because of the radionuclide accumulation ability of *Thuja pyramidalis*.

From the comparison of the 5-year plants, it is obvious that the hydroponic ones in Ararat Valley accumulate 1.2 and 1.6 times more technogenic and natural radionuclides than hydroponic and soil ones in DFES. It can be because of the different distance of studied areas from the ANPP: as much territory is far from the ANPP, so much it is less affected by the radionuclides.

As it is shown in Table 4, in absorbed radioactivity the ^{90}Sr is about 6.5-9.5 % and ^{137}Cs is about 2.7-3.4 %. Other RN include technogenic (^{89}Sr, ^{134}Cs, ^{141}Ce, etc.) and natural (^{40}K, ^{234}Th, ^{210}Pb, etc.) ones and is about 87.3-91.4 %.

Thuja pyramidalis is an evergreen tree, which means that it is covered with green needle leaves the whole year. Evergreens' leaves have big longevity [14]. For example, average leaf longevity of western red cedar is 8.9 years [15]. All these mentioned and the ability to accumulate RN make *Thuja pyramidalis* beneficial in city greening during the whole year. This is especially important for the cities that are near to the NPPs, like Yerevan. Encircling such cities with trees of *Thuja pyramidalis* may reduce penetration of RN into the city atmosphere from the side of NPP decreasing air pollution.

Table 2. The content of ^{90}Sr, ^{137}Cs in water and soil of IHP and DFES

Zones where samples were taken from	Sample type	^{90}Sr	^{137}Cs
30 km radius from ANPP, Territory of IHP	artesian water / irrigation water	0.044±0.002 Bq/L	0.003±0.0001 Bq/L
	nutrient solution	0.44±0.03 Bq/L	0.03±0.001 Bq/L
	soil (0-30 cm)	7.2±0.27 Bq/kg	8.0±0.25 Bq/kg
90 km radius from ANPP, DFES	tap water	0.037±0.002 Bq/L	0.002±0.0001 Bq/L
	soil (0-30 cm)	11.9±0.3 Bq/kg	7.0±0.22 Bq/kg

Table 3. Total β -activity of leaves of *Thuja pyramidalis* in Ararat Valley and DFES

Zones, where samples were taken from	Culture conditions	Tree age	Total β – activity, Bq/kg
30 km radius from ANPP, Territory of IHP	hydroponics	3	110±22
		4	130±26
		5	190±26
		8	220±20
90 km radius from ANPP, DFES	hydroponics	5	160±20
	soil	5	120±26

Table 4. RN share in gross-radioactivity in leaves of *Thuja pyramidalis* in Ararat Valley and DFES

Zones, samples were taken from	Culture conditions	^{90}Sr	^{137}Cs	Other RN
		in total β-radioactivity, %		
Territory of IHP	hydroponics	6.5	3.4	90.1
DFES	hydroponics	5.8	2.7	91.4
	soil	9.5	3.2	87.3

4. Conclusion

Growth of *Thuja pyramidalis* is similar for roots and over ground part during first years but later root growth becomes inferior. Instead of that, the thickening of the cingulum is activated with age.

Ararat Valley is more suitable for the *Thuja pyramidalis* hydroponic and soil growth than DFES and hydroponic technology is more effective than soil.

Evergreen *Thuja pyramidalis* with its property of leaf longevity and ability to accumulate RN may be effectively used in the greenings of cities near to NPPs.

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