Improving the efficiency of greenhouses systems by developing algorithms for the synthesis of an optimal lighting spectrum based on the fundamental principles of agrophotonics

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Abstract. The question of creating an optimal microclimate for maximum realization of the genetically inherent potential in plants is far from being resolved. This is due to the multi-factor nature of the biotechnical system of greenhouses, the dependence on the number of controlled components of the microclimate and the consistency of their work: light, temperature, etc. Based on this task, we conducted initial research and developed additional lighting algorithms for greenhouse systems. Based on the work of previous years and existing scientific research, the most optimal method for optimizing artificial lighting and linking its intensity to the microclimatic parameters of the system has been determined.

1. Introduction
Algorithmization of management processes for various systems increases both their energy efficiency and quality for a wide range of indicators. The question of creating an optimal microclimate for maximum realization of the genetically inherent potential in plants is far from being resolved. This is due to the multi-factor nature of the biotechnical system of greenhouses, depending on the number of controlled components of the microclimate and the consistency of their operation: light mode, temperature mode, humidity mode, gas composition and nutrition mode. [1,2] In this paper, we consider the principle of algorithmization of the synthesis of the optimal lighting spectrum based on the fundamental principles of agrophotonics. To form the correct algorithms, we formed an experimental base, the objects of which were vegetable and green crops. In this work, the fundamental principles of agrophotonics are: the dependence of plants on lighting, its frequency and intensity, as well as the reaction of plants to a wide range of external influences. [2] The fundamental complexity of this work is to determine the basic criteria of efficiency associated with the principles of agrophotonics and the resulting experimental base. [2]

2. Application of the least squares method for creating agricultural lighting systems with optimal illumination
Many tasks of agrophotonics require the synthesis of irradiation with a given spectrum to stimulate plant growth processes at different stages of development - from seed germination to maturity. The spectral characteristics of lighting significantly affect both the physical parameters of the developing plant and...
its heredity, which leads to an increase in the viability of crops and their productivity. [1] the Use of this technology significantly increases the energy efficiency and modularity of additional lighting systems used in agro-cultivation of vegetable and green crops. However, after conducting a patent analysis and searching for scientific materials, we found that this technology is still at an early stage of development [1,8,9]. And the development of smart lamps is a little-studied area of agro-cultivation. Thus, we decided to consider the existing and developed methods of forming a given spectral density with a different set of LED LEDs present on the market.

We discussed the detailed formulation and analytical solution of the optimal spectrum approximation problem in the article "Simulation, identification and dynamic control of the luminaire of the synthesized spectrum" [7]. Our method is based on the least squares method, where the optimization function will be in the form (1):

$$J(k_1, k_2, \ldots, k_n) = \int_{\lambda_1}^{\lambda_2} \left( S(\lambda) - \sum_{i=1}^{n} k_i S_i(\lambda) \right)^2 d\lambda_{k_1 \ldots k_n} \rightarrow \min$$

where integration means that the approximation will not be based on the envelope, but on the total power of radiation and the spectral range from $\lambda_1$ to $\lambda_2$; $S(\lambda)$ – the functional or tabular spectral density to which the approximation is made; $S_i$ – the functional or tabular spectral density of the LEDs used [7].

Thus, the use of the least squares method provides high accuracy of approximation, allows you to get an approximation with the smallest error when using LEDs with an abnormal view of the spectrum, such as full-spectrum LEDs, white, mixed type. The first graph in Figure 1 shows all the led modules we use. An example of approximating the spectral densities of discrete light sources can be seen in Figure 2, where graphs of the relative intensity from the radiation wavelength are shown.

![Figure 1. Spectral densities of 4 types of LEDs](image-url)
Figure 2. Approximation spectral densities of 4 types of LEDs to sunlight, modified when passing through 3 mm of soil. [6]

To reduce the intensity of the spectra at a length from 400 to 550 nm, long-wave filters with a transmittance of 550 nm are used. Figure 3. [8, 10]

Figure 3. Approximation using a filter [6]

3. Adjustment of algorithms of stimulation of seeds on the microclimate

Having conducted a significant number of tests for tomato, lettuce and radish seeds, we have identified the most favourable microclimate conditions at the moment. Seeds are a dynamically developing biological object that requires equally dynamically changing conditions. Despite the fact that it is not yet possible to analyse the issues of microclimate modelling comprehensively due to the huge number of factors and state variables that occur in a biological object, we have identified the main parameters of the installation - biological object system based on the
research database, which at the moment can be regulated or controlled in any way, and determined their periodic fluctuations [1].

Based on the results obtained from the tests, it was determined that small temperature fluctuations (within 2 – 3 °C) do not significantly affect the culture of radish, lettuce and tomato seeds. The method of forming the temperature regime can be considered on the example of an algorithm for maintaining a microclimate for lettuce seeds.

The entire preparation period, for example, for lettuce seeds, the most favourable temperature is formed at 6–15 °C. The temperature changes from the lowest temperature point to the highest and Vice versa occurs in accordance with the period of light stimulation that occurs at the time of seed preparation. The stimulation period is selected for each crop and has a range of effective action, for example, for lettuce seeds, the smallest period is 18 hours. During this time, the light intensity increases to the maximum value and fades out according to the normal law. An example of temperature and light correlation for lettuce seeds is shown in Figure 4. This schedule is based on intermediate tests on the use of variable light stimulation when preparing seeds for germination.

![Temperature and light correlation for lettuce seeds](image)

**Figure 4.** Correlation of temperature and light for lettuce seeds over 25 hours (~2 lighting periods)

Thus, the correction of the temperature regime is carried out by a sinusoidal law with the formation of a favourable temperature regime that correlates with the illumination with an approximately equal period.

Temperature changes that correlate with illumination are individually selected for each seed culture we studied.

### 4. Conclusion

The algorithmization of pre-lighting processes proposed in this paper determines the possibility of energy-efficient and all-season closed-type agrocultivation. Thus, for the further development of light-stimulation algorithms, it is necessary to constantly develop the experimental base. The application of our methods increases the percentage of germination and the rate of germination of vegetable and green crops while maintaining their high level of viability. Potentially, the use of the synthesized spectrum, taking into account the correlation with the microclimate, provides an increase in germination by 15-20 % [6]. Statistics are based on studies of the reaction of plants to synthesized lighting, which were considered in the article "study of the influence of the main spectra of discrete light sources on the seeds of greenhouse crops". [11]
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