Effect of various LED lighting on the growth and development of garden strawberry *Fragaria ×ananassa* Duch. and groundcover rose *Rosa hybrida* L. at greenhouse conditions

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**Abstract.** The purpose of this study was to determine the role of various LED (light-emitting diode) light units in ensuring high-quality growth and development of plants, as well as to obtain high-quality seedlings of strawberries and ground cover rose. We studied the physiological reactions of garden strawberry ("Melga" variety) and ground cover rose ("Fairy" variety) plants under controlled conditions and obtained the data on the effect of light quality on plant biological productivity, dynamics of growth processes, photosynthesis rate and transpiration. Regardless of the type of studied crops, the tallest plants were obtained under conditions of supplementary lighting by the lamp with blue / green / red ratio in the spectrum 17/29/54 % (option 1) and the lamp with ratio 18/45/37 % (option 2). At the same time, the dry weight of leaves and roots, as well as the biological productivity of strawberry plants in experimental options 1 and 2 exceeded by 41% than in the control plants (under high pressure sodium lamp). For garden strawberry we recommend the LED in the option 2, for the ground cover rose optimal is the option 1.

**1. Introduction**

It is well known that plant growth and development are closely related to environmental conditions. Until recently, such light sources as incandescent lamps, fluorescent, high-pressure sodium lamps were used as additional illuminators for growing plants. However, in recent years, light-emitting diode (LED) lighting technology has begun to be used as an additional source of lighting for the cultivation of agricultural and forestry crops. Red and blue wavelengths of LED lighting are usually chosen to increase the efficiency of the plant photosynthesis [1-3].

When consumers are choosing light sources, the main focus is on its spectral characteristics and intensity [2, 4]. A number of authors have shown the regulatory effect of light on growth, development, photosynthetic processes and productivity at *in vivo* as well as *in vitro* cultures [2, 5, 6].

To obtain healthy and normally developed plants, as well as an economically profitable harvest in the autumn-winter period, especially for the countries located in latitudes with short daylight hours, the plants must be grown under the conditions of the supplemental lighting of greenhouses [4, 7, 8].

Due to this it is necessary to study the possibility of growing agricultural and woody plants under illumination with phytolamps, which have not only high efficiency, but also the most optimal spectral composition for plants. The high biological and energy efficiency of artificial lighting sources as a result...
determines the economic effect of supplemental lighting and the possibility of its wider application in greenhouses in Russian Federation [3, 9, 10].

Modern super-bright LEDs make it possible to create a luminous flux density sufficient for growing plants [10, 11]. Modern studies show the possibility and efficiency of using LED supplemental lighting for growing greenhouse plants [2, 12, 13]. Compared to other sources of artificial lighting, LEDs are safe, long-term in use, and also have relatively low power consumption [11, 13, 14].

However, despite the considerable experience in growing plants under artificial lighting, there is no consensus on the optimal levels of plant irradiation and the spectral composition of radiation in relation to certain species of plants at present time. In almost every case, when developing technologies for the year-round production of one or another type of agricultural product, it is necessary to create an original artificial lighting system that meets the physiological requirements of the grown plants as much as possible. In this case, the effect of the method of organizing the light flux on other components of supplemental lighting technologies - the temperature regime of growing, the mineral nutrition of plants, and the gas composition of the environment must be taken into account [4, 10, 15].

The purpose of this study was to determine the role of various LED light units in ensuring high-quality growth and development of plants, as well as to obtain high-quality seedlings of strawberries and ground cover rose.

2. Methods and materials

The objects of the study were plants of groundcover rose (Rosa hybrida L.) of the variety ‘Fairy’, at the age of 45 days and garden strawberry (Fragaria×ananassa Duch.) of the variety ‘Melga’ at the age of 65 days. These objects were declared by farmers to create highly productive and decorative plantations on their lands.

Regenerated plants in vitro of rose and strawberry were obtained from the apical and axillary meristems, and they were cultivated for 21 days on Murashige-Skoog agar nutrient medium (MS). Plants were kept in a climatic room under LED lamps Jazzway PFL-C-30w (China) under the following climatic conditions: 16-hour photoperiod at an illumination of 30 µmol·m⁻²·s⁻¹, a temperature was about 24±2 °C. To carry out the multiplication process, MS medium was used with the addition of growth regulators - 300 μg/L benzylaminopurine (Sigma-Aldrich, USA) and 200 μg/L gibberelic acid (Sigma-Aldrich, USA). All manipulations with in vitro plants were carried out under aseptic conditions in laminar boxes (Lamsystems, Russia).

Obtained by the method of clonal micropropagation plants were transplanted into pots with height 10 cm, diameter 9 cm, volume of 500 cm³ (PND-Group, Belarus) using a peat nutrient substrate based on neutralized high-moor peat of the brand “Pelgorskoye-M” (Russia).

Three options of supplementary lighting of plants were used in the experiment (table 1).

Evaluation of the energy efficiency of the optical radiation flux was carried out using a spectrophotometer brand "TKA-Spectrum" (Russia), which allows you to measure the absolute spectral distribution (λ) of light sources, as well as the photon flux density of photosynthesis (PPFD) in µmol·m⁻²·s⁻¹.

The air temperature was maintained at 22-24 °C during the day and 18-19 °C at night, the photoperiod was 16 hours. The care of the plants consisted of regular watering, feeding with micronutrient fertilizers and loosening the soil. The experiment was carried out for 30 days. During the entire study, observations were carried out. The morphological description of the prototypes of the rose and strawberry included the determination of plant height by using a measuring ruler and the number of leaves per plant.

We used an improved measurement technique using a digital camera to measure the leaf area of each genotype [16]. To determine the dry biomass of the aboveground (leaves and stems) and underground (roots) parts of plants, we used the electronic scales “Ohaus PA2102C” (USA). Specific leaf weight (SLW), which characterizes the ratio of leaf dry weight to its area, was determined by weighing each of 10 leaves of the same age separately [17]. To obtain an absolutely dry weight, the leaves, stems and roots were dried in a drying cabinet of the brand “Binder” (Germany) at a temperature of 100 °C.
Biological productivity was calculated as the summary dry weight of leaves, stems and roots per one plant.

Table 1. Technical characteristics of light unit types.

| Parameter                     | Option 1                                      | Option 2                                      | Option 3                                      | Control                   |
|-------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|---------------------------|
| Model of light unit           | VCSF-I-180-PW (VCS Lighting, Russia)          | VCSIN-I-180-NW (VCS Lighting, Russia)         | VCSF-V-40-DHCL (VCS Lighting, Russia)         | HPS lamp (Reflux, Russia)  |
| Model of lamp                 | Citizen CLU04H 85/200-PW (Citizen Electronics, Japan) | Citizen CLU048-1818C4-403M2M2-F1 (Citizen Electronics, Japan) | Horticulture lamp 250*500 vv 200 led Myrilia, (Flytech, Taiwan) | High pressure sodium lamp (Reflux, Russia) |
| Power consumption, W          | 180                                           | 180                                           | 40                                            | 600                       |
| Photon flux density, μmol·m⁻²·s⁻¹ | 200                                           | 200                                           | 165                                          | 200                       |
| Blue / green / red ratio in the spectrum, % | 17/29/54                                      | 18/45/37                                      | 21/12/67                                      | 11/41/48                  |

The measurements of photosynthesis and transpiration were carried out on leaves of the same age, not separated from the plant, during daylight hours from 10 to 14 hours. Photosynthetic CO₂ gas exchange and leaf transpiration were studied using a portable infrared gas analyzer GFS-3000 (Walz, Germany) under optimal for photosynthesis conditions. A well-lit leaf was placed in a clothespin camera with an artificial light source (light-emitting diode, PAR 1200 μmol·m⁻²·s⁻¹) at a temperature of 25 °C and a relative humidity of 60 %. To measure the intensity of photosynthesis, we took well-lit leaves of the same age of the upper shoot, which reached 80% of the maximum leaf area. The measurements were carried out on the same leaves, with the exception of the total leaf area, where all the leaves of the plant were taken into account.

The experiment was carried out at least three replicates, and each replication included 5 experimental plants. The data obtained were processed using statistical methods using MS Excell and Statistica software. The significance of differences between experimental and control plants was estimated using Student's t-test at p≤0.05.

3. Results and discussion
The effect of various lighting options on the plant growth and development parameters was established during the experiment (figures 1, 2).

For both studied species, the tallest plants were obtained under supplementary lighting at options 1 and 2, which have similar spectral characteristics of the blue light sources. The comparative analysis of the methods of lighting of the ground cover rose plants showed an insignificant increase of the total leaf area (figure 1) and as a result, in the dry biomass of the aboveground plant parts in the first option, compared with the second option (figure 2). Based on the analysis of the data, it was found that the first two options can be combined into one cluster with similar characteristics in terms of influence on the growth parameters of the studied crops. The lowest values of morphometric characteristics of all studied modes of supplementary lighting was observed in the garden strawberry and rose plants in the third option, where a lamp with dynamic controlled multispectral module VCSF-V-40-DHCL was used. It should be noted that the level of PPFD was 18% lower than in other options, which, apparently, was one
of the reasons of weaker plant growth. Control plants in the studied crops showed the middle position for most biometric traits.

![Graph 1](image1.png)

**Figure 1.** Total leaf area of garden strawberry and ground cover rose plants in different light conditions.

![Graph 2](image2.png)

**Figure 2.** Dry weight of leaves and roots (g per plant) of garden strawberry and ground cover rose plants in different light conditions.

The same regularities can be observed in terms of the leaves and root dry weight that was confirmed by the visual inspection: plants in the options 1 and 2 were much larger. More precise gradation of the morphometric parameters is observed in the garden strawberry ‘Melga’. Thus, the dry mass of leaves, root and, consequently, the whole plant biological productivity, in the first two options were two or more times higher than in the third experimental option. The intermediate values were obtained in the control plants illuminated by the high pressure sodium lamp. Thus the prevalence of red light in the lamp spectrum at the options 1 and 2 promotes more intensive vegetative growth, as evidenced, in particular, by the significant increasing of the total leaf area.

It is known that in the region of PAR absorption of light is very high and it has there two distinct absorbance maxima - in the blue (400 - 500 nm) and red (600 - 700 nm) areas. These maxima are primarily due to the content of the chlorophyll a and b in leaves. On average, about 80–90% of the incident radiation is absorbed in the blue and red regions of the spectrum [10, 18]. The spectral composition may have a strong effect on the optical properties of leaves, changing their absorbency, as well as on the leaf blade size and thickness [19]. Besides, it has a significant effect on the structure and
functioning of the photosynthetic apparatus, and also affects the cell metabolism and gas exchange during photosynthesis [20-22].

An important integral indicator of the leaf mesostructure is SLW. This indicator reflects biomass content per unit area of the leaf surface and can indirectly serve as a measure of its thickness, the larger the value of SLW, the more effective are the photosynthetic processes, since per unit of the leaf area the larger biomass is synthesized. Besides, the leaf SLW value has a genetic basis and differs in different genotypes [22, 23]. The studied plant species reaction on the conditions of the irradiation was reliably different: the highest values of SLW were found in options 1 and 2 (5.6 ± 0.21 and 5.8 ± 0.10 for garden strawberry, respectively; 6.1 ± 0.19 and 6.6 ± 0.13 for the rose, respectively), the lowest values – in the option 3 (5.0 ± 0.10 for garden strawberry and 5.4 ± 0.31 for the rose).

The dry mass growth during the study period in all options was 420 - 2000% of the initial plant weight. The maximum organic matter increase was observed in the garden strawberry ‘Melga’ in the range from 830 to 2020%. At the same time, during a short vegetative growth period (1 month), strawberry plants in the options 1 and 2 accumulated twice more dry mass compared with the option 3 and 41% more than in the control plants.

The dry mass growth dynamics of the groundcover rose ‘Fairy’ was similar, but its absolute value was smaller (from 420 to 800%). As well as for the dry mass increase, the difference between the lighting variations for the total leaf area was more significant in the 1 and 2 options, regardless of the plant species. However, the assimilation leaf area traits of the groundcover rose plants were only slightly inferior to the same of the garden strawberries and even slightly exceeded the control plants. Probably, the genetic model of the leaf apparatus ontogenetic development of experimental plants was programmed in a similar way.

Analysis of the intensity of photosynthesis (figure 3) of the groundcover rose showed a significant excess of its absolute values in option 1 compared to control plants (9.64±0.14 and 5.63±0.47 μmol·m⁻²·s⁻¹, respectively). At the same time, two other experimental lighting options (options 2 and 3) did not reveal significant differences in the photosynthetic assimilation of CO₂ (4.78 ± 0.10 and 5.33 ± 0.72 μmol·m⁻²·s⁻¹, respectively). Although photosynthetic carbon uptake does not always correlate with productivity, leaf area formation may be the best integral indicator of growth processes. The individual leaf area, as well as the total leaf area of a plant, can be a promising indicator that determines the potential productivity of the species [24-26].

![Figure 3](image)

**Figure 3.** Intensity of CO₂ photosynthesis μmol·m⁻²·s⁻¹ of garden strawberry and ground cover rose plants in different light conditions.

Such a character of structural and functional changes, apparently, corresponds to the optimal range of PAR intensity, at which the maximum accumulation of biomass per unit time is observed. Under these conditions, the rate of photosynthesis and growth are well balanced. It was experimentally
established that at this stage of ontogenetic development, photosynthetic assimilation of CO₂ in garden strawberries of the variety ‘Melga’ did not significantly differ in experimental options 1 and 2. The intensity of transpiration of experimental rose plants was 2 and more times higher than that of strawberries (figure 4).

It is known that transpiration depends on both the species characteristics of plants and the climatic conditions of their growth, having a significant impact on the productivity of agricultural crops [27, 28]. The obtained results showed that there were no significant differences between the experimental options, within the studied genotypes of rose and strawberry. At the same time, stomatal resistance to the flow of carbon dioxide into the leaf did not significantly affect the parameters of the resulting carbon dioxide gas exchange, which is in good agreement with our earlier conclusions about their coordinated work in optimal environmental conditions [28].

4. Conclusion
We revealed the specificity in the formation of the aboveground and underground parts of plants, depending on the lighting option. The predominance of the blue spectrum in the spectrum of lamps of options 1 and 2 provides more intensive vegetative growth, as evidenced, in particular, by a significant increase in the leaf area and the accumulation of biomass. It was found that at a fixed PPFD level, garden strawberry responds positively to the spectral composition of radiation with a high, compared to the control, proportion of blue light, while for a ground cover rose, in addition to blue light, the proportion of red is important for the normal growth. For garden strawberry of the variety ‘Melga’, we recommend mainly the lamp with the ratio of blue / green / red emission in the spectrum (%) 18/45/37. For the ground cover rose of the variety ‘Fairy’, the lamp with a spectrum ratio of 17/29/54 is recommended. The obtained results can be applied for commercial cultivation of rose and strawberry in greenhouse conditions.

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