Ground-based “Pot-in-Pot” system and its effectiveness in growing *Thuja occidentalis* “Smaragd” planting material in a nursery

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**Abstract.** For the sparsely wooded regions of Russia, and in particular, the Central forest-steppe, new technologies for growing seedlings and seedlings of tree species are extremely important. It provides rapid growth and high survival rate, which is compared to classic technologies. The purpose of our experiment was to establish the effect of temperature screens from pots of various sizes on the temperature in the root zone of the substrate, and, as a consequence, on the growth and productivity of *Thuja occidentalis* “Smaragd” in plastic pots for three seasons. The most favorable temperature conditions for plants are formed in large pots, which is facilitated by smooth temperature drops in the substrate and a large area of contact between the substrate and the root system. Agrotechnical methods of growing plants have shown the main advantages of “Pot-in-Pot” technology. This is accelerated plant growth due to more efficient use of water and fertilizers on a specially prepared substrate under conditions of minimal temperature fluctuations. Plants, especially large ones, will have a favorable presentation due to better leafing, a well-developed crown, and a large crown diameter. High safety during wintering also increases the efficiency of the technology providing a higher yield and subsequent more intensive growth.

1. Introduction

Successful forest restoration requires the planting of quality seedlings with optimal growth potential. Thus, nurseries need to produce seedlings with plant attributes that provide the best chance of successful establishment when it is planted in the field. The production of planting material of trees and shrubs in pots has shown rapid growth over the past two decades in the nurseries of Russia and Europe. In the USA, the volume of containerized products has already exceeded ground production [1, 2].

The success of a forest establishment effort depends on the quality or traits of the seedlings, which are used, as well as the ability to survive under an anticipated range of environmental conditions [3]. Thus, an increased seedling quality during the nursery phase is deemed necessary to ensure that the newly planted seedlings will exhibit the desired level of growth and survival under harsh conditions in arid and semi-arid environment.

Nursery practices are considered to have a major influence on seedling quality during the nursery or hardening phase of the seedlings, and these qualities are likely to be maintained in the early establishment phase in the field. One of the reported determinants of seedling quality is a pot characteristics, which affect the morpho-physiological characteristics of the roots. Specifically, a pot
depth influences water holding capacity, humidity, temperature and aeration, which is considered an important factor determining root architecture and phenology.

When growing planting material in pots the temperature plays an important role. Warming effects on the physiology of woody plants have been studied primarily in mid- and high-latitude ecosystems. A number of authors [3-5] consider temperature changes as the most significant determinant affecting the vital activity of plants. High temperature is the main limiting factor affecting the intensity of life processes in a plant. The substrate temperature in pots located on the surface of the soil, due to the direct exposure to sunlight on the dark surface of the pot, can reach more than 50°C.

Growing planting material in planting pots of various volumes has a number of advantages over soil, which are the following: lower labor costs for maintenance, transportation, excavation, etc., more rational consumption of water and fertilizers, more rational logistics and expansion terms of sales and planting of plants during the entire vegetative period, the possibility of shipments of plants in the summer, etc. However, when growing plants in a limited volume of substrate, a number of problems appear: high price for the initial equipment of pot sites, the need for frequent and regular irrigation and fertilizing with mineral fertilizers, etc. The main problem is to overcome the effects of extremely high and low temperatures, because at <15°C and >27°C root growth decreases, at 30…35°C the growth of roots stops and the mode of water and nutrients absorption changes, while at higher temperatures, cell membranes degrade, proteins begin to denature, that leads to cell death [5, 6].

To overcome this factor, the breeders of Europe and the USA use various technologies, one of which is “Pot-in-Pot” [7-9]. The main principle of this method of growing is that the pot in which the plant is located is placed in a similar or larger pot. The pot in which the seedling further grows is called the insert pot, and the pot in which the insert pot is placed is the nest pot. A pot-nest is buried in the soil or exposed on its surface; the main thing is that the external pot acts as a screen from exposure to solar radiation [10, 11].

In the last decade, abnormally high temperatures in the summer months have been observed in the southern regions of Russia. In this regard, the specialists clearly faced the problem of overheating of pots, which requires a solution in the conditions of tree-decorative nurseries.

The purpose of our experiment was to establish the effect of temperature screens from pots of various sizes on the temperature in the root zone of the substrate, and, as a consequence, on the growth and productivity of plants in plastic pots.

2. Methods and materials
The research methodology is based on the issues of identifying priority factors and evaluating the qualitative parameters of growing planting material, including the development of new technological solutions of “Pot-in-Pot” technology for the Central forest-steppe of Russia. In accordance with this, it was essential to plan experiments, select basic tree and shrub species.

The samples where the development and testing of a complex of agrotechnical measures for growing planting material with a closed root system was carried out were “United Nurseries” (Voronezh region, Russia), “Savvateev Nursery” (Tula region, Russia), “Paer+” (Moscow, Russia). Promising species and varieties of deciduous and coniferous trees and shrubs actively grown in nurseries of the Central forest-steppe of Russia were selected as the studied breeds.

The research target was Thuja occidentalis “Smaragd” (Thuja occidentalis L.) characterized by moderate growth. “Smaragd” was obtained in 1950 in Denmark (Kvistchfird) and became the most promising in the Central zone of Russia. It is a slowly growing highly decorative tree with a pyramidal crown 4-6 m high. The average life span of Thuja is 150 years, and it is actively used in landscaping settlements due to its resistance to air pollution by smoke, gases and dust as well as high decorativeness.

Statistical processing of the results of shoot measurements was carried out using Excel 2015, Statistika 13.0, Stadia 8.2 with the establishment of the average value, error, accuracy and reliability of the experience. One-factor variance and correlation-regression analyses were performed. To determine the significance of the differences in the averages obtained by the method of moments, the Fisher criterion (F) was calculated, the differences between the two distributions were calculated $\chi^2$. To
To establish possible relationships between individual indicators, we used methods of multidimensional analysis: cluster and factorial.

The smallest significant difference (SSD) was a kind of division price, the resolving power of the experiment when evaluating the difference of sample averages. The criterion NSR = t·0.5·Sd indicated the limit error for the difference between the two sample averages.

If the actual difference was greater than SSD 0.5 (d ≥ SSD 0.5), then it was significant, significant, while d ≤ SSD 0.5 was insignificant. To determine the SSD, it was necessary to calculate the generalized mean error based on the data of variance analysis: Sx = √S2/n and the mean difference error Sd = √2S2/n.

In the multifactorial experiment, the effect and interaction of several factors on the variability of the effective feature was studied, therefore, several gradations were assigned to each factor. This allowed us to study the effect of each of it with several gradations of other factors.

The effect of the interaction of factors was that part of the overall variability that was caused by the different action of one factor at different gradations of another. In field experience, the effect of the joint application of the studied factors could often be higher (synergism) or lower (antagonism) than the sum of the effects from the separate application of each of it. In the first case, there was a positive, in the second one – a negative interaction of factors. If the factors did not interact, then the effect of joint application was equal to the sum of the effects of its separate application (additives).

The same principles and calculations of variances were used in the variance analysis of the data of the multifactorial experience as in the one-factor analysis. However, this complicated the mathematical model of analysis.

To solve this problem, in the production nursery of the United Nurseries (Voronezh Region, coordinates: N 51 o 48.368` E 38 o 57.037`), a pilot training ground was laid, where thuja plants were planted in 5 L plastic pots (figure 1).

![Figure 1. “Pot-in-Pot” experimental polygon (United Nurseries).](image1)

For containerization we took two-year-old plants of our own production, obtained by green cuttings and planted in seedlings and placed on a substrate from a natural mixture of sapropel and lowland peat with the addition of 9/1 river sand. Inner pots with the volume of 5 L with transshipment plants were placed in outer black pots with a volume of 5, 7.5, 10, and 15 L, and then put on a landfill. In each variant, 10 plants were taken. 5 L pots with arborvitae without screens were used as control. Each plant was assigned a serial number. When placing pots at the landfill, the randomization method was used.

Experimental plants were fed once per season with fertilizer of prolonged action Osmicate Exact Standard High K (11:11:18 + 1.5 MgO + Me) 5-6 m. The substrate temperature was measured by electronic thermometers for solid media TP 3001 having the range of measured temperatures –50…+300°C, graduation price 0.1°C. The probe of stainless steel was placed in a substrate to a depth...
of 10 cm at four points of the pot: from the north, south, west, and east sides 2.5 cm from the pot wall. The surface temperature of the pot was measured in the same way, focusing on the cardinal points with an IR-66 infrared pyrometer designed for non-contact measurement of the temperature of surfaces of solids by its thermal radiation. Measured temperature range was from –35°C to +230°C (±0.1°C). The air temperature was recorded using the Uniel UTV-72L portable weather station with a wireless weather sensor and an external sensor. Temperature measurements were taken during the three summer months. Measurements of growth in diameter and height were carried out monthly for each plant, taking into account the assigned serial number.

3. Results and discussion

We found that, unlike the soil in natural conditions, the temperature of the substrate in the pot is more affected by the environment, and the configuration of the pots also affects the temperature regime of the substrate in the pot.

As a result of processing the temperature data, it was found that the maximum summer heating of the walls of the outer pot and the inner pots, as well as the substrate, occurs from the south, south-west, and west sides in the interval of 14.00-18.00 h. Data analysis shows that at almost the same temperature of the surface of the outer pot, the temperature of the inner wall of the pot and the substrate are significantly different.

So, the temperature of the substrate in the control without a screen on the south side is 13.3…13.5°C higher than with a screen of 10 and 15 L pots. An important point is the presence of a layer of air, circulating freely. Here, the temperature of the substrate was practically the same. At the same time, in 5 L pot the substrate warms up more, apparently due to the tight fit of the walls in the upper part of the pots (tables 1-2).

Table 1. Growth progression of Thuja occidentalis “Smaragd” in height.

| Date       | Height of tree, m in outer pots with different volume of outer pot (V) |
|------------|---------------------------------------------------------------|
|            | V=0 L  | V=5 L  | V=7.5 L | V=10 L  | V=15 L  |
| 06 June    | 15.65±2.2 | 15.36±2.1 | 16.24±2.3 | 15.45±1.8 | 15.92±1.6 |
| 06 July    | 19.60±1.7 | 21.00±2.9 | 21.20±2.6 | 21.20±1.6 | 21.30±2.9 |
| 06 August  | 24.20±1.7 | 26.60±4.1 | 25.50±2.8 | 26.20±2.8 | 26.70±4.0 |
| 06 September | 26.00±1.4 | 29.40±5.05 | 28.10±2.9 | 28.40±3.8 | 29.60±4.1 |
| 06 October | 26.90±1.4 | 30.9±5.0 | 29.50±2.6 | 29.30±3.7 | 30.60±4.0 |

An exposure to high temperatures above 40°C caused a regular lag in the growth of control samples. The impact of high temperatures (>40°C) caused a natural lag in the growth of control samples. This trend is consistent with studies conducted in other climatic zones [12-14]. The height growth in plants according to “Pot-in-Pot” approach began in the hottest period of July-August and reached maximum values at the end of the vegetative period.

Table 2. Growth progression of Thuja occidentalis “Smaragd” in diameter.

| Date       | Height of tree, m in outer pots with different volume of outer pot (V) |
|------------|---------------------------------------------------------------|
|            | V=0 L  | V=5 L  | V=7.5 L | V=10 L  | V=15 L  |
| 06 June    | 0.44±0.09 | 0.41±0.07 | 0.42±0.08 | 0.43±0.07 | 0.44±0.09 |
| 06 July    | 0.5±0.08 | 0.5±0.06 | 0.52±0.08 | 0.52±0.04 | 0.56±0.09 |
| 06 August  | 0.61±0.08 | 0.64±0.07 | 0.65±0.07 | 0.68±0.09 | 0.68±0.04 |
| 06 September | 0.7±0.07 | 0.74±0.08 | 0.79±0.12 | 0.76±0.11 | 0.81±0.07 |
| 06 October | 0.81±0.07 | 0.83±0.09 | 0.87±0.09 | 0.82±0.1 | 0.90±0.06 |

Actual differences between the particular average values of the height and diameter of the experimental plants are presented in table 3.
Table 3. Actual differences between the particular average values of the height and diameter of the experimental plants of Thuja occidentalis “Smaragd”.

| Volume of outer pot, L | Actual average difference | Fisher F fact | Student t fact | Fisher F fact | Student t fact |
|------------------------|---------------------------|---------------|----------------|---------------|----------------|
|                        | Diameter, cm | Height, cm | Diameter, cm | Height, cm | Diameter, cm | Height, cm |
| 5                      | 0.02         | 4*          | +            | 2.4         | +            | 3.5         |
| 7.5                    | 0.04         | 2.6*        | +            | 2.7         | +            | 2.9         |
| 10                     | 0.05*        | 2.4*        | +            | 1.8         | +            | 2.2         |
| 15                     | 0.09*        | 3.7*        | +            | 2.7         | +            | 2.9         |
| SSD                    | 0.04         | 1.92        | $t_{0.05} = 2.1$ | $t_{0.05} = 2.1$ |

*The actual average difference exceeds the smallest significant difference (SSD) at 5%.

As the data in the table 3 show, statistical data processing confirms differences in growth in height and diameter. Control reliably differs from shielded pots, which within the cluster have no differences at 5% significance. It should be noted that inhibition of control plants also leads to the loss of presentation. Seedlings grown in pots with screens have better coverage and crown development. Under production conditions, exceeding the control height by a quarter can cause the batch to transfer to the next condition, which will give an economic effect significantly exceeding the cost of the second pot. Reducing the substrate overheating will reduce moisture evaporation, which in turn will significantly reduce the flow of irrigation water in large pot areas.

Prolonged exposure to direct sunlight leads to the destruction of plastic pots and increases the fragility of the walls of the pot. In the case of using a second pot, we partially prevent the mass breakdown of pots during loading and transportation in cases of multiple use of technological pots. An important aspect of the use of double pots is the prevention of root sprouting through drainage holes and the substrate into the ground, which is especially important for long-term cultivation at pot sites. The interlayer between the bottom of the pots, formed when one pot is placed in another, causes an air pruning of the roots when the root cover exits through the drainage holes.

Shielding the walls of technological pots with plants in nurseries using larger pots reduces the temperature of the substrate in the root zone by 10-13.5 °C. The increase in height of the plants participating in the experiment significantly (with 5% significance) differed in the group of screened specimens in comparison with the control and did not differ within the group. The best growth dynamics in height was demonstrated by experimental plants in pots placed in pots of 5 and 15 L (an excess of 14.7% and 15.6%), in a diameter of 7.5 L and 15 L (an excess of 10% and 11.2%).

Growing plants in pots is completely artificial. Among the numerous abiotic factors affecting the growth of both the root system and the ground part in the process of pot production, the temperature determinant plays a special role. The most favourable temperature conditions for plants are formed in large pots, which is facilitated by smoothed temperature differences in the substrate and a large area of contact between the substrate and the root system. Statistical processing of the experimental data obtained and calculation of the sample linear correlation coefficient showed the presence of a high level of feedback between the pot volume and the temperature regime of the pot substrate in the time interval from 13:00 to 16:00 ($r_{xy} = -0.97$).

Thus, as the results of the study show, the most comfortable conditions for the growth of the root system are provided in 5 L pot, shielded by 10 and 15 L pots. The influence strength of the “screen” factor increases with the increase in the volume of the outer pot. In the variant of a 5 L pot placed in a pot of the same volume, the power of influence is at the level of the accuracy of the experiment. The most comfortable conditions for the growth of the root system are provided in a 5 L pot shielded by 10 and 15 L pots. The 5 L pot (control) showed the least favorable results here with a root length of 647.8 cm, with an extremely high indicator of the strength of the factor. The experience of a sample in 15 L allows us to conclude that the more the pot is used for the seedling, the greater the air layer, and,
accordingly, the more comfortable conditions for growing. The pot plants in regions with severe and little snowy winters are under significant stress under the influence of freezing temperatures and other negative factors. “Pot-in-Pot” technology allows you to neutralize the impact of winter factors. The best plant preservation was in “Pot-in-Pot” (100%), the lowest – in the open area (68.3%).

The theoretical significance of the research results lies in the fact that the results of the use of the innovative “Pot-in-Pot” system were obtained and its effectiveness was established in comparison with the traditional pot technology in the conditions of nurseries of the Central forest-steppe. The advantages of the technology (increased root capacity, growth characteristics, development of the root system of woody plants) are revealed as a causal relationship between the use of innovative methods of agricultural cultivation “Pot-in-Pot” and the growth parameters of pot seedlings.

The use of the “Pot-in-Pot” technology ensures a moderate temperature regime for growing plants. When using the “Pot-in-Pot” technology, the temperature even at the peak hours does not exceed the critical 35°C, which creates favorable conditions for plant growth. The cause-and-effect relationships between the growth and development of seedlings and the temperature regime indicate the minimization of temperature stress, which has a positive effect on the growth of containerized plants both in height and in the diameter of the root neck.

The development of a uniform root system for planting material is achieved by optimizing the size of pots and creating conditions for the development of the horse system. According to the results of factor analysis, a reliable influence of the temperature factor on the growth of the roots of Thuja occidentalis grown in “Pot-in-Pot” was established (the influence force is 0.9).

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4. Conclusion

Thus, the modern trend in the production of nursery products is the introduction of modern resource-saving, environmentally friendly and science-intensive technologies that allow the rational use of water resources and mineral fertilizers.

In this regard, container nurseries are innovative sites where it is possible to create technological lines that will prevent water erosion caused by irrigation, soil contamination with fertilizer and herbicide residues, and save significant amounts of water by reusing it after collection and treatment. It is also possible to use the nursery area more efficiently by increasing the volume of products produced. The transition to new technologies for growing planting material in low-forest regions is determined by the growing demand for woody plants resistant to adverse climatic factors. A large segment of the forest planting material market both in the Russian Federation and in foreign countries is occupied by plants grown using container technologies. The transfer to new technologies for growing planting material in the Central forest-steppe of Russia is determined by the growing demand for woody plants resistant to adverse climatic factors. A large segment of the planting material market both in the Russian Federation and in foreign countries is occupied by plants grown using container technologies. Growing plants in containers is completely artificial. Among the numerous abiotic factors affecting the growth of both the root system and the ground part in the process of pot production, the temperature determinant plays a special role. The most favorable temperature conditions for plants are formed in large pots, which is facilitated by smoothed temperature differences in the substrate and a large area of contact between the substrate and the root system.

As the results of the experiments show, the substrate warms up less in “Pot-in-Pot”, and the seedlings grown using this technology have significant advantages in the growth rate.

The practical significance of the research results lies in the development of practical recommendations for the use of technological schemes in the department of pot cultivation of a nursery.
“Pot-in-pot” technology is used in the practical activities of the limited liability company “United Nurseries” (Voronezh region, Russia), the nursery of the limited liability company “Paer+” (Moscow, Russia).

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