Chapter

Advantages of Growing Vegetable Crops in Modern Greenhouses

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Abstract

There are numerous advantages in growing vegetable crops in modern-equipped greenhouses and protected spaces without daylight, compared with the traditional production (open-field), or with the production in ordinary greenhouses. In modern greenhouses, particularly in the glass ones, it is possible to control the climate conditions entirely, plant nutrition, implementation of CO_2 and other necessary installations, or automation of production process. That enables all-year round and/or off-season production, which is increasingly in demand in markets all over the world. It particularly goes for vegetables crops typical of warm season (tomatoes, cucumbers, peppers), but also for those of cool season (lettuce, spinach, radishes, broccoli). The USDA organization has developed a software program, which is titled a Virtual Grower. It helps growers to calculate the heating costs of their greenhouse. The software can be used to predict heating and energy consumption specific for the location, greenhouse design, crop produced, and preferences of management. The software program, and a short video, too, can be downloaded for free from the following Web site: https://ag.umass.edu/greenhouse-floriculture/fact-sheets/virtual-grower-link-to-usda-software. There is a widespread question among the expert circles whether the vegetable crops are going to be "moved" to greenhouses due to the large-scale climate changes, and in this sense, what the possibilities are for the vegetable crop production. Therefore, any innovation in science is highly important for future patents that may be applicable in agriculture and consequently in vegetable crop growing practice.

Keywords: vegetable growing, advantages, horticulture, innovations

1. Introduction

Vegetable production is an applied scientific discipline that studies biology and technology of vegetable crops growing in open field and greenhouses. The main target is to gain high-yield vegetable crops, high quality of edible parts that have to be safe for human consumption, and preservation of the environment. Vegetables are divided into annual, biannual, or perennial herbaceous plants, which rarely develop a woody stem by the end of its vegetative period, mostly in the lower section of the stem. The vegetable edible parts are rich in water (mainly about 95% of water), and can be used fresh and raw, or processed. Once picked, the edible parts may be stored for a short period of time (several days, up to 9 months at the most, what depends on type of storage place and its equipment). The vegetable edible parts are as follows: roots and tubers, stems and stalks, sprouts, bulbs, leaves, leaf stems, immature inflorescences, fruits (mature or immature), and seed (mature or immature). Due to data of UN DESA [1] report about world increasing population in the coming decades (about to reach 8.5 billion by 2030, then 9.7 billion in 2050) decreasing labor-intensive climate changes, it is necessary to consider new solutions in food production, in general. From that point of view, it is interesting to consider current advantages of crops growing in various protected areas, especially in modern greenhouses. Primary plant production is a part of fresh and processed food production, which requires innovative methods of current types of plant growing or new technologies. It is important especially in greenhouses with or without daylight, where it is necessary to apply innovative methods, software, various innovative automations in plant production and handling after harvesting, and with full equipment, which would provide necessary climate conditions for successful plant empowerment. In brief, it means further developing and applying in practice the newest crops production technologies in modern greenhouses, with high commercial effect, too. On that way, it would be possible to get healthy, high-quality, and safe food, and provide high protection of the environment and economy results. Vegetables are used in pharmaceutical industry, too, because of medicinal compounds. In general, vegetables are of low-calorie, low-fat, and low-protein comestibles. At the same time, they are a significant source of some of the most needed vitamins, minerals, and microelements in human consumption. Average recommended vegetable intake in human consumption is about 400 g per day [2]. There are interesting dietary guidelines for vegetable consumption that the USDA posted on their Web site (USDA Dietary Guidelines for Americans). There is a detailed description of daily servings of vegetables for people living in different parts of world. There are numerous advantages in growing vegetable crops in modern greenhouses compared with the traditional production or with the production in ordinary greenhouses [3]. In modern greenhouses, particularly in the glass ones, it is possible to control the necessary climate conditions entirely. One of the advantages is a possibility of growing vegetables in periods when it is impossible to do in open field. This enables all-year round and/or off-season production, which is increasingly in demand in markets all over the world. This particularly goes for vegetables crops typical of warm season (tomatoes, cucumbers, peppers), but also for those of cool season (lettuce, spinach, radishes, broccoli). In Serbia, winter production of vegetables, as an off-season production, generally is not economical as the renewable sources of energy (geothermal, solar, wind, biomass, etc.) are not still in use in their full capacity. However, the significance also lies in a possibility of arranging for early and late greenhouse production of warm climate vegetable varieties. In early spring and late autumn, the warm climate vegetable varieties cannot be grown in open-field environment, although there is a high demand for them, as well as with high prices. During the cold periods, greenhouses can also yield the cool-season varieties (lettuce and spinach), which are also in high demand on the market. By combining the warm and cool-season vegetable crop varieties, the modern greenhouse can be used for almost all-year round and saved in the deep winter, when it is freezing cold, and the energy prices in Serbia are rather high. The winter period, when no vegetables are grown in the greenhouse, usually can be used for cleaning, disinfecting, and preparing it for the new season and new crops. In most of the North-West European and in some East European countries, a winter break in the greenhouse vegetable crop growing lasts from the end of November until mid-January. The USDA organization has developed a software program called a *Virtual Grower* that helps growers calculate the heating costs of their greenhouse. Users can use the software to predict heating and energy use specific to their location, greenhouse design, crop produced, and the management preferences. The software program, as well as a short video, can be downloaded for free from the following Web site: https://ag.umass.edu/greenhouse-floriculture/fact-sheets/-virtual-grower-link-to-usda-software.

Due to specific climatic conditions, in southern parts of Europe, a great number of warm-season vegetable crop varieties can be grown all-year round in both the greenhouses and open field. That means that the vegetable crop growers from South Europe are in a much better position when compared with those from the cooler regions of our continent. However, even in those countries with warm and humid or warm and dry climate, there are periods that are not so favorable for the open-field vegetable crop growing or in simple greenhouses (e.g., plastic tunnel greenhouse). Therefore, a well-equipped modern greenhouse is the only wise choice in vegetable crop growing. Hemming et al. [4] describe a method, based on a number of mathematical models, which helps in predicting an appropriate greenhouse model for the given climatic conditions. The local climatic conditions (light intensity, temperature, humidity, and wind velocity) are the input data needed for making a greenhouse and vegetable crop growing technology model in a given area. The climatic conditions and crop growth within such greenhouse can be easily simulated [5], and the obtained data can be used as initial information for making greenhouse an economical model. In this way, the most suited greenhouse for a specific area can be designed. The world population is constantly increasing, and it is necessary to find out possibilities for intensifying agriculture in general and horticulture in particular. In this way, it is important to increase the production per area unit, economise on energy (fossil fuels) and water consumption, and use less chemicals (pesticides in particular) and fertilizers, thus improving the quality of all the edible vegetable parts, as well as overall food safety. For that reason, it is necessary to expand cultivated land areas under greenhouses (modern glass and plastic ones) and to intensify growing various vegetable crops under such protected conditions. Furthermore, the recognised competent and expert institutions in the field of agriculture should, among other things, organize and arrange for experimentation and testing of new technologies, their further development in horticulture through devising cultivation strategies and skills, and finally, provide education through participation in such projects ("learning by doing"). Therefore, it is important to come up with a good strategy for organizing the entire production, experimentation, and application in practice. It is necessary to do a feasibility study, either a limited or a comprehensive one. With regard to such "preventive" projects, there are other aspects to be considered: A carefully selected location that could be appropriate for devising the crop growing strategy, a greenhouse functional design, laid out project requirements depending on the vegetable growing strategy. Also, it would be very important for the initial projects to be organized and well suited to the potentials of a given location or region. With regard to the preventive measures in horticulture and growth of vegetable crops, operational support and production monitoring of a particular crop may be of utmost importance. So, to that end, proactive management and production planning should be implemented, individual support provided, as well as guidance through learning and working (well-trained consultants), along with a support and production monitoring [6] by foreign experts, that is, countries with already highly developed horticulture.

2. Greenhouse site selection in vegetable crop growing

A modern greenhouse (a glass or plastic one) is actually a mechanical barrier between the outdoor climatic conditions and the indoor area with the controlled climatic conditions that are optimal for growing the selected vegetable crops. In this way, the vegetable crops are protected from the extreme temperatures, wind, snow, rain, hail, birds, and insects [7]. The work efficiency and productivity in a greenhouse depend on its type and on the type and quality of the indoor fixtures and installations [2]. When selecting a location for building a modern greenhouse, the following factors are to be taken into account:

2.1 Site microclimate

At different geographical latitudes and longitudes, the climatic conditions may differ substantially, and certain factors may even pose limitations for vegetable crop growing—insufficient daylight intensity, frequent fogs, extremely bad weather conditions, too much shade from trees, or high mountains, etc. Such outdoor climatic conditions are unfavorable for growing most of the vegetable crop varieties, which means that it would require substantial investments in indoor installations if one would opt for building a greenhouse in such a location. One of the most important factors is the wind rose chart. One should gather all the data from a relevant hydro-meteorological service for a larger number of years (up to 30, and if the data can be obtained, it would be best to get it for many years, even up to a 100, so as to know what the microclimatic extremes could expected in a given area).

2.2 Water availability and quality

Water source and supply for greenhouse crop irrigation and other necessities are often overlooked. Enough quantities of good-quality water are highly important for the vegetable crops grown in a modern greenhouse, as vegetables are very sensitive to water deficiency. Before starting with any type of vegetable crop production, either in open field or in a greenhouse, it is crucial to send samples of a potential water supply to an irrigation water testing laboratory for analysis—quality test, along with both chemical and biological ones. A water testing laboratory should be a recognized and accredited one (ISO 17025). Water chemical testing is very important for modern greenhouse crop irrigation, due to an application of modern technologies and modern irrigation systems and vegetable crop feeding. Particularly significant factor is the concentration of nitrates and certain microelements, which in high doses may be toxic to plants (e.g. iron (Fe) compounds). In such cases, there are particular technological ways of decreasing the unfavorable concentrations of certain elements and compounds. For greenhouse irrigation and other necessities, the main sources of water are groundwater from wells, surface water (rivers and ponds), rain, and municipal water. Irrigation water microbiological analysis is important for two reasons:

- Presence of pathogenic microorganisms that may affect the crops,
- Presence of pathogenic microorganisms that may affect people.

2.3 Greenhouse site physical requirements

The topography of the site affects where a growing structure is built. (Topography refers to the shape of the land, e.g., hilly, steep, rocky, flat.) The surface of the ground should be level. A 0 to 5 percent slope is recommended. Placing a growing structure on a flat surface is efficient because it facilitates easy adjustments to various mechanical controls in the greenhouse, which is economical. On steep terrains, it is recommended to build several separate greenhouses with axes parallel to contour lines [8]. Provisions must be made for the evacuation of rainfall water, and greenhouses should not be situated in hollow lands prone to landslides.

2.4 Space for expansion of the nursery

Additional space of land, which is larger than the grower's current needs, is acquired. Such area should be counted on the predicted figured out area, in order to accommodate service buildings, storage, access drives, a parking lot, etc. It means that extra space could be allotted to cover unforeseen needs.

2.5 Availability of labor force

Present and future labor needs should be estimated correctly, in order to provide necessary labor on time. Availability of labor supply has been a perennial problem in the horticulture industry. It is necessary to determine if available labor is skilled to perform routine, harvest-time, and post-harvest-time duties.

2.6 Infrastructure

Proximity to transport networks (e.g., roads, railway), access to communication systems (e.g., telephone, Internet), and availability of energy (e.g., gas, electricity) must all be considered when selecting a site for the greenhouse. Greenhouses also need convenient access to materials for growing plants (growing media, fertilizers, pesticides, etc.).

2.7 Legal considerations

When selecting and purchasing a site, there are various legal considerations. Permits, licenses, and zoning regulations govern where a greenhouse may be built and often even dictate what type of building materials may be used. Such considerations may also involve relevant mandates from the Occupational Safety and Health Administration that ensures employee safety. Selecting an appropriate site also involves how the greenhouse operation affects its neighbours (schools, hospitals, parks, farms or ecological areas, etc.).

2.8 Greenhouse orientation

General recommendation is to place the greenhouse in north-west orientation [2] so that the growing plants would be exposed to optimal total light and heating, which is of a particular consideration for winter season vegetable crops. When the greenhouse is in an east-west orientation, it means that the longer sides of the greenhouse should face north and south, with the shorter ends facing east and west. A greenhouse could be built on various terrains and at different slope grades. Also, climate regions may vary, like a desert, a Monsoon region, or a cold one, but in that case, appropriate parameters should be taken into account. Before making a final decision, a feasibility study should be done in two versions: a short one and an extensive one.

3. Types of greenhouses

The aim here is to give a detailed description of the types of greenhouses in vegetable crop growing industry. Also, there will be parameters that should be considered when selecting a type of the greenhouse to be built, as well as the vegetable crops to be grown. Modern greenhouses are structures where the predetermined climatic and other conditions necessary for the vegetable crops production can be closely monitored and controlled automatically. In case of some sudden changes, one can respond immediately and re-establish the climatic conditions. For such elaborate greenhouse structures, there are special expert teams involved in order to come up with the best solution for an investor. Expert teams from various fields provide various software programs [9], which, by way of special sensors distributed around the greenhouse, collect information on the certain crop growing conditions and process them so that they are then compared with the predetermined values necessary for the given crop production. If any change in the conditions occurs, it is displayed on special computers built just for horticulture (different from the conventional ones). Crop growers get instructed in any new software, so that they can manage the greenhouse easily. Anyway, when a computer and the software are purchased from a renowned company, they provide excellent additional services. Also, there numerous mobile phone apps that help monitor any changes in the greenhouse vegetable crop growing.

3.1 Greenhouse type selection

The greenhouse type selection is of crucial importance in the investment profitability. It should mitigate the investment with regard to the time and the production means, as well as increase the crop yield. There are also special needs and abilities of the investor to be considered, as well as climatic conditions of the given area. Furthermore, when selecting a type of the greenhouse [8], their other important factors are to be considered before making a final decision.

Defining the grower's or investor's requirements

- Type of crops and the desired final produce quality,
- The necessary time frame for growing the desired crop(s),
- The climatic and food requirements for the crops,
- Investment planning,

The greenhouse selected crop production automatization and control level.

Climatic data:

The area climatic data should include the following:

- Minimal and maximal temperature values,
- Relative air humidity,
- Duration and intensity of daylight,
- Wind and gusts speed and direction,
- Storms, precipitation (rain and snow in particular),
- Topography (land shape),
- Types of soil or availability (obtain/use) of organic or hydroponic substrates,

- Sources and availability of good-quality water with regard to its chemical and biological properties,
- Wind rose (meteorology).

Structural solutions:
There are a number of considerations when opting for a greenhouse:

- Height, width, length,
- Number of arches or ridges,
- Number of benches,
- Ventilation (roof, lateral, or combined),
- Types of covering (plastic or glass),
- Quality irrigation and plant-feeding systems,
- Heating system (water or air),
- Hydroponic substrates,
- Fertigation and climatic control systems.

Planning:

- Defining a greenhouse structure,
- Greenhouse directional orientation, depending on the sunlight orientation and wind strength,
- Terrain sloping grade and the precipitation drainage system,
- Automatization,
- Indoor climatic conditions control (temperature and humidity),
- Irrigation and fertigation systems,
- Climatic conditions and fertigation command controls and their connection to the main power source,
- Labor.

Feasibility study:
A greenhouse feasibility study makes it possible to have an overall view of the existing abilities and a desire for modernization or for building a new, modern greenhouse. It can provide a framework within the given climatic conditions and predict the vegetable crops probable yield and quality, as well as a suitable profit. If the feasibility study shows that the greenhouse project is sustainable, then the next step is to prepare and draw a detailed business plan. Both the feasibility study and

the business plan should be left to experts who shall, in the best of ways, introduce the growers or investors to the world of the greenhouse vegetable crop production.

Modern greenhouses include the following:

- Modern plastic-covered greenhouses and
- Modern glass-covered greenhouses.

The two types of greenhouses have similar characteristics with regard to its structure and indoor installations. Protection against external environment, vegetable early ripening (its edible parts), a shorter vegetation period, simplicity in controlling the climatic conditions optimal for the crop(s) growth and development, protection against diseases (conventional protection and/or biological) are just some of the numerous important aspects and necessities in the greenhouse vegetable crop growing.

Factors to consider in opting for the greenhouse vegetable crop growing are as follows:

- Longer vegetation period of certain vegetables,
- Insufficient length of a continuous frost-free period,
- High demand for the off-season vegetable produce,
- Global climate change,
- Greenhouse and open-field vegetable crop growing combination,
- A need to supply various markets, local and foreign, with the vegetable produce all-year round.

Considering the aforesaid, most of the vegetable varieties (tomatoes, peppers, eggplants, cucumbers, watermelons, cabbage, lettuce, etc.) are grown as follows:

The modern greenhouses are tall (4.5 m and more) made up of plastic or glass structures, equipped with various indoor installations that provide favorable conditions for the selected vegetable crops, as well as complete control in growing crops for the duration of the entire vegetation period (control of the crops feed, irrigation, timely implementation of agrotechnical measures, disease monitoring, and preventive actions). A general recommendation is to build the greenhouse on a flat terrain (or on a low-gradient slope, 1–2%). On the other hand, if necessary and financially sound, such structures may be built on a higher-gradient slope, but with the help of proper engineering technology that can provide a flat production area. This means that the land parcel selected for the modern greenhouse has to be leveled so that the foundation of the structure can be built properly to last for a number of years (15–20 or more). In fact, when considering investing in the modern greenhouse and its long-lasting quality usage, there are three important factors to be taken into account and never economized on the following:

1. **Terrain leveling** of the area designated for building the modern greenhouse, as well as leveling the production area and building the foundation. The modern greenhouse should last for quite a long time (10–20 years or more) and there is folk proverb that says “no good roof without a good foundation”, or better still, no good greenhouse.

2. **Greenhouse frame** should be strong and sturdy, well-built, and the best material for that is galvanized steel. If possible, the galvanized steel frame should be perforated and painted in white so as to increase indoor lighting (particularly in overcast weather during the vegetation period). As the frame casts a large shadow during the day, white paint and perforation help increase the light intensity. One should always bear in mind that modern greenhouses are mostly used for growing warm season vegetable varieties that need lots of light and its higher intensity during daytime (tomatoes, peppers, eggplants, melons, and watermelons up to 1 kg). The greenhouse roof frame is usually built of aluminium construction of various profiles.

3. **A boiler room**, well built, with at least two boilers (or more, depending on the greenhouse total area and volume). One type of fuel or even different types may be used for boilers. It is very important that best-quality boilers are used and that the fuel is readily available on the market. So, in case one boiler breaks downs, the other is ready to be used. It is of utmost importance for the early spring and late autumn vegetable crop production. The fuel used in boilers may be oil derivatives, coal, gas, wood, pellets, geothermal sources, biomass, solar energy. The boilers heat the water that goes to the greenhouse, pumped through a system of pipes or tubes. Those then heat the indoor space quite evenly. The hot water pipe system can be arranged in several levels along the indoor space sides. Depending on the climatic conditions during the cold season and the crop vegetation period, the heating levels are decided upon.

The modern greenhouse total area depends on various factors. It usually covers 1 ha and goes up to dozens of hectares. The volume of such structures is huge, which makes it difficult for the air to circulate and refresh the space. So, the ventilation can be improved by the greenhouse vents on the roof and/or on the sidewalls, as well as by the use of fans, usually fixed along the ceiling. The optimal number of fans per area/volume unit, as well as the area and type of the vents is determined upon certain greenhouse parameters, the vegetable crop climatic needs, as well as the outdoor climatic conditions of the particular region where the greenhouse is located.

During the building of a greenhouse, one of the most important things of the construction process is building the foundation of the greenhouses. Among several types of foundations, the right type of foundation can be determined by the style of greenhouse and building codes. It is important to emphasize that the foundation is the complete system on which the greenhouse structure sits. One of the most important components of the foundation is the footing. Footers are typically poured concrete and their exact depth is determined by local building codes and the location's frost line to avoid structural damage, which can occur with the freezing of surface-level soil. Generally, the climatic conditions of a region are a crucial factor in selecting a type of the greenhouse and all its structural elements and indoor installations. It is advisable to collect all the data from a relevant hydro-meteorological service for a larger number of years, of minimum 10 or up to 30 (or even more, if possible) in order to see what the extreme climatic conditions are, which helps define the greenhouse foundation and frame types, as well as the type and quality of the covering material to be used for the construction. Thus, a team of experts of various professions in charge of the greenhouse design and construction can easily propose the best of solutions for a particular greenhouse where particular vegetable crops are to be grown and in a particular region. The modern greenhouse has specific structural elements, as well as indoor installations.

4. Some major greenhouse structural elements

1. **Foundation/footing** is one of the most important elements in the modern greenhouse construction for building the foundation. There are several different ways of doing it, but the particular foundation or footer type depends on the selected greenhouse style and the local building codes [2]. Actually, the foundation is the base for the entire greenhouse and should ensure its strength and stability for a number of years, even in conditions of slight terrain movement. Here, the most important factor is the soil type or structure, the land where the footer is to be placed. Footers are typically poured concrete and their exact depth is determined by local building codes and the location's frost line to avoid structural damage, which can occur with the freezing of surface-level soil.

2. **The modern greenhouse frame**—The best material for the frame is galvanized steel, while the roof frame should be made of aluminium. The greenhouse walls and roof frames depend on the greenhouse style. Many side posts and columns supporting the structure cast a lot of shadows inside the greenhouse, which affects the intensity of the photosynthesis process. So, the entire frame should be perforated and painted in white, so as to increase the indoor light intensity, particularly in the plant's vegetation period.

3. **Roof and side walls**—The roof and side wall surfaces are usually made of various types of glass or different plastic materials.

4. **Roof and side wall vents**:

    a. Modern glass greenhouses are usually built only with roof vents,

    b. Modern plastic greenhouses may be built with only roof vents, but may also have both roof and side vents.

5. **Roof and side wall vent insect screens**—Insect screens prevent or at least curb insect and birds' intrusion into the greenhouse. Insects may cause or transmit numerous diseases, and pathogenic microorganisms, while birds, besides transmitting disease, most often may destroy the crops physically.

6. **Doors**—The greenhouse doors, both indoor and entry ones, their size, and number depend on the size and type of the greenhouse. It is advisable to have as few entry ones as possible.

5. Some major greenhouse indoor installations

- **Heating system installation** usually consists of a boiler room, a fuel tank, and a hot water pipe system that heats the greenhouse. Besides hot water heating system, the greenhouse can also be heated with hot air. There should be at least two boilers in the boiler room. The fuel may be the same for both or different. One boiler always serves as backup in case the other breaks down. The fuel used in boilers may be oil derivatives, coal, gas, wood, pellets, geothermal sources, biomass, solar energy.

- Cooling system

- Plumbing

- Electrical installations
- Lighting system
- Shading and thermoregulation systems
- Plant tie support system
- A system of devices that control temperature, humidity, direct sunlight intensity, or diffuse light, as well as additional lighting intensity
- Carbon dioxide supplementation system
- Benches and tables
- Hydroponic plant growing installation system
- Crop biological protection system
- A small weather stations
- Special computers and software programs that monitor and control the greenhouse climatic conditions; in a case of change, the preset parameters can be easily reset
- A power transformer substation

The modern greenhouse vegetable crop production can have various purposes:

- From seeds (or from the purchased seedlings) until the entire fruit is formed, ripened and ready to be picked
- Seedling or plug production for greenhouse or open-field plant growing (important for early warm season crops)
- From seed to seed (vegetable seed production)

The twenty-first century greenhouse has a major role in extended vegetable crops growing period, providing a great variety of produce in different times of the year [10]. Advantages of greenhouse vegetable crops growing are really numerous.

- Protection from outdoor weather conditions,
- Early plant and fruit ripening,
- Off-season vegetable production (with ever so high market demand, particularly in the North-West Europe regions),
- Control of climatic conditions favourable for the crops growth and development,

- Possibilities of controlled irrigation—the drip irrigation system,
- Simpler ways of biological and conventional protection of crops against pathogenic microorganisms and pests,
- Easier tasks for greenhouses workers,
- Environment protection and many other factors that will be discussed further on.

Generally speaking, the most important aspect, the twenty-first century vegetable crop greenhouse highlight is dominant computerisation of all the processes and the initial steps in robotic application in performing and implementing certain agrotechnical measures, thus replacing human labor that is rapidly decreasing, which is actually a contradiction to an ever-increasing global population. Estimates predict that by 2015 there will be about 10 billion people on this planet of ours, and they will all have to be provided with basic living conditions, such as potable water and food. To that end, many scientific facilities and institutions, universities, and big companies involved in agricultural sector, horticulture in particular, all do research in creating possibilities for finding solutions to numerous challenges in the food and water production industry for the years to come.

6. Glass greenhouses

Glasshouses are the best protected indoor area for growing vegetables in regions where climatic conditions are unfavourable for their growth and development in either open field or plastic-glazed greenhouses. They are the best environment for controlling the climatic conditions and the mineral feed of the crops during their vegetative period. At the same time, also, the warm season crop vegetative period could be prolonged when compared with growing such crops in open field. Furthermore, the modern glass greenhouses are perfect with regard to applying modern technologies and scientific developments in growing crops. Of course, the economic factor is of utmost importance for commercial crop production. So, both short and extensive financial plans have to be made. Glass greenhouses are built mostly in cold climates, but as they provide the environment where the climatic conditions can be completely controlled, they are also a good choice for growing vegetables even in warm climate regions. Modern vegetable crops growing in glass greenhouses are very intensive from the perspective of capital investments, application of the latest production technologies, know-how, labor, energy, substrate, hydroponics. The greatest issue in modern greenhouses is the high cost of energy. There have been, however, some significant shifts toward reducing the cost of heating. The Venlo greenhouse type [8] is probably the most-built type worldwide and the most economical one among the professional vegetable crop growers. The design of the Venlo greenhouse is suitable for all sorts of crops and under various climatic conditions. This type of greenhouses was developed in the Netherlands and was named after the region and the place of Venlo where it was first made (southeast the Netherlands, toward the German border). The whole region has one of the largest concentrations of greenhouse horticulture.

The Venlo greenhouse is the galvanized steel frame structure, as the best and most durable material that can deal with the weight of the entire greenhouse and the roof frame. The roof frame can be made of aluminium or galvanized steel of various profiles. The roof frame also carries the windows/openings that in the Venlo glasshouse can be opened from both sides and make 20–30% of the total glass surface area. As the frame structure consists of a great number of columns of various sizes and dimensions, there is actually much shade inside the greenhouse that affects the crops. For that reason, it is advisable for the entire frame structure to be perforated and painted in white so as to increase the indoor lighting. The crops that are mostly grown in greenhouses are as follows: tomatoes, peppers, eggplants, cucumber, melons and small watermelons (up 1 kg), lettuce, spinach, grapes, raspberries, blackberries, strawberries, blueberries, and, of course, seedlings of vegetables and flowers and various edible berry fruit. Often grown in greenhouses are also broccoli, cauliflower, leek, bananas, ginger. Actually, all horticultural varieties can be grown in greenhouses, but it would be best to check first how cost-effective it could be, that is, to do a feasibility study. If a feasibility study has to be done as a guaranty for the bank loan or a subsidy, then such a study should be detailed and done by a recognized firm or a consultant. Since greenhouses provide the environment for almost complete control of the selected crop production, the grown crops are safe for human consumption. That means they meet the best standards with regard to both safety and quality. Furthermore, there is a minimal environmental pollution. Other benefits are that the early crops come to market sooner and also, high yields are achieved. For instance, in hydroponic tomato production (on the rockwool growing substrate), the yield can be even up to 100 kg/m^2, or 1000 t/ha per annum. The fact is that the yield (or the production rate) in the modern glass greenhouse can be 10 times as much as in the open field. High yields are achieved through intensive growing methods and by prolonging the production season. Besides the vegetable quality and the environment pollution reduction, the yield should be high also because of a return of the investment and payments of additional costs. The majority of the glass greenhouses manufacturers put on offer glasshouses and the horticultural production technology, which may provide optimal production under the given market conditions, so that the additional costs would pay out through the earnings from the additional production. Consumers in most of the developed countries expect to find good-quality vegetable produce grown in glass greenhouses on their respective markets. In most cases, it is the improved quality of the vegetable produce that gives a motive for starting the glasshouse vegetable production. For different types of produce and different markets, there are also different parameters for food quality. The quality parameters for the fruit and vegetables required on the market may include the following: taste, flavor, aroma, size, color, stage of ripeness, firmness or softness—texture, shelf life, the absence of any spots or defects, minimum or no waste, no signs of pests or disease, with or without leaves, and many more. One of the most important standards in the primary agricultural production, which is also a quality guarantee of both the primary agricultural production and the produce itself, is the GLOBALG.A.P. standard/certificate. According to the construction and engineering characteristics, appearance and purpose, there are several types of glass greenhouses that could be single-span, multi-span, lean-to, gabled.

6.1 Single-span greenhouses

- Single-span glass greenhouses occupy a single area that is not partitioned in any way.
- They are easy to air and ventilate, but are hard to heat.

6.2 Lean-to greenhouses

- Usually of small dimensions/area (e.g., 80–200 sq. m)

- Its north side is usually higher than its south side, and with its north side, it leans to the south wall of another structure (but necessarily)
- Usually used for growing vegetable seedlings and vegetables in containers or pots arranged on shelves or benches.
- Width, length, and height (from the ridge board to the eave) can be at will,
- Lean-to-glass greenhouse vertical cross section (front): about 80–200 sq. m, 2.0–5.5 m (or higher)

6.3 Gabled glass greenhouse

- Gabled roof
- Area: 500–1000sq.m (or more)

6.4 Multi-span glass greenhouses

- In structural terms, the multi-span greenhouse consists of a number of even span greenhouses connected along the length of the house.
- At the attaching points, there is only the frame without glass glazing. If the area has to be partitioned, it can be done with both glass panes and plastic film that can be easily put up or down (whatever is necessary).
- The total area of the multi-span glasshouses can be from 1 ha to several ha (10 ha–15 ha or more) (**Figure 1**).

The ratio between the glass (cooling) surface and the multi-span greenhouse total volume is such that can cut the heating costs, but are hard to ventilate through vents (windows). In such cases, it is necessary to install a special ventilation system (including fans as well) that allows good indoor air exchange and circulation (**Figure 2**).

Figure 1.
The 21st century multi-span greenhouses with a clearly defined road network and the meticulously kept weedless lawns (The Netherlands).

Figure 2.
Multi-span greenhouses, ancillary structures, and a weather station on one of the production complex ancillary buildings (Serbia).

A modern greenhouse weather station usually consists of instruments that in regular intervals measure some of the weather parameters that are significant for the greenhouse crop production. Such instruments may include an anemometer, a wind vane, a thermometer, a hygrometer, a barometer, then sensors for measuring rainfall, solar radiation (direct and diffuse solar radiation). The obtained data are used locally for arranging the greenhouse production. Also, the data can be sent, in a special computer format, to the World Meteorological Organization (WMO) to help build a model for weather forecasting all over the world. WMO is a specialized UN agency and is dedicated to international collaboration and cooperation between the countries in terms of climate conditions control on this planet of ours, as well as making a model for the horticultural production monitoring and control.

7. Glass greenhouses basic structural elements

- **Foundation**—consists of a footer (20 cm–50 cm high); built of concrete or concrete slabs.
- **Supporting frame**—consists of columns (galvanized steel), trusses, beams, purlins and braces, making a grid-like frame, painted in white, and usually of small profiles so as not to cast shade.
- **Roof and side glass glazing**—consists of glass panels 3 mm–5 mm thick with (usually) aluminum frames; glass fixed with silicone sealant.
- **Roof and side vents/windows**—make about 20–30% of the total glass area; in modern greenhouses they are mostly on the roof.
- **Doors**—can be single or double doors; the number depends on the greenhouse size and type.

The photos below show the greenhouse galvanized, painted in white steel frame and the roof frame, vent insect, and bird screens (preventing penetration of insects that may cause or carry diseases to crops and birds that can damage the plants). Also, it could be seen a glass outer surface cleaning machine (**Figures 3–6**) [2].

Figure 3.
Greenhouse cleaning, washing and disinfection (Kucura, Serbia).

Figure 4.
Glass greenhouse-galvanized steel frame (the Netherlands).

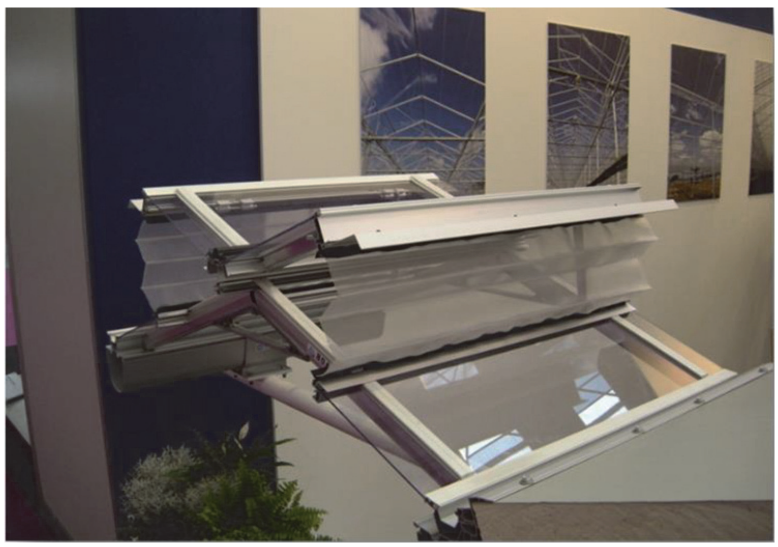

Figure 5.
Roof and side vent insect and bird screen (crop protection against insects and birds).

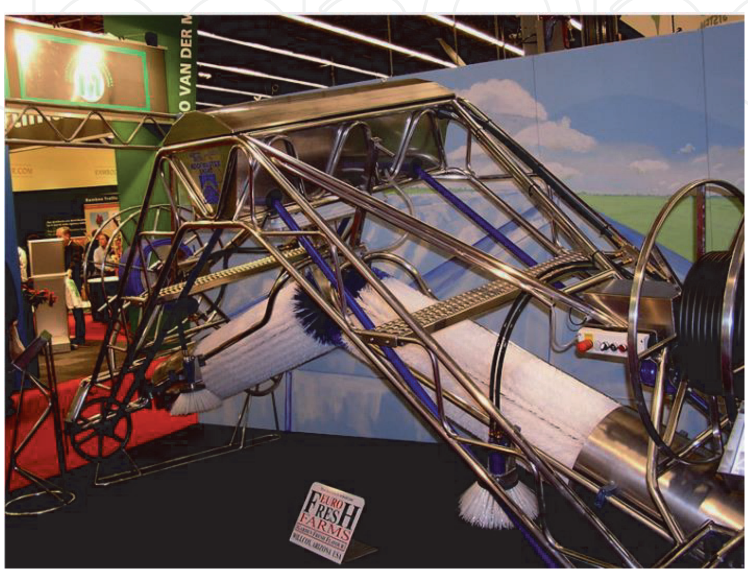

Figure 6.
Greenhouse glass roof washer.

8. Glass greenhouse essential systems

8.1 Heating system

One of the essential greenhouse installations is the heating system, for the commercial reasons and for creating the suitable indoor climatic conditions. However, it may be the most expensive of the greenhouse installations and a major concern in the vegetable crop production. The system consists of a boiler room with suitable boilers—at least two (**Figure 7**) and an array of pipes which carry, say, the warm water, which is pumped through the pipes, heating the environment. The total area and length of the heat radiating pipes depend on the greenhouse size, water input temperature, both indoor and outdoor air temperatures, and so on. On the other hand, it is the best way to heat the greenhouse indoors as the heat is released evenly, so the air is heated evenly, without major oscillations in temperature. The warm water carrying pipes may be arranged on several levels, particularly along the glass walls. At moderately cold weather, only the first level of pipes is in use. But if the winters are very cold, then the second and third levels may be put in use. In this way, the upper zone is also heated, the zone under the roof, which allows roof glass defrost or snow melt and its discharge.

The heating system has to provide heat that may be lost in various ways:

- Heat loss through the glass glazing (conduction),

- Heat losses of the greenhouse can be occurred through ventilation and infiltration (fans and air leaks). Such heat transfer includes the movement of air and the movement of water vapor. When water in the greenhouse evaporates, it absorbs energy, and when water vapor condenses back to a liquid, it releases energy. It means, if water vapor condenses on the surface of an object, it releases energy to the outside environment.

- Another type of heat loss is air infiltration, which depends on the age, condition, and type of greenhouse. Older greenhouses or those in poor condition could have invisible cracks around doors, or perforations in covering material through which large amounts of cold air may enter.

- Radiation heat transfer occurs between two bodies without direct contact or the need for a medium such as air. There are two types of radiation that affect greenhouses: solar, or shorter wavelengths and longer wavelengths, or infrared (IR) radiation. Shorter wavelengths from the sun pass through the glazing and heat the greenhouse plants, soil, and structures. The amount of radiant heat loss depends on the type of glazing, ambient temperature, and amount of cloud cover. Greenhouse radiation cooling is most noticeable on clear winter nights.

Nowadays, many types of heating systems are available for the greenhouses. And selecting the proper heating system is important. Some heating systems cost less to buy, or can use less expensive fuels. Others may have a higher initial cost, but they are more efficient, easier, and safer to operate. The most common and least expensive is the unit heater system. In this system, warm air is blown from unit heaters that have self-contained fireboxes. Heaters are evenly located throughout the greenhouse, depending on its volume. These heaters use electricity, which increases its consumption, although the heaters themselves are not expensive. The best and the safest heating system is a central boiler—a boiler room, and a system of

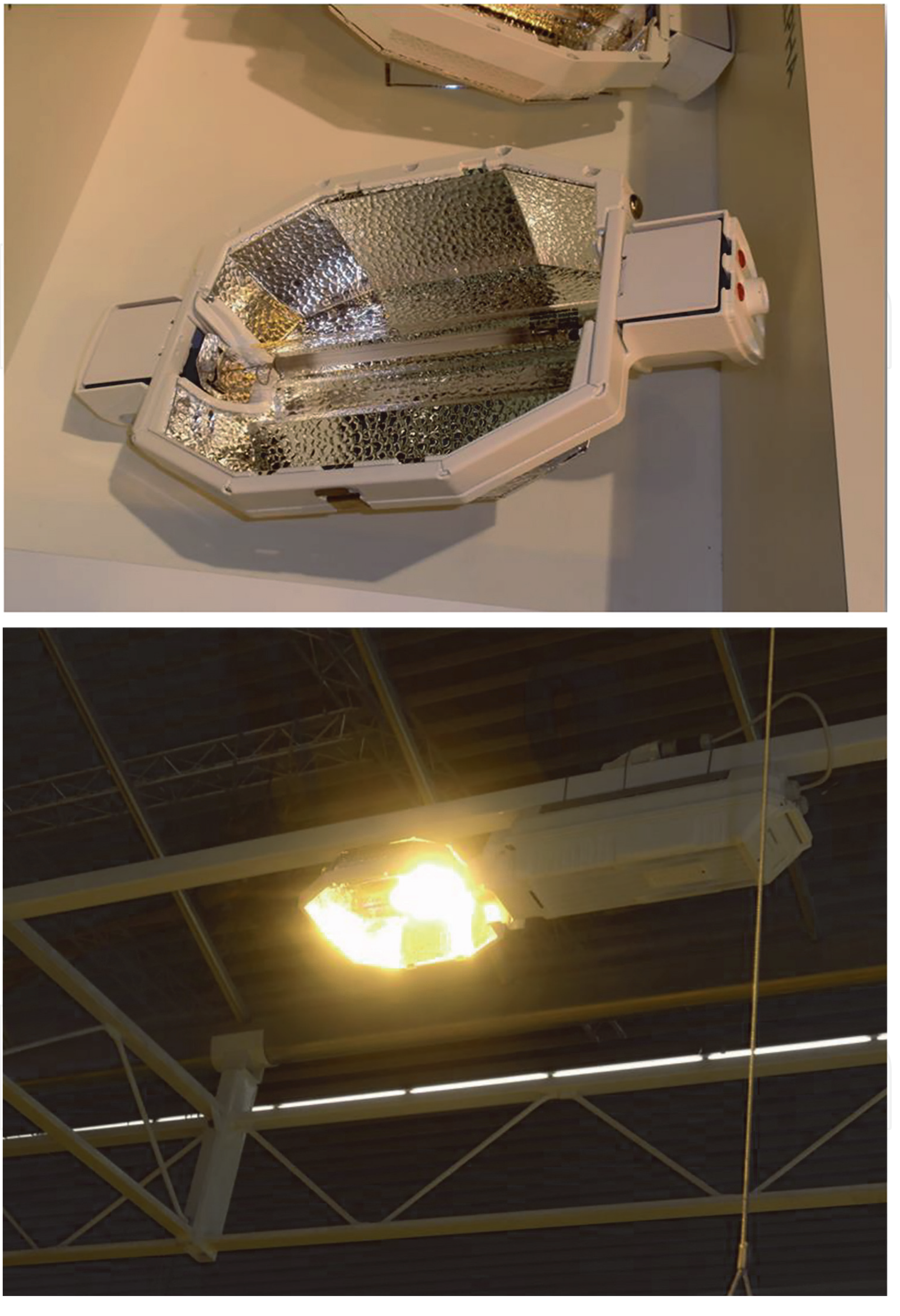

Figure 7.
Supplemental lighting lamps (the Netherlands).

pumps and pipes that distribute hot water or steam. The best system is where the water is heated in the boilers and is then distributed around the greenhouse with a system of pumps and pipes. The warm pipe surface evenly radiates heat and also evenly heats the glass or plastic greenhouse indoors. Types of fuel for the greenhouse heating system may be solid, liquid or gaseous, then electricity (generated using wind power), and for some time now, the solar power has had an important role in heating various structures, including greenhouses. Types of fuel that are mostly used are fuel oil, coal, wood, biomass (if there is a steady source of biomass), natural and LP gas, geothermal sources. Electricity can also be generated using wind power harnessed by wind turbines erected in windy places and the generator converts the wind power into electricity. And, of course, there is the solar energy, where solar panels convert it to electricity. The cost and availability of these sources will vary somewhat from one area to another or from one country to another. Convenience, investment, and operating costs are all further considerations so as to select a type of heating that is most suitable for modern, successful, and economical crop production. Savings in labor force (or where it is not readily available) could justify a more expensive heating system with automatic controls (**Figures 8–12**).

Due to a rapid exhaustion of natural resources that are used for fuel and so in order to be environment friendly, the renewable energy sources are increasingly in use in modern crop growing industry. The renewable energy sources are solar energy, wind and water power, and geothermal springs.

8.2 Plumbing and irrigation systems

The greenhouse plumbing and irrigation system is designed according to the requirements for the particular vegetable crops that are to be grown indoors, a selected irrigation system, and the chemical and biological quality of the water

Figure 8.
A boiler in the greenhouse boiler room (the Netherlands).

Figure 9.
A geothermal spring (Serbia).

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Figure 10.
A greenhouse unit heater (the Netherlands).

Figure 11.
Solar panels that convert solar energy to electricity (the Netherlands).

coming from an available source. Selecting a modern greenhouse irrigation system is an important step as it has to meet all the requirements of the modern vegetable crop production. It also has to be an efficient system as the supply of potable water is in decrease, which goes for the agricultural water, as well. So, the main goal is to achieve high-yield and good-quality vegetables with a highly controlled use of water. The water supply coming from an available source should be of good quality in chemical and microbiological terms. The chemical properties of the irrigation water are very important because the source itself (even the large rainwater collection tanks and ponds near the greenhouse) may contain undesirable elements or compounds, particularly the microelements that even in small quantities can be toxic to the crops or may make compounds that the crops cannot use. Also, the irrigation water may contain compounds (e.g., calcium carbonate) that can plug the plumbing system, particularly if it is a drip irrigation system. There is also a microbiological property of water. The water may contain a number of pathogenic microorganisms that may be harmful to the crops, causing diseases

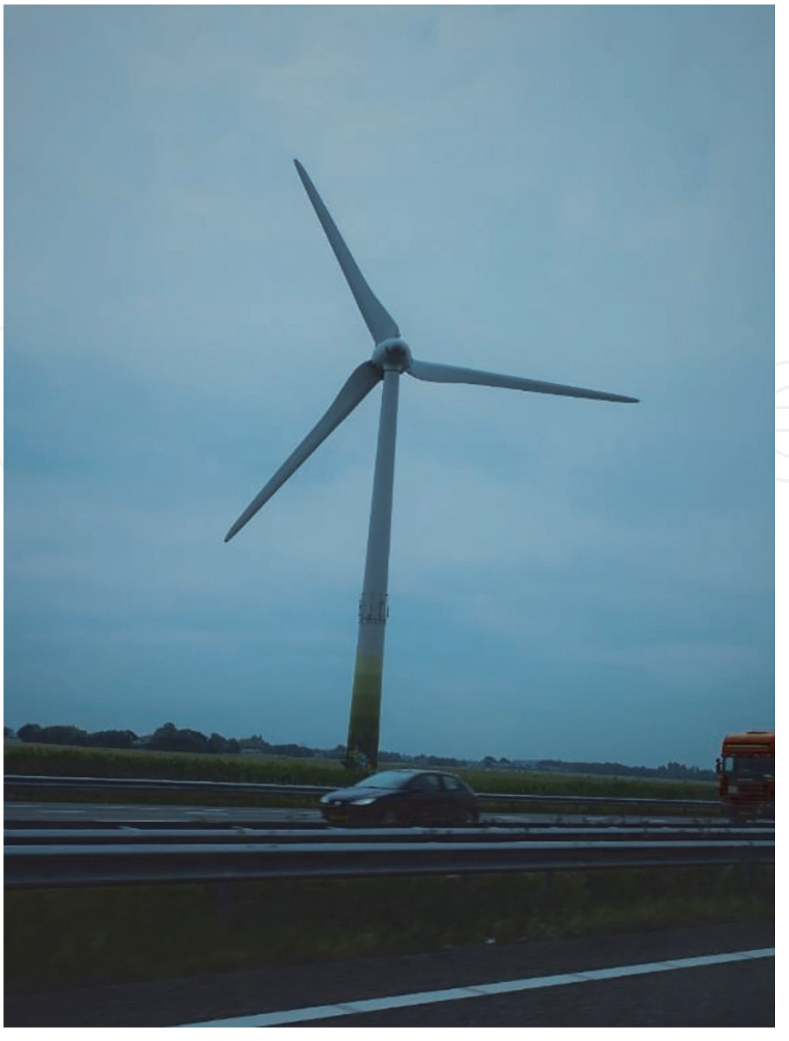

Figure 12.
A wind turbine that converts solar energy to electricity (the Netherlands).

in plants. Moreover, such water may contain microorganisms that are harmful to people, as they may be found in the vegetables we eat (although never in concentrations harmful to people). However, such microorganisms may be found on the surface of vegetables, thus causing some of the infectious diseases in people (due to poor hygiene after harvesting or if consuming unwashed vegetables at our homes). The most common pathogenic bacteria are *Escherichia coli*, *Listeria sp.*, and others.

A recommended irrigation system for greenhouses is the drip system. Due to all the above-mentioned reasons, the greenhouse irrigation system has to be selected wisely, has to be a good-quality one, and well maintained afterward. The quality of water is perhaps the most serious factor when selecting the irrigation system. If the water is of a poor quality, the system will not operate properly and will be hard to maintain. A water analysis may provide the investor/grower with a much clearer picture of the potential problems on a given location, with regard to the water supply and its use in the drip system. Also, a water test may be of help in considering all the possible solutions to the irrigation problems. The water analysis should include tests to pH values, dissolved solid matter, manganese, iron, hydrogen sulfide, carbonates, and bicarbonates. The amount and the size of the particles of certain compounds should be determined, as it determines the size of the emitter filters. The drip irrigation system may provide favorable grounds for the development of bacteria, which results in the formation of sludge deposits and anaerobic environment. Certain bacteria may cause a build-up of manganese, sulfur, and iron

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compounds deposits, which may plug the drip system. Furthermore, there are certain algae that may enter the irrigation system from the water supply and build up larger particle deposits. It often occurs when the irrigation water has a high biological activity and high iron and hydrogen sulfide content. The soluble iron compounds (Fe^{2+}) are the primary source of energy for certain bacteria, thus leading to iron deposits (**Figure 13**).

For all the stated reasons, it is important to use the high-quality water, as well as the high-quality system filters, or the poor-quality water may cause a lot of trouble which does not allow the modern vegetable crop production. So, regardless of the quality of water, the greenhouse irrigation water filtration has to be regularly maintained. The system has to be cleaned frequently and the water chemically treated, if necessary. There are some steps to be taken in order to plan further actions: regular basic water quality checkup, water flow and water pressure monitoring, and watching for the color of the water itself. In many countries, the main irrigation water source is rainwater collected in large ponds (wherefrom it cannot leak to the ground) and regularly tested at accredited laboratories where chemical and microbiological content is checked and then, certain measures are undertaken to make it suitable for its safe use in vegetable production (**Figure 14**).

Figure 13.
Rainwater pond for the greenhouse irrigation (the Netherlands).

Figure 14.
Tanks for water, nutrient solution, and nitric acid used for adjusting the nutrient solution pH.

Drip irrigation system basic components:

- A pump station consisting of a motor and a centrifugal well pump and a turbine. The pump is used to distribute water evenly to each and every individual plant, with even flow and pressure values.

- An array of pipes and emitters consisting of a main duct and side pipe network. After filtration, the main line brings water to the greenhouse and on, through the sub-main line to the lateral ones.

- Computerized measuring that the correct amount of water has been used and delivered to the greenhouse. This is to record advances in irrigation efficiency for the better management of changes or improvements of the irrigation system itself. Meticulous and precise water measuring in the crops determines the correct volume of water to be used.

- Opaque tanks to prevent chemical and microbiological changes in the nutrient solution and water under the influence of sunlight.

- Filters, as already mentioned, have an important role in preventing the drip system plugging and blockage. There are various types of filters, depending on a source of blockage, which can be determined in water testing.

- A correct choice and placement of valves in the irrigation system is crucial. The valves control the water pressure, flow, and distribution through the system, particularly under various conditions that may occur while the irrigation system is in operation.

- Water flow gauges to measure the flow between the water source and the greenhouse (**Figure 15**).

8.3 Electrical installation

Electrical installation may well be the most important one in the glass greenhouse as it is necessary for various production operations. A crucial one is starting a

Figure 15.
Drip irrigation water/nutrient solution pumps (The Netherlands), Drip irrigation system—drippers around the plants on the white gutters (the Netherlands).

motor that supplies power to different devices (opening and closing the vents/windows, shading, switching on/off the fans, additional lighting, etc.). Every glass greenhouse for professional and commercial production has to have its own power transformer substation so as to provide a reliable energy supply in a case of a power cut, which would otherwise impede the production.

8.4 Greenhouse 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, cucumber). 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 should not be confused with photoperiodic lighting, which is applied to create long days, thus controlling the plant growth and development processes. Supplemental lighting is high-intensity light (6000–7000 lx or more), whereas photoperiodic lighting is of a much lower intensity (70 lx–100 lx). For now, in the vegetable crop production practice, the high-intensity discharge (HID) lamps and LED lightning are in use, which provide wavelength light from 300 to 700 nm (which is needed for the photosynthesis process). The HID lamps, besides needed light wavelength, emit high heat (up to 50%), so they must be placed at about 02 m or more above the crops. Otherwise, such lamps could overheat the greenhouses (what change the climate in the greenhouses) and could damage the plants, too. The LED lightning are placed at about 40 cm or more above the crops or in between the crop's rows in a greenhouse, as they almost do not produce heat and could not damage the crops. There are studies about the ways how 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 of the leaf area index (LAI) [11–16] (**Figure 16**).

Figure 16.
Block-greenhouse with supplemental lighting.

8.5 High-intensity discharge (HID) lamps

The high-intensity discharge lamps include two types of lamps:

- Metal halide (MH)

Metal halides (MH) lights are commonly used during vegetative plant growth but are less popular than HPS lamps for flowering and fruiting. If MH lamps are used in the flowering or fruiting stages, they are often of a higher rated power to provide more red-light output.

- High-pressure sodium (HPS)

High-pressure sodium (HPS) lamps produce light mainly in the yellow and red end of the light spectrum, which makes these lighting systems a great fit for late-phase (flowering and fruiting) plant growth. They can also deliver greater light intensities than lamps used exclusively for vegetative growth (for instance, MH lamps).

8.6 LED lightning and modern urban vegetable growing light-emitting diodes (LEDs)

Light-emitting diodes (LEDs) represent a technology for the indoor vegetable production, which has technical advantages over traditional lighting sources, as well as a significantly positive impact on the plant photosynthesis process and on the crop yield. LED lightning has been 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. It is used in growing leafy vegetables and herbs, as well as in the production of tomato, pepper, cucumber, and some more vegetables in greenhouses. Depending on the vegetable varieties and their edible parts (vegetative part, fruit, immature flower heads), LEDs could be designed to emit light recipes for each phenophase of the crop's growth and development. One of the most important features of LEDs for vegetable growing is that the LED lightning almost does not produce the heat, which could damage the plants. There is a combination of additional lightning and its quality and supplemental carbon dioxide empowerment vegetable growing in the greenhouses. 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. Controlling climate conditions and nutrition in protected area, without or with daylight, gives opportunity to produce vegetables, which is safe for humans and environment. It is called ""City Farming" or "Urban Agriculture." The most important factors are the LED lighting, carbon dioxide concentration, air humidity, and conditions that keep the leaf stomata open in order to uptake carbon dioxide [14–19] (**Figure 17**).

8.7 Light quality in supplemental lighting

The suitable light quality in the greenhouse per vegetable species refers to the wavelengths (colors) that are efficient in triggering photosynthesis and other growing processes in vegetable crops. Successful growing vegetables in greenhouses depend on the visible spectrum wavelengths of about 390 nm to 760 nm, which is only a small portion of the sunlight (radiation) spectrum. In general, the visible light consists of the following: violet (380 nm to 430 nm), blue (430 nm to

Figure 17.
LED lighting (The Netherlands), Growth chambers without natural daylight, providing optimal conditions for vegetable crops growing under LED lighting (the Netherlands).

500 nm), green (500 nm to 570 nm), yellow (570 nm to 590 nm), orange (590 nm to 630 nm), and red light (630 nm to 760 nm). The most important visible light range mainly corresponds to the PAR from about 400 nm to 700 nm. Those wavelengths have the right amount of energy for the biochemical processes, and their participation in the available light is important for the quality of light during vegetable growing. About half of the incoming sunlight energy participates in the photosynthetic processes. The rest of the energy is from the sunlight short wavelength spectrum (UV—ultraviolet radiation) and sunlight long wavelength spectrum (IR—infrared radiation).

Blue section of the spectrum is known as a cool light, which encourages vegetative and leaf growth through strong root growth and higher intensity of photosynthesis. **Red section of the spectrum** induces stem growth, tuber and bulb formation, flowering, and fruit production, and chlorophyll formation. **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 could be a challenge with the greenhouse vegetable crop production due to possible shading, or due to the reduced plant vegetative space. **Green and yellow sections of the spectrum** that reach the plants are reflected. Most of the absorbed sunlight belongs to the blue and red part 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 [8]. For the time being, in the greenhouse vegetable crop growing practice, the high-pressure sodium (HPS) lamps are used, but also the LED lightning, which gains an increasing significance in the plastic and glass greenhouses as well as in the special chambers for vegetable production without daylight. Also, in The Netherlands, the latest studies at the research centers of Wageningen and Maastricht universities 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, higher yield (**Figure 18**).

8.8 Supplemental carbon dioxide in the greenhouse

The carbon dioxide (CO_2) gas is the essential component for the process of photosynthesis. Plants uptake it through their stomata on the leaves. Photosynthesis is the biochemical processes where the light energy is used to convert carbon dioxide and water into complex sugar compounds (carbohydrates) and oxygen (O_2) gas. The sugars in plants, formatted in the process of photosynthesis, are then used for the plant development and growth. In the air (outside the greenhouse), there is about 400 ppm of carbon dioxide. The CO_2 concentration in greenhouses could be increased specific installation in the greenhouses, for example, from boiler room, when energy sources are burnt. However, inside the greenhouse, the amount of CO_2 may be significantly depleted as plants use it intensively in the process of photosynthesis, or through the greenhouse windows, and it may lead to a decreased crop productivity and yield. For that reason, "CO_2 fertilization" or "CO_2 enrichment" is a standard practice in modern greenhouses and should be controlled in order not to form too high concentration (over 1500 ppm), which could be toxic for the vegetable crops (**Figure 19**).

Figure 18.
LED lighting between the rows of cucumber plants growing on rockwool in a modern glass greenhouse (the Netherlands).

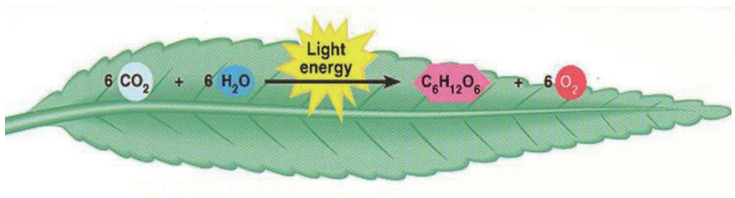

Figure 19.
Photosynthetic process equation.

Since there is about 500 times more oxygen in the air than carbon dioxide [17], 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.

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 ppm to 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 [17]. 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 crop development and growth are quite satisfactory for the vegetable grower. At the same time, 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. If the crop quality and production are below the satisfactory level, carbon dioxide supplementing should be the next measure. The vegetable production in cloudy period of the year, or cloudy days, increases the potential need for CO_2 supplementing the greenhouse air, which actually corresponds to a lower ventilation rate due to mainly low outdoor temperatures. According to Kamp and Timmerman [9] normal ventilation provides an amount of carbon dioxide that is similar to its levels in the outdoor air (350 ppm–400 ppm). But then, frequent ventilation in the greenhouse may not be economically desirable for the enrichment indoor air with CO_2. 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. 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 CO_2 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. That way of supplementing the CO_2 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 crop productivity, provides easy control of the carbon dioxide levels, and is more flexible for supplementing the CO_2 when necessary. Also, it would be advisable to install a proper system that registers the CO_2 concentration and then distributes it in the greenhouse. Such a system, like in other greenhouse installation operations, has corresponding sensors that are linked to 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, and potential damages of the vegetable crops could be easily prevented (**Figure 20**).

The distribution of CO_2 depends mainly on-air movement within the greenhouse, as CO_2 does not travel very far through diffusion systems. One of the pure CO_2 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 CO_2 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 (**Figure 21**).

8.9 Greenhouse screens

Greenhouse screens provide enough light and may reduce oscillations in the indoor climatic conditions. Today, there is a vast variety of greenhouse screens made of different materials. For shading, polyethylene, polyester, acryl, and aluminium knitted cloth is used. They may be of various types of knit, physical characteristics, and colors. Besides regulating the greenhouse lighting, they may be great in controlling the indoor temperature and relative air humidity, thus saving on heating and electricity. Depending on a particular use and a usage period, they are made of cloth, plastic, or aluminium. The choice of material, fiber thickness, and the type of knitting/weaving should correspond to the screen purpose. There is also a possibility of automatic, semi-automatic, and manual screen operating system. The choice of the screen or curtain system depends on the purpose, production period, the necessary crop growing conditions, the amount of the necessary lighting, certain climatic parameters in a given geographical area, the greenhouse total volume and ultimately on the quality of the shade screens, as well. The shading screen is mostly used to prevent a negative effect of sunlight radiation during daytime and excessive cooling during night or cold periods. In regions of moderate climate and a great number of overcast days, the screen system actually saves

Figure 20.
Liquid carbon dioxide tank for supplementing it in the greenhouse (Serbia).

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Figure 21.
Plastic perforated pipes distributing CO_2 (The Netherlands).

energy, transmitting light and controlling the air temperature and humidity. The screen system can be installed horizontally (under the roof) or vertically (along the side walls). Horizontal systems have an important role in controlling the air relative humidity and can be installed at different heights in the greenhouse. Also, vertical screens or curtains can be installed as a mobile boundary and/or a partition wall, separating individual climatic units within the greenhouse. This is very useful when crops of different climatic requirements are grown. The screen systems are classified and designed according to their use in controlling the greenhouse climatic conditions, transmission of light, air temperature, and humidity, so that the environment parameter optimal values for growing crops can be reached. This can be achieved with either open or closed screen systems. If, say, only temperature has to be controlled (preserving heat), transparent energy-saving screens reduce energy consumption and allow nearly complete light transmission. If the greenhouse vegetable crop production goes on during the best part of the year, including both sunny and cloudy, both warm and cold parts of the year, then all the greenhouse parameters should be taken into account for the crop production cycle. If this is the case, a double screen system should be installed: An upper-level screens, closer to the roof, and a lower-level screen, installed below the former. The upper-level screen material should be of various woven plastic or aluminiums fibres, while the lower-level positioned ones should be transparent to transmit light, but also to maintain balanced humidity and temperature, and to save the indoor heat, too. Certain screen system is used for various purposes: protection against ultraviolet radiation or just for shading (light is not transmitted), or for transmitting and maintaining a section of the sunlight spectrum (wavelengths from 400 nm to 700 nm), which is crucial for the process of organic matter synthesis, thus producing good-quality vegetable crops (**Figure 22**).

Figure 22.
Greenhouse screens (The Netherlands).

Also, it is very useful to install the screens on the greenhouse windows/vents. When vents are open, the screens protect against insects, birds, dust, or litter that winds may blow into the indoor area. At the same time, the screens maintain the indoor climatic conditions. The basic screen material component is polyethylene or polyester, so in a case of a greenhouse fire, the screens pose a great threat. For that reason, it is important to provide enough spacing between the screens or curtains (follow the manufacturer's recommendations) or if that is not possible, the screens should be selected from fire-resistant materials, so that the fire could be localized to just one section of the greenhouse. Such fire-resistant screens have fibers that are coated with fire-resistant material. In the modern greenhouse that covers a vast area (several hectares or tens of hectares), the screen and curtain system is moved around with special motors that automatically respond to the indoor climatic changes. Screen are necessary in greenhouses, particularly in the glass ones, as they are a great help in providing good or even optimal climatic conditions necessary for the crop's development and growth (**Figure 23**).

The screens are usually installed under the roof, and inside the greenhouse, they prevent heat from escaping (during night or cold periods) or excess heat (during summer). For this purpose, knitted polyethylene, polyester, acrylic, and aluminum curtains are used, but also curtain strips, plastic and aluminum film, or roof are painted with lime or special paints.

Figure 23.
Curtains, Screens, guide wires, and plant-supporting strings (The Netherlands).

8.10 Crop support system

The crop support system may be permanent, temporary, or a combination of the two. The system consists of support posts, guide wires, and strings that are tied to individual plants to support their growth. The design of these structures has to correspond to the needs of the crops, so it can vary. The plant support system is made of support posts usually made of galvanized metal and horizontal guide wires to which the strings (plastic and hemp string) that support the plants are tied. The metal guide wiring is positioned at various heights or levels relative to the greenhouse floor. So, for instance, the guide wiring for cucumbers is positioned at a height of about 2 m and for tomatoes at 4 m – 4.7 m. In order to fix the crop to a string or guide wire to support the plant stem (cucumbers) or flower clusters (tomato), various in type, size, and purpose plastic clips and hooks are used (**Figures 24** and **25**).

8.11 Greenhouse climate control system: humidity, temperature, and other factors

Here, we have various types of sensors for measuring and registering various climatic parameters in the greenhouse. The sensors are linked to a computer and computer software developed just for that purpose. In this way, the registered data can be viewed and saved and acted upon or responded to if some of the data values vary from the set parameters. Computerized monitoring of all or most of the parameters is highly significant for the development and growth of the crops as it provides that the production of the given crops is satisfactory and allows for timely response in a case of any undesirable changes to the already set production parameters (**Figures 26** and **27**).

8.12 Shelves, benches, and plant substrate gutters

Shelves and benches are now used for contemporary production of seedlings (in containers, pots, peat briquettes, etc.), as well as potted vegetables. Usually, they are constructed of reinforced concrete or metal that reacts poorly or not at all with acids from the leachate, and may be movable or immovable. Movable shelves and benches

Figure 24.
Tomato crops tied to the supporting strings and guide wires (the Netherlands).

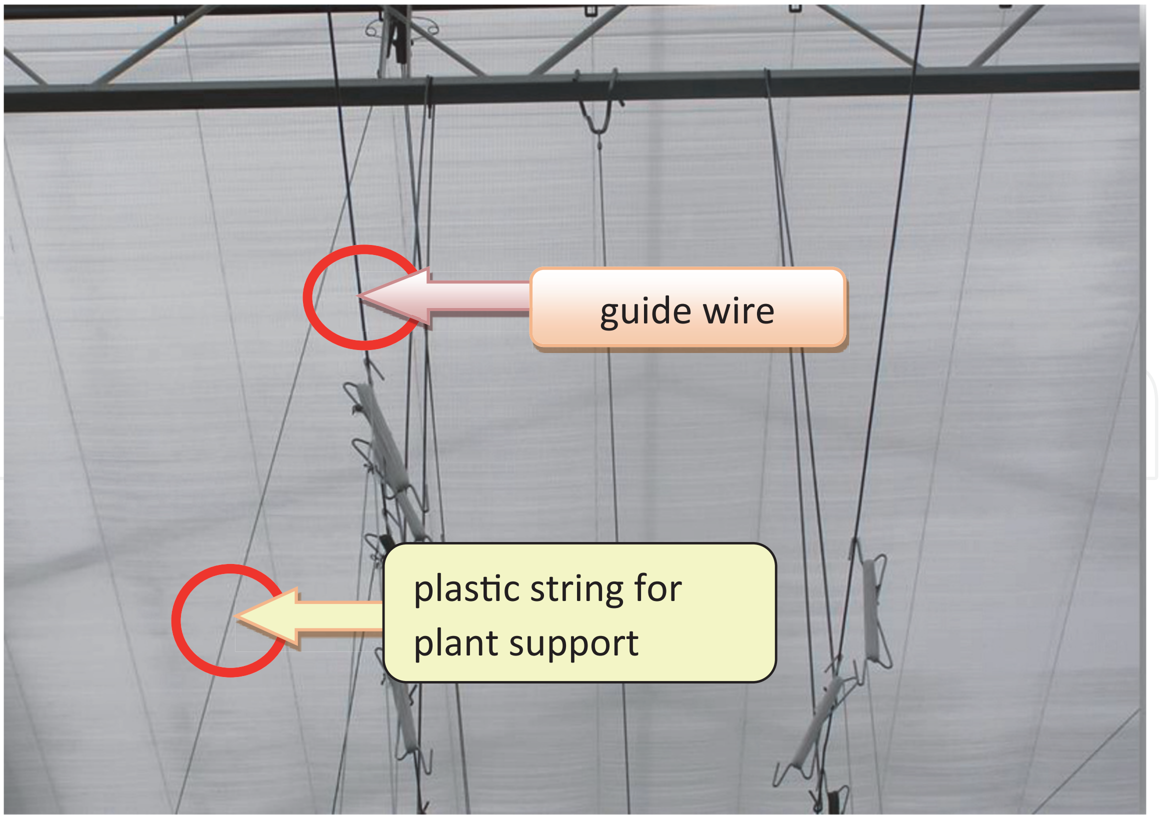

Figure 25.
Crops support structure and guide wires (The Netherlands).

Figure 26.
Plastic film placed under the roof inside the greenhouse for catching water droplets from condensation, protecting the crops (Serbia).

are very good for an efficient production of seedlings or potted vegetables, as well as for hydroponic production of certain leafy vegetables. The gutters should be resistant to acids that the plants have not used and are drained from the nutrient solution (for instance, due to a fast flow of the nutrient solution through the hydroponic substrate). Such compounds can damage the material the gutters are made of (but also the shelves and benches), which can then affect the nutrient solution (as they may react with the solution due to gutter corrosion, thus changing the chemical composition of the solution) and generally the whole crop production process (**Figures 28** and **29**).

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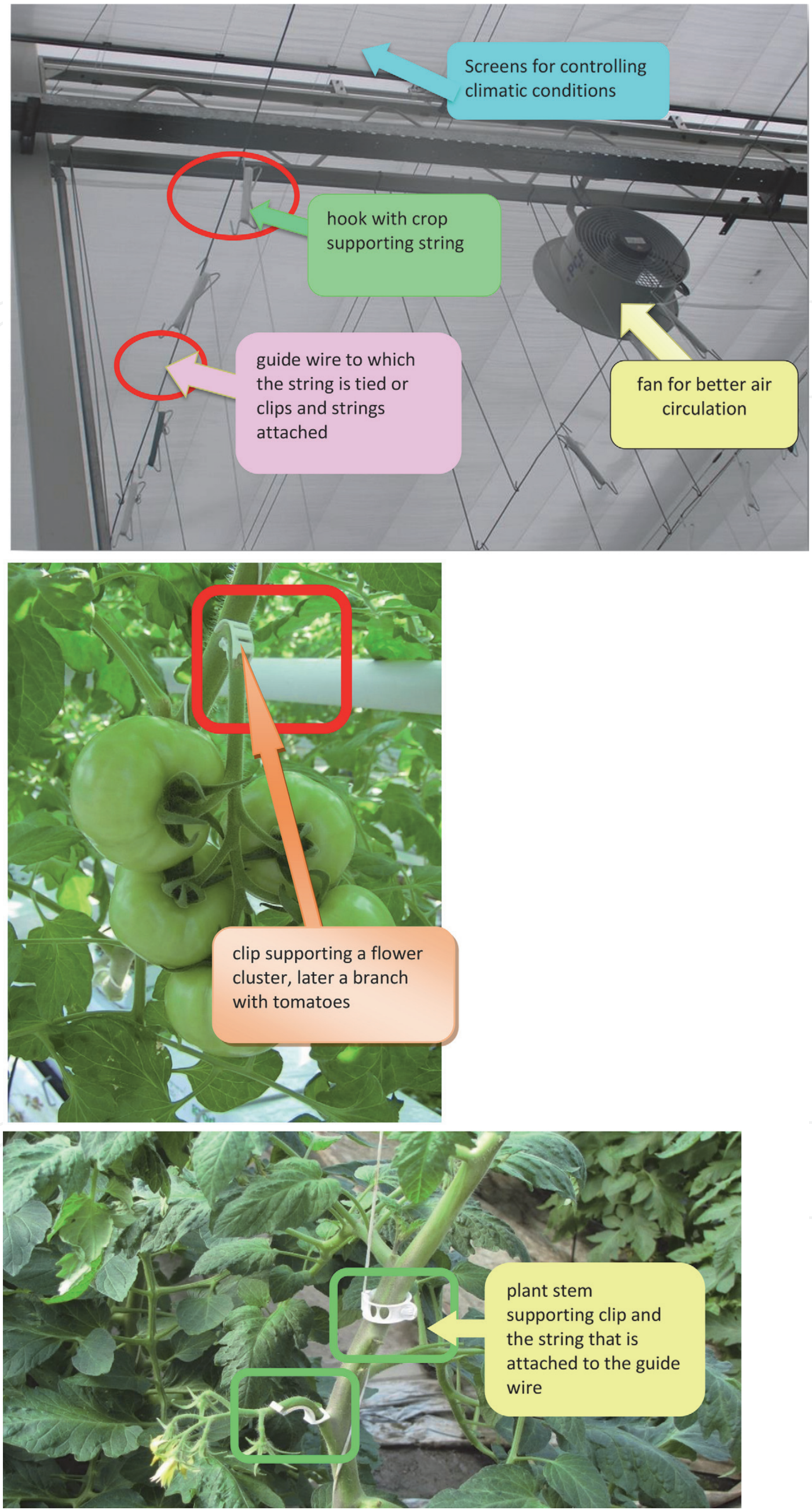

Figure 27.
Clips for supporting flower clusters or branches with tomato fruits to prevent it from breaking under the weight of the fruits (Serbia).

Figure 28.
Benches for the seedling or potted plant production (The Netherlands).

8.13 Significance of computerization and automation (robotics) in the twenty-first century greenhouse production process

The modern greenhouse vegetable crop production requires a proper environment climate control. The most important factors are efficient and proper use of energy, water, and fertilizers. In order to meet those requirements, the vegetable crop production process has to be computerized, using special computer software that can, in a simple way, monitor and control the environment climatic conditions, how the boilers are running and timely and have precise water availability. Special computers and software allow environment control in several sections in the greenhouse and reporting on the climatic conditions in those sections—so, in different greenhouse sections, it is possible to grow different vegetable crops that require different conditions for their development and growth. Such a system allows a simplified production process management where the information is available at any given time. Such computer systems are easy to use. There is a greenhouse map placed in the center of all the operations, so the climatic situation in entire area can be viewed. Both hardware and software can be adjusted to any of the production special features, but can also be upgraded easily in the case of the production improvements or enhancements. The plant ontogenesis is followed by multiple quantitative and qualitative processes occurring within the given crop, which result in its productivity. Numerous ecological factors have an impact on the crop productivity, so different development and growth stages require suitable and optimal conditions for achieving its productivity

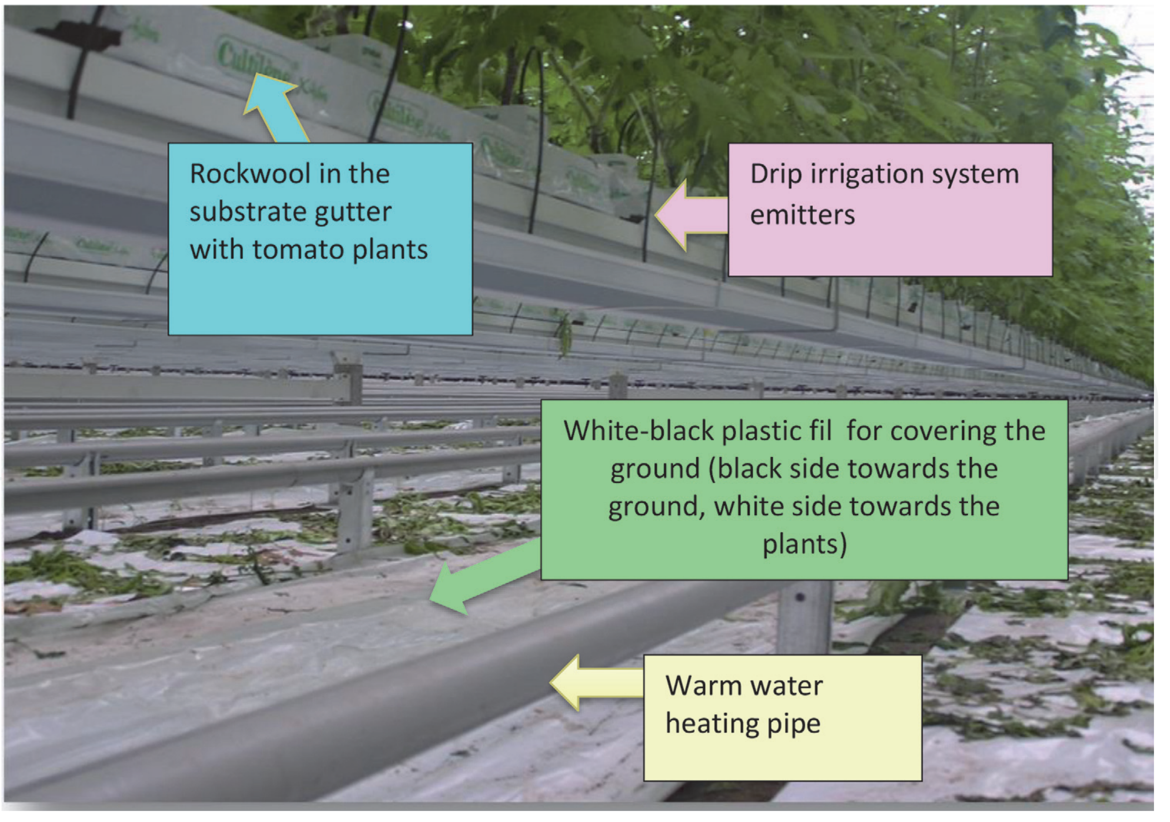

Figure 29.
Gutters for plant growing substrate; below are the greenhouse heating pipes and the plastic black and white film for covering the ground (The Netherlands)

maximum. The environmental factors have an impact on the crop development, growth, and biological yield in the greenhouse because they directly influence its physiological processes [6, 20]. The environment is actually a complex and dynamic system resulting in an effect of combined climatic, soil, and biological factors [6, 21]. So, according to Krug [20], each of these factors consists of numerous elements that

Figure 30.
Computer with software for monitoring crop production in the glasshouse (The Netherlands).

Figure 31.
Tomato de-leafing robot (The Netherlands).

differ from each other in the way and intensity they influence on the plants, such as the climatic factors, sun radiation in particular, temperature, air humidity, wind, CO_2 concentration (**Figure 30**).

The system consists of a control station and its digital nodes installed at different spots in the greenhouse. It also saves the amount of cable in the case the greenhouse has to be extended, as it is possible just to add new digital nodes.

Automation and robotics in the modern greenhouse vegetable crop production is increasingly coming into practice, which facilitates timely and precise vegetable harvesting, removal of excess leaves, and crop spacing, and it also saves labor, which is becoming quite scarce. The use of robots in the vegetable production process is increasing in the agriculture industry, in greenhouses in particular, since all the activities and processes take place according to the set parameters, at precisely set timing. It also reduces the need for labor force in the agriculture industry (**Figure 31**).

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