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OPTIMISATION OF LIGHTING PARAMETERS OF IRRADIATION IN LIGHT CULTURE OF LETTUCE PLANTS USING LED EMITTERS

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ABSTRACT

The results of the ending phase of photo biological studies of capacity of lettuce and basil grown in conditions of a phytotron with irradiation by radiation of different ratio of fractions in the red-blue and blue-green-red regions of photosynthetic active radiation (PAR) are presented[1].

The spectral variants of PAR providing the maximum or near to maximum capacity of the specified cultures are found.

The complex and multiple-valued nature of effect of main PAR spectral regions on photo energetic and photo regulatory processes in plants providing their capacity is highlighted, which makes it impossible to determine common unified requirements to optimal parameters of artificial irradiation for growing of plants. These requirements shall be defined on the basis of direct photo biological experiments with main species of agricultural plants and be the most important element of the general photo culture macro technology.

The general principles of fulfilment of the specified requirements to PAR spectra of phytoemitters are reviewed, including with consideration of setting of normal vision conditions for personnel of greenhouses and other protected ground structures.

Keywords: photo biological studies, light (photo) culture, LED-based phytoemitter, photosynthetic active radiation (PAR), action spectrum, photosynthetic photon flux (*PPF*), photosynthetic photon irradiance or flux density (*PPFD*), photosynthetic photon efficacy (*EPPF*)

1. INTRODUCTION

Opportunities to obtain direct experimental data on the effect of radiation in particular regions of PAR on capacity of specific species of plants using light emitting diode (LED) emitters stimulate photo biological studies (FBS) throughout the world. The priority of the specified direction was confirmed during the *GreenSys* 2019 International Symposium on advanced technologies and management for innovative greenhouse which took place in June 16–20 in Angers (France).

Nowadays, the problems of application of LED in plant growing are becoming practical ones, in particular, due to rapid widening of application of *City Farm* installations for vertical multi-layer growing of lettuce and leaf vegetables.

Lettuce and leaf vegetables is the third largest group of vegetables grown in the Russian greenhouses (Fig. 1), and due to the fact that the country's demand for fresh and rich in vitamins greengrocery is satisfied for not more than (20–30)% during winter, the potential of production development in this area is high and scientific achievements are strongly sought-for.

The article [1] presents the results of the first phase of the FBS conducted by the authors using a phytotron in lettuce and basil photo culture

[1] See also article [1].

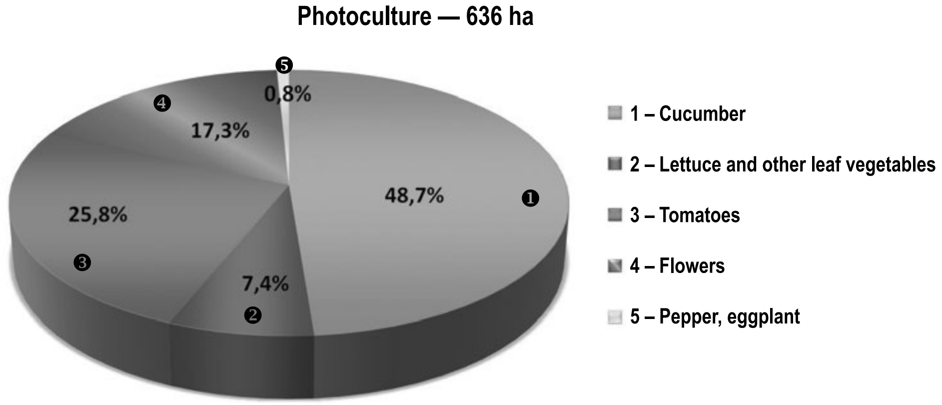


Fig. 1. Areas occupied by vegetable photo cultures in the Russian greenhouses in 2019

(at K.A. Timiryazev RGAU-MSKhA) using the developed special quasi-monochromatic LED-based phytoemitters (PE). For the first time, the data obtained in the wide range of varied lighting parameters (spectrum in the PAR region and irradiation level) allows us to start solving the problem of optimisation of PE spectral characteristics for industrial growing of the specified salad crops.

2. FBS METHOD AND THE EXPERIMENT INSTALLATION

As a result of the first phase of the FBS [1], the region of *PPFD* in interval of (160–180) µmol/(s·m²), corresponding to maximum capacity of Landau lettuce and Russian Giant basil, was established. Afterwards, all experiments with red-blue (*RB*) and red-green-blue (*RGB*) PE were conducted at *PPFD* equal to 170 µmol/(s·m²) ±10 %. That is allowing to reduce the number of expensive and rather long-term vegetation periods and complies with the provisions of the "surrogate optimisation" method used in contemporary biology in the course of research of the effects of external factors on plants [2–4].

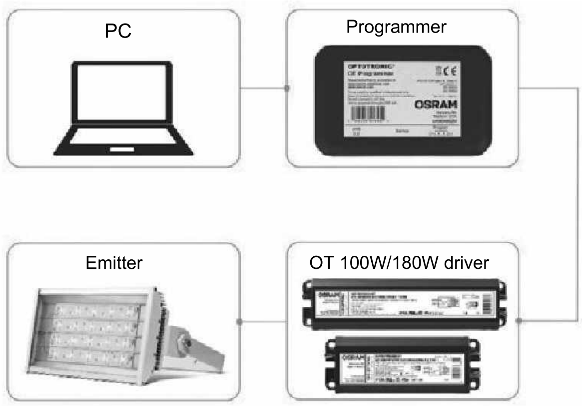


Fig. 2. Flow graph of regulation of LED-based phytoemitter parameters in the FBS

The goal of the second phase of the FBS, which was also conducted using the phytotron of K.A. Timiryazev RGAU-MSMKhA, was to study the effects of joint radiation in the main regions of PAR.

The experiment was designed in the following manner: first, the impact of the ratio of radiation levels in the red (*R*) and blue (*B*) regions (*RB*, "binary optimisation") was studied, then different fractions of the green region of PAR were added (*RGB*, "triad optimisation").

In accordance with this, by order of VNISI, two groups of PE devices, accordingly *RB* and *RGB*-types, with parallel switching on of LEDs of the said colours and function of independent control of currents and the *PPF* using two or three colour channels respectively, were manufactured by AO KETZ factory.

Like at the first phase of the FBS, high-output *R*, *G* and *B* LEDs manufactured by *CREE* were used (Table 1). By changing the current in each channel (previously, dependence between *PPF* and current had been determined), it was possible to vary the fraction of each region in the total irradiation from 0 to 100 %. For regulation of PE current, the controlling device (driver) *OT180W/UNV1250C* and *Optotronic OT programmer* manufactured by *OSRAM* were used (Fig. 2).

The measurements of PE radiation spectrum were made by means of the *PC100N* spectrometer by *UPRtek* (Taiwan) with software by Intekh-Lighting (Russia), the values of *PPFD* in each region and total irradiation were determined by means of the *PPFD* meter *Li-250A* with quantum detector *Li-190R* (*LI–COR*, USA).

Table 1. Main Parameters of the Colour (*R*, *G*, *B*) LEDs used in FBS

Item	LED type (manufacturer)	Peak wavelength, nm	Spectral region of radiation, nm (at 0.5 level)	Current adjustment range, mA
1	*XPEEPR-L1–0000–00901, XPE HE Photo Red Light Emitting Diode (CREE)*	656	645–666	350–800
2	*XPEBGR-L1–0000–00F01, XLamp XP-E Light Emitting Diode Green (CREE)*	517	500–540	500–1100
3	*XTEARY-00–0000–000000Q01, XLamp XT-E Light Emitting Diode Royal Blue (CREE)*	447	435–458	500–1200

Table 2. The Results of Binary Optimisation

Item	1	2	3	4	5	6	7	8
Spectrum type	*R*100 % *B*0 %	*R*90 % *B*10 %	*R*80 % *B*20 %	*R*0 % *B*40 %	*R*50 % *B*50 %	*R*40 % *B*60 %	*R*32 % *B*68 %	*R*0 % *B*100 %
Weight (lettuce), g	92.5 ± 13.2	71.5 ± 5.2	98.7 ± 10.5	56.7 ± 13.9	76.9 ± 7.6	59.0 ± 12.2	66.6 ± 14.8	69.3 ± 3.5
Weight (basil), g	25.8 ± 5.7	55.1 ± 12.3	65.9 ± 14.7	51.2 ± 6.9	58.2 ± 5.0	65.9 ± 5.7	30.5 ± 7.8	18.7 ± 8.5

The other conditions of the experiment complied with the requirements of the technology of growing of lettuce and leaf vegetables adopted for the specified phytotron are the next:

- The experiments were conducted with permanent 18h photoperiod at day and night air temperatures of 22 °C and 18 °C respectively. The plants were grown in vegetation vessels with Agrobalt S nutrient mixture, 3 (lettuce) or 5 (basil) plants in each vessel. The substrate was high-moor neutralised peat with low degree of decomposition, humidity not exceeding 65 %, and containing limestone (dolomitic) meal and a complex fertiliser (N_{total} – 150 mg/l, P_2O_5–150 mg/l, K_2O – 250 mg/l, *Mg* – 30 mg/l, *Ca* – 120 mg/l, microelements) with *pH* in range 5.5–6.6. Watering was conducted in accordance with weight, humidity was maintained at the level of 70 %, repeatability was equal to four times.
- Crop biomass accounting and other determinations were conducted 35 days after sprouting, total biomass per vessel was taken into account.

3. FBS RESULTS AND DISCUSSION

- Binary Optimisation

The spectra of the implemented eight *R-B* combinations and corresponding fractions of $PPFD_R$ and $PPFD_B$ in total irradiance $PPFD_{R+B}$ are presented in Fig. 3 and Table 2. The same figure and table contain the vegetation results achieved in these conditions: the capacity *N*.

It shall be noted that dependences of *N* and the *R* and *B* ratio of radiation fractions are significantly different for lettuce and basil (Fig. 4). By substituting the range of *N* values of lettuce in the functions of this ratio using linear approximation (Fig. 5), we can see that the role and impact of *R* region of PAR on synthesis of biomass are obviously particularly important. At the same time, with growth of *R* fraction of radiation *N* of lettuce increases as well as it decreases with growth of *B* fraction of radiation. Unlike lettuce, the dependence of *N* of basil on ratio of *R* and *B* fractions may be presented by a curve with maximum corresponding to *R* fraction of (50–80)% and *B* fraction of, correspondingly, (50–20)%. The common requirement for both cultures is the *B* fraction of radiation in the PAR region at the level of about 20 % (sufficient level).

- Triad Optimisation

Research of dependence of *N* of lettuce and basil on ratio of *R*, *G* and *B* fractions of radiation (Fig. 6) was the following and final phase of surrogate optimisation of spectrum for the specified cultures.

Table 3 and Fig. 7 show the data on the eight implemented vegetations with different ratios of the *R*, *G* and *B* fractions and corresponding results of *N* for lettuce and basil, and Fig. 8 presents a 3D visuali-

Table 3. The Results of Triad Optimisation

Item	1	2	3	4	5	6	7	8
Spectrum type	*R*77 % *G* 12 % *B*11 %	*R*75.2 % *G* 13.0 % *B*11.8 %	*R*62.4 % *G* 17.7 % *B*19.9 %	*R*49.0 % *G* 36.0 % *B*15.0 %	*R*43.6 % *G* 21.5 % *B*34.9 %	*R*30.0 % *G* 50.0 % *B*20.0 %	*R*27.0 % *G* 31.1 % *B*41.9 %	*R*17.2 % *G* 13.7 % *B*69.1 %
Weight (lettuce), g	78.9 ± 14.4	84.7 ± 14.8	72.8 ± 4.0	62.5 ± 3.8	67.5 ± 12.4	76.5 ± 14.8	68.6 ± 11.9	50.8 ± 6.4
Weight (basil), g	49.8 ± 8.6	45.9 ± 11.1	73.1 ± 8.1	54.7 ± 15.7	26.6 ± 4.8	54.7 ± 5.0	37.0 ± 6.4	43.7 ± 8.5

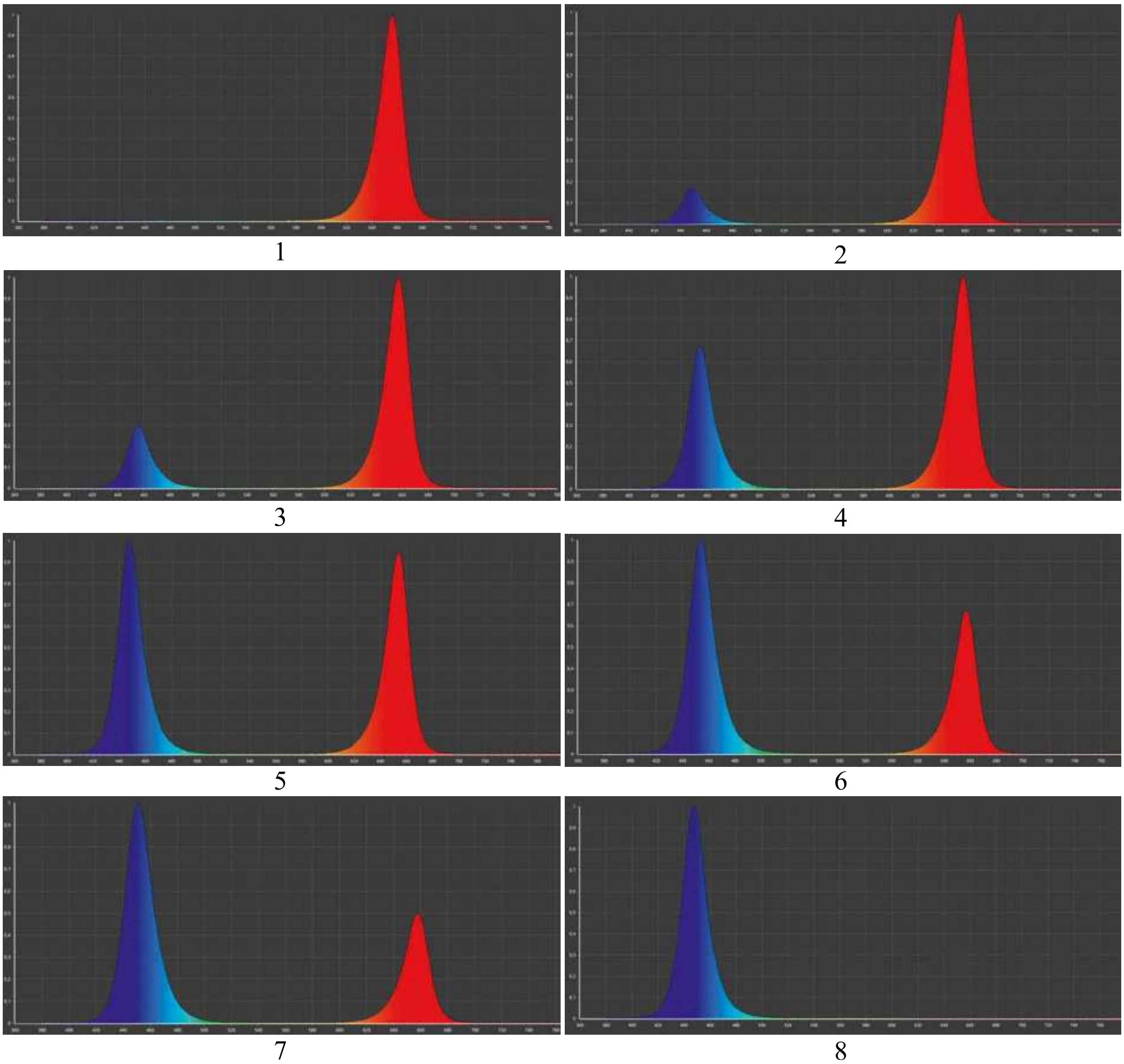


Fig. 3. Spectral variants in binary optimisation:
1–100 % *R*, 0 % *B*; 2–90 % *R*, 10 % *B*; 3–80 % *R*, 20 % *B*; 4–60 % *R*, 40 % *B*; 5–50 % *R*, 50 % *B*; 6–40 % *R*, 60 % *B*; 7–32 % *R*, 68 % *B*; 8–0 % *R*, 100 % *B*

sation of the dependence of capacity *N* (biomass, g) on *R* and *B* fractions of radiation (considering that *G* = 100 – (*R* + *B*)) compiled by means of *Wolfram Mathematica* using a 3D grid and linear interpolation. The colour of the surface of the graphic model corresponds to the real colour of spectrum in the given regions *R* and *B* along the axes of coordinates.

Clarity of the presented *3D* models allows us to state the following qualitative estimations of joint action of *R*, *G* and *B* fractions of PAR:

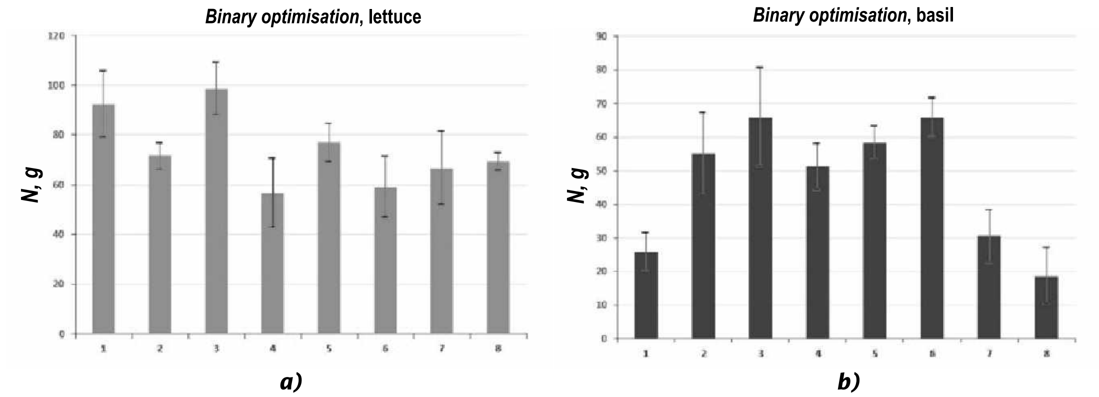


Fig. 4. Capacity diagrams of lettuce (*a*) and basil (*b*) with binary optimisation

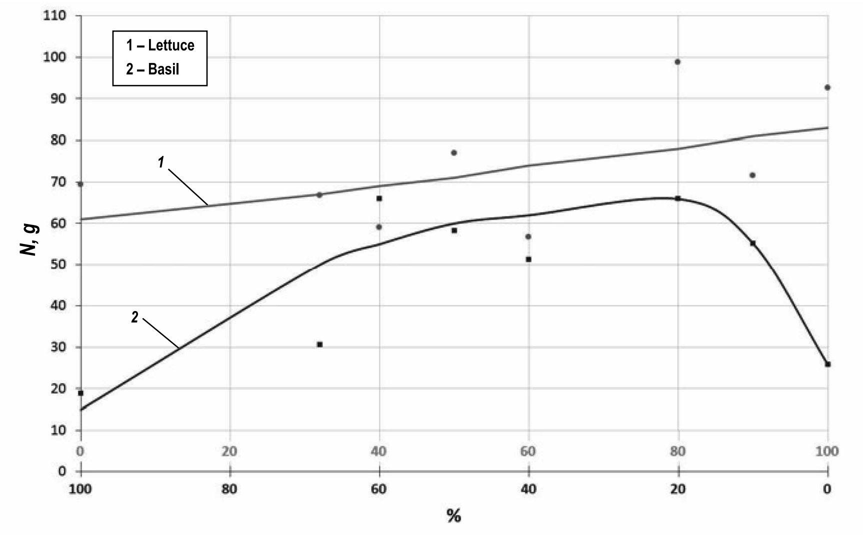


Fig. 5. Graphic interpretation of the results of binary optimisation

- In the region of maximum capacity of both cultures, priority of *R* (red) radiation is obvious, especially for lettuce;
- Prevailing fraction of *B* (blue) radiation leads to dramatic reduction of *N*. Tables 2,3 and Fig. 4, *a* and 7, *a* show that maximum values of *N* of lettuce were reached at fully *R* radiation ($R_{100\,\%}$) as well as at variants $R_{80\,\%}$: $B_{20\,\%}$ and $R_{75.2\,\%}$: $G_{13\,\%}$: $B_{11.8\,\%}$. Decrease of *N* down to 40 % and less corresponded with significant prevailing of *B* radiation. Availability of *G* (green) radiation in the PAR region is not mandatory but is acceptable.

The corresponding data on basil (Table 2,3 and Fig. 4, *b* and 7, *b*) confirms complex nature of joint effect of *RGB* radiation on this culture; the best results in terms of biomass weight (*N*) were reached in vegetation with a triad combination $R_{62.4\,\%}$: $G_{17.7\,\%}$: $B_{19.9\,\%}$ and the results with the nearest values of *N* were achieved for binary *R*-*B* combinations $R_{80\,\%}$: $B_{20\,\%}$ and $R_{40\,\%}$: $B_{60\,\%}$.

It shall be noted that, apparently, availability of even minimum fractions of *R* radiation in the polychromatic spectrum is absolutely necessary for basil. At the same time, with full *B* radiation, *N* was equal to just 25 % of the possible maximum. But irradiation of basil with only *R* radiation is also very unfavourable (about 35 % of the maximum value of *N*).

Fig. 9 presents the spectral combinations providing maximum or nearly maximum capacity for lettuce and basil. It is obvious that this data will be different in the photosynthetic photon and energy systems of quantities. The relation between the values of radiation fractions in the studied regions is defined using the expression $E_{PPFD} = K \cdot E_e$ [μmol/(s·m²)], where

E_e is the irradiance [W·m^{-2}],

$$K = (h \cdot c \cdot N_A)^{-1} \times$$
$$\times \int_{400}^{700} e(\lambda)\lambda d\lambda \,/\, \int_{400}^{700} e(\lambda) d\lambda \, [\mu\text{mol} \cdot \text{J}^{-1}],$$

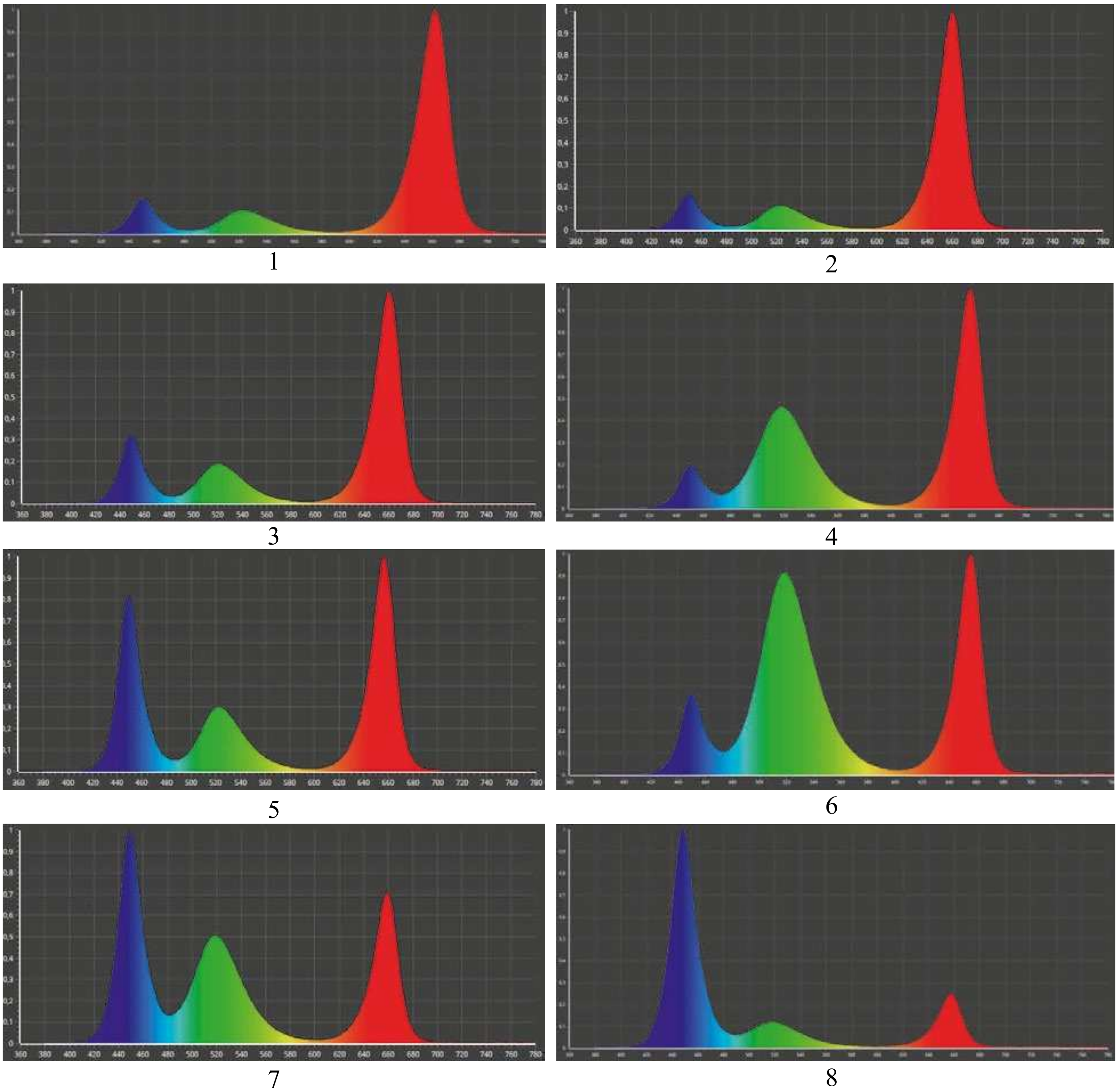


Fig. 6. Spectral variants in triad optimisation:
1–77 % *R*, 12 % *G*, 11 % *B*; 2–75.2 % *R*, 13 % *G*, 11.8 % *B*; 3–62.4 % *R*, 17.7 % *G*, 19.9 % *B*; 4–49 % *R*, 36 % *G*, 15.0 % *B*; 5–43.6 % *R*, 21.5 % *G*, 34.9 % *B*; 6–30 % *R*, 50 % *G*, 20 % *B*; 7–27 % *R*, 31.1 % *G*, 41.9 % *B*; 8–17.2 % *R*, 13.7 % G, 69.1 % *B*

where

$e(\lambda)$ is the spectral irradiance [$W \cdot m^{-2} \cdot nm^{-1}$],

λ is the radiation wavelength [nm],

h is the Planck constant [J·s],

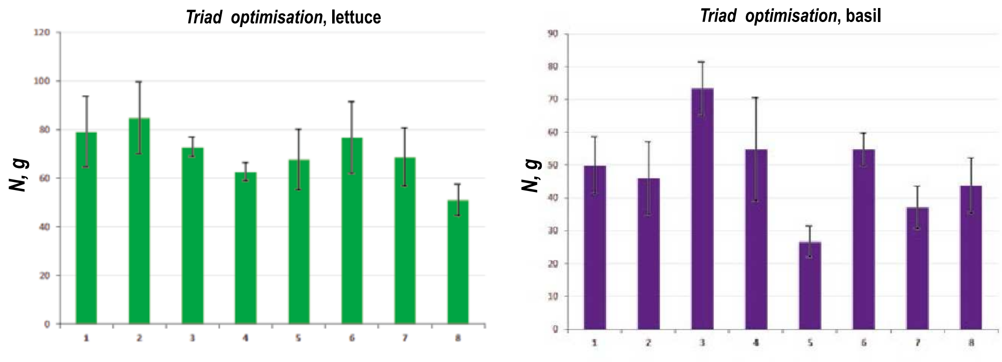
c is the speed of light [m/s],

N_A is the Avogadro constant [μmol^{-1}].

We would also like to note a very practically important fact that, when using *RB* or *RGB*-type PAR spectra, at fraction of *R* radiation less than 75 % for lettuce and less than 50 % for basil, it is not possible to reach high value of *N* for these cultures.

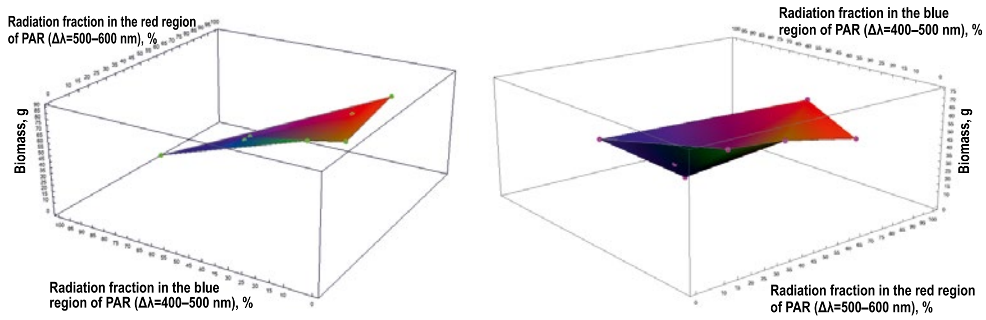
Over the last year, there were a number of interesting studies containing the results of FBS on *N* of leaf vegetables with PAR spectrum variation. It is of interest to briefly compare their data with that presented in this article.

In one of the first of the serious works regarding application of LED-based PE devices, [5], it was noted that addition of *G* radiation to *RB* radiation (by means of green fluorescent lamps (FL) with rather wide spectrum) at *G* fraction of 24 % increased *N* of lettuce by about 1.5 times, whereas



a) b)

Fig. 7. Capacity diagrams of lettuce (*a*) and basil (*b*) with triad optimisation



a) b)

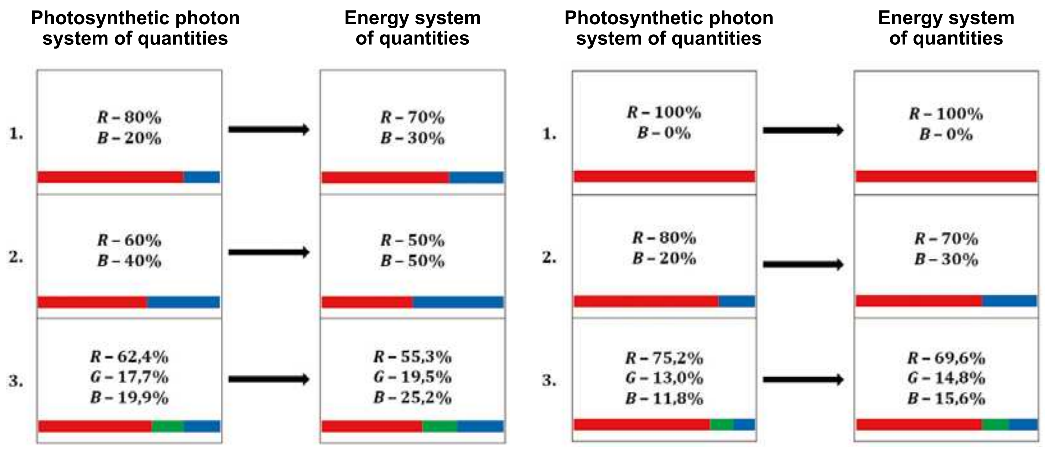
Fig. 8. *3D* models of capacity for lettuce (*a*) and basil (*b*) with triad optimisation

increase of this fraction up to 51 % negatively affected *N*.

The article [6] states that the data of many studies of *G* radiation affecting on *N* of leaf vegetables are very ambiguous and vary between “adverse” and “extremely useful”.

In the work conducted by the specialists of Taiwan National University using a phytotron, the *Boston lettuce*-breed lettuce was grown in 35 days at *PPFD* of 210 μmol/(s· m²) with photoperiod of 16 h with irradiation by means of a LED-based PE with *RB* and *RWB* (addition of white, *W*) spectra as well as under cold white FL [7]. The maximum value of *N* corresponded to the *RWB* combination, the FL variant was 10 % lower and the result of the *RB* combination was 17 % less than the maximum one.

We would also like to mentioned a small-scale experiment conducted by *Samsung* in cooperation with the Seoul National University in South



a) b)

Fig. 9. The most favourable spectral characteristics in the PAR region for lettuce (*a*) and basil (*b*)

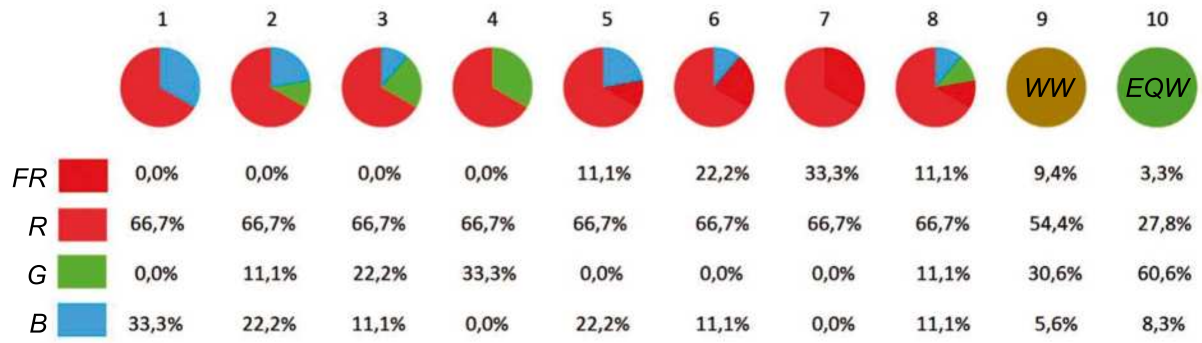


Fig. 10. Variants of the experiments in the work [10] with different spectral combinations of PAR and near-IR regions

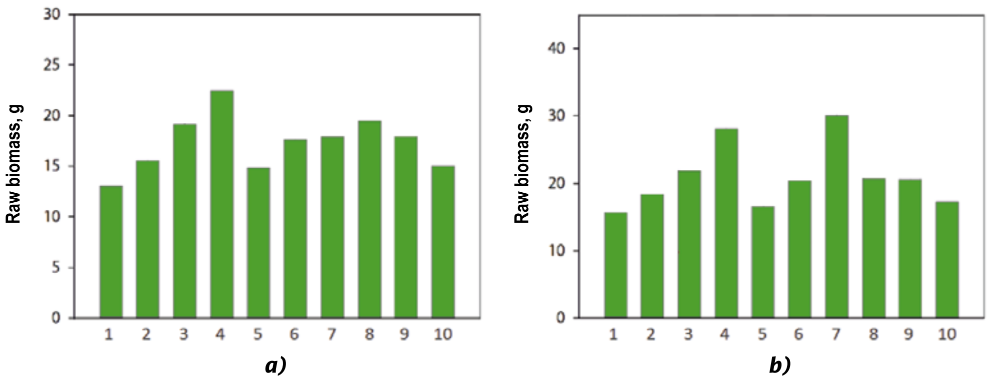


Fig. 11. Capacity diagrams of *Rex* (*a*) and *Rouxai* (*b*) breeds of lettuce with different spectral combinations of PAR and near-IR regions [10]

Korea [8–9]. Lettuce and basil were grown at *PPFD* equal to160 µmol/(s·m²), which is close to the one taken in our FBS using PEs with different spectrum variants: $R_{44.5}G_{44.5}B_{11}$; $R_{40}G_{40}B_{20}$; $R_{79}G_{14}B_7$, and $R_{80}B_{20}$. The best value of *N* for lettuce was with the first one (with equal fractions of *R* and *G* and the minimal *B* fraction), whereas the worst result (with capacity decreased by 56 %) was shown by the binary combination of $R_{80}B_{20}$. At the same time, the differences in efficiency of the specified variants for basil did not exceed 15 %.

The most serious study of radiation affecting with different spectra in the PAR region [10] also shows at ambiguity of the data of different authors on spectral efficiency of PAR in terms of yielding capacity. It mostly relates to the effect of *G* fraction of radiation. Negative effect of reduction of *R* and *B* ratio (*R*: *B*) in the PAR region on growth and development of vegetables is also noted. In their own FBS, using the original method, first, lettuce of two breeds, *Rex* and *Rouxai*, was grown in conditions of a phytotron for 10 days under white light with T_{cc} of 2700K (*FR*: *R*: *G*: *B* = 10.1 %: 54.5 %: 28.85 %: 6.5 %) with *PPFD* of 180 µmol/(s·m²)[2]. Then the plants were moved to the lighting installation (LI) with different spectral variants (Fig. 10). It shall be noted that the *R* fraction of radiation was constant in absolute terms: $PPFD_R$ of 120 µmol/(s·m²) which was equal to 66.7 % of the total radiation ($PPFD_{PAR}$ and $PPFD_{PAR+IR}$). In the last two variants, warm (*WW*) and cold (*EQW*) PEs with full (*FR-R-G-B*) spectrum were used.

The results of these FBS are presented in Fig. 11. Maximum value of *N* of *Rex* lettuce was reached in variants with *RG* (!) radiation (*R*: *G* = 66.7 %:33.3 %), whereas for *Rouxai* lettuce, the maximum was reached with *FR-R* radiation (*FR*: *R* = 33 %:66.7 %).

The increased efficiency of *G* radiation discovered by the author of the reviewed article allowed him to state an opinion that the effect of the *G* range of PAR region on *N* of lettuce is comparable with that for the *B* range and is approximately equal

[2] As we can see, apart from the effect of PAR, the effect of IR radiation in the spectral region of (760–800) nm (*FR* radiation) on *N* of lettuce was also assessed.

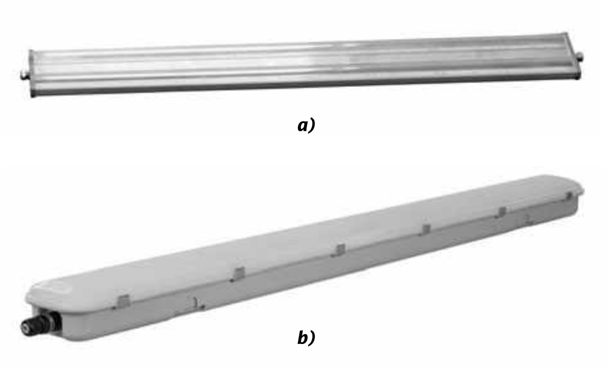


Fig. 12. *Top* emitter with *Galad Top Line Phyto LED*, power of 230W (a), and *Galad* LED-based emitter for multi-layer installations *Arcline Phyto LED*, power of 30W and 60W (*b*)

to 50 % of efficiency of *R* radiation. Also, in some cases, with significantly different spectral characteristics of PE, he achieved equal or close results of *N* for both breeds of lettuce.

Summing up the discussion of our own results and their comparison with the results of foreign studies of *N* of leaf vegetables, we would like to note the following:

- The results of our study and a rather large amount of data in the cited works allow to state that assessment of joint effect of different spectral ranges of PAR on *N* of plants, as exemplified by lettuce and leaf vegetables, is complicated by synergetic (super-additive) or, on the contrary, antagonistic effects of interaction which seem to be common for plants as complex receivers of radiation with large amount of photopigments. In other words, the term "optimal spectrum of radiation for growing of plants" is a rather abstract and ambiguous term. Even for one species of plants, requirements for the favourable spectrum providing the maximum value of *N* may vary notably.
- The complex nature of interaction between photo-energetic and photo-regulatory processes in plants may lead to achievement of the same or close effects (*N*) for regions of PAR and near IR radiation with significantly different spectra. The data of our FBS with lettuce and basil and the results of works by other researchers confirm it. Therefore, we may propose that the concept of **equifinality** formulated by the Austrian biologist L. von Bertalanffy is applicable to the effect of radiation on the plants. The effect of photo-equifinality as a property of such self-balancing system as a higher plant may obviously be a subject of further studies.

4. PRACTICAL IMPORTANCE OF THE RESULTS

In one of the main reports of the *GreenSys 2019* symposium [11], the increase of the scale of plant FBSs with application of LED-based equipment was embraced, however, it was noted that there is some gap between the scientific results and their practical application. We would like to note that, while planning this FBS [1], we stated that practical focus was its main goal. In other words, the requirements to spectral characteristics of PE for conventional *top* irradiation of lettuce and leaf vegetables in greenhouses and for their growing in *City Farm* multi-layer vertical phyto-installations shall be set with consideration of the results of this FBS of lettuce and basil.

The data we achieved on the basis of the direct experiments provide developers with irradiating devices with a certain freedom of choice allowing to define the spectral characteristics of the latter not only based on the condition of minimisation of *N* of plants but also with consideration of LED energy efficiency, cost parameters and, which is absolutely necessary, prevention of adverse effect of blue radiation on sight of maintenance personnel [12, 13]. In some cases, consumers may specify another requirement significant for phyto-installations: necessity of correct visual perception of greengrocery products (visual organoleptic) for assessment of their quality and appearance (colour or chromaffin cells of leaves, non-availability of spots, lesions by insect pests, etc.).

With consideration of these circumstances, the problem of selection between the variants of quasi-monochromatic *R*, binary *RB* or *RGB* spectra may be solved in favour of the latter both for lettuce and basil.

Based on the FBS practical requirements to spectral characteristics of the PE fulfilment shall be performed with consideration of the level of *EPPF* of the used LEDs. Table 4 contains the main parameters of colour LEDs based on the own data of the leading manufacturers (as of mid-2019).

EPPF of LEDs is very important and defines competitive advantages against phyto-HPSL with their *EPPF* equal to (1.8–2.1) µmol/J (its value for a HPSL luminaire is 1.55–1.8µmol/J).

The Table 4 shows that a PE with *EPPF* of quasi-monochromatic *R* LEDs may reach (3.3–3.4) µmol/J (with consideration of electric losses

Table 4. Main Parameters of Colour LEDs from Leading Manufacturers

Manufacturer (country)	Type	Calculated minimum *PPF*, µmol/s	Dominant wavelength, nm	Direct current, mA	Direct voltage, *V*	*EPPF*, µmol/J
CREE (USA)	XPEBPR-L1–0000–00D01 XP-E2 Photo Red	2.5	min 650 max 670	350	2.05	3.44
	XPGDRY-L1–0000–00601 XP-G3 Royal Blue	2.8	min 450 max 465	350	2.82	2.83
	XPEBGR-L1–0000–00F01 XLamp XP-E Light Emitting Diode Green	1.11	min 520 max 535	350	3.2	0.99
OSRAM Opto semi-conductors (Germany)	GH CSSRM3.24-V5V7–1 Oslon Square Hyper Red	5.27	min 646 max 666	700	2.1	3.52
	GD CSSPM1.14-UO OSLON SSL 120 Deep Blue	2.63	min 439 max 457	350	2.85	2.33
	GD CSSRM2.14-ARAT-24–1 Deep Blue	5.25	min 444 max 457	700	2.9	2.59
Lumileds (The Netherlands)	*LUXEON SunPlus 20 Line Royal Blue L1SP-RYL0002F00000*	2.25	min 445 max 455	350	2.5	2.3
	LUXEON SunPlus 35 Line Deep Red L1SP-DRD0002F00000	2.08	min 655 max 670	350	1.95	2.9
Samsung (Repubic of Korea)	LH351H Deep Red	2.32	min 650 max 670	350	2.1	3.12
	LH351H Blue	2.8	min 440 max 460	350	2.86	2.8
	LH351H Far Red	1.96	min 720 max 740	350	1.9	2.91
Prolight Opto Technology Corporation (Taiwan)	PK2N-3LDE-HSD-U Royal Blue	2.84	min 448 max 458	350	2.9	2.8
	PK2N-3LME-HSD-T Crimson	2.64	min 650 max 670	350	2.05	3.83
	PK2N-4LME-HSDL–X2 Crimson	5.78	min 650 max 670	700	2.15	3.92

in the controller and optical losses of about 12 %), whereas for PE with binary *RB* spectrum it may reach (3.0–3.1) μmol/J.

When designing PE with *RGB* spectrum, with consideration of currently low energy efficiency of green LEDs (*EPPF* < 1μmol/J), it is more necessary to provide the required spectral composition of PAR by means of a combination of a blue LED with phosphor and a red LED.

The specified approaches are implemented in the course of design of phytoemitters for *top* irradiation of leaf vegetables in conventional greenhouses as well as for growing of the same cultures in *City Farm* phyto-installations (Fig. 12) in cooperation with the specialists of the OAO KETZ manufacture. The structure of the emitters allows us to implement the above-mentioned spectral combinations with consideration of distinctions and a set of requirements of a specific project.

The expression of the phyto-installation LI efficacy criterion $EPPF_{IL} = PPFD_{aver} / P_1$, where $PPFD_{\text{aver}}$ is the average *PPFD* of cenosis, μmol/(s·m^2) and P_1 is the specific installed electric power, W/m^2 [14] implies that only with higher *EPPF* of PE at least 40 % reduction of power consumption as compared with HPSL may be reached.

CONCLUSION

The conducted FBS defined the requirements for favourable radiation spectra of LED-based PEs providing maximum capacity of lettuce and basil. The difference between these requirements shows inevitability of application of an experimental approach to solving of such problems.

Due to the fact that the physical principles of LED-based equipment allowing to fulfil the favourable spectrum requirements discovered by this FBS but also, which is not least important, the irradiation level requirements [1], it can be said that there is an opportunity to create a light engineering technology (as the most important element of the macro-technology of a specific plant photo culture) with computer-controlled industrial growing of plants (*cyber-agriculture*).

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