Efficiency of an alternative LED-based grow light system

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Abstract. This article is dedicated to the assessment of the usage influence of LED lights of varying color spectrum on plant growth and development, and determining their usage impact. The research interest is focused on the usage of LED-based light system inside greenhouses for optimization of lighting conditions.

Research methods. The current research focused on the following Green-LP™ LED-based grow lights: GLP-FH-56-B (30/70 % red(660 nm)/blue(445 nm) spectral composition), GLP-FH-56-R (70/30 % red/blue spectral composition) and GLP-FH-56-RB (50/50 % red/blue spectral composition). Examination of the influence of plant lamps on the growth processes was carried out at the laboratory conditions (23 °C during the day and 20 °C at night, humidity from 75 % to 80%, with the varying PAR intensity and the daylight of 16 h (supplementary illumination was provided for 6 to 8 hours)) with lettuce as a subject. Phenological observations and biometric registrations were conducted according to generally accepted techniques. Chlorophyll content was measured using the express method with atLEAF+ device.

Results. Based on the results of the conducted experiments the highest germination rate was observed under the lamps with blue and blue-red spectral peaks, salad seedlings had largest shoot fresh weight under grow lights with red and blue-red spectrum peaks (0.235 and 0.250 g, respectively). The shoot weight exceeded that of control group of plants 1.8 to 2.1 times. Additionally, plants grown under the lamp with a blue spectral peak had 17 to 29 % more powerful root system than those grown under red one and 43 to 73 % higher than control group. Highest chlorophyll content was observed in plants grown under the lamps with blue spectral peak (440-450 nm), which exceeded by two times that in plants grown without supplementary illumination and was 1.8 times higher than that of plants grown under a high-pressure sodium arc lamp.

Conclusion. LED lamps with different illumination spectrum can serve as an additional light source for plants grown inside greenhouses, positively affecting both growth and development of plants, and economical efficiency.

Introduction

Currently, energy efficiency and energy saving are among the five strategic directions of prioritized technological development, with decreasing the energy consumption of domestic industry being one of the strategic goals [1-3]. In order to recognize and evaluate the energy saving potential of the
engineering solutions in question it is necessary to possess deep knowledge of the variety of the LED lights options, as their properties and performance characteristics are quite diverse [4-6]. Investments into the implementation of new specifically developed greenhouse plant growing technologies for healthy plant growth at maximum speed can result in significant decrease of power costs during the operation time. Thus, we should consider the positive experience of both foreign researchers and those in the regions of Russia where thanks to use of new modern electric technologies even with reduction in cultivated area a significant increase of productivity and energy economy was achieved. Considering the unceasing cost growth of energy carriers, scientific justification of the technical solutions for the introduction of electrical technologies is undoubtedly relevant [7].

In order to ensure the quality photosynthesis process in the plant cells a full light spectrum mimicking that of the sunlight is needed, at 440-450 nm and 650-660 nm wavelengths in particular. Thus, artificial illumination has to be as identical to the sunlight as possible, containing light of various wavelength and color (except for green). Most interesting studies of efficient spectral compositions for plant growth are presented in [8-13].

The artificial influence on plants can significantly decrease the costs for thermal and electric energy used for growing plants in greenhouses. Thus, it is expedient to find a scientific basis for determining the optimal PAR spectral composition for each plant species cultivated in the greenhouses. Thereby, the goal of present work was the study of influence of the 440-450 nm and 650-660 nm peaks in the spectral composition of the experimental LED lamps on the phases of crop development.

**Research methods**

The current research focused on the following Green-LPT™ LED-based grow lights: GLP-FH-56-B (30/70 % red(660 nm)/blue(445 nm) spectral composition), GLP-FH-56-R (70/30 % red/blue spectral composition) and GLP-FH-56-RB (50/50 % red/blue spectral composition). Two control groups used a sodium arc discharge lamp or no supplementary illumination.

Examination of the influence of plant lamps on the growth processes was carried out at the laboratory conditions with cruciferae family vegetable crop (lettuce) as a subject. The plants were grown at 23 °C during the day and 20 °C at night, humidity from 75 % to 80%, with the varying PAR intensity and the daylight of 16 h inside Petri dishes. Supplementary illumination was provided for 6 to 8 hours. There were four replications of the experiment. Phenological observations and biometric registrations were conducted according to generally accepted techniques. Chlorophyll content was measured using the express method with atLEAF+ device.

**Results and comprehensive assessment**

Usually, sowing of the early maturation vegetables is done during the period of low solar activity and short daytime. The daylight length required for production of strong and healthy planting stock is at least 10 to 15 hours, but natural conditions in our latitude cannot ensure such lighting mode. Thus, the primary task of any vegetable grower is the organization of supplementary illumination.

Currently, the primary means of supplementary and full artificial lighting are obsolete lamps, such as incandescent lamps and gas-discharge lamps. Those, like all the luminescent ones, are subject to degradation – exhaustion of the luminous flux. After 6 months in action, luminous flux strength of such lamp drops by 30%, and after one or two years it decreases twofold. Besides, there are serious deviations in the spectral composition of the emitted light. Because of this, it is necessary to replace such lamps every half a year to a year, and their reliability suffers. The main downside of incandescent lamps is lack of blue light radiation in their spectrum and very low luminous efficiency of 17 to 25 Lm/Wt. Additionally, they create excess heat: when placed at a height below 1 m they may cause a burn of plants, and when placed at a height above 1 m they are not able to provide efficient illumination. In order to ensure the balanced spectral composition it is recommended to alternate gas-discharge sodium lamps with metal halide lamps, which is a labor-intense procedure.
The material used in the semiconducting element of an LED determines its color, and the intensity of the emitted light can be regulated by varying the electric current. A complex lighting fixture consisting of several LEDs, each emitting the light of its own part of the spectrum, can be controlled by changing current through each of the components [14] to emit light of any color.

It is traditionally assumed that the cruciferae family plants are the most sensitive to external influences [15]. A study of influence of light of specific wavelengths on growth process has shown that the highest germination rate was under the lamps with blue and blue-red peaks in the spectral composition (89 and 88 %), but the highest mass was obtained by salad sprouts under the lamps with red and blue-red peaks in the spectral composition (0.235 and 0.250 g per 20 specimen respectively).

Table 1 – effect of light of specific wavelengths on growth process of lettuce.

| No. | Options                                      | Germination energy, % | Germination rate, % | 20 seedlings’ total weight, g |
|-----|----------------------------------------------|------------------------|---------------------|------------------------------|
| 1   | Control (no supplementary illumination)      | 45                     | 82                  | 0.165                        |
| 2   | Control (high-pressure sodium arc lamp)     | 60                     | 83                  | 0.184                        |
| 3   | LED lamp (440-450 nm) (660nm-30%: 445nm-70%) | 47                     | 89                  | 0.212                        |
| 4   | LED lamp (650-660 nm) (660nm-70%: 445nm-30%) | 42                     | 81                  | 0.235                        |
| 5   | LED lamp (440-660 nm) (660nm-50%: 445nm-50%) | 57                     | 88                  | 0.250                        |

The influence of light of specific wavelengths on lettuce mass gain dynamics is shown in Figure 1:

Figure 1 – Lettuce weight gain dynamics for different lighting modes.

Analysis of the results demonstrated that lamps with blue and red spectral peaks have had the greatest influence on the growth process of lettuce, and until a certain point there was no observable difference between the two. Later, plants grown under the lamp with the red spectral peak began to gain biomass more intensively. The difference when compared to control group specimen was 1.8 to 2.1 times, and the lettuce control specimens were even visually observed having some light deficiency. However, under the lamp with a peak in the blue part of the spectrum, a more powerful formation of the root system was observed, 17-29% higher compared with those grown under the lamp with a peak in the red part of the spectrum and 43-73% higher compared with the control group [16].

The measurement of chlorophyll content in plants’ leaves has demonstrated that the highest amount of chlorophyll was found under the lamps with the blue spectrum peak (440-450 nm), which was two times higher compared than that without the supplementary illumination and 1.8 times higher than under the high-pressure sodium arc lamp (Table 2).
Table 2 – effect of light of specific wavelengths on chlorophyll content (scores).

| No. | Options                                                                 | Chlorophyll content (scores) |
|-----|--------------------------------------------------------------------------|------------------------------|
| 1   | Control (no supplementary illumination)                                  | 11.3                         |
| 2   | Control (high-pressure sodium arc lamp)                                  | 12.5                         |
| 3   | LED lamp (440-450 nm) (660nm-30%: 445nm-70%)                             | 22.8                         |
| 4   | LED lamp (650-660 nm) (660nm-70%: 445nm-30%)                            | 19.5                         |
| 5   | LED lamp (440-660 nm) (660nm-50%: 445nm-50%)                            | 20.7                         |

Analysis of LED lamps economic efficiency has shown that low electric power consumption was one of the advantages of the tested lamps. And most importantly, these lamps could be placed close to plants without any harmful consequences, as the lamps did not overheat. Additionally, the number of watering could be reduced, since the soil was not drying out too quickly.

Economic and energy characteristics of the instruments under study indicate their high reliability and economic feasibility [16, 17]. Despite the fact that the cost of LED lamps is 1.7 times higher than that of the discharge lamps, they consume 2.7 times less electricity and possess a 5 times longer guaranteed lifetime (Table 3).

Table 3. Economic and energy characteristics of the tested lamps.

| Lamp                        | Manufacturer | Price with VAT, rub | Nominal power consumption, W/hour | Warranty, years | Expected service life, years | Expected service life, hours |
|-----------------------------|--------------|---------------------|-----------------------------------|----------------|-------------------------------|-----------------------------|
| GLP-FH-56-R                 | Green-LP     | 5,800               | 56                                | 5              | 10                           | At least 60,000             |
| GLP-FH-56-B                 | Green-LP     | 5,700               | 56                                | 5              | 10                           | At least 60,000             |
| GLP-FH-56-RB                | Green-LP     | 5,800               | 56                                | 5              | 10                           | At least 60,000             |
| High-pressure sodium arc lamp | Russia (entire procurement set) | 3,500 | 150 | 1 |                            |                             |

Conclusions
Studies conducted demonstrated that LED lamps with different illumination spectrum can serve as an additional light source for plants grown inside greenhouses, positively affecting both growth and development of plants, and economical efficiency.

References
[1] Kasyuk S.T. Energy saving and energy efficiency policies in the European union. Proceedings of the higher educational institutions. ENERGY SECTOR PROBLEMS. 2015;(9-10):95-98. https://doi.org/10.30724/1998-9903-2015-0-9-10-95-98
[2] Gorshkov A S, Vatin N I, Rymkevich P P and Kydrevich O O 2018 Payback period of investments in energy saving Mag. Civ. Eng. 78 65–75
[3] Savina N.V., Artjushevskaja E.J. Actual problems of realization of the federal law № 261 from 23.11.2009 in the Russian Federation in the part of heat supply. Proceedings of the higher educational institutions. ENERGY SECTOR PROBLEMS. 2017;19(3-4):31-40. https://doi.org/10.30724/1998-9903-2017-19-3-4-31-40
[4] Zubkov V I, Evseenkov A S, Orlova T A and Zubkova A V 2015 Monte Carlo Simulation of the Radiation Output from a Led Structure with Textured Interfaces Russ. Phys. J. 58 1172–80.
[5] Yisihakefu A. Development of measuring complex for research of quality of led lighting
devices. *Proceedings of the higher educational institutions. ENERGY SECTOR PROBLEMS*. 2017;19(7-8):144-148. https://doi.org/10.30724/1998-9903-2017-19-7-8-144-148.

[6] Yisihakefu A., Tukshaitov R.H. Control the body temperature of LED lamps at work in different lighting devices. *Proceedings of the higher educational institutions. ENERGY SECTOR PROBLEMS*. 2017;19(9-10):146-150. https://doi.org/10.30724/1998-9903-2017-19-9-10-146-150.

[7] R.G. Bolshin. Increasing the efficiency of the potato meristem plants irradiation by LED phyto installations // Dissertation for a degree of Candidate in Technical Sciences/ M.: ARIAE SSE, 2016, page 148.

[8] N.N. Protasova. Importance of individual spectrum sections for plants photosynthesis, growth and productivity (under irradiation performed with energy or number of quanta). *Greenhouse Service information bulletin / N.N. Protasova // 1995, No. 6-7, pages 24 -25.*

[9] D.A Aliev. Photosynthetic activity, mineral nutrition and plants productivity // D.A. Aliev. Baku: Elm, 1974, page 344.

[10] V.V. Malyshev. On the possibility of assessing quantitative criteria for the different spectrum lamps in plant growing according to light parameters // Association of Greenhouses of Russia information collection. 1999. No. 2, pages 16-19.

[11] N.P. Kondratyeva. Increasing efficiency of electric irradiation installations in sheltered ground // Dissertation for a degree of Doctor in Technical Sciences/ M.: ARIAE SSE, 2003, page 251.

[12] A.N. Vinokurov. Thermal regimes of DORADO high-power LEDs / A. Vinokurov // Components and Technologies, No. 5, 2006.

[13] A.A. Tikhomirov. Light spectral composition and plant productivity. A.A. Tikhomirov, G.M. Lisovskiy, F.Ya. Sidko / M.: Novosibirsk, 2001, page 163.

[14] L.P. Varfolomeyev. LEDs and application thereof / L.P. Varfolomeyev - M.: News of lighting engineering, issue 3, 2000, page 131.

[15] E.G. Kulikova. Study of the urban ecosystems soil phytotoxicity // XXI Century: Results of the Past and Problems of the Present Plus, Periodical Scientific Publication, Penza State Technological Academy Publishing House, 2011, pages 88-91.

[16] E.G. Kulikova. Study of the special spectrum lamps influence on the Solanaceae family plants growth processes / In the collection: Agro-industrial complex: state, problems, prospects. Penza: PSAU ISSRC, 2017, pages 44-46.

[17] http://green-lp.ru/