Woody plants seedlings irradiation lighting parameters by using LED transmitters in small-sized irradiation installations

D S Ivushkin¹, V A Petrukhin¹, S V Volobuev¹, A S Feklistov¹ and P V Prokofiev¹

¹ Volgograd State Agricultural University, 26, Universitetskii Avenue, Volgograd, 400002, Russia
E-mail: ivushkinds@yandex.ru

Abstract. The use of planting material with a root-balled tree system is one of the promising directions for creating artificial plantations. It is associated with radical changes in the cultivation of planting material and significant changes in the forest crops production technology [1]. The technology of widespread, woody plants year-round cultivation in the artificial environment can be implemented by using small-sized forms of cultivation structures - irradiation chambers and cabinet units, grow boxes, phytotrons, etc. In this case, the main technological operation is the light regime necessary for plants: with the radiation spectrum necessary for their development and growth, with the required intensity and irradiation regime. The results of photobiological studies on the qualitative indicators of woody plants grown in phytotron conditions under irradiation by radiation with different proportions in the blue-red and blue-green-red ranges of the photosynthetically active radiation zones are presented. The photosynthetically active radiation spectral variants, providing the highest or extremely close to it productivity of the indicated crops, were established. The complex and ambiguous nature of the photosynthetically active radiation main spectral ranges influence on the photoenergy and photoregulatory processes in plants, which ensure their productivity, is indicated, which makes it impossible to determine the general unified requirements for the artificial irradiation optimal parameters for growing plants.

1. Introduction
The number of grown seedlings with a root-balled tree system increased by 18% over three years, which forces greenhouse complexes and seed centers scientists and specialists to carry out research in the field of plant photoculture, developing new technologies and technical means. In this case, the main adjustable technological parameter of the artificial environment for growing plants in greenhouses is the seedlings’ “correct” irradiation with the radiation spectrum, mode and intensity necessary for their development and growth [2].

Light is essential for the normal development of plants for three reasons. First, it is needed to carry out the process of photosynthesis. Second, light regulates the appearance of plants, their constitution. Third, the light and darkness periods relative length governs a variety of natural physiological processes in the plant development.

Each of the three main zones of the photosynthetically active radiation (blue, green and red), taken separately, is not very suitable for growing plants under artificial irradiation conditions and areas isolated from the external environment, and only radiation formed in a certain ratio of energy across the entire spectrum can provide full-fledged woody plants cultivation with high quality indicators [2].

Thus, the spectral content of light, as well as its intensity, is a strong morphogenetic factor that regulates both growth and photosynthetic reactions in the life support system of the whole plant. At the same time, the following energy ratios are recommended for the photosynthetically active radiation spectrum in artificial radiation sources: 25-30% - in the blue zone (380-490 nm), 20% - in the green one (490-590 nm) and 50% - in the red zone (600-700 nm). That is, for the plants predicted growth and their normal development, as well as for obtaining the required amount of plant products with the desired biochemical characteristics, it is extremely important to optimize the optical radiation source spectral composition and search for the problem...
of the plants irradiation process energy consumption reducing without the seedlings obtained quality decrease [3,4].

2. Materials and methods

The main requirements for small-sized structures for the plants intensive photoculture technology implementation are the following: installations must be technologically efficient with agro-technological processes maximum automation; installations should consume a minimum of energy, which should be used with maximum efficiency in the main technological operations - supplementary lighting, watering, maintaining the temperature and humidity of the air and soil, etc.

In the laboratory of the Volgograd state agrarian university, the prototype of the irradiation installation for growing woody plants was assembled (Figure 1) using quasi-monochromatic phyto-irradiator with LEDs by the manufacturer “CREE” (Table 1).

![Figure 1. Appearance of LED irradiation chamber for woody plant growing.](image)

| №  | LED type (manufacturer)                                      | Peak wavelength, nm | Spectral range of radiation, nm |
|----|-------------------------------------------------------------|---------------------|---------------------------------|
| 1. | Cree XPE 3535-Deep Red light Emitting Diode, HotRed Official Store | 660                 | 650-666                         |
| 2. | Cree XP-G3 3535 XPG3 – Royal Blue Emitting Diode, HotRed Official Store | 445                 | 435-458                         |
| 3. | Cree XPE 3535 – Green Emitting Diode, HotRed Official Store | 520                 | 500-540                         |
| 4. | Cree XPE 3535-UV Emitting Diode, HotRed Official Store       | 395                 | 390-395                         |

The control circuit is based on the Microchip pic 16f1937 microcontroller; the following main automation elements are connected to it: to collect information about the environmental parameters - moisture and temperature sensors SHT10 (DD2) and air ones DHT11 (DD3); for information output - graphic LCD with LED backlight WG128x64 (DD4) with adjustable contrast by means of R2 divider; to configure the block - an incremental encoder (BR1) with a clock button (SB1) EC11; to control the process of lighting and ventilation by means of pulse-width modulation (PWM) - field-effect transistors with an insulated gate IRL3705 (VT1-VT5). The whole circuit is powered from a 220 V network, through the switching power supply (PSU) with the IC7805 (DA1) integrated voltage stabilizer. Clock source DD1 is built-in, with the frequency of 32 MHz. For the modes controlling convenience, the current parameters of the irradiation process and operating modes are represented on the display built into the control unit, also the parameters are input (Figure 2) that ensure the normal functioning of the chamber (operating time of timers, temperature and humidity of soil and air, etc.) (Figure 3).
Figure 2. The appearance of the graphic LCD display for representing the information.

Figure 3. The scheme of the processes control unit in the irradiation chamber.

The main species of woody plants, grown in nurseries of the Volgograd region and used in the creation of protective plantations in the Southern Federal District, Crimean pine (*Pinus nigra subsp. Pallasianna*), eastern thuja (*Thuja L.*), black locust (*Robinia pseudoacacia L.*) were chosen as the subject of the research. The work on determining the effect of artificial irradiation on woody plants started in 2019. Experiments in the irradiation chamber were carried out with a constant 15 hour photoperiod at the air temperature in the chamber of +22 ... +25 °C and humidity of 40 ... 55%, the soil temperature was +22 ... +24 °C with the humidity of 50 ... 60%. Woody plants were grown in rigid plastic cassettes from Plantek 64f, which have
vertical slits and guide ribs in the cell walls, which contribute to the most natural and correct development of the root system. A ready-made soil with a ratio of nutrients (mg/l) N (180-360) was used as a substrate; \( \text{P}_2\text{O}_5 \) (180-360); \( \text{K}_2\text{O} \) (270-530); \( \text{pH} \text{K}_2\text{O} \) (4.9-5.6). Watering was carried out in the automatic mode according to the maintained humidity, it was repeated for four times. Biometric parameters of plants were taken into account in 50 days after germination.

The research of the studied woody plants biometrics dependence on the RGB ratio of the radiation fractions was the first stage of staged experiments to optimize the radiation spectrum for these crops grown in greenhouses. Measurements of the phytoirradiators emission spectrum were carried out by using a spectrometer "TKA-Spektr" (RF) with the software Spectroradiometer (photosynthetically active radiation) version 2.3.4.

3. Results
The results of phytobiological studies on the development of woody crops seedlings grown under phytotron conditions under irradiation with different ratios of the proportions radiation in the signal code zone ranges of the photosynthetically active radiation zones are given in the Table 2 with the corresponding results of the development biometric indicators.

| Spectrum type | Variants | Robinia pseudoacacia L. | Pinus nigra subsp. Pallasiana | Thuja L. |
|---------------|----------|-------------------------|-------------------------------|----------|
|               | Tap-root length, cm | Plant height, cm | Tap-root length, cm | Plant height, cm | Tap-root length, cm | Plant height, cm |
| R 60% | R 60% | R 33.3% | R 60% | R 45% | R 40% |
| R 60% | G 0% | G 20% | G 33.3% | G 30% | G 10% | G 40% |
| B 40% | B 20% | B 33.3% | B 10% | B 45% | B 20% |
| 19 ±3.46 | 26 ±4.56 | 21 ±5.66 | 19 ±4.1 | 24 ±4.0 | 23 ±5.21 |
| 18 ±2.39 | 17 ±1.21 | 11 ±3.58 | 12 ±2.61 | 9 ±1.11 | 8 ±1.36 |
| 23 ±4.5 | 23 ±2.2 | 21 ±1.12 | 18 ±1.45 | 21 ±2.14 | 21 ±1.58 |
| 5.2 ±1.25 | 6.3 ±0.58 | 5.8 ±1.21 | 5.4 ±1.08 | 5.9 ±0.87 | 4.8 ±0.51 |
| 29 ±1.28 | 28 ±1.01 | 22 ±2.08 | 21 ±1.37 | 28 ±1.74 | 21 ±1.08 |
| 6.8 ±0.81 | 6.9 ±0.47 | 6.1 ±0.58 | 5.8 ±1.01 | 6.7 ±0.81 | 5.1 ±0.49 |

It is noted that for the maximum height of seedling development, the priority effect of red radiation is obvious, and the predominant share of blue radiation clearly sharply reduces the plant height. The highest values were achieved with the ratio options R - 60%, G - 0%, B - 20% and R - 60%, G - 20%, B - 20%. The presence of green radiation in the photosynthetically active radiation zone is not optional, but acceptable. The artificial irradiation influence on the development of the root system is not unambiguous and requires further experiments to obtain more accurate results.

In addition, the following circumstance is very important for practice: when added to RB-radiation, G-radiation with its share of 20% increased the development of experimental seedlings, and the increase in this share had a significantly negative effect on woody crops.

The results of our research and a fairly large volume of literature data allow to assert that the assessment of the photosynthetically active radiation different spectral ranges combined effect on the woody plants qualitative indicators is complicated by synergistic (superadditive) or, conversely, antagonistic interaction effects, which are apparently characteristic of plants as complex radiation receivers with a large number of photopigments. In other words, the concept of "optimal spectrum of radiation for growing plants" is rather abstract and vague. Even for plants of the same species, the requirements for a favorable spectrum, which provide the maximum quality indicators, can vary markedly.

The complex nature of the photoenergetic and photoregulatory processes interaction in plants can lead to obtaining the same or similar effects of action for significantly different radiation spectra in the photosynthetically active radiation zone. This is evidenced by the data of photobiological studies. Therefore, it can be assumed that the concept of equifinality, which was formed in the 1960s by the Austrian biologist L. Bertalanffy, is applicable to the effect of radiation on plants. The effect of photoequifinality, as a property of a self-regulating system, which is a higher plant, can certainly be the subject of the further research [5-7].
4. Conclusion

The data obtained on the basis of direct experiments give a certain "freedom of choice" to the irradiation devices developer, allowing the spectral characteristics of the latter to be determined not only from the condition of maximizing the quality indicators of woody plants seedlings, but also taking into account the LEDs energy efficiency, their price parameters and, which is absolutely necessary, the exclusion of harmful impact of "blue" radiation on the operating personnel vision [8-9]. In some cases, the consumer may put forward another requirement essential for phytoinstallations: the need for correct visual perception of woody plants green zones ("visual organoleptic") in order to assess its quality and marketable condition ("coloration" of leaves, absence of spots, damage by insect and pests, etc.).

Taking into account all these circumstances, the problem of choosing between the binary RB or RGB spectra can be solved in favor of the latter for a number of woody crops. The carried out photobiological studies determined the requirements for favorable emission spectra of phytoirradiators with LEDs, which ensure the woody plants seedlings development maximum quality indicators. The significant difference in these requirements for these cultures shows the inevitability of using an experimental approach to solving such problems.

Due to the fact that the LED technology physical principles allow to fulfill the requirements identified by the photobiological studies data not only to a favorable spectrum, but, which is no less important, to the level of irradiation [10, 11], it can be stated that there is a possibility of creating lighting technology (as the most important element of specific woody plants macrotechnology of photoculture) with computer control of such plants economic cultivation.

References

[1] Igor Yudaev et al 2019 IOP Conf. Ser.: Earth Environ. Sci. 403 012078
[2] Igor Yudaev et al 2019 IOP Conf. Ser.: Earth Environ. Sci. 403 012084
[3] Koziel S, Ciaurri D E and Leifsson L 2011 Surrogate-Based Methods Computational Optimization, Methods and Algorithms 33-59
[4] Shahriari B, Swersky K, Wang Z, Adams R P and De Freitas N 2015 Taking the human out of the loop: A review of Bayesian optimization Proc IEEE 104(1–P) 148-175
[5] Kim H H, Goins G D, Wheeler R M and Sager J C 2004 Green-light supplementation for enhanced lettuce growth under red-and blue-light-emitting diodes HortSci. 39 1617-1622
[6] Bugbee B 2016 Towards an optimal spectral quality for plant growth and development: The importance of radiation capture ActaHortic 1134(1) 1–12
[7] Kuan-Hung Lin, Meng-Yuan Huang, Wen-Dar Huang, Ming-Huang Hsu, Zhi-Wei Yang and Chi-Ming Yang 2013 The effects of red, blue, and white light-emitting diodes on the growth, development, and edible quality of hydroponically grown lettuce (Lactuca sativa L. var. capitata) Scientia Horticulturae 150 86-91
[8] Dieleman A, Weerheim K and Kruidhof M 2019 Design of lighting strategies for sustainable horticulture Greensys 2019 – International symposium on advanced technologies and management for innovative greenhouse
[9] Qingwu Meng 2018 Spectral manipulation improves growth and quality attributes of leafy greens grown indoors Phd dissertation Michigan State University
[10] Yudaev I, Kokurin R, Charova D, Feklistov A and Vinnikov A 2018 Rural machine operator 7-8 24-25
[11] D V Zelyakovskiy et al 2021 J. Phys.: Conf. Ser. 1801 012032