LIGHT PULSED IRRADIATION IN GROWING SEEDLINGS

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Abstract: This work presents the research results of dynamic characteristics of ARPL-1W LEDs with a narrow-spectrum composition of luminescence (red, green, blue) using switching power supply of U-shaped pulses. Based on the results of increase and decrease of light flux and analysis of the kinetics of photosynthetic processes, from light absorption to absorption of CO_2 from the atmosphere and the formation of carbohydrates, the LED irradiation installation is designed and approbated for growing seedlings. According to the results of experimental studies it is shown that pulsed irradiation stimulates faster plant growth without losing their morphometric parameters.

Keywords: *pulse irradiation, plants lightculture*

1. Introduction

The efficiency of plant growing systems in a controlled environment largely depends on energy consumption, most of which is for lighting. The spectral composition, intensity and period of irradiation play a leading role in the regulation of photosynthesis processes and, accordingly, determine the morphogenesis and productivity of plants.

Changing the intensity and spectral composition of the light affects the formation of structural and functional organization of the photosynthetic apparatus, prevention of metabolic reactions and morphogenesis of plants. Energy metabolism requires a large number of pigments that absorb a significant portion of solar radiation in the photosynthetically active part of the spectrum. In contrast to energy metabolism, photoregulation reactions can be carried out with a very small amount of pigment that absorbs a small part of the incident light. In this case, the energy of Therefore, it is important to comprehensively assess the effect of radiation of both individual and various combinations of spectral ranges on the photosynthetic activity of cenoses throughout the growing season using light irradiation with those spectral and energy characteristics that are really suitable for full crop conditions.

Radiation intensity and its spectral composition are one of the many factors that determine not only the yield but also the quality of crop products. When growing plants under artificial irradiation, its level is usually lower than in natural conditions. Therefore, the formation of pigments depends largely on the spectral composition of radiation. In turn, the content of pigments in the leaves determines their absorption of energy flow and the intensity of photosynthesis. The photosynthetic apparatus of plants responds to different light regimes, adapts and is characterized by its activity. The degree of plants resistance to light of different spectral composition is determined by the pigment composition.

Recently, alternating and light-pulsed irradiation is used in the lightculture of indoor plants. The system of utilization of light energy and the dynamics of its transformation in plants attract special attention. It opens up the possibility to find the most effective radiation sources and optimal radiation regimes.

In this work, based on the analysis of the photosynthetic processes dynamics and the kinetics of LED light sources luminescence, an irradiation unit with narrow-spectrum LEDs was made and its experimental tests of growing pepper seedlings in greenhouse conditions were performed.

Kinetics of photosynthetic processes. Photoenergetic processes in plants begin with the absorption of light quanta by pigment molecules and the transfer of absorbed energy to the reaction centers. The main pigment in plants is chlorophyll a and b. Its absorption spectrum is shown in Fig.1. Its energy scheme, which corresponds to this spectrum, is shown in Fig.2 [1-3].

There are two levels of excitation in the chlorophyll molecule as there are two absorption bands in the blue-violet and red regions of the spectrum. In the unexcited state, the chlorophyll molecule is at the basic singlet level S_0, when all electrons are arranged in pairs, and their total spin is equal to zero. During absorption in the blue-violet region, the molecule moves to the highest energy level S_2, at which the total spin moment of the electrons remains unchanged. The lifetime of the chlorophyll molecule in this state is 10^{-12} s. During light absorption in the red part of the spectrum, the molecule moves to a lower singlet level S_1 with a lifetime of $10^{-9} - 10^{-8}$ s. This transition also occurs without changing the spin moment of the electron. The maximum lifetime of the chlorophyll molecule in the triplet state is T_1 - $10^{-4} - 10^{-2}$ s. This transition runs with a change in the spin of the electron. In addition to chlorophyll, the light-harvesting complex also includes carotenoids and phycobilins. They absorb light in those spectral regions where the absorption of chlorophyll is weak and thus increase the photosynthetic efficiency of light [4].

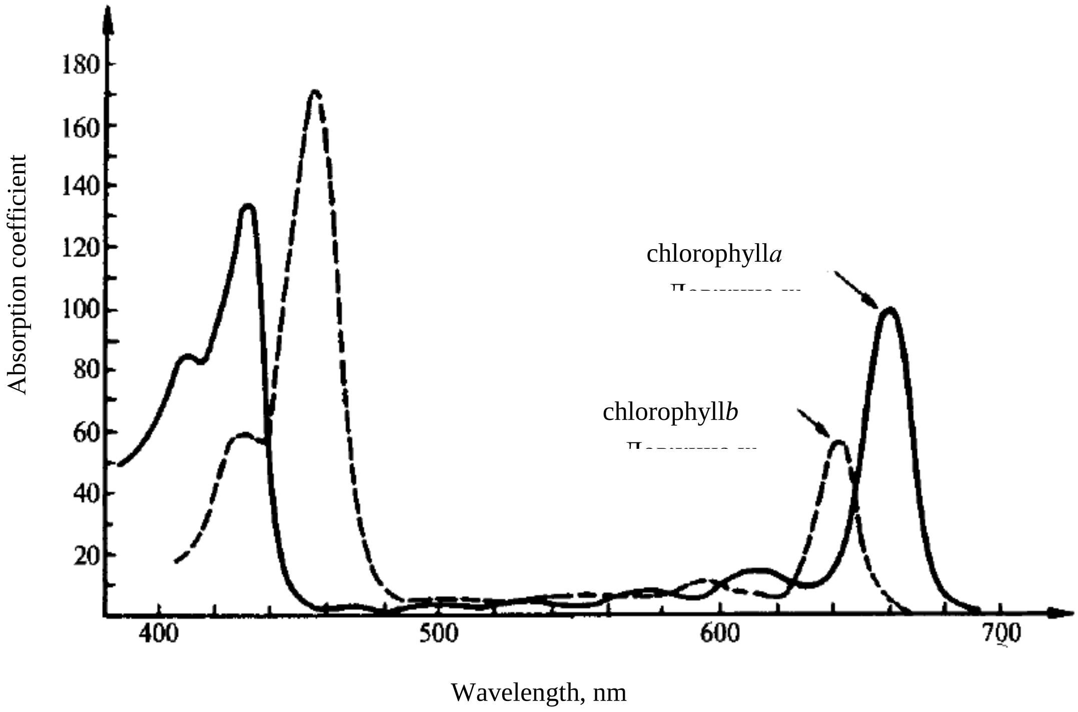


Fig.1 Absorption spectra of chlorophyll.

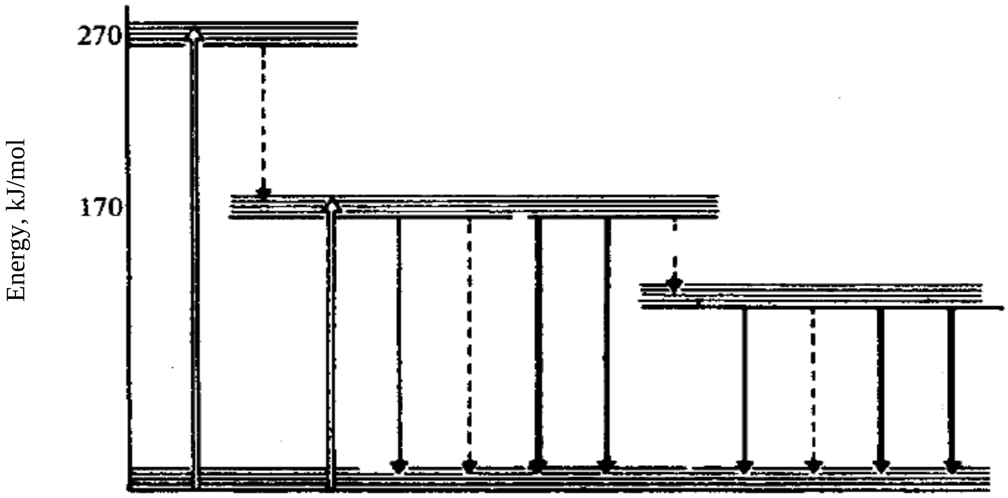


Fig.2. Energy levels of chlorophyll molecules.

The following photovoltaic process is the transfer of absorbed energy to the reaction centres. Energy is transferred to the reaction centre through a chain of pigments. The energy transfer between the pigment molecules occurs mainly by resonance way without charges separation with high speed. The energy transfer time from one chlorophyll molecule to another is 10^{-12} s. It is less than the lifetime of the chlorophyll molecule in the excited state S_1. While transferring, energy is partially lost, so the final energy state of the chlorophyll molecule to which energy flows is the S_1-state. Thus, the duration of the initial photophysical stage of absorption and transmission of light energy, which ends with the transfer of energy to the reaction centre, does not exceed 10^{-6} - 10^{-5} s [5].

The next stage of light energy conversion in plants, which runs in reaction centres, is photochemical. It like the absorption and transfer of energy, is part of the light phase of photosynthesis. Photochemical stage proceeds using light energy to reduce CO_2 to carbohydrates and oxidize H_2O to O_2. The general equation of photosynthesis is the following:

$$6CO_2 + 12H_2O + h\nu \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O.$$

Here the water in the right part of the equation is produced from CO_2.

The time of photochemical processes is short and does not exceed 10^{-5} s.

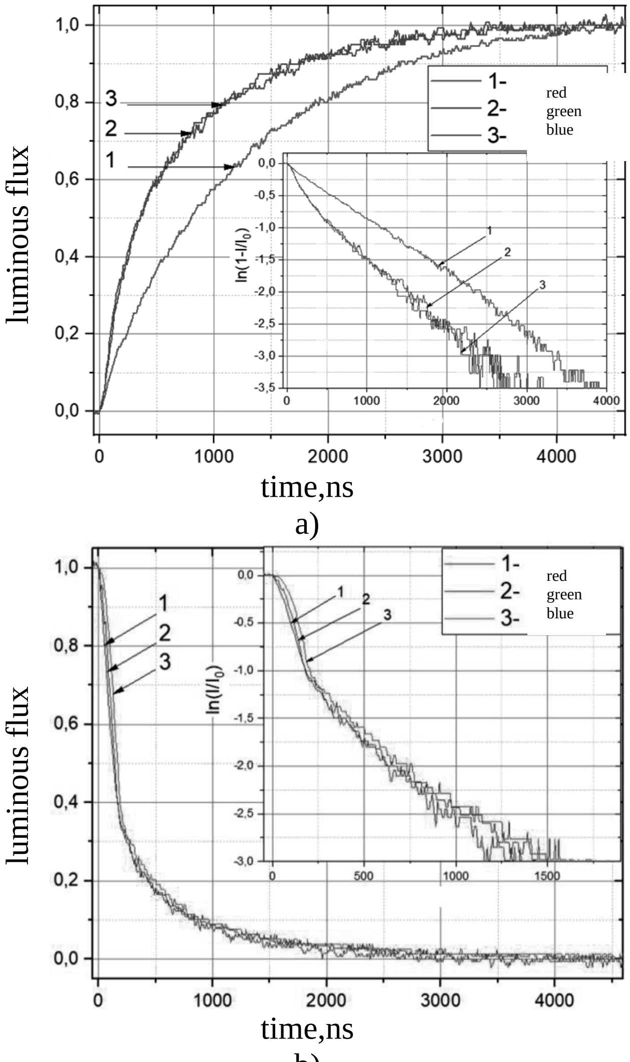
The next stage of the conversion of absorbed energy is enzymatic. It proceeds without quanta of light and is called the dark stage of photosynthesis. At this stage, CO_2 is absorbed from the atmosphere and carbohydrates are formed. The enzymatic stage proceeds with a number of complex biochemical reactions. The time of dark photosynthesis reactions is more long-lasting than light and is about 10^{-2} s.

2. Research results and their discussion

This analysis of the kinetics of photoenergetic processes is the important information for planning experiments using alternating and light-pulse irradiation of plants. Experiments with pulsed light showed that the maximum intensity of photosynthesis is observed not in continuous, but in pulsed lighting, especially in cases where the duration of dark intervals was 0.04-0.06 sec, and the flash time is about 10 sec. The high efficiency of pulsed light proves the presence of dark reactions in photosynthesis, because dark processes are slower than photochemical ones[1].

Creating a pulsed irradiator, it was assumed that LED light sources are the most effective at this stage. They allow to form an irradiating installation with a given spectral distribution and the necessary lighting characteristics, switching power supplies with wide modulation. The information about the glow kinetics of LEDs is important for designing a pulsed irradiation system. The processes of increasing and decreasing luminous flux of narrow-spectrum LEDs of red, green and blue glow were studied.

To study the kinetics of the increase and decrease of the LEDs luminous flux, the photocurrent pulses of the photodetectors were used both at the output of the monochromator and the integrated photometer. Fig. 3 shows the front (a) and rear (b) fronts of photocurrent of the photoelectronic multiplier (PhEM) pulse for single-color ARPL-1W LEDs. They are also presented in a semi-logarithmic scale, which indicates the exponential nature of the increase and decrease of luminous flux. Time constants τ were determined from these graphs.



a)

b)

Fig.3 Front (a) and rear (b) fronts of PhEM photocurrent pulse of the single-color LED ARPL-1W.

Two components - fast and slow – are observed on the curves of increase and decrease of light flux. The values of their time constants at a pulse frequency of 50 kHz are given in table 1.

On the increase curves, the proportion (area) of the fast component is very small, which is 0.05-0.1 of light pulse amplitude, and for some of the studied samples (red glow LEDs) it is absent.

Table 1

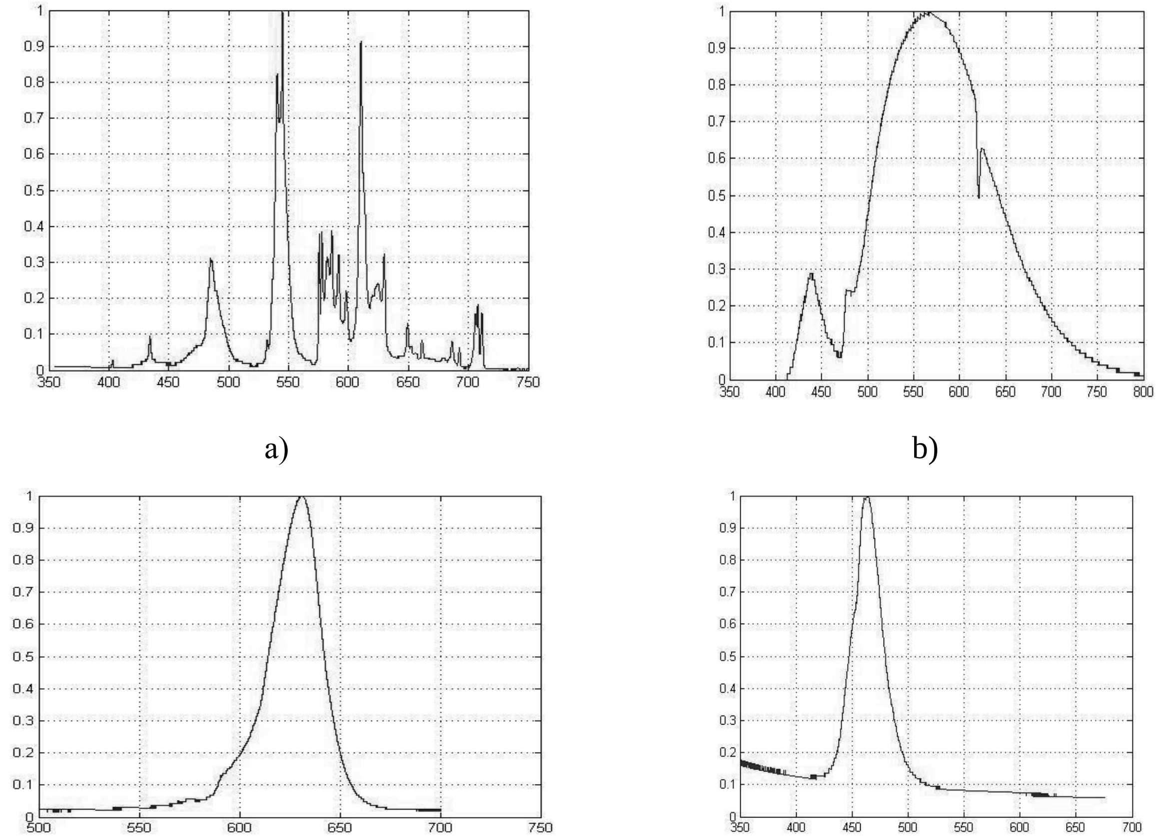
Time constant of decrease and increase of luminous flux at a pulse frequency of 50 kHz.

Glow	LED type	decrease		increase	
		τ_1,(*ns*)	τ_2,(*ns*)	τ_1,(*ns*)	τ_2,(*ns*)
Red	1W	90	420	1200	
	3W	282	564	1497	
Blue	1W	100	495	1100…1200	
	3W	268	790	382	1212
Green	1W	250	500	1000	
	3W	245	581	500	1131

Determining the maximum pulse frequency f and the amount of filling D, it is necessary to take into account τ of increase and decrease of luminous flux.If it is assumed that the transient process in a LEDs electric circuit ends within 5τ, then $fmax = 5\tau / D$. For the studied narrow-spectrum LEDs, f_{max} does not exceed the pulse frequency of 75 - 100].

Based on previous studies, where a Magnum LNF 150 luminaire and a pulse power device were used as a pulsed irradiator, light pulses in the dark are ineffective, so an experiment in which pulsed light acted as an additional light on the background of constant light irradiation of compact fluorescent lamps was set up.

Seedlings of pepper [illegible] were used



a) b)

c) d)

Fig.4 The emission spectrum: a) CFL; b) white LEDs; c) red LEDs; d) blue LEDs.

To assess the effectiveness of pulsed irradiation, the fluorescence intensity of the plant leaf was measured. Fluorescence parameters are the indicators of the state and efficiency of photosynthesis processes, because the decrease of the efficiency of light energy in photosynthesis leads to the increase of fluorescence intensity. Usually during fluorescence there is a shift of luminescence radiation relative to the absorption towards greater wavelengths.

To excite the fluorescence of chlorophyll [10], in the range spectrum of 660-800 nm, used radiation with a wavelength of 480 nm or 532 nm. Under favourable conditions, no more than 3% of the energy of electronic excitation of chlorophyll is converted into the energy of fluorescence light in the form of so-called background fluorescence. If its value is small, it indicates the active use of energy of absorbed light by cells. This level of fluorescence corresponds to the conditions when all the reaction centres of the photosystem are in the so-called "open" operating state, in which they are unsaturated. Then the absorbed light energy is no longer used for photosynthesis, and the fluorescence of chlorophyll increases, reaching a maximum value. Saturation of the reaction centres can occur with increasing light intensity. Therefore, the intensity of chlorophyll fluorescence spectral lines is influenced not only by the current conditions of the plant but also by the intensity and duration of the light flux of excitation.

In the general case, the fluorescence intensity is proportional to the concentration of the fluorescent substance. However, this statement is valid only for relatively small concentrations. With the increasing concentration of the fluorescent substance, there are a number of effects. Due to these effects, the dependence of fluorescence intensity on concentration experiences significant deviations from linearity. Calibration graphs based on fluorimetry of the reference solutions are used in analytical fluorimetry and photometry procedures.

The results of the pulsed irradiation effect on the photosynthesis efficiency are presented in [5]. Based on chlorophyll fluorescence measurements, it was found that additional pulsed irradiation on the background of constant irradiation with compact fluorescent lamps led to the changes in the functional state of the photosynthetic apparatus and subsequently had a positive effect on plant productivity.

2 CFL of Osram Duluxstar 18W/840 type operating in continuous mode and providing 3000 lx radiation level were used for lighting in the first greenhouse.

The second greenhouse also used Constant irradiation produced by LED irradiation facility, consisting of red and blue LEDs with total capacity of 13.5 W was also used in the second greenhouse (2) and was installed above plants.

2 CFL of OsramDuluxstar 18W/840 type were used as permanent exposure in the third greenhouse. LED matrix of white luminescence with 1ms impulse duration and interval between pulses of 10s was used for pulsed irradiation. Its power consumption is 17.3 W.

Also measured morphometric parameters of plants (leaf area, cheese and dry weight of the leaf, growth parameters). To determine the morphometric and growth parameters of plants, 15 samples were cut and used to get the average measurement results. Received results are in table 2.

During the experiment, a constant temperature of the environment and the operating mode (16 hours of irradiation) was observed.

Table 2 shows that the raw and dry weight of leaves and the weight of the plant as a whole, which are important indicators for seedlings, as well as chlorophylls a and b, the area and % of dry matter with additional pulsed irradiation are higher, compared to those that were not accompanied by light pulses.

Table 2

Morphometric parameters at different irradiation modes

Morphometric parameters	Constant irradiation (CFL)	CFL + LED Red + Blue matrix (pulse)	CFL + LED White matrix (pulse)
raw mass of plant, g	0.73	0.75	0.78
raw mass of leaves, g	0.54	0.56	0.61
raw mass of the taken leaves, g	0.48	0.47	0.53
dry mass of leaves, g	0.08	0.09	0.1
% of dry matter	17.6	18.8	18.6
chlorophyll*a*	7	5.9	8.1
chlorophyll*b*	12.8	10.1	13.6
area, cm^2	23	25	30

3. Conclusions

From the analysis of the kinetics of photosynthetic processes, the duration of absorption and transmission of light energy to the reaction center does not exceed 10^{-6} - 10^{-5}sec. The time of photochemical processes does not exceed 10^{-5} sec. The time of dark reactions of photosynthesis is about 10^{-2}sec.

Based on the results of studies of the LEDs glow kinetics in pulsed power supply, a LED irradiation unit was designed, which was tested in the cultivation of pepper seedlings.

According to the results of experimental studies, it has been shown that pulsed irradiation stimulates faster plant growth without losing their morphometric parameters.

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