DOI: 10.22620/agrisci.2016.20.015

НЕОБХОДИМОСТ ОТ ПРИЛАГАНЕ НА ДОПЪЛНИТЕЛНО ОСВЕТЛЕНИЕ В ОРАНЖЕРИИТЕ В БЪЛГАРИЯ
NEED OF SUPPLEMENTARY LIGHTING IMPLEMENTATION IN BULGARIAN GREENHOUSES

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Abstract

Vegetable production in greenhouses through the winter months presents various difficulties. One of them is the lack of enough solar radiation to ensure the normal development of the plants. The comparison of the lighting conditions between Bulgaria and the Netherlands, where supplementary lighting is applied, shows that despite our more favourable geographical location, they are almost the same. During the typically winter months the requirements for the main greenhouse vegetable crops are not provided to a sufficient extent and that is why the application of supplementary lighting is needed. Application of supplementary lighting under the conditions of insufficient amounts of natural light significantly increases the growth, development and productivity of the plants. The expenses for the production of the crops compared with the traditional method are decreased and, at the same time, the yields and intensity of the production are increased, and that defines the promising outlook of this technology.

Key words: supplementary lighting, vegetables, greenhouses.

INTRODUCTION

Main tendency of modern farming is the increase of the yields per unit area with optimization of the of the financial costs and the application of innovative technological practices. The yields and the quality of vegetable crops depend on multiple processes but the major role is played by the photosynthesis since it influences directly their development and the formation of the yield.

In modern greenhouses it is possible to control all parameters of the microclimate - temperature, humidity, concentration of CO_2, nutritional regimen, light. In some areas of the world, where there is not sufficient amount of light necessary for the optimal development of the crops, systems for supplementary (artificial) lighting are created. The best developments are in the Netherlands, Sweden, Norway, the USA and Canada where greenhouse production uses the latest scientific achievements.

AIM AND TASKS

The aim of the present study was to define the need for supplementary lighting during the winter months in the conditions of our country.

For the implementation of the aim, the following tasks were assigned:

1. Definition of the parameter of the light which influence the photosynthesis.
2. The units of measure for the solar radiation.
3. Light requirements of the greenhouse vegetable crops.
4. Comparative characterization of the climate conditions between the Netherlands and Bulgaria.
5. Devices used to indicate solar radiation.
6. Used sources of artificial light.
7. Location, regimen and control of the supplementary lighting.
8. Benefits of the supplementary lighting.
9. Expenses for the use of supplementary lighting.

OVERVIEW OF THE TOPIC AND STATE OF THE PROBLEM

The construction of lighting systems in our country started several years ago mainly in the block polyethylene greenhouses but also in some glass greenhouses. One of the reasons for their relatively poor market penetration is that there are few scientific studies in this area. Such studies were conducted around the middle of the last century at the Maritsa Vegetable Crops Research Institute (MVCRI), Plovdiv and just in the last several years some private companies have started conducting them. The other reason is that during the typically winter months (November, December, January) the greenhouse production is not sufficiently cost effective, so it is implemented in more suitable periods. However, during the autumn and spring period some disturbances are observed in the growth and development, expressed in extension of the vegetational period and the ripening of the fruit; less growth, flower formation, and fruit bearing.

Implementation of supplementary lighting under our conditions may be reasonable if the requirements of the plants and the light conditions for growing are known. To clarify the problem, firstly it is necessary to specify the parameters of the light which have the most significant influence on the process of photosynthesis, and namely, its quantity (intensity), quality (spectral composition) and duration of action (photoperiodism). Regarding the intensity, separate vegetable crops have different requirement, as for the less demanding ones it is around 16000 lux, and for the more demanding – 30 000 lux.

The quality of the light is characterized by its spectral composition, i.e. in what wavelengths light energy is radiatied in. Most important for photosynthesis is the so called photosynthetically active radiation (PAR), which covers the range 400-700 nm (Deram, 2013). Within these limits the red and the blue rays have the biggest influence, while the green ones have the smallest.

The duration of the daylight affect mainly the moment when the plants enter generative phase (flower formation, fruit bearing). This phenomenon is popular as photoperiodism and in greenhouse farming it is used successfully for the control of the plant growth and development.

Units of measure for solar radiation

The whole energy which is contained in the light radiation is usually measured in watts (W) per unit area (m^2). Due to the specificity of the process photosynthesis is measured in differenet units – $mol/m^2/s$ ($mol/m^2/d$). It represents the quantity of photons from the area of PAR (400-700 nm) which fall on 1 m^2 for a certain amount of time: second, minute, hour, day and so on. Those photons contain different energy as the blue ones have the biggest and the red ones have the smallest. Other units of measure are also popular and they are used more often in the engineering sciences and to indicate the sensitivity of the human eye (Table 2).

Measuring the solar radiation which reaches the earth's surface through the different days, months, years and the energy used by the plants is possible with the help of special devices. Since the PAR also falls into the measured energy, some have offered coefficients which can be used to measure its precise quantity. According to some authors, from the whole quantity that reaches the earth the plants use around 43%. However, it is practically very hard to determine its exact value because of numerous factors – release of part of the energy as heat, reflection, uneven use of the different rays by the plants and others.

The type of the covering material also has a significant impact on the amount of PAR which passes through and the other types of rays (Table 3). The single pane glass and the single acrylic cover have the highest permeability, and the double polyethyle-ne, the double polycarbonate and the double pane glass have the lowest one.

Table 1. Influence of different wavelengths on the plants (Deram, 2013)

Wavelength	Influence on the plants
200-380 nm	Includes harmful ultraviolet rays and those which are neither harmful nor beneficial to plants.
380-400 nm	The beginning of the visible spectrum where the chlorophyll starts to absorb light.
400-520 nm	Includes violet, blue and green rays. Strongly influences photosynthesis and stimulates the vegetative growth.
520-610 nm	Includes green, yellow and orange rays. They are less absorbed by the pigments (photoreceptors).
610-720 nm	Includes red rays. It has the most significant influence on photosynthesis. Stimulates the formation of flower buds and flowering.
720-1000 nm **>1000 nm**	There is little absorption by the chlorophyll

Factors determining the necessity of supplementary lighting

The necessity of artificial lighting is determined by: the length of the day for the relevant period; the average percentage of sunshine hours; intensity and the angle which the sunrays fall in; constructive elements of the structure which create shading; the requirements of the crop which will be grown.

Requirements of the crops to the light regimen

During the seedlings period, tomatoes*, cucumbers and peppers require length of the day of 12-24 hours and solar irradiation of minimum 8-15 W/m^2 (4,8-6,0 mol m^{-2} d^{-1}). At a later stage of their development, however, tomatoes and cucumbers require 30 mol m^{-2} d^{-1}, and the pepper and lettuce require around 12-13 mol m^{-2} d^{-1} (Table 4).

Table 2. Transformation of the units of measure from different sources of light (Runkle, 2006)

Light source	μmol/ m^2/d	Foot candles	Lux	W/m^2
Sun	1	5,0	54	0,51
Incandescent lamps	1	4,6	50	2,58
Cool-white fluorescent lamps	1	6,9	74	0,54
Metal halide lamps	1	6,6	71	0,59
High-pressure sodium lamps	1	7,6	82	0,56

Table 3. Light characteristics of the covering materials

Covering material		% light transmission (PAR)*	% long wave (IR) transmission (<700 nm)*	Heat transmission "U" Factor*	Estimated lifespan (years)
Glass	Single	85-92	3	1,1	25+
	Double	75-81	1	0,7	25+
Polyethylene	Single	83-89	71-80	1,1	2-5
	Double	76	63	0,7	2-5
Fiberglass	Single	80-88	3	1,0	10-15
Acrylic	Single	93	<5	1,0	20+
	Double	83	<3	0,6	20+
Polyester	Single	85-88	30	1,1	7-10
Polycarbonate	Single	87	<3	1,0	10
	Double	79	<2	0,6	10

Transmission values are for dry covering materials
Source: Argus Control Systems Ltd. (2010)

Table 4. Requirements of the main greenhouse vegetable crops to the intensity of the light and the length of the day

Crop	Levels of PAR	Day length
Tomato	30 mol m^{-2} d^{-1}	12-18 h*
Cucumber	30 mol m^{-2} d^{-1}	12-24 h
Pepper	12 mol m^{-2} d^{-1}	12-24 h
Lettuce	12-13 mol m^{-2} d^{-1}	12-24 h

Source: Argus Control Systems Ltd. (2010)

Application of additional lighting to lettuce in Canada at levels 12-13 mol $m^{-2}d^{-1}$ resulted in the realization of more than 18 vegetations within a year. The use of 50-100 μmol m^{-2} s^{-1} for 16-24 h during the winter increased the biomass with 1,4-2,7 times and shortened the production cycle by 25% (Gaudreau et al., 1994). At the same the concentration of nitrates was decreased by 10-26%.

The lighting for cucumbers with 30 mol m^{-2} d^{-1} shortened the growing period to 10 days, while at 5,5 and 10 mol m^{-2} d^{-1} it was 24 and 17 days respectively. Studies in Canada established that at 300 μmol m^{-2} s^{-1} the vegetative growth increased and the winter yield was increased by 3 times for 5 months and there was a shortening of the period until the first yield is ready to 19 days after planting. With the year-round production, lighting with 180-200 μmol m^{-2} s^{-1} increased the yield by 70-80% (Blain et al., 1986).

The use of supplementary lighting for tomatoes with values of 120-150 μmol m^{-2} s^{-1} increased the speed of growth by 5 to 53% depending on the stage of development of the plants and the values of natural light (Yelle et al. 1987; Dorais et al., 1992). In the Netherlands, lighting with 118-235 μmol m^{-2} s^{-1} (8,5-16,9 mol m^{-2} d^{-1}) for 20 hours a days, combined with additional introduction of CO2 in a concentration of 1000 μmol has increased the yields with 67 to 115%. The increase of the light intensity from 100 to 150 μmol m^{-2} s^{-1} increased the sugar content, decreased the titratable acidity and increased the percentage of first quality fruit from 77 to 81 %.

The pepper production at levels 120 μmol m^{-2} s^{-1} (average 18,7 mol m^{-2} d^{-1} for the winter months) increased the total weight of the fruit by 18-33%.

Comparative characterization of the climate conditions: The Netherlands - Bulgaria

Table 5 shows a comparison between Plovdiv and Rotterdam (The Netherlands) regarding the average percentage of sunshine hours by season for the period 2002-2006. In the winter months it is higher by around 1% in Plovdiv, while in the spring and the autumn it is higher in Rotterdam by 9%. The average percentage of sunshine hours during the summer is irrelevant in this case because then the light conditions provide sufficient development of the crops.

Make comparison between Plovdiv and Rotterdam regarding the share of sunshine and cloudy hours in relation to the total light part for the period 2002-2006. The share of the sunshine hours is almost identical for both places, with a difference of 2% in favour of Rotterdam.

From the analyses made until now, we can claim that both under our conditions and under the conditions in the Netherlands, the light requirements of the crops are not sufficiently ensured, despite the more southern geographical location of our country.

Table 7 shows average values of PAR during the separate months of the year for the town of Petrich and Naaldwijk (The Netherlands). The lower values of natural PAR during the winter months in Naaldwijk necessitate artificial (additional) lighting. Thus, higher levels of PAR are achieved which ensure the sufficient levels to grow vegetable crops in comparison to the levels in the town of Petrich. As a result, the obtained production comes out to the market earlier than in our country.

From the experiments conducted in our country for stimulating winter production of cucumbers in November, December, January, February,

Table 5. Average percentage of sunshine hours during the period 2002/2006

	Spring	Summer	Autumn	Winter
Plovdiv	35,6%	48%	29%	33,8%
Rotterdam	44%	42,4%	38,4%	33%

Source: IRA-D OOD (2008, №1)

Table 6. Average percentage of sunshine and cloudy hours during the period 2002/2006

2002/2006	Rotterdam		Plovdiv	
	Hours	%	Hours	%
Sunshine hours	1725	39%	1619	37%
Cloudy hours	2698	61%	2804	63%
Total light part	4423	100%	4423	100%

Source: IRA-D OOD (2008, №1)

and March, lighting installation that provides an equiavent of 11 mol/m²/d natural PAR light per day is used (Table 9). Being added to the natural average daylight energy present these months (Table 8), it meets the requirements of the plants.

From the provided data it can be seen that the achieved values of light energy in the greenhouses of the town of Petrich exceed the natural winter light energy for countries like Egypt, where winter and early spring production is exported.

Table 7. Average monthly values of PAR for the towns of Petrich and Naaldwijk

	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol /m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d
Petrich (natural)	6,8	10	14,5	21	25,1	28,7	28,8	25,7	19,2	13,5	8,2	5,2
Naaldwijk (natural)	3	6,1	10,6	17,5	22,3	24,5	23	19,5	13,3	7,7	3,6	2,3
Naaldwijk (nat.+art.)	14	17,1	21,6	17,5	22,3	24,5	23	19,5	13,3	18,7	14,6	13,3

Source: IRA-D OOD (2011, № 8)

Table 8. Average monthly values of PAR for the town of Petrich, the island of Crete and Egypt during the period 2000/2010

	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d
Petrich (natural)	6,8	10	14,5	21	25,1	28,7	28,8	25,7	19,2	13,5	8,2	5,2
Crete (natural)	9,5	13,7	17,9	24,8	28,5	32,3	31,4	28,2	23,3	16,3	10,4	8,2
Egypt (natural)	14,6	16,8	21,8	27,8	32,9	37,4	34,8	31,3	27,6	21,1	15,3	13,4

Source: IRA-D OOD (2011, № 8)

Table 9. Average monthly values of PAR for the town of Petrich (nat. + artif.), the island of Crete and Egypt during the period 2000/2010

	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d	mol/ m²/d
Petrich (nat.+artif.)	17,8	21	25,5	21	25,1	28,7	28,8	25,7	19,2	24,5	19,2	16,2
Crete (natural)	9,5	13,7	17,9	24,8	28,5	32,3	31,4	28,2	23,3	16,3	10,4	8,2
Egypt (natural)	14,6	16,8	21,8	27,8	32,9	37,4	34,8	31,3	27,6	21,1	15,3	13,4

Source: IRA-D OOD (2011, № 8)

Devices for measuring the solar radiation

The light sensors are necessary for planning the location of the luminaires, and later for their control. **Photometric sensors, pyranometers, and PAR sensors** have found their application. **Photometric sensors** can be used as a reference point for the intensity and the evenness of the lighting on the relevant crops**.** They are not that suitable for greenhouses as they do not provide data for the spectrum irradiated from different sources. **Pyranometers** are used in the meteorological stations of the greenhouses and they are connected to the microclimate control systems. They give reference data for the evenness of the light falling on the plants, the quantity of the light let by the covering material, the rate of shading of the structural elements of the facility, and the rate of self-shading (by the plants themselves), but they are not suitable for the assessment of artificial sources. **PAR sensors** are applied in scientific studies for measuring PAR in greenhouses and the chambers for growth and germination. They are used to compare PAR from different points of the facility in regard to its evenness and intensity required in the design of the lighting installations.

The choice of the location of the sensors must be done according to the presence of shadings that are not typical or characteristic for the measured area, as well as to the daily and seasonal changes of the angle in which the sunrays fall (Both, 2000). When putting the sensors on the relevant place, it is important for them to be fixed stable and in horizontal position, and to be occasionally calibrated (every one or two years).

Sources of artificial light

In greenhouse production the sources of artificial light are used in three directions: (1) for complete substitution of the natural radiation in the premises or the growth chambers; (2) for supplementary lighting on periods of insufficient natural solar radiation; (3) to control the photoperiod.

In contemporary greenhouse production four types of sources of artificial light are used: incandescent lamps, fluorescent lamps, high intensity discharge lamps (the metal halide lamps and the high-pressure sodium lamps) and light-emitting diodes (LED).

Incandescent lamps emit only around 15% of the energy in the area of PAR (400-700nm), 75% is released in the form of infrared rays (850-2700nm), and the other 10% are in the form of thermal energy (>2700nm). They help lengthening the light part of the day in autumn, winter and spring months. Their advantage compared to the other options is that they require relatively low installation and exploitation costs. They are used less due to their low effectiveness and relatively short lifetime.

Fluorescent lamps are more effective that incandescent lamps and have a much longer lifetime. However, their spectrum in the PAR area is not satisfactory enough. At lower working temperature the quantity of light emitted by them may fall down to around 50%. It is established that after about 10 000 hours of work, the quantity of light emitted by them decreases with up to 60%. They are used in growing plants without daylight as well as in growth chambers.

Metal halide and high-pressure sodium-vapour lamps are most widely used in greenhouse vegetable production at this stage of its development. Metal halide lamps provide the best overall spectral distribution compared to all the sources of artificial light. Their disadvantage is that they are not effective enough in transforming energy within the PAR range. Unlike them, high-pressure sodium lamps have a spectrum that is strongly concentrated in the area of the yellow-orange-red (500-600 nm), but is relatively low in the blue range (Fisher et al., 2001).

Light-emitting diodes allow control of the spectral composition and the intensity of light in accordance with the requirements of the plants (Olle and Virsile, 2013). Compared to the other sources, they consume up to 70% less electric power, as, at the same time they do not emit heat. The installation is with smaller dimensions, their management is significantly easier, and the lifetime – around 50 000 hours (Bourget, 2008). The basic reason for their low rate of use is the high initial investments (Nelson and Bugbee, 2014).

When choosing a luminaire its effectiveness, lifetime, intensity, spectral composition, price and electric power consumption must be taken into consideration.

Location of the luminaires in the greenhouse

There are different ways to locate the luminaires in the greenhouse. They depend mostly on the power of the respective luminaire, the used reflectors, the requirements of the crop, the features in the structure of the facility, etc. The construction of a whole installation can be done best by making a preliminary virtual model using special computer software (computer simulation).

Supplementary lighting regime

It is established that the provision of less amount of light for a longer period of time is more effective compared to bigger quantity of light for a shorter period. Thus, plants use the light more effectively, and at the same time fewer luminaires, cables, etc., are necessary, which decreases the initial investments. It is proved that the lighting in the dark part of the day is more effective that in the light one. There are three regimens of supplementary lighting: cyclic; night break lighting and extending the daylength (Eng, R.Y.N. 1991). Cyclic lighting consists in rotating light and dark periods. In the second regimen, night is interrupted by a source of artificial light. This regimen is not only more economical, but also more effective for creating conditons for long days compared to the use of artificial lighting at the beginning and at the end of the day. It is used with crops that are influenced by the length of the day, like ornamental plants (Poinsettia, Chrysanthemum). The lighting in this regimen usually switches on from 22:00h to 2:00h. With the third regimen, conditions of a longer day are established, which requires extension of the day for the particular period. Tinus and McDonald (1979) recommend switching on supplementary lightining 4-8 hours after sunset or before sunrise. With cucumbers, for example, the lighting may be 24 hours a day, while with tomatoes – up to 16-18 hours.

Controlling the regimen of supplementary lighting

The lighting system may be managed automatically by different clocks (timers) or with special computer programmes. In large greenhouses, it is impossible to switch on all the luminaires simultaneously, as the electric system is not able to cover such consumption. The use of computer systems provides the opportunity to control the lighting systems according to a number of parameters:

- Time – (1) cyclic lighting for controlling the photoperiod and (2) for controlling the duration of the supplementary lighting
- Lighting – daytime levels of lighting
- Synchronization with the system for supplementary introduction of CO_2

In the planning of the lighting regimen, it is important that the inslallation be working for a longer period of time, as the great number of cycles within a certain period (day) may significantly decrease the lifetime of the luminaires. A light controlling integrated system must include: (1) Period of lighting; (2) Preset parametes; (3) The amount of daylight accumulation; (4) Preset reaction time (5) Miminum period of time they have to be switched on.

Benefits of supplementary lighting

One of the significant advantages from the application of supplementary lighting is the shortening of the seedling period and the improvement of the quality of seedlings. The latter has stronger root system, improves the formation of branches, develops shorter and thicker internodes, larger and functional leaves, improves the flowering, decreases the loss of flowers and seedbuds (IRA-D OOD, 2011, №10). The so called ‘blind growth’ (plants without apical bud), which results from shortage of light and energy, is prevented.

As a result of supplementary lighting, it is possible to realize high technological production, i.e., it starts earlier and lasts shorter. This makes possible the rotation of more crops in a greenhouse within one calendar year, and, respectively, more efficient use of the equipment and the workforce.

The application of supplementary lighting influences, to some extent, the resistance of the plants against some fungal diseases, rusts, soilborne plant pathogens (*Pythium, Rhizoctonia*), etc. It is also possible to improve the biological control of some insects, which is done with biopesticides. The production has better transportability and storage capabilities.

Expenses in the use of the supplementary lighting

It is necessary to make a careful expense economical analysis which helps to design such lighting installation and to choose such a regimen that will provide optimal biological and economic effect in the same time. For this purpose, the following factors are taken into consideration: the climatic features of the particular region; the requirements of the crops; the price of electrity in accordance with the time zones; the period of production; the installed output of the luminaires; the lighting regimen – how many hours and which hours of the day; expenses for electricity; expenses for heating; additional expenses for servicing the production. At the estimation of the expenses for heating it is necessary to consider that with every 1000 lux of lighting with high-pressure sodium or metal-halide lamps, the temperature of the greenhouse rises with 0,7°C. (IRA-D OOD, 2011, № 6).

Based on conducted experiments in our country, it is established that with the production of cucumber seedlings with light, 40% economy of costs is realised compared to the variant without lighting (IRA-D OOD, 2011, № 6).

CONCLUSION

1. The light conditions in Bulgaria and the Netherlands, where supplementary lighting is applied, are almost the same.

2. During the typically winter months the requirements of the main greenhouse vegetable crops are not met, and this necessitates application of additional lighting.

3. In some Bulgarian regions (Petrich, Stara Zagora, Nova Zagora, Sofia, Haskovo, Harmanli, Svilengrad) there are greenhouses, which are equipped with installations for supplementary lighting.

4. The achieved great production results as well as the smaller amount of the costs for the production of the vegetable crops determine the promising outlook of these installations in our country.

5. The present review may serve as a base for further and deeper scientific studies regarding the choice of luminairs and their location in the greenhouse, the regimem and the control of the supplementary lighting which should be applied to specific region in the country in order to achieve maximal cost efficiency from its application.

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