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The control of lighting up regime of greenhouse plants with LED irradiators

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Abstract. A system for controlling the lighting up regime is proposed in the article, which gives the opportunity to reduce the cost of consumed electricity. The main element of the proposed control system is a processor, which calculates the necessary power of LED irradiators and the lighting up regimes according to a specially programmed program. For selecting the power and the regime of radiation of a given spectrum, a mathematical model of the geometry of the plant stalk in the process of its growth, obtained from the experimental data, is given. A two-factor experiment was carried out to determine the quantitative effect of the red and blue spectra emitted by LED sources on the geometry of the formed stalk of seed potatoes. The paper presents the results of the experimental studies on a genetically homogeneous material of potatoes grown from meristematic cells, making it possible to obtain reliable responses to different spectral composition of blue and red radiation of LED irradiators. The given system of controlling the lighting up regime allows growing the healthy plants in optimal photosynthesis with the minimal costs of electricity.

1. Introduction

The main source of light of modern greenhouses is sodium lamps, which limit the control of the process of lighting up though it is possible. [1, 2]. The lighting up process lasts for 20 hours which is not economically correct.

In one's time, the experiments were carried out to study the intensity of photosynthesis of cucumber plants at the development stage of 2–4 leaves and the diagrams were obtained that clearly showed a sharp decrease in photosynthesis after several hours of intensive lighting up [3, 4]. At the same time, the plant breathes intensively and consumes accumulated nutrients. Consequently, it is necessary to find the correct lighting up regime and to optimize it using more modern irradiators which permit to control the process.

Nowadays, there has been a tendency to use more modern and economical light sources, the production technology of which is being improved, and the production becomes cheaper every year. These are LED-irradiators, consisting of a certain number of LED elements. They have already come to industrial greenhouses and they convert electricity not into heat, but into a certain emission spectrum, the one that plants need most of all [5, 6]. However, the experiments with LED irradiators are still at the initial stage, and so far a small number of plants have passed through the stage of the primary researches. However traditional long-lived greenhouse vegetable plants with a growing season of up

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to 10-12 months are still little studied and the information on this subject appears in literary sources rarely [7-9].

The purpose of lighting up of the plants is to attain the correct geometry of the stalk in the process of its growing. Only then we can be sure that the quality of the seeds from the healthy plant will be the best.

2. Materials and Methods

In the process of growing greenhouse plants it is important to control the process of lighting up. The process of irradiation is the lighting up the plants with a given spectrum and the power of emission.

The research of the influence of the red-blue emission spectrum of LED in the process of lighting up the plants has shown the regularities. Maximum photosynthesis is possible only with the optimal combination of the percentage of blue and red spectra with the obligatory radiation from the lamps of a wide solar spectrum [10-12].

The emission spectra in the process of irradiation have a different effect on the geometry of the greenhouse plants. So an unreasonable lighting up with given emission spectra can make the stalk of a plant oblong. Then the number of leaves will be decreased, there will be a large distance between the leaves, which reduces the intensity of photosynthesis. It is also possible that the plant can slow down its growth, as the number of fruit ovaries will decrease.

Then it is necessary to control the emission parameters according to a given algorithm. It requires the development of the mathematical model that relates emission parameters to plant growth rates.

The mathematical models can and should be used to control the technological processes. This feature of automatic control systems permits to relate the consumed resources properly to gain high-quality products.

Modern capabilities of science and technology allow gaining the mathematical models of various processes occurring in biological objects. Some models are incredibly complex, but rather accurately allow us to predict the rate of plant development, a set of their biological mass, and the geometry of the stalk and fruit changes [13]. The others include regression-type models [14], and they are able to quantify the effect of various combinations of environmental factors on the vital activity of plants, without in-depth analysis of the biological processes occurring in them. At the same time, not all factors can be used, but only a part of them, leaving others outside the plan of experimental studies. These models include the mathematical models of the intensity of photosynthesis or dark breathing [15].

The factors affecting the vital activity of plants, but not included in the experiment, are nominally present in it as averaged parameters of the habitat without the possibility of their variation. In this case, the experiment will be recognized as correct, and the results of the study calculated from the model can be used to regulate the conditions of plant growing in the greenhouses [16, 17].

At present, there is no recommendation on the lighting up of greenhouse plants, the implementation of which would allow growing the healthy plants with optimal photosynthesis with the minimal costs on electricity [18]. Then it is relevant to study the influence of emission spectra on the vital activity of plants, and to learn how to control them to minimize the necessary costs for the production of greenhouse products

2.1. Formulation of the problem

The experimental researches are needed to study the influence of the spectral composition of LED irradiators on the vital activity of greenhouse plants. The experimental technique should include special climatic chambers or phytotrons.

According to the experimental data, it is necessary to develop the mathematical model of plant growth, depending on the emission spectrum and the irradiation regime. They will further optimize the regimes and control the process of irradiation.

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Today, greenhouses are not massively equipped with LED-sources. Therefore, to determine the optimal spectral composition of emission from LED light sources, the expensive experimental studies have been required.

To study the behavior of a potato plant at different levels of the blue-red emission spectrum of irradiators based on LED-elements, a photo set was created. The final aim of the experiment is to attain the mathematical model of the growth and the diameter of the stalk. On the basis of the obtained model, it is necessary to create an algorithm for controlling the growth characteristics of a plant in the course of its vital activity with the minimal lighting up costs [19-21].

2.2. Research methods.

During the research, it is important to identify the emission spectra necessary for a plant life. At the same time, plants with a short lifespan and a rapid onset of the generative phase of development have been studied. Most of the experiments were carried out on leafy green plants or potatoes, to obtain elite seeds [22-25].

The setup shown in Figure 1 was used for the research; it consists of LED lights, a control unit, as well as a measuring complex based on the ACP ZET–210. Plant growth (height) was determined using the ODROID-C1 + minicomputer, which is capable of processing frames captured by a web-camera. The level of irradiance of the space above the plants was regulated by means of a controller and a specially created computer program in accordance with the developed algorithm. The processing of the information obtained during the experiment was carried out by certified programs [26].

Figure 1. The general view of the experimental setup.

To take the main characteristics of the lighting fitting, a certified instrument TKA-Spectrum Spectrophotometer was used. The level of irradiation was measured with an APDS – 9250 light sensor which was calibrated with a spectrophotometer.

The emission level of the LED-elements was regulated by the number of switched on LEDs in the work, while it was possible to provide the required spectral composition. The microclimate inside the phytobox was maintained by a special control unit.

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The experiment was realized on a genetically homogeneous material of potatoes grown from meristematic cells and the research materials are given in [27]. This approach permits to gain reliable responses to the influence of different spectral composition of the blue-red emission of LED - irradiators.

A two-factor experiment was carried out to determine the quantitative effect of the red and blue spectra emitted by LED sources on the geometry of the formed stalk of seed potatoes. Table 1 shows the planning matrix of the experiment in coded units, and Table 2 shows the values of the levels and the intervals of variation of the specified factors.

Table 1. The levels of factors variation.

№ experiment	Levels of variation: red X1	Levels of variation: blue X2
1	–1	–1
2	+1	–1
3	–1	+1
4	+1	+1
5	–1	0
6	+1	0
7	0	–1
8	0	+1
9	0	0

Table 2. Emission intensity for a given level of variation.

Name and designation of factors		Emission intensity, % –1	0	1	Variation intervals
The intensity of red spectrum, %	X1	40	60	80	20
The intensity of blue spectrum, %	X2	40	60	80	20

The experiments carried out with the purpose of gaining the mathematical models are justified if they allow the use of modeling results for the purpose of controlling the most important plant growth factors.

3. Results

In the process of experimental researches, the influence of LED - irradiation on the potatoes, the data array was obtained. After processing the results, the dependences shown in Figure 2 were obtained.

As can be seen from the given graphs the dependences of the growth of the length of the plant stalk has the form of an inverted parabola and the graph of the diameter of the stalk has the appearance of a conventional parabola. A combined solution to optimize the two radiation spectra is not possible.

Then, using the experimental data, it is necessary to obtain the mathematical models for each considered geometric size of the stalk, depending on the emission spectrum. The mathematical models permit to investigate how the geometry of a potato stalk will vary with different combinations of the examined spectra of LED emission sources [27].

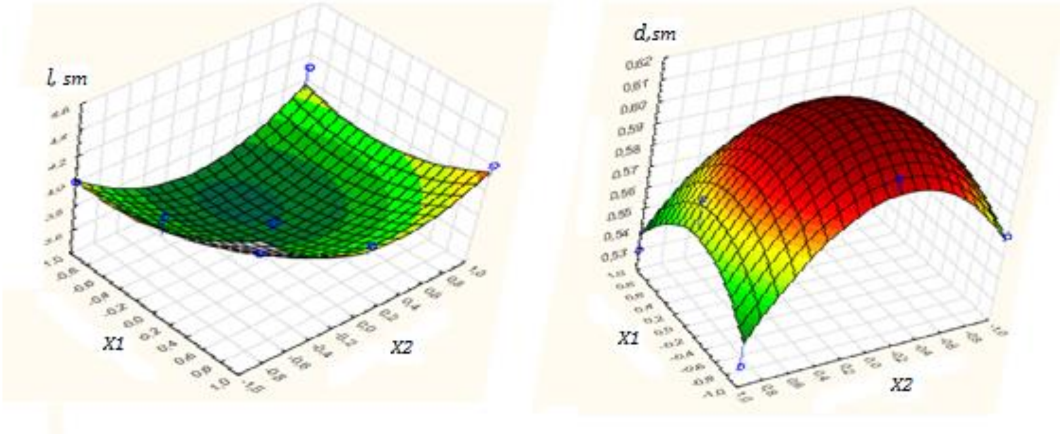

Figure 2. The dependences of the growth of the length (a) and the diameter (b) of the plant stalk with lighting up of LED sources.

As a result of processing the experimental data, a mathematical model of the stalk length increase of the following type was developed:

$$l_{st}(X1,X2) = 3.6222 + 0.1667\ X1 - 0.1\ X2 + 0.1667\ X1^2 - 0.075\ X1\ X2 + 0.366\ X2^2 \qquad (1)$$

and for defining the diameter of the incremental segment of the stalk:

$$d_{st}(X1,X2) = 0.6089 - 0.0067\ X1 - 0.0033\ X2 - 0.0233\ X1^2 + 0.005\ X1\ X2 - 0.0433\ X2^2 \qquad (2)$$

The given mathematical models allow us to construct the graphical dependencies of the frontal projections and to analyse them. Figure 3 shows the frontal projection of graphs of the increment of the length of the new plant stalk segments (the curves 1, 2, 3) and the diameters of these segments depending on the change in the amount of the red component of the LED spectrum — X1 emission. In this case, the values of emission in the blue spectrum are strictly fixed at the conditional points of the experiment, i.e. when X2 = –1; 0 and +1 in accordance with the adopted plan, shown in the table 1.

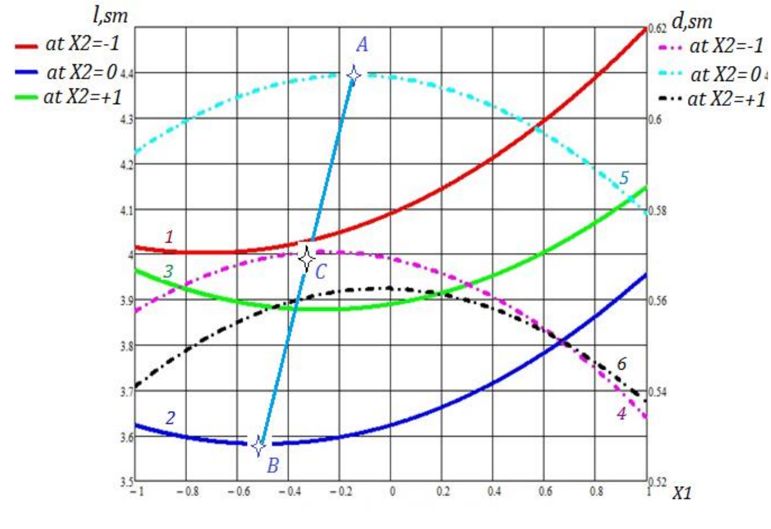

Figure 3. The dependences of the increment l_{st} and d_{st} from the coded factors X1 and X2.

4. Discussion

The experimental curves 1, 2, 3 increments in the stalk length of potatoes have a clear shown minimum. Moreover, the minimum point of the graphs begins to shift in the coordinate system from the conditionally negative area of the X1 axis to the central point of the experiment when the X2 parameter for the blue spectrum changes. It should be noted that the maximum length of the stalk growth is expected with the parameters X2 = –1 and X1 = +1, i.e. the smaller the blue spectrum in the emission of the LED source; the less the plants are stretched. Therefore: the red spectrum helps to accelerate the growth of the stalk, and the blue spectrum inhibits the ability of plants to stretch.

The arrangement of the group of the curves for lst (1,2,3) indicates that the smallest growth of the stalk (the curve 2) is achieved if X2 = 0, which corresponds to the central point of

the experiment. The curve (3), corresponding to X2 = +1, is much higher, which does not correspond to the logic of reasoning. Based on the analysis of the curves, it follows that the minimum growth of the stalk will occur when X2 = 22 W/m2. A higher or lower intensity of the blue spectrum does not affect the growth indices of the plant stalk.

The graphical interpretation of the equation (2) is presented in Fig. 3. The curves 4, 5, 6, characterize changes in the diameter of the stalk increment depending on the intensity of the LED emission in the red and blue spectra.

The analysis of the data shows that the group of graphs looks like an inverted parabola. Optimum graphs are the maximum values of the diameters of the incremental portion of the stalk. The curve 4, at X2 = 0 is located above the rest and the optimum of the curves 5 and 6 are shifted along the X1 axis relative to the optimum of the curve 4 to the left and to the right, but the stalk diameter is almost at the same level.

It can be preliminarily concluded that the intensity of LED emission in the blue spectrum, as in red, does not contribute to an excessive increase in the diameter of the stalk. The optimum at X1 = +1, less than optimum at X1 = –1, although not significantly, but less than optimum at the center of the experiment (see tab.) At X1 = 0. It means that in reasonable doses (X1 = 0) the blue spectrum also affects the geometry of the stalk, thickening its diameter.

For practical application of the results of the experiment, a compromise should be found between the amount of emission of LED-irradiators in the red and blue spectrum, in particular, to obtain a potato plant with the suitable stalk geometry. At the same time, the mathematical models of the length and the diameter of the stalk do not have the point of intersection that satisfies the solution for optimizing the lighting up regimes.

To solve this problem, we use the method of the direct compromise, examined in several articles [28]. Graphically, it looks like this. From the optimum of the stalk diameter graph dst at X2 = 0 (the curve 5) to the minimum of the stalk growth graph lst (the curve 2), we draw a straight line segment AB (see figure 3). Then determine the coordinates of the point C, which is the geometric midpoint of the segment AB. On the abscissa axis, determine the corresponding value X1 = 0.3, and on the ordinate axis = 4 cm. The values of the coordinates of the midpoint of the segment AB determined by the compromise method are substituted into equation (1) and the value of X2 is determined from the solution of the quadratic equation, which satisfies the compromise and which is the third coordinate.

In fact, the middle point of the compromise C lies in the area of the optima of all the other curves 1, 3 and 4, 6.

Express the coordinate values calculated by the compromise method into the model (1) and determine the value of X2 from the model equation. Provided that X1 = - 0.3, and lst = 4cm, we get:

$$4 = 3.62 + 0.17\,(-0.3) - 0.1\,X2 + 0.17\,(-0.3)2 - 0.06\,(-0.3)\,X2 + 0.37\,X2^2$$

so

$$0.37\,X2_2 - 0.08\,X2 - 0{,}45 = 0$$

$X2_1 = 1.2$ (relative unit) or $X2_2 = -1.05$(relative unit)

With the help of the proportions and the data in the Table 1, you can recalculate and get that:

$$X2_1 = 96\% \text{ or } X2_2 = 42\%.$$

The results of the research show that for the growth of a plant it is offered the lighting up with a blue spectrum using 96% of all the LED elements of the corresponding spectrum, or using only 42%. Naturally, to save the energy, it will be enough to turn on a smaller number of LED elements, and the plant will not be harmed. This is the principle of control according to the mathematical model.

Thus, the percentages of emission are transferred into the energy of one or another emission or to the number of LED-elements included in the lighting up device. The plant will receive a sufficient amount of special emission for its safe growth with the minimal costs on the lighting up.

For the realization of the research results of the influence of the blue and red spectra on the growth and the development of any greenhouse culture, a system of automatic control of the lighting up regime has been developed (Figure 4).

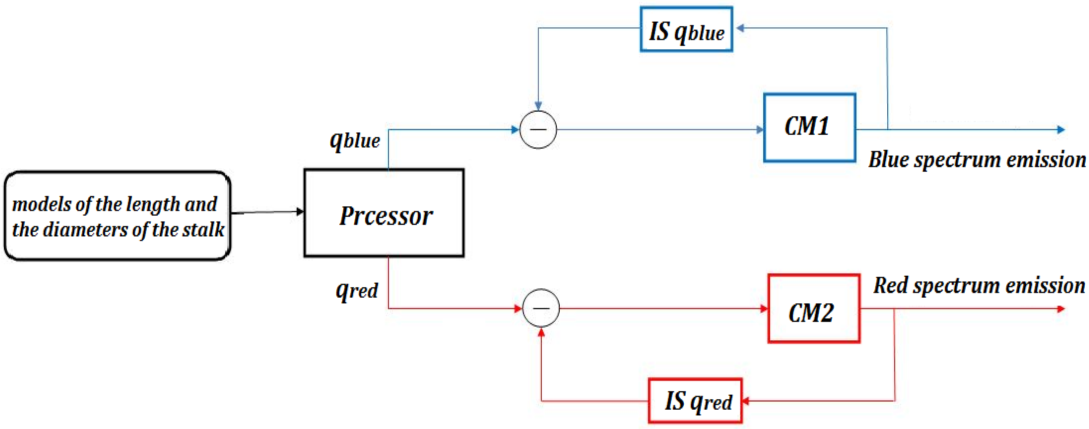

Figure 4. The system of control the optimal LED–lighting up. Initial sensor (IS) qblue and qred – blue and red emission sensor, respectively; CM – control module LED–emission sources; qtbl and qtred – CPU-calculated tasks for optimal emissions in the blue and red spectra.

The important element in the control system is the processor, which, on the basis of the offered mathematical model (1 and 2) and according to a specially programmed program, calculates the power of blue and red emission LED necessary for lighting up. The mathematical models for the growth of potato stalks can be obtained for other crops, like tomatoes, cucumbers and flowers.

The offered system contains sensors for each spectrum of emission from the LED-irradiator. In principle, these sensors are able to determine the total radiation coming from the sun and LED-irradiator. This approach will realize the rational irradiation of plants.

The processor generates a signal to turn on a certain number of blue and red LEDs, the emission of which will contribute to the correct geometry of the formation of new segments of plant stalks. At the same time, the general light can be turned off after 12 hours of operation, which makes it possible to save energy. It is necessary to turn on the LED lighting up on the task calculated by the processor in order to shorten the dark period when breathing and burning of accumulated carbohydrates is carried out.

5. Conclusion

For greenhouse plants it is necessary to light up different emission spectrum, contributing to the proper growth of the plant stalk in the process of its cultivation. The research has revealed that the most important components of the spectrum necessary for a plant life are the red and blue emission of LED irradiators. At the same time, plants with a short lifespan and a rapid onset of the generative phase of the development were studied and the experiments were carried out on deciduous green crops or potatoes to receive elite seeds.

The researches of the influence of the red-blue emission spectrum of LED in the process of lighting up the plants have revealed regularity. Thus, maximum photosynthesis is possible only with the optimal combination, in percentage, of the blue and red spectra with the required presence of radiation from the lamps of a wide solar spectrum. The researches of their influence are important, since the blue and red spectra have different effects on the formation of the geometry of the plant stalk.

Processing the experimental data, we have not obtained a single-valued model that allows optimizing the growth processes of the plant. In this case, a compromise decision was made to adapt the obtained models to the intensity of photosynthesis. The results can serve to control the environmental factors depending on the level of emission in the red and blue spectrum for the lighting up and the natural source of light, solar radiation.

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