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Urban Horticulture and Its Modernization by Using LED Lightning in Indoors Vegetable Production

Žarko M. Ilin and Dubravka M. Savić

Abstract

Urban horticulture also includes the production of vegetables, mostly leafy vegetables, in high tech protected areas with or without daylight. Vegetable crop growing is a scientific discipline that studies biology and technology in growing vegetable crops in either the open-field and greenhouse environment. The objective is to gain high-yield agricultural crops, good quality edible parts that are safe for human consumption and a minimal environmental pollution. Vegetables are annual, biannual or perennial herbaceous plants that rarely develop a woody stem during its vegetative period, mostly in the lower section of the stem. The vegetable edible parts are rich in water and are used either fresh and raw or processed. Once picked, the edible parts may be stored for a short period of time (several weeks, up to 9 months at the most). The vegetable edible parts are: roots and tubers, stems and stalks, sprouts, bulbs, leaves (cruciferous or headed vegetables), leaf stems, immature flower heads, fruits (mature or immature), and seed (mature or immature). Vegetables could be grown in urban areas, in protected areas with or without daylight. LED lightning represent one of the most important modernizations and implementation of vegetable production in urban areas.

Keywords: horticulture, vegetable production, modernization, LED lightning

1. Introduction

According to a new UN DESA report (United Nations, Department of Economic and Social Affairs “World Population Prospects: The 2015 Revision,” 2015), the current world population of 7.3 billion is expected to reach 8.5 billion by 2030, then 9.7 billion in 2050, and 11.2 billion in 2100.

Due to mentioned data of UN DESA report, it is necessary to consider new solutions in food production, generally. Plant production is a part of food production and it requires innovative types of plant growing, especially in modern glasshouses or other types of protected areas without daylight. In such protected areas full equipment which would provide optimal climate conditions for successful plant growing is necessary. It means developing and applying the newest crops production technologies in modern greenhouses. On that way, it would be possible to get healthy, high quality, and safe food, which is connected with high protection of

environment. It is very important for smaller and urban areas. Plant production in urban areas is a great contribution in food production for growing population, generally. One of such kind of plant production is vertical crop production in modern greenhouses or closed systems, both equipped with all necessary installation for providing optimal climate control. In such environment pests, control is efficient, too.

Vegetables have an important role in human consumption as fresh products, food, and pharmaceutical industry. They are mostly low calorie, low fat, and low protein foods, but are a significant source of some of the most needed vitamins, minerals, and microelements. Average recommended daily intake for vegetables is about 400 g [1]. Interesting dietary guidelines vegetable consumption USDA posted on their website (USDA Dietary Guidelines for Americans). In the mentioned post there is a detailed description of daily servings of vegetables for people living in different parts of world.

Vegetables reaction on the global climate changes is very sensitive and vegetable production is becoming more difficult by time. At the same time, with the increase in population on the planet, demand for vegetables is increasing. Therefore, the modernization of horticultural production has been catching the attention of scientists for years. One way to modernize horticultural production generally is to use LED lighting in a protected space, with and without daylight in urban areas.

Urban farming comprises production of various crops in urban areas, in objects with artificial light and without daylight, completely controlled environment in order to provide successful process of photosynthesis and crop productivity. It is one of the solutions for food production for a growing population on the planet. It is solution for the food production in the near future, and nowadays.

Such objects are provided with all necessary installations for optimal crops growth, high productivity, clean, and safe fresh food.

High-tech urban farming can be conducted in various spaces, like special rooms, chambers, buildings intended for such purpose, removable grow-trainers. It is sustainable production without pesticide usage.

Some of very important equipment is light emitting diodes (LED) for horticulture, which are made to provide needed light recipe for every phenophase of crop growth. It is important for photosynthesis and crop productivity. The other important installation, especially in closed systems without daylight, is possibility to provide needed CO₂ implementation, which is also very important for process of photosynthesis and crop productivity. Thus, it is possible to get, for example, high quality various vegetables and safe for human consumption.

According to Sprecht *et al.* [2] greenhouses could be placed on the roofs of the buildings in the cities, for example, what belongs to urban horticulture.

2. Supplemental lighting

Supplemental lighting is necessary in seedling production, as well as in growing vegetable crops that have a longer vegetative period and high demands for light (tomatoes, peppers, and cucumber), and for vegetables with smaller habitus growing in climate chambers in various urban facilities. In greenhouses, it is usually needed during long winter months and periods of overcast. The supplemental lighting prolongs a day, compensates for a natural light limiting effect in winter, and enhances the amount of the available light. Supplemental lighting support photosynthesis in plants and empower plant growth, so they become more resistive on various diseases. Supplemental lighting should not be confused with photoperiodic lighting, which is applied to create long days, thus controlling the plant growth and development processes.

Fundamental issue is lamps and diodes production technologies because they have to be adapted for horticultural crop production. Some of the lighting technologies include incandescent bulbs, halogen incandescent bulbs, fluorescent lamps, compact fluorescent lamps, high-intensity discharge lamps, and light-emitting diodes.

For now, in the vegetable crop production practice, the High-Intensity Discharge (HID) lamps and LED lamps are in use. The HID lamps emit high heat (up to 50%), so they must be placed at about 2 m or more above the crops. The LED lamps are placed at about 40 cm or more above the crops (depends on the species) or in between the crop's rows in the greenhouses, as they do not produce heat that could damage plants.

Nowadays, there are very intensive studies in the ways the plants use the incoming photosynthetic active radiation (PAR) which is based on a principle of an exponential increase of absorbed photosynthetic active radiation with the increase in leaf area index [3].

3. Importance of LED lightning

Importance of LED lightning in urban horticulture and generally, horticultural production in protected areas could be seen on many official and representative movies of companies which have been cooperating in official scientific projects with eminent universities around the world.

Many scientific examinations in the recent years showed that LED lightning save energy and improve and empower plant growth and modern urban vegetable growing—in protected areas with and without daylight.

Light-emitting diodes (LED) represent a promising technology for the greenhouse industry that has technical advantages over traditional lighting sources, as well as a significantly positive impact on the plant photosynthesis process and therefore on the crops yield. They are only recently being tested for horticultural applications, both in greenhouses and in special chambers with a total control of climatic and other conditions necessary for the crop's growth and development. For the time being, they are mostly used in growing leafy vegetables and herbs. LEDs are solid-state light-emitting devices that emit broad-band (white) spectrum light that is necessary for both the vegetative and the reproductive crops phases. Depending on the vegetable varieties and their edible parts (vegetative part, fruit, and immature flower heads), LEDs could be designed to emit light for each phenophase of the crops, so as to adjust it to particular crops and production goals. One of the most important features of LEDs for horticultural application is that the generation of light in LEDs does not produce heat in the beam of light, and LEDs are cool to the touch. So, LEDs can be placed at 40–50 cm above the rows of crops or in between the rows in the greenhouse, and there will be no damage to the plants coming from excess heat.

Besides the crucial role of light and its special qualities for the process of photosynthesis, a combination of light or photosynthetically active radiation (PAR) and supplemental carbon dioxide is also very important in the greenhouse. It is vital that both light and carbon dioxide are provided in sufficient amounts within the greenhouse, or otherwise, a lack of either may pose a limiting factor for the photosynthetic process and consequently for the crop's productivity. Therefore, when supplemental lighting is applied for purposes of increasing the crops productivity, it is necessary at the same time to maintain a suitable carbon dioxide concentration in the greenhouse.

In this way, it is possible to grow vegetables in the greenhouses without natural daylight but with the application of the suitable LED lighting (depending on the crops variety, its edible parts, growing requirements and other) and other controlled climatic conditions for optimal plant growth. LED lighting lasts approximately 18 hours and 6 hours plants are in the dark.

4. Light quality in supplemental lighting in vegetable growing in completely controlled environment without daylight

The suitable light quality in the greenhouses actually refers to the wavelengths (colors) that are efficient in inducing photosynthesis in plants and other growing processes. The light wavelengths are expressed in nanometers (nm). The visible spectrum wavelengths range from about 390 to 760 nm, which is only a small portion of the sunlight (radiation) electromagnetic spectrum. The visible light consists of: violet (380–430 nm), blue (430–500 nm), green (500–570 nm), yellow (570–590 nm), orange (590–630 nm), and red light (630–760 nm). The visible light range mostly corresponds to the Photosynthetically Active Radiation (PAR) from about 400 to 700 nm. The stated wavelengths have the right amount of energy for the biochemical processes, while their ratio in the available light is of crucial importance for determining the quality of light. About half of the sunlight energy participates in the photosynthetic processes. The rest of the energy comes from the sunlight short wavelength spectrum (UV—ultraviolet radiation) and sunlight long wavelength spectrum (IR—infrared radiation).

Blue section of the spectrum, also known as cool light, induces these wavelengths that encourage vegetative and leaf growth through strong root growth and intense photosynthesis.

Red section of the spectrum induces stem growth, tuber and bulb formation, flowering, and fruit production, and chlorophyll production.

Far-red light may cause plants to stretch (elongate) and may trigger flowering in some long-day plants. The plants are exposed more to the far-red than to the red light, which may become a problem with the greenhouse vegetable crop production due to possible shading (for whatever reason) or due to the reduced plants vegetative space.

Green and yellow sections of the spectrum that reach the plants are reflected, thus giving them their green color. Most of the absorbed sunlight wavelength belongs to the blue and red range of the spectrum. However, the recent studies have shown that plants do also absorb some green and yellow light, using it in the process of photosynthesis [4]. Generally, a light source that provides light in the entire visible range will better meet the needs of the plant.

For the time being, in the greenhouse vegetable crops growing practice, the high-pressure sodium (HPS) lamps are used, but also the LED lamps are gaining (**Figure 1**) an increasing significance in the plastic and glass greenhouses and in special chambers vegetable production. Also, in The Netherlands, the latest studies at the Wageningen and Maastricht universities research centers have their guidelines for greenhouse lighting with little or no natural daylight for special feature vegetable crops growing—increased vitamin C content, reduced nitrates content, increased sugar content, and higher yield.

With red, white, and far red light, it is possible to prepare ideal light recipe for particular vegetable species and improve process of photosynthesis and production of assimilates which empower plants. The most important is how plants response on various recipes. So, plants become more resistant toward unfavorable conditions for its growth and toward diseases. In case of adding combination of red, blue, and far red light to combination of red, white, and far red light, it is possible to reach more

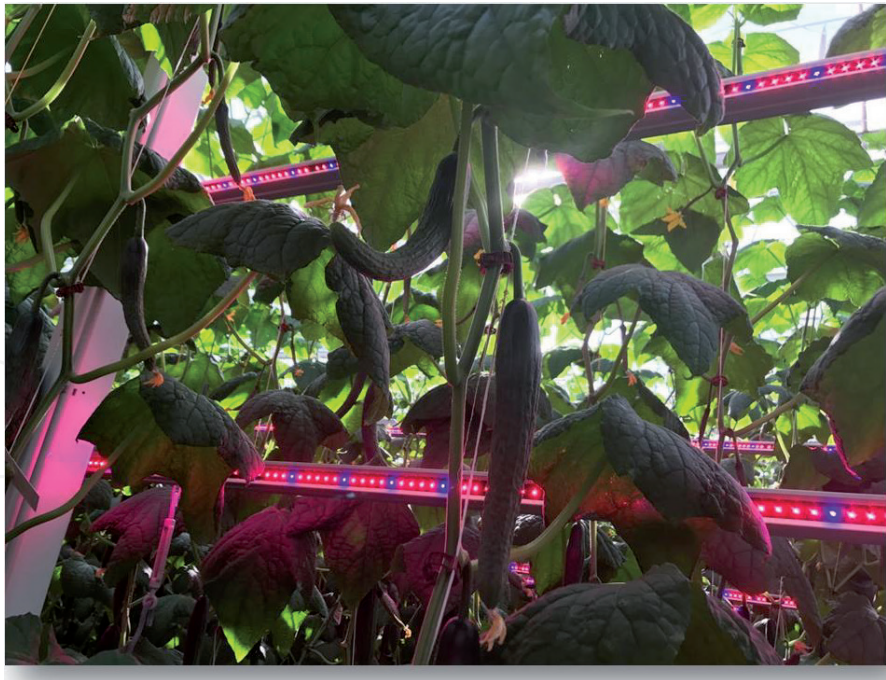


Figure 1.
LED lightning in between rows of cucumber plants with daylight in modern glasshouse.

than 20 various recipes of plants lightning. Then, in combination with CO₂, temperature, various substrates, and humidity, it is possible to obtain ideal light recipes for optimal plant growth. Such kind of experiments could be expensive, but with good plan and expertise (know-how) costs could be lower.

According to Goldammer [5] besides optimal light recipe for the particular crops, it is necessary to understand process of plant growth in order to apply it in the practice, and to do optimizing all the other parameters like climate, irrigation, nutrition, software, sensors, seeds, substrates. Actually, all parameters in indoor plant environment are gathering via sensors and special software in computer where it is possible to control and manage them. The right interaction between all mentioned parameters and growing crops give the best results in indoor completely controlled environment in vegetable crop production. Vegetable crops are kept out of bugs and pests, taste optimized, could be produced all year around in natural way, with less waste in fresh food production, generally. On that way, food is clean, healthy, and nutritious, and production is efficient.

The most suitable for urban horticulture are usage of NFT systems, combined NFT system, and rockwool cubes, and LEDs above the crops, or LEDs could be used between plants rows grown on rockwool substrates. Which type of crops growing and type of LEDs which would be applied depend on morphology of plants species [4].

Generally, nowadays, trend in horticulture is vegetable production under the LED lightning because of numerous advantages in comparison with other types of supplemental lighting.

5. Supplemental carbon dioxide in vegetable production in completely controlled environment and in the greenhouses with LED lightning installation

Carbon dioxide (CO₂) gas is the essential component for the process of photosynthesis, and the plants uptake it through their stomata on the leaves.

Photosynthesis is a chemical process occurring in plants in which the light energy is used to convert carbon dioxide into water and sugars (carbohydrates) and oxygen (O_2) gas. The sugars in plants, obtained in the process of photosynthesis, are then used for the plant development and growth through the process of respiration.

In the objects with LED lightening and completely controlled environment, without daylight, enrichment of the air with CO_2 is necessary because of process of photosynthesis and crop productivity. Due to lack of sun light, in such objects is very important to define right amount of CO_2 .

In the air (outside the greenhouse), there is about 400 ppm of carbon dioxide. The CO_2 concentration is increased when coal, natural gas, oil, and kerosene are burnt. Inside the greenhouse, the amount of CO_2 may be significantly depleted as plants use it intensively in the process of photosynthesis (**Figure 2**; [4]), which may lead to a decreased crops productivity or yield. For that reason, “ CO_2 fertilization” or “ CO_2 enrichment” is a standard practice in modern greenhouses.

Since there is about 500 times more oxygen in the air than carbon dioxide [4], it makes sense to increase the CO_2 concentrations in the greenhouse (particularly in highly equipped glasshouses). It has a positive effect on the oxygen-carbon dioxide ratio. The photosynthesis is higher by 30–50% at CO_2 concentrations of about 1000 ppm, regardless of the amount of light.

The increased concentrations of carbon dioxide are good as long as they do not limit the process of photosynthesis. Photosynthesis depends on light, temperature, air humidity, and carbon dioxide contents in the greenhouse. There is often a question of what is the optimal concentration, but it is hard to give a correct answer to it as the process of photosynthesis does not depend solely on CO_2 . Also, a point should be made that climatic factors affect the stomatal opening mechanism (through which the plants uptake CO_2). Generally, a small increase in the plant photosynthesis process may be achieved at 1000–1200 ppm, but then, there is also an increased possibility of damage to the crops. One experiment done on eggplant crops showed that the first damage to the plants occurred at a constant CO_2 level of 800 ppm [4]. Quite often, the intensity of the photosynthesis may be higher at lower doses of carbon dioxide and higher intensity of light, and the other way around.

Supplementing the greenhouse air with carbon dioxide may not be necessary at all as long as the processes of the crops development and growth are quite satisfactory for the vegetable grower. Also, in a case of intensive greenhouse ventilation, the carbon dioxide concentration may drop below a level that is necessary for the normal photosynthesis process, so increasing the CO_2 concentration may not be an economical measure (unless the greenhouse ventilation rate is lowered).

If the crops quality and production are below the satisfactory level, however, carbon dioxide supplementing should be the next measure. Generally, the production period from late autumn to early spring increases the potential need for CO_2 supplementing the greenhouse air, which actually corresponds to a lower ventilation rate due to low outdoor temperatures.

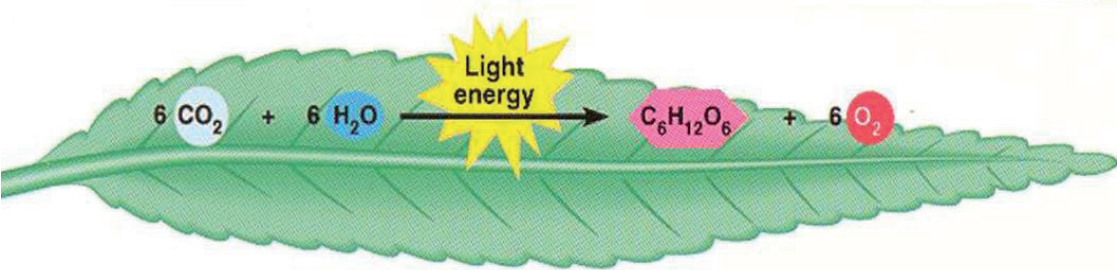


Figure 2.
Photosynthetic process equation.

Normal ventilation provides an amount of carbon dioxide that is similar to its levels in the outdoor air (350–400 ppm). But then, frequent ventilation in the greenhouse is not desirable, so that CO₂ supplementing has long been a common practice in vegetable crops growing. The necessary greenhouse carbon dioxide concentration is determined upon the type of the crops grown in the greenhouse, the greenhouse total volume and ventilation, lighting, temperature, air humidity, and stomatal opening [6].

Since carbon dioxide is one of the products of burning (e.g., fuel for greenhouse heating system), this segment of the heating process can be used for supplementing the greenhouse air. There are various ways of extracting carbon dioxide from other products of burning (fuel), so that the CO₂ from the boiler room can be dosed and at certain times directed and distributed into the greenhouse.

Also, pure carbon dioxide can be used, which is delivered to growers in special tanks, in liquid form and then can be converted into gas and distributed in the greenhouse. This way of supplementing the CO₂ has become increasingly popular as it eliminates any potential damage to the crops, allows control of other greenhouse climatic conditions that regulate the process of photosynthesis and crops productivity, provides easy control of the carbon dioxide levels, and is more flexible for supplementing the CO₂ when necessary.

One disadvantage of the liquid CO₂ is that it is usually more expensive than that obtained from burning fuel, e.g., natural gas.

Also, it would be advisable to install a proper system that registers the CO₂ concentration and then distributes it in the greenhouse. Such a system, like in other greenhouse installation operations, has corresponding sensors that are linked to a special computer software that registers, monitors, and controls all the greenhouse environment parameters. In this way, it is possible to detect a cause of each change and correct it in a short period of time.

The distribution of CO₂ depends mainly on the air movement within the greenhouse, as CO₂ does not travel very far through diffusion. One of the pure CO₂ distribution ways is by a central pump that pushes it into a system of flexible perforated plastic pipes (made of polyethylene or other plastic material). The pipes for CO₂ distribution are placed below the substrate special gutters with plants (if crops are grown in such gutters) or in the lower sections of the crops (if the plants are not grown in gutters). Then, through the pipe perforation, the carbon dioxide is distributed in the air around the plants. Very important is to obtain conditions that keep the leaf stomata open in order to uptake carbon dioxide [4].

In greenhouses, LED lightning could be placed on the top of the crops or in between rows of the particular crop. LED light does not have high emission of heat and cannot damage plants if they are placed in between rows in the crop. Even, that type of LED lightning is possible to be moved up and down, what depends on the crop development. Combination of LED lightning and sun light in greenhouses is an excellent combination for saving electrical energy and to empower crops growth.

With the progress of the scientific research about LED lightning (**Figure 3**) for horticulture and its interaction with plants in order to achieve better quality of edible parts and improve energy efficiency [7] in crop production, it could be high yield, uniform color, firmness, nitrate control in edible parts of plants. Intensity of LEDs which is enough for various recipes is approximately $600 \mu\text{mol m}^{-2} \text{s}^{-1}$ [8, 9].

LED lightning [10] is an efficient source of light in horticulture needed for photosynthesis and plant productivity. Advantages of LED lightning in horticulture than the other types of lightning are relatively low energy consumption, lower radiation heat, long lifetime, flexibility in positioning above or inside a crop, the ability to control the light spectrum and produce high light levels. Important characteristic of LEDs is possibility to control and make various light recipes which participate

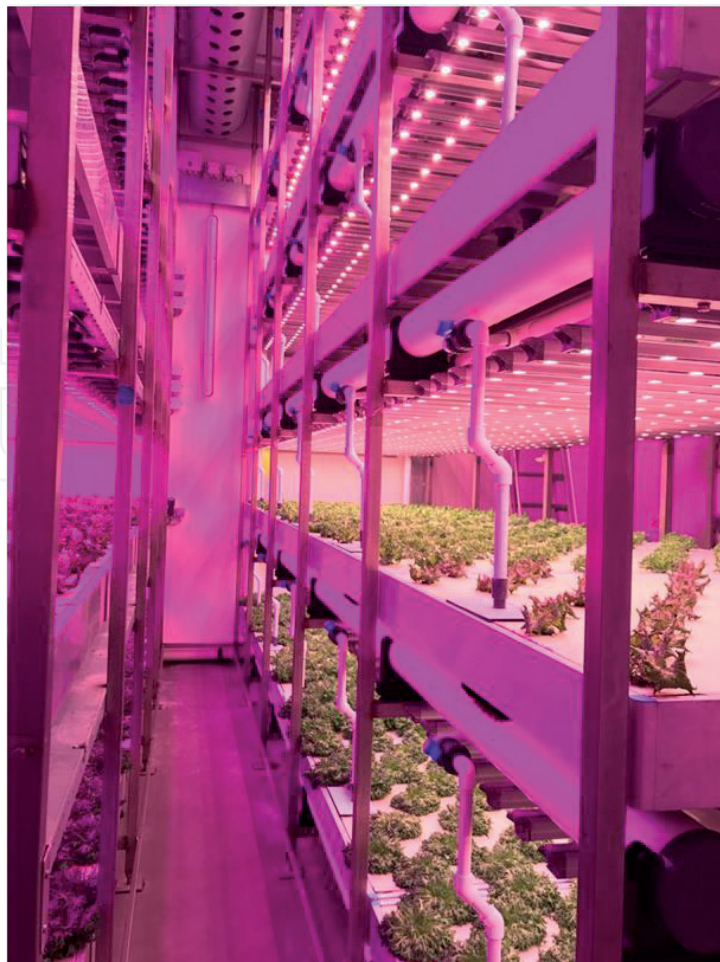


Figure 3.
LED lightning in protected area without day light.

in optimizing photosynthesis, photomorphogenesis, and nutrient contents. LEDs make easier monitoring of nitrogen absorption by leafy plants and avoid harmful nitrate concentration in leafy plants and its influence on human health.

Urban farming is carried out mainly hydroponically (NFT system or rockwool) with or without daylight with complete controlled environment [10], which bring some benefits like controlled usage of water, nutrients, pesticides multiple crops per year, high quality of edible parts, less labor, and easier harvesting.

Urban farming provides remarkable reduction in electricity cost for transplants production by using thermally insulated walls, multi-shelves, advanced lighting and air conditioning systems, etc.

Urban farming enables vertical production of propagation plant material and regular crop production in fully controlled environment. It means that the area for urban farms can be various. It can be placed in supermarkets, or other places where people gather and want to refresh with fresh vegetables or fruits, for example. Urban farms can be smaller or larger areas (e.g., of several square meters), and with vertical cultivation, the crop yield is achieved as in larger areas (e.g., in modern greenhouses or completely controlled objects without sun light).

6. Conclusion

Further development of LED lightning in horticulture, especially in vegetable production, would bring many advantages in producing clean, safe, health food for humans, but for animals, too.

Due to significant climate change and growing population on the planet, there is a need for new solutions regarding safe and high-quality food production. One of the solutions is improvement and usage of LED lightning in controlled environment without sun light or greenhouses with LED light as a supplemental light in the particular crop production.

In order to achieve global food security goals, it is possible to implement alternative farming methods that could increase horticultural outputs and reduce negative climate impacts on the food production. It means that urban areas could be used for high quality food production and using LED lightning.

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