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Ecological Intensification of Natural Resources for Sustainable Agriculture

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Preface

The population explosion has taken place at an unprecedented rate which is expected to reach more than 9 billion by 2050. Thus, it was observed that 70% higher production in the agricultural sector is required in 2050 when compared to the last two decades (FAO 2018). These indicate a higher level of agricultural intensification is required through ecological intensification. It is also questionable whether the earth's carrying capacity would sustain such an unprecedented rate of intensification which is totally unsustainable. Under this context, the concept of eco-intensification is the need of the hour which aims to reduce the pressure on earth resources along with maintaining the balance and harmony in production sectors.

Ecological intensification comprises genetic intensification and socio-economic intensification to give an all-round eco-friendly development. Policies under ecological intensification should be synergistic in the approach to keep the balance between the production sector and consumer sector. The development of new farming systems of intensive to semi-intensive in nature may promote natural resources conservation. Ecological intensification is such an issue which has not been explored properly till date. It encompasses better food production at a low environmental cost, broader perspectives in environmental conservation, and maintaining the integrity of the earth ecosystem. Under these circumstances, new research and development need to be done to exploit the possibility and opportunity for sustainable eco-intensification, hence the target to develop new principles and management policies towards sustainable development. Ecological intensification tends to improve the productivity of various production systems as well as reduce the ecological footprint. It also helps to conserve the diverse ecosystem services such as maintaining soil quality, inhibition of soil degradation, reducing GHGs emission, establishing proper source–sink relationship of carbon to maintain carbon balance, soil and water conservation, maintaining bio-resource, ecosystem resistance and resilience to autochthonous and allochthonous changes along with overall sustainability of the ecosystem.

The present book discussed the critical issue of ecological intensification to fulfill the current demand for food as well as address the issue of sustainability in relation to natural resources and sustainable agriculture. Natural resource is the central point of all social, economic, and environmental development. Therefore, proper management requires proper priority. The present title is an attempt to understand the concept of ecological intensification, its role towards natural resource management and its approach towards sustainability of the agroecosystem. In the introduction, various aspects of ecological intensification have been clarified for resource management and sustainable productive perspective. Further, specific issues such as food security, biodiversity conservation, climate change, sustainable agriculture, soil contaminant, eco-modeling, eco-designing, and animal breeding in relation to ecological intensification were addressed. The book also covered some allied aspects of mulching, vertical greenhouses, pollination, ecosystem services, and soil carbon stock and sequestration in a holistic way to provide a pathway of sustainable agricultural practices for the learned society of the globe. The book concluded the proper management strategies with various issues related to natural resource, environment, ecology, sustainable agriculture, and allied fields with new updated knowledge that would enrich and create a platform of discussion on ecological intensification at the global level.

From a global perspective, multidisciplinary approach is required to address the issue of sustainability and conservation. It includes wide disciplines such as forestry, agriculture, environmental science, and ecology. Reference textbook and separate edited volumes are not available addressing specific issues of "Ecological Intensification of Natural Resources for Sustainable Agriculture." However, most of the books are focused on natural resources and their conservation. The integration of the concept of ecological intensification with natural resource is the biggest challenge of twenty-first century. It is also a limiting factor in terms of knowledge for academicians, scientists, research scholars, and policymakers of the present time. This edited book would act as a basic to update knowledge base for the scientists and academicians for the future goal. The objectives of this book are: (1) to address the issue of ecological intensification for natural resources, (2) to generate awareness and proper understanding of the concept and its associated issues and challenges, and (3) to educate the learned society about the recent trend and development to formulate strategies for future research and development.

The present attempt is for the national and international audience to clearly understand the concept of ecological intensification and its applicability in the field of natural resource management and sustainable agriculture. Highly professional and internationally renowned researchers are invited to contribute, authoritative and cutting-edge scientific information on a broad range of topics covering agroecology, environment, ecological footprints and sustainability. All the chapters are well illustrated with appropriately placed data, tables, figures, and photographs and supported with extensive and most recent references. The submitted chapters are reviewed by the members of the Editorial Committee in the relevant field for further improvement and authentication of the information provided. The editors also provided a roadmap for ecological intensification for natural resources aiming towards sustainable agricultural development.

Ambikapur, India — Manoj Kumar Jhariya
Varanasi, India — Ram Swaroop Meena
Ambikapur, India — Arnab Banerjee

Contents

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Arnab Banerjee is an Assistant Professor, Department of Environmental Science, Sant Gahira Guru Vishwavidyalaya, Ambikapur, Chhattisgarh, India. He completed his M.Sc. and Ph.D. (Environmental Science) from Burdwan University and M.Phil. in Environmental Science from Kalyani University, West Bengal. He won the University Gold Medal for securing first class first position in M.Sc. examination. He has been awarded Young Scientist Award for the best oral presentation at the international conference held at the University of Burdwan. He was a project fellow under UGC-sponsored major research project. To his credit, he has published 67 research papers in reputed national and international journals, 8 books, and 27 book chapters. He is a life member of the Academy of Environmental Biology. He has supervised 23 postgraduate students and engaged in postgraduate teaching and research.

9 Vertical Greenhouses Agro-technology: Solution Toward Environmental Problems

Evgeniya P. Klyuchka and Marko Petkovic

Abstract

Population growth and urbanization, climate change, and the environmental disadvantages of traditional agriculture have reached a critical limit. Global processes can reduce the amount of industrial waste and find environmentally friendly ways of recycling, abandon hazardous food products, solve problems in the market for organic products, and reduce food waste. World forums discuss topics such as sustainable development theory, environmental rents, the prospects for the green revolution, and the 4.0 science and technology revolution industry. Greenhouse productions are aimed at solving some of the environmental and food problems. Greenhouse production could be divided into three groups: the technology of growing plants without soil, the practical application of LED lighting systems, and the capabilities of digital IT technologies. Greenhouse production is located on a "scale of comparison," from the simple technologies without soil in a house, office, on roofs, on the street, all the way to the system with various microclimate systems, a system of nutrient solutions, heating and air conditioning systems, humidification and dehumidification systems, lighting systems, gas generation systems, monitoring, and control systems, and other microclimate systems. The production efficiency would be increased by technical equipment and electrical installations, improving biotechnological methods and rising energy costs. The higher the manufacturability of greenhouse production, the higher the energy intensity of the process of growing plants. We are introducing digital IT technologies and are approaching the extreme point of the "scale of comparison" on which cyber-physical systems are located. Greenhouse

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technologies have varying degrees of success. Israel has no fertile soil, half of the territory in the form of a desert, and a lack of fresh water. However, Israel produces 17% of fruits and vegetables from all agricultural products. The agricultural sector represents approximately 5% of the population, which satisfies Israel's needs for agricultural products by 92%. The success of Israel crop production is based on greenhouses, hydroponic systems in the field; drip irrigation of plants through a network of flexible tubes; plant breeding; digital IT technologies of phyto-monitoring, etc. The global achievement of greenhouse production in Japan is the practical application of new concepts: the Internet of Things (IoT) and cyber-physical systems (CPS). The greenhouse business in Japan has confirmed environmental safety, the prospect of growing clean organic products, and making a profit.

Keywords

Agro-technology · Cyber-physical systems · Urbanized agricultural production · Vertical greenhouse

Abbreviation

ACPS	Agricultural Cyber-Physical Systems
ADM	The Australian grain producer
AgTech	Agriculture Technology
BSG	Boston Consulting Group
CPS	Cyber-Physical Systems
EEC	European Economic Community
EU	European Union
FAO	Food and Agriculture Organization
FinTech	Financial Technology
LED	Light Emitting Diodes
NOSB	National Organic Standards Board
UN	United Nations
USA	United States of America

9.1 Introduction

Population growth, urbanization, climate change, and a decrease in the quality of ecology have revealed problems in traditional agriculture. Traditional agriculture has reached the limit of increasing the amount of food through crop production and land exploitation. Land and water resources are declining in quantity and quality (FAO 2020).

World processes should lead to new trends for maintaining a delicate ecological balance, such as the desire to reduce the amount of industrial waste and the search for environmentally friendly ways of disposal, stabilize food security and self-sufficiency in food, reduce food waste and solve problems in the market for organic products (Raj et al. 2020; Banerjee et al. 2020; Jhariya et al. 2019a, b). In this regard, it is clear that the most discussed topics at world forums are: the theory of sustainable development, environmental rent, the prospects of the Green Revolution, and the scientific and technological revolution Industry 4.0. Thus, these large-scale trends require new innovative methods of food production, which is city farming. It is necessary to pay attention to the preparation of public opinion and the upbringing of a completely new young generation on current world trends and global events (CAP 2020).

The current global trend, which is the subject of debate, is the technology of urban agriculture or AgTech (agriculture technology) urbanized agricultural production. The development of AgTech technologies as a combination of innovative, highly effective agrarian practices for the production of crop products is directly related to the environmental and food safety of the country, and the health of the nation.

The need for AgTech development is recognized at the world level following paragraph 95 of the implementation plan of the New Urban Development Program, the Quito Declaration on Ecologically Sustainable Cities and Communities for All has been drawn up (Habitat III Conference 2016). The "New Urban Development Program" was adopted at the UN-Habitat III Conference on Housing and Sustainable Urban Development and approved by the UN General Assembly. A 197 UN member states have declared a commitment to "support agriculture and farming in urban settings."

The number and scope of vertical farm projects in different countries of the world over the past 10 years, indeed, have begun to acquire impressive proportions, which speaks not only of the viability of this technology, but it also affects many areas: environmental, economic, social, market. In particular, the organization of logistics, infrastructure, food prices, the diet of the population, and much more (Kozai et al. 2020; Meena et al. 2018).

Among such economically and socially significant projects are the company's farms: Pasona in city offices (Japan); AeroFarms in New Jersey; 9-story farm in Dronten (Netherlands); Plenty Farms (Seattle and San Francisco); Bowery (North Carolina and New York); Farm one (New York); Panasonic (Singapore); a vertical farm at the Paignton Zoo (UK); Farm-360 (Indianapolis); Metro Group installations (Europe); Urban Crops (Kortrijk, Belgium), La Caverne (Paris, France); AeroFarms, SunDrops and Farms Badia Farms (Dubai, Saudi Arabia); 142-m skyscraper farm in Linkoping (Sweden); Plantagon Agritechture and Sweco Architects (Sweden); Mirai Corp (Tokyo metropolitan area, Japan); vertical farms in Target chain stores and IKEA hydroponic installations.

Greenhouse technologies have varying degrees of success. For example, Israel has no fertile soil, half of the territory in the form of a desert, and a lack of fresh water. However, Israel produces 17% of fruits and vegetables from all agricultural products. The agricultural sector accounts for approximately 5% of the population, but the work of these people meets the needs of Israel for agrarian products by 92%. The unique experience of Israel agriculture has confirmed the success of the application of technologies for growing plants without soil in open rocky areas. The success of Israel crop production is based on: Israel greenhouses, hydroponic systems directly in the field; drip irrigation of plants through a network of flexible tubes; plant breeding; digital IT technologies of phyto-monitoring, and more. Another example illustrates the high-tech greenhouses that Japanese scientists created. The global achievement of greenhouse production in Japan is the practical application of new concepts: the Internet of Things (IoT) and cyber-physical systems (CPS). The greenhouse business in Japan has confirmed environmental safety, the prospect of growing clean organic products, and making a profit.

The idea of vertical farms is promising, giving a reason to rely on significant results that the construction of such facilities can lead to several certain and uncertain consequences. Therefore, the present chapter describes the role of vertical green agro-technology in solving environmental problems.

9.2 Global Problems of Modern Greenhouse Agricultural Complexes

According to forecasts, by 2050, the World's population will reach 9.7 billion people, with 70% of the people living in urban conditions (United Nations 2016). Based on the reports of the FA (FAO 2020), the following conclusions could be drawn. The growth and aging of the World's population lead to an increasing concentration of the people in cities (Meena et al. 2020a, b). According to the UN forecast, in the future, the share of urban residents in the World will increase steadily, according to various sources, from 55% in 2016 to 60% by 2030 and 70% by 2050. Twenty-five percentage of fertile land has already degraded, which directly affected 15% of the World's population; it would also be expected that by 2030 another 2.4% of highly productive areas would be "absorbed" by growing megacities. A report released by the UN on 27 November 2007, on environmental changes that have occurred since 1987, noted that, by general definition, humanity is in a state of ecological crisis, and there are no signs of its easing (Kantor 2013).

The indicative trend line was determined using data from the FAO (FAO 2018), with the observed difference correlates with the global recession of the early 1990s (Fig. 9.1, Benke and Tomkins 2017).

Pesticides that are used in traditional agriculture negatively affect water quality and reduce the number of water resources, pollute the air, contribute to the extinction of living organisms, pollution and deterioration of food quality, and the accumulation of industrial waste and household garbage (Meena et al. 2020). Traditional agriculture is the reason that the soil is degraded and depleted of nutrients, pollutes the environment with herbicides and nitrates, is the cause of death of animals and insects. It is understood that it is the economically developed countries that cause the most significant harm to the environment, consuming more than other countries, both natural raw materials and finished products, polluting the planet with

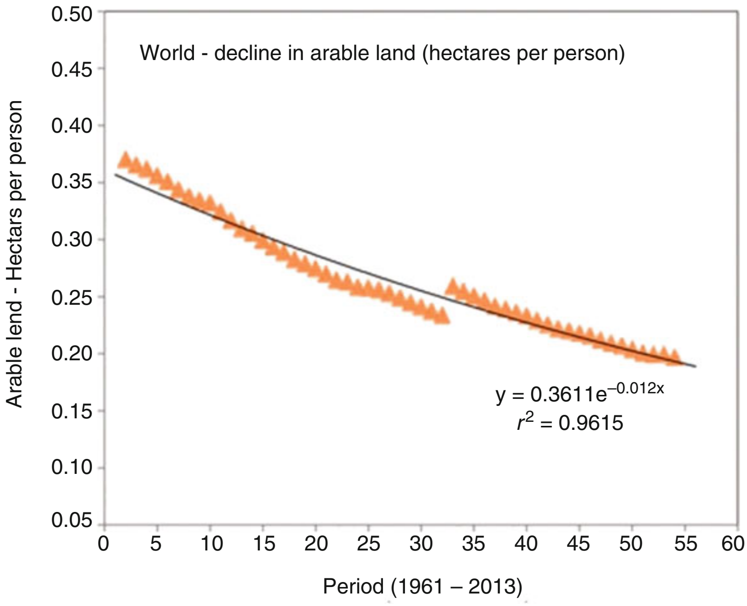

Fig. 9.1 Reduction of stocks of arable land in the world (Benke and Tomkins 2017)

production and consumption waste. There was an understanding that progress can be achieved by using predatory natural resources, cheap dirty technology, which only leads to a decrease in environmental safety (Meena and Lal 2018; Kumar et al. 2020).

Currently, economists around the world are discussing the theory of sustainable development, in which it is possible to ensure reproductive capital and environmental protection, due to the invested rent from natural resources, defined as the difference between the market price of supply and the marginal cost of its use (Dixon et al. 2003; Schulze et al. 2015). Products obtained in traditional agriculture are much more expensive, but not much expensive because no one currently takes into account all costs associated with depreciation and restoration of natural resources, which have the property of limitation and depletion.

A direct consequence of human activities is climate change on the earth (carbon dioxide emissions, global warming). The climate becomes the primary limiting (limiting) factor in the development of traditional agricultural production, so this industry becomes unstable, located in a high-risk area of manufacturing. Today we received a high harvest, and next year it may not be at all.

Territories with mass food production are far from consumer markets, this leads to the formation of large amounts of food waste, to the loss of food in the production logistics chain: storage, sorting, packaging, rejection, and failure during long-term transportation and the period of sale of products. At the same time, there is a catastrophic decline in quality due to the use of barbaric technologies, the transformation of immature crop products to a state of external commercial attractiveness.

The need to transport food from the place of mass production to the location of mass consumption leads to the fact that (according to various sources) from 10 to 40% of its volume is turned into food waste. The entire projected increase in the amount of traditional agricultural production was estimated by the Food and Agriculture Organization of the United Nations. The amount is 1.5% per year in the next decade and can be entirely offset by the outstripping rates of urban population growth (with an increase in food demand) amid huge food loss during transportation (FAO 2020).

There is a tendency for the exhaustion of ecosystem resources, including the support of the oceans (FAO 2018). The extinction rate of species (according to various estimates) is 50–100 times higher than the natural ones, and as suggested, they will only increase sharply. Given current global trends, extinction threatens almost 34,000 species of flora and 5.2 thousand species of fauna including the disappearance of every eighth bird species (Ripple et al. 2020; Briggs et al. 2015). For thousands of years, humanity has been breeding a considerable number of cultivated plants that occupy an essential place in our food chain. However, this treasury is impoverished as modern traditional agriculture emphasizes a relatively small number of varieties of cereals.

A negative trend is noted, which is increasingly strengthening the position of the agricultural monopoly. According to Greenpeace (Greenpeace International Public Environmental Organization 2020), four corporations—ADM, Bunge, Cargill, and Dreyfus—control about 80% of the global grain trade. Seed behemoth Monsanto's consolidation in the production and sale of seed with the chemical giant Bayer is currently being published. The turnover of both monopolists exceeds $ 62 billion and has long dominated the food industry in America with genetically modified seeds and gamma toxic pesticides. According to ETC Group estimates, which use only official data voiced, Monsanto controls more than 30% of seeds worldwide, in the USA this monopolist controls 93% of the soybeans market and more than 70% of cotton sales and judging by the trends in the world, these numbers will only grow. The corporations are under total control over how food is produced and what the world's population eats. The complete absorption of the global food market by single players threatens the implementation of environmental innovations and developments, biodiversity, and, ultimately, the food security of each country.

An increase in population, extensive urbanization, and an increase in industrial capacity pose a threat to environmental well-being and global biodiversity (Khan et al. 2020a, b; Raj et al. 2018). These are the reasons why tremendous pressure is created on the market for organic products. There is a real process of changing consumer preferences toward the priority of "healthy," "natural," "organic" food. Consumers are increasingly looking for and buying products: without stabilizers and flavor enhancers; not frozen ripe, not harvested for ripening during transportation and storage; grown without chemicals, pesticides, herbicides, antibiotics, steroids; with high transparency of production and supply chain. In this regard, development issues such as an alternative system of uninterrupted supply or self-sufficiency of cities with foodstuffs, and food security in the whole country are raised with particular urgency (Gorchakov and Durmanov 2002; Gorchakov 2004, 2009).

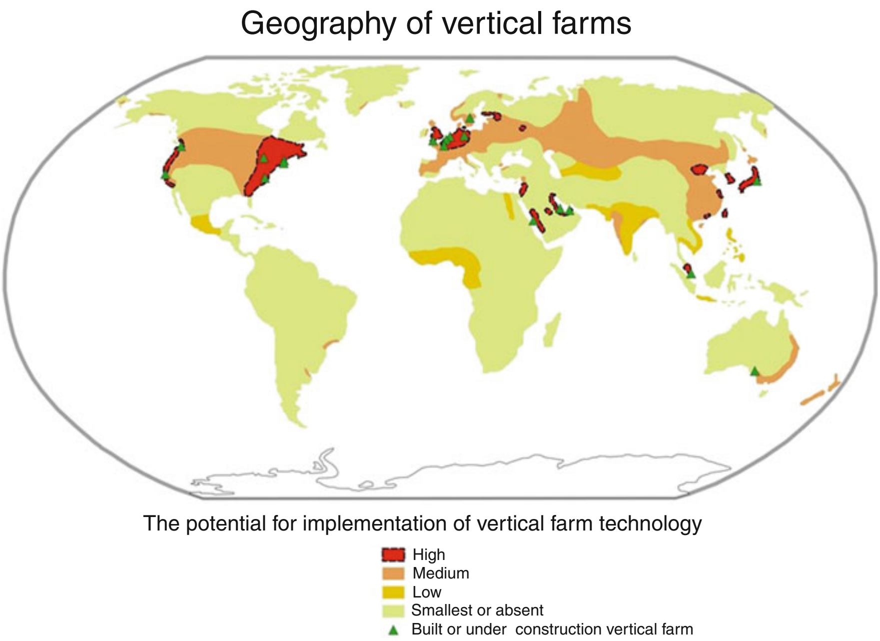

Fig. 9.2 The schematic map and the geography of vertical farms AgTech (Gres et al. 2019)

The EU and the USA were the first to start the process of consolidating the status of organic food at the level of legislation, certification, and standardization. In 1991, the European Council of Ministers adopted Agricultural Regulation (EEC) № 2092/91 on organic farming and the corresponding labeling of agricultural products and food products. The introduction of these rules as part of the reform of the Common Agricultural Policy of the EU (Common Agricultural Policy) represents the previous process's completion. Organic agriculture received official recognition (CAP 2020; US Department of Agriculture 2020).

Organic food research in the USA has been underway for over 20 years. National Organic Standards Board (NOSB), on 1 November 2017, decided to make eligible the container greenhouses that use hydroponics and aeroponics technology for certification of products as organic (National Council of Organic Standards NOSB 2020). Vertical farms function on the territories is shown in Fig. 9.2 (Tornaghi 2014; Gres et al. 2019). Currently, vertical farms have proven their viability.

According to a study by the Swiss financial institution (Union Financial institution of Switzerland 2020), innovations in food and agriculture, the vertical greenhouse production market will have an annual average annual growth rate of 39.6% over the next 5 years. The global market will reach $ 1.1 billion by 2024, compared with $ 1.480 million in 2019. Some of the key players in the market of vertical farmers and plants: According to the report, they have recently absorbed significant amounts of investment capital and will become a market of $ 700 billion by 2030. Private commercial companies are currently promoting the ideas of AgTech.

Commercial companies do not disclose AgTech technology, which is a trade secret. Large players of this industry prefer to keep their technology and profitability information closed. We can assume that the AgTech technologies have an individual specificity associated with a specific territory. There are several reasons for this.

The first reason is that the commercial product sold might be both the technology itself and the cultivated plant products. It all depends on the goals of the project being created. Indeed, some vertical greenhouses are just a demonstration, an advertising product of a particular "breakthrough, innovative technology."

The second reason explains the confidentiality of information; all vertical greenhouses, depending on one degree or another of understanding the problems, are, in fact, an experimental site where field trials are conducted, and innovative technologies are introduced. There is no unambiguous understanding and interpretation of the results.

And the third reason is that in the world practice, there are no statistics on vertical greenhouses. Information on vertical greenhouses is promoted, but we regularly receive information on the bankruptcy of companies engaged in the greenhouse business. This information does not have a system; it does not give a realistic picture of why the greenhouse stopped working.

Despite the lack of coverage of this problem, an attempt was made to highlight the distribution factors of vertical farm technology in various countries of the World (Kemp and Loorbach 2003; Lovell 2010; Miller 2011; Kapelyuk and Aletdinova 2017; Iconographer 2018). The fourth level of the territories is mostly poorly populated or not related to Oecumene (Antarctica, Amazon, and others). The third level of the regions is traditional agricultural areas (a frequently observed phenomenon of pseudo-urbanization), such as Russia, India, Egypt, or Tropical Africa. The second level of the territories is territories with a relatively high level of socioeconomic development and a developed agricultural sector (France, Italy, and others).

Finally, the first level of territories includes territories corresponding to a particular set of conditions, such as a high level of urbanization, the presence of large agglomerations or megalopolises and solvent population, a high standard of living and socioeconomic indicators, and a lack of highly productive agricultural land near agglomerations/megacities. There is a request for the implementation of projects from citizens and an understanding of the benefits of these innovations among the population. The presence of advanced institutes of science and social networks, with the help of which the accumulation of knowledge and the relay of knowhow is possible. Territories of the Eastern and Western coasts of the USA, coastal highly urbanized areas of the PRC, South Korea, Japan, Singapore, the United Arab Emirates, the coast of Saudi Arabia, Northern Europe, and others are more consistent with similar conditions.

The fourth industrial revolution, Industry 4.0, is democratizing the production of greenhouse plants. Knowledge becomes available with the development of information, communications, the Internet, and the means of production are becoming less and less expensive, more and more efficient and manageable. The basis of this global technological restructuring is preceded by investments in new agricultural technologies comparable, for example, with investments in the field of innovative financial technologies FinTech.

Over the past decade of emerging technology, the problems of transition to sustainable development have gained growing attention. Sustainable development is a process in which "the satisfaction of present needs does not compromise future generations 'capacity to meet their own needs'"(Pfeiffer 2017). Moreover, without radical changes in production business processes, such a transition is impossible. These changes are primarily due to the introduction of technology 4.0.

Today, scientists agree that the industry has created the necessary preconditions for the fourth industrial revolution when highly digitized processes are integrated with the internet and smart technologies (Rojko 2017). The BCG Consulting Company identifies nine critical technologies aimed at forming the fourth industrial revolution: autonomous robotics, simulation, horizontal and vertical system integration, augmented reality, the Internet of things, cloud computing, additive manufacturing, cyber security, and big data. This change also includes more global trends, the introduction of the digital economy, CPS, smart cities, smart buildings, intelligent greenhouses, and others.

Industry 4.0 will allow production costs to be reduced by 10–30%, logistics costs by 10–30%, and quality management costs by 10–20% (Rojko 2017; Lisovsky 2018). Industry 4.0 innovations are designed to minimize the time taken to market new products on the market, improve the quality of consumer service, and allow more effective use of resources (Lee et al. 2015; Trachuk and Linder 2018).

The most successful innovation growth strategy in South Korea was "Strategy 3.0," which describes smart plants as production systems, where all business processes are automated and incorporated into a single information system. The operation of the plants is ensured by the CPS, which allows the creation of virtual twins. CPS is designed to incorporate devices that are directly connected with the external world and existing processes by utilizing data collection and processing facilities over the Internet. Current CPS research focuses primarily on principles, emerging technology, information architecture design, existing problems, and new avenues of growth within the context of Industry 4.0. An integrated model for CPS into production processes is proposed via smart communication, data translation into information, virtual space transfer, knowledge management, and system configuration.

9.3 Concepts of Vertical Greenhouse Agro-Technology

Today, new technologies appear in the protected soil industry related to the creation of high-tech automated phytocomplexes for intense energy and resource-saving production. They are gaining wide popularity around the world and are called "urban farms" or "vertical greenhouses AgTech." Phytocomplexes include energy-efficient vegetative lighting systems of various modifications and original design solutions. These parameters are in conjunction with multiple microclimate systems for automated maintenance. The technology for growing plants on the shelves using electric lighting (or light culture) is currently the most advanced when growing plants require a strict balanced diet and additional artificial lighting. This environment is optimal when growing seedlings of vegetables, flowers, lettuce, green crops, medicinal plants (Benke and Tomkins 2017; Blok et al. 2017; Beacham et al. 2019).

The AgTech vertical greenhouse technology combines several independent areas, and if at least three of the six mentioned characteristics are present, then we can attribute this technology to city farming. Vertical greenhouses have a distinctive feature: technological surfaces are located one above the other and form a multi-level design. The main principle is to grow the most substantial amount of plant products in the smallest area, due to compaction and placement of levels vertically. Application of technologies for growing plants without soil: hydroponics, aeroponics, aggregatoponics, and many hybrid technologies.

The use of artificial light sources applies to either for illumination in conditions of decreasing natural light and reducing daylight hours, or light culture technology when plants are grown using only artificial light. LED lighting systems are considered the most promising, which reduce the energy intensity of the entire production (in comparison with low and high-pressure discharge lamps), and are also a tool for influencing the biochemical composition of plants, shortening the growing season and increasing the harvests.

Production should be waste-free and environmentally friendly. Therefore, it includes closed-loop recycling systems, as well as systems for cleaning and preparing the air and water environment for plants. Methods are needed that control what photocomplexes give into the environment and what they take from the environment (the urban environment is quite aggressive).

The use of renewable energy sources: solar panels, bioreactors, wind turbines, the use of rainwater, condensate, and more. Autonomy and independence from external sources of energy, water supply, sewage, and more are needed.

Automation/robotization of all production processes: technological, economic, logistics, and others. High expectations are laid on artificial intelligence, which should give an accurate answer to the choice and optimization of a particular technology in specific working conditions.

Vertical greenhouses AgTech of city farming have a rather diverse form of self-expression. The critical point for characterizing a vertical greenhouse is the degree of innovation of the technologies used. We will create a conditional classification according to the above-voiced characteristics (Fig. 9.3, Beacham et al. 2019). The lowest level (fourth) is made up of a home/office environment. It is the closed living microclimate and working rooms of vegetative lighting installations. At the same time, they can diversify the diet with organic plant products and carry an aesthetic burden. They can combine groundless technologies, artificial lighting systems, partial automation of individual systems.

The third level consists of industrial vertical greenhouses, which solve the difficult task of integration in an urban environment (Fig. 9.4, Vertical Farm in Romainville, France 2020). These are greenhouses in non-functioning industrial buildings and skyscrapers, on the roof, in basements, in utility rooms, as well as the task of growing greenhouse plants in a small area with a seal of planting material

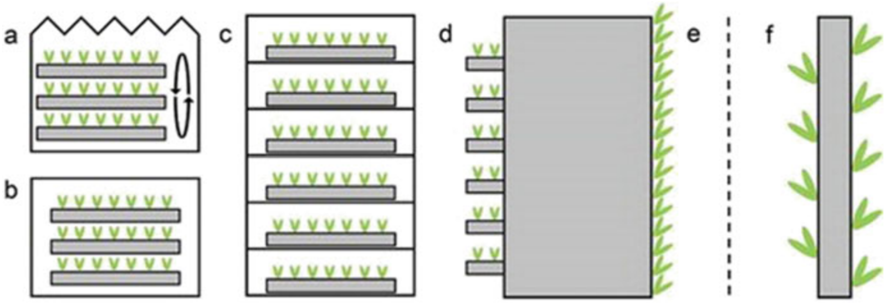

Fig. 9.3 Structural diagram of options (a–f) for placing plants in greenhouses of the third level, denoting different forms, i.e., options for placing plants in greenhouses of the third level (Beacham et al. 2019)

Fig. 9.4 Vertical farm in Romainville (France) (http://ifarmproject.ru/verticalfarmphotonews)

due to the location of technological surfaces one above the other. The main feature of these greenhouses is the likeness of the "classic" greenhouse technologies that are used in extensive agricultural holdings. In addition to the techniques of soilless cultivation, LED lighting systems, automation of production, there must be control over the incoming and outgoing environment. The use of this technology does not aggravate the ecological state of cities and does not call into question the issue of organic products.

The second level consists of modular or container installations (Fig. 9.5, Japanese company Mirai Mirai Corp 2020). It is necessary to solve many issues related to autonomy, which involves the use of renewable energy sources, closed water supply, and more. Only artificial light is used. It is advisable to use fully automatized control systems for artificial microclimate.

Finally, the first level (highest) consists of fully robotic cyber-physical systems (Figs. 9.6, 9.7, 9.8, 9.9, 9.10, 9.11, and 9.12), the technology product of the fourth industrial revolution Industry 4.0. The Farmbot system is a unique representative of the cyber-physical system. Farmbot-3 is an open-source digitally controlled

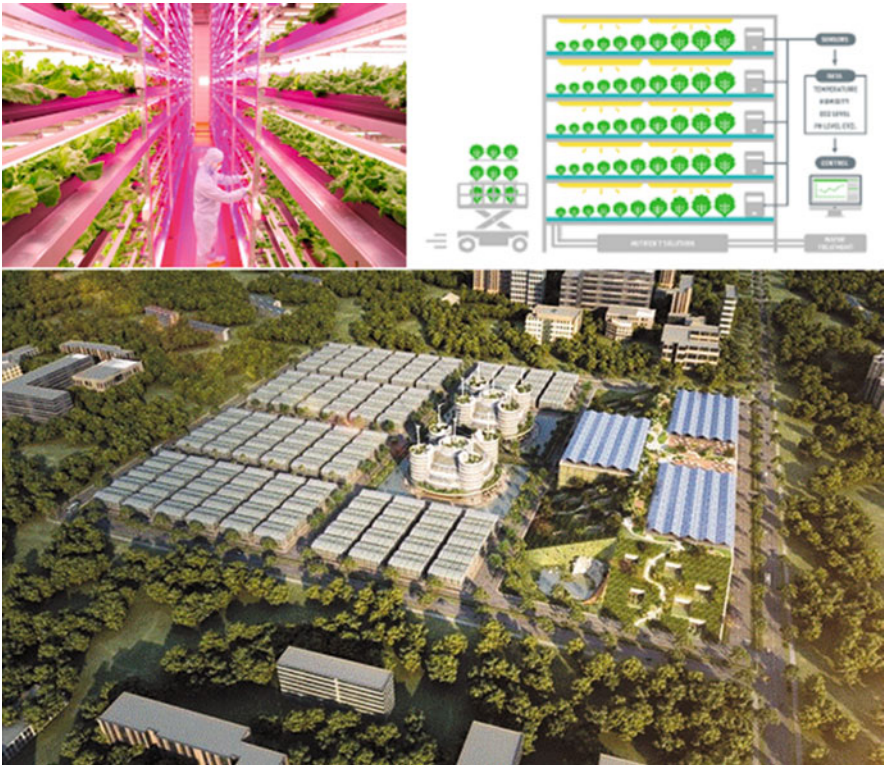

Fig. 9.5 Japanese company Mirai Mirai Corp (http://3476.jp/en/about/profile.html)

Fig. 9.6 French Startup Agricool (2020) (https://propozitsiya.com/francuzkiy-startap-stvoryuie-vertikalni-fermi-; http://green-city.su/gorodskie-fermy-potreblyayut-na-90-menshe-resursov/)

numerical control (CNC) computer. The Farmbot system is attractive in terms of availability and is entirely autonomous because solar panels power it.

The goal of robotics is to outsource all harvesting work, which accounts for 20% of all agricultural work, to robots to increase agricultural efficiency. Automation of

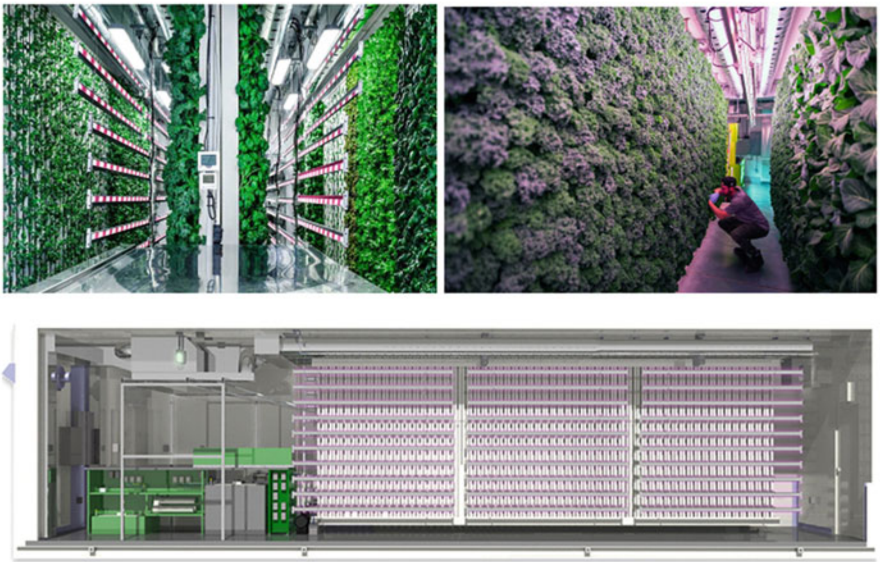

Fig. 9.7 Australian Container Farm Primary Module (2020) (Module http://www.modularfarms.com.au/primary-module-2/; Module http://www.modularfarms.com.au/primary-module-2/#)

Fig. 9.8 California (USA) Company (Fodder Works) (2020) (https://www.fodderworks.net/products/fodderworks-instruction-manual)

Fig. 9.9 Farmbot-3 (2020) (https://farm.bot/)

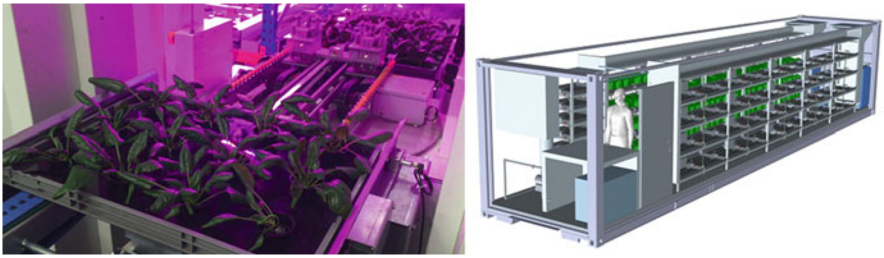

Fig. 9.10 Belgian company Urban Crop Solutions (2020) (https://urbancropsolutions.com/ru)

Fig. 9.11 American Robot Greenhouse Firm Iron Ox (2020) (http://www.iksmedia.ru/news/5536161-Robotizirovannaya-ferma-sposobna.html)

collection will save 20% of farm labor. Calculations showed that about 40% of labor costs are taken up by plants and 40% by calibration, sorting, and packing of tomatoes. For harvesting, using robots is relatively simple. The main advantage of robots is the ability to work at night. And the people who come to work in the morning have to pack the tomatoes collected at night. High technologies have been introduced in the greenhouse complex since its construction: computer control of temperature, humidity, lighting, irrigation, fertilizer, and carbon dioxide supply. The main problem was how to develop the "picking" robot to determine the degree of tomato ripeness. To do this, the designers focused on identifying the robot color and shade of the tomato. The work taught to record the image of the fetus and compare it with the reference image of a ripe tomato, which is introduced by farm workers.

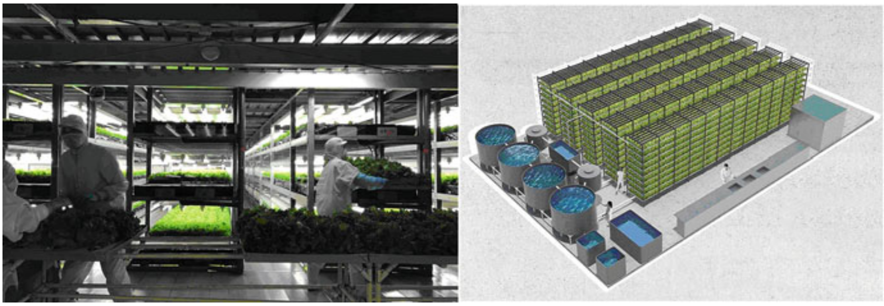

Fig. 9.12 Japanese Robotic Greenhouse by technology company Spread Co (2020) (https://www.agritecture.com/blog/2018/12/2/japan-plants-to-open-worlds-largest-automated-leaf-vegetable-factory)

In agriculture, robotization has not begun yet: the financing problem holds back—it is not always possible to convince the investor of the effectiveness of the project. However, according to experts from the Massachusetts Institute of Technology, this is one of the ten most promising areas of robotics.

Robotization of the greenhouse development should be integrated into cyber-physical systems (CPS). CPS is computer systems focused on and reliant on the combination of computing and physical components. New CPSs will be coordinated, distributed, and linked, and must be reliable and responsive. CPS technology can change the way people communicate with the systems they have developed, just as the Internet has changed the way people interact with knowledge (National Science Foundation 2020). More precisely, the CPS is a system in which computing/information processing and physical processes are tightly combined and inseparable from a behavioral point of view. The system functionality and characteristic are manifested as a result of the interaction between physical and computing objects. Computers, networks, devices, and their environments have been interacting with physical properties, consume resources, and contribute to the overall behavior of the system.

In the twenty-first century, the next generation of agricultural enterprises must incorporate the vision, demands, and intellect of the "consumer" in the supply chain. It will be a performance-oriented organization that responds rapidly to consumer needs and minimizes resource use, maximizes environmental sustainability, and economic competitiveness. To get such a high level of results, it is necessary: preparation (training, education) of a new generation for new conditions, development (research, modeling) of innovative technologies and business development on these technologies. We have global work to prepare specialists with a high environmental culture who will see the prospects for the development of new technologies and be able to apply these technologies for the benefit.

Currently, vegetative plants on the market have been implemented in which plants and crops are controlled by computer algorithms. Agricultural Cyber-physical Systems (ACPS) provide an opportunity not only to copy experiments easily, but also to collect, analyze, and study the data obtained to reveal new features and

Fig. 9.13 The Grocon Pixel building is an example of a green office building and greenhouse (Melbourne, Australia) (https://stephenvaradyarchitraveller.com/2018/02/11/melbourne-pixel-building-australia/)

patterns. ACPS can help with plant optimization methods that provide more autonomous, efficient, and intelligent plant growth models by integrating robotic control loops in innovative vegetation devices with an artificial microclimate. At present, safe environment systems are based on open-source principles. The choice in the review, we focused on openly accessible technologies that can be implemented independently.

The Grocon Pixel building is an example of a green office building in Carleton, near the central business district of Melbourne (Fig. 9.13, Grocon Pixel green office building and greenhouse 2020). The multi-level building in the background features roof-mounted wind turbines and customizable side panels to monitor the effects of solar radiation. Once converted to a vertical truss, solar panels can be used on roofs and sidewalls, and high-performance LED sources are used for indoor lighting. A million-liter reservoir is being installed in the nearby Lincoln Square for local storm water reuse. The construction of the dwelling of a residential tower with a vertical truss is demonstrated.

9.3.1 Advantages of Vertical Greenhouses Agro-Technology

The main advantages of the vertical greenhouses AgTech are:

- Protecting crops and plants from harsh weather is one of the essential benefits of vertical farming. This advantage makes it possible to obtain year-round crops of certified organic products and growing plants in any extreme conditions of deserts, the North, military bases, drilling rigs, and more.
- In the “walking” accessibility from the consumer, these provide tremendous benefits for improving the quality of plant products and thereby contribute to a healthy lifestyle of the nation. This fact gives a significant advantage in the fight against food waste.
- Saving water resources and non-productive costs. A comparative analysis of vertical and traditional agriculture shows that the first method significantly

reduces water consumption. Almost 70% of the World's drinking water is used in conventional agriculture, while vertical agriculture needs only 20–40% of water resources, and in the future, this indicator will only decrease (FAO 2018). Plants grown in closed conditions trigger the evaporation process. This process allows the reuse of water for irrigation purposes. Water consumption is approaching a minimum level. Thus, vertical farms contribute to the rational use of natural resources.
- Constant control of the internal environment eliminates the need for financial costs for the purchase of pesticides and insecticides. Since all crops are cultivated in a controlled environment, the chances of pests, insects, and diseases are minimal.
- Lack of food waste. The risk of product spoilage is extremely small or equal to zero. A feature of vertical farming is that the crop is consumed immediately after harvest. The need for transportation costs is excluded since all crops are intended for consumption within the city.
- Vertical city farming greenhouses are needed to solve environmental problems. With a stable and constant supply of plant products to the urban population, the tension on traditional agriculture is relieved. It enables you to maximize the available land, growing more crops in a smaller area with a highly efficient system, with an opportunity to preserve some of the soil for conservation, to raise reserves, and much more.

9.3.2 Disadvantages of Vertical Greenhouses Agro-Technology

Opponents question the potential profitability of vertical farming. The primary and main negative argument not in favor of vertical greenhouses is that technology opponents put forward relatively high capital and operating costs. But in this matter, not everything is so simple. For the period only after 1960, food production in the world increased 2.5 times, water consumption two times, deforestation three times. As the population grows, the availability of agricultural land decreases: in 1980, 0.3 ha of arable land fell per capita in 2011, 0.24 ha (Final Report Vertical Farm 2.0 2015). The reduction of land resources as a global trend is due to the rejection of productive land for enterprises, cities, and other settlements, the development of the transport network. Vast areas of cultivated land are being lost because of erosion, salinization, waterlogging, desertification, physical, and chemical degradation.

Attention should be focused on the problems with world land, water, and forest resources. Over the past 10–15 years, awareness of environmental protection and to the development of new principles of state regulation to achieve more sustainable economic growth has noticeably increased.

One of the debated issues that affect the theory of sustainable development is the concept of natural rent, that is, payment for the use of natural resources. Scientists argue: the current rejection of the scientific definition of the nature and extent of natural rent leads to significant losses in the national economy. The primary purpose of calculating natural rents is the selection of unique macroeconomic indicators that would allow us to assess the dynamics of changes in the physical state of the environment. Natural rent should serve to coordinate the pace of macroeconomic development, improve the environmental situation, as well as fluctuations in the cost parameters of human and natural resources that are part of the full composition of national wealth. The general meaning of these discussions is the need to take into account the environmental costs of amortization and restoration of natural resources when calculating production efficiency. Further, this means only one thing that the cost of production in traditional agriculture is much higher and incomparably more significant than that presented in official reports.

The theory of sustainable development is gaining strength and significance, against the background of environmental degradation, depletion of natural resources, excessive pollution, which indicates failures in the market mechanism. The market allows you to evaluate only one function of the environment: the provision of natural resources. Another feature is not taken into account: the assimilation of waste and pollution, the performance of environmental functions (aesthetic, recreational, etc.). The feature that is related to the environment does not find its adequate reflection in market valuation.

Thus, if we consider the costs of building and operating vertical greenhouses against the background of a decrease in environmental well-being, quality of life, food security, and public health, then these expenses will seem not so big. But this is what concerns the comparison of greenhouse technology and traditional "classical" agriculture.

Currently, the elaboration of the successful theory of AgTech vertical greenhouse production is practically based on vegetative lighting and irradiation equipment in conditions of artificial controlled parametric microclimate.

Despite considerable experience in growing plants under artificial lighting, there is currently no single view of the optimal intensity (power) of illumination, the spectral composition of radiation, the dose of plant irradiation, photoperiod, etc. In almost every case, a peculiar lighting system is created that best meets the physiological needs of the cultivated plant (Fredani 2010; 6th Global Botanic Gardens Congress Geneva, Switzerland 2017). This direction is at the stage of formation and development.

9.4 Global Scenario of Vertical Greenhouse Agro-Technology

The production of vegetables in the open field remains a difficult problem for the production of environmentally quality plant products, which requires high costs (both physical and financial), time, and environment. The use of enclosed structures of protected soil (greenhouses, hotbeds) for the off-season growing of plants significantly facilitates by reducing adverse environmental factors. All the contradictions that arise during the creation and current operation of biotechnological systems have not been resolved. The more technologically advanced greenhouse production is the higher the energy intensity, the energy consumption of the process of growing greenhouse products. So far, no one has managed to create an innovative developer of greenhouse technology, which is fully recouped due to the significant energy demand. The main contradictions are as follows:

- Firstly, at the present stage of technical development, not a single greenhouse has solved the problem of enormous heat losses. At low ambient temperatures, there is a need for energy costs to maintain the optimum temperature inside the greenhouse. When the external temperature rises, a "greenhouse effect" appears, and the need arises to divert excess energy. Thus, either energy is expended for a favorable temperature environment or there is a need to get rid of excess energy with transoms, curtains, ventilation, air conditioning, which incurs additional costs.
- Secondly, with all the variety of lighting developments with various light sources, the question of lighting systems for greenhouses that fully satisfy the needs of the plant has not been resolved. The use of artificial irradiation for their illumination only increases the cost of greenhouse products. The principal contradiction is that the plant's light environment requires specific characteristics in terms of light intensity, spectral composition, and duration of exposure. Only 10% of the optical energy is used by plants in the process of photosynthesis in a controlled closed biotechnological system. The remaining 90% is a technological loss. Plants do not adequately absorb light energy, do not use all the energy in the biomass that they consumed, and have maximum active photosynthesis of 3–6% of total solar radiation. Closed systems of artificial microclimate allow plants to increase the efficiency of photosynthesis by up to 10%. The plant has internal processes: reflection and transmission of light energy, as well as a competing process in the form of photo-respiration and photosynthesis. Photosynthesis may be ineffective in certain conditions. Excessive light energy is dissipated to avoid damage to the photosynthetic apparatus. Excessive light energy is dissipated in the form of heat (non-photochemical quenching) and emits in the form of chlorophyll fluorescence (Ke 2001; Medvedev 2012).
- Thirdly, the environmental component means the use of large areas of land, light pollution from luminous agricultural complexes, the absence of closed systems and recycling systems. Automation of individual systems and inconsistency of work between systems is a massive waste of natural resources. This production requires a high level of specialists since decision making in the technological process depends on the expert assessment of a specialist. The low level of automation of labor-intensive processes requires manual labor.

Based on the previous, it is recognized that substantial greenhouse complexes have developed their resource for further technological and technical development. Such an organization of the greenhouse business incurs significant energy losses, considerable financial costs, and poses a severe environmental problem. Future technologies in greenhouse production should be based on the foundation and applying essential principles, such as a high environmental friendliness (closed-loop technology), the development of autonomy (renewable energy sources), energy-saving at all levels of production (technology of LED lighting systems), reduction in energy intensity (technology of soilless plant growing), automation, and robotization of closed systems of greenhouse production.

9.5 Technologies in Vertical Greenhouses

Vertical farming or vertical greenhouses AgTech there is a practice of growing crops at vertically located levels. Vertical greenhouses, as a rule, combine the most advanced technologies: soilless plant growing, LED lighting systems, automation/ robotics, and many processes (constructive, engineering, technological, economic, and many others). The use of these technologies has now led to a more than tenfold increase in crop yields compared to traditional farming methods. The modern concept of vertical farming was proposed by Dickson Despommier, professor of public and environmental health at Columbia University (Despommier 2009, 2011). There are several developing concepts for vertical farming: Peyton (Devon, England) (2020); Israel (Green Zionist Alliance 2020), Singapore (Association for Vertical Farming in Singapore 2020), Baltimore (Company Gotham Greens–Baltimore, Maryland, USA 2020), Germany (Das Münchner AgTech-Unternehmen Agrando 2020), London (London-based startup Wefarm 2020), Japan (AgTech Innovation in Japan 2020), USA (American startups Freight Farms 2020); Brisbane (Eat Street’s Modular Farm Brisbane in Australia 2020) and others.

9.5.1 Technologies for Growing Plants Without Soil

Hydroponics uses the ability of plants to consume nutrients dissolved in water. Natural soil acts as a source of minerals, but the presence of soil is not necessary for plant life. We know that plants feed on mineral salts in the form of electrically charged ions. There is currently no accurate and complete classification of hydroponics. We offer conditional classification by review and analysis of scientific literature (Fig. 9.14). Specialists distinguish three main methods of hydroponics: substrate culture (hydroponics and substrates); water culture (hydroponics); air culture (aeroponics).

We classify hydroponics according to the following criteria: environment around the roots, with or without substrate. Hydroponics has a feature of the environment around the roots: aquatic environment; the environment that forms the fog; an environment with an organic substrate; medium with an artificial substrate; combined medium.

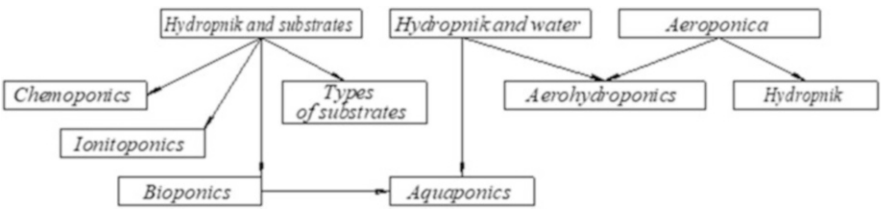

Fig. 9.14 Classification of technologies for growing plants without soil

Hydroponics is divided into active and passive. Active hydroponics uses a pump when water enters the reservoir with roots. Passive hydroponics uses the property of a substrate to raise moisture the voids and tubules with an artificial or organic substrate due to the surface tension force.

Aeroponics has a distinctive feature when there is no substrate. Aeroponics can be reversible and irreversible. Aeroponics has a reversible nutrient solution supply system, where the solution circulates continuously and flows back to the original reservoir. Aeroponics has a non-reversible nutrient solution supply system, where the solution is used once, so there is no need to control the parameters of the nutrient solution.

Aero-hydroponics is classified by a technical solution. Technical solutions may use a water pump, air pump, whirlpool ultrasonic generator.

Chemoculture, or culture of dry salts, is called a viable method in which the rooting of plants occurs in an organic substrate, which is saturated with nutrient solutions. Periodically, such a system is moistened with a nutrient solution. The main advantage of such a system is the possibility of the horizontal and vertical laying of the substrate on the plane. Chemoculture allows you to grow plants in adverse conditions (if there is no constant watering). Today, quite different methods have been created for introducing nutrients into horizontal and vertical chemoculture systems.

Ionitoponics is a method of growing plants in which ion-exchange materials are used as a substrate. Ionitoponics has the main difference from other methods; hydroponics uses substrates that can retain nutrient components for a long time. Therefore, you can water the plants directly with plain water without the additional introduction of macro and trace elements. However, watering should be required because the exchange of ions occurs in the aquatic environment. The intensity of the transfer of nutrients from the substrate to the decay products of the plant depends on many external factors: temperature, plant lighting, air humidity, and others.

Bioponics is organic hydroponics, in particular, the so-called aquaponics. Bioponics uses large microbial populations, which become the main obstacle to pathogens. Roots protect beneficial organisms with proper oxygenation, save water and fertilizer, and increase good quality food production.

Thus, the classification of hydroponics is the objective of the study of many scientific teams. This topic does not have a final methodological development. The rating and the effectiveness of certain types of hydroponics wait for further scientific study.

9.5.2 Hydroponics and Aeroponics

In recent decades, technology for growing plants without soil has taken many forms: hydroponics (growing plants in a nutrient aqueous solution and their roots are fixed in an inorganic permeable substrate), aquaponics (a type of hydroponics in which nutrients are extracted from fish waste), and aeroponics (growing plants from freely hanging roots in the air, which are periodically sprayed with a nutrient solution) (Kozai 2013; Schnitzler 2013; Lakhiar et al. 2018; Imran et al. 2018).

Table 9.1 The attractiveness of hydroponics technology

Techniques	Harvest (crop) (%)	Ripening speed (%)	Water consumption (%)
Aeroponics	130	150	10
Hydroponics	110	120	30
Traditional farming	100	100	100

Advantages of soilless plant cultivation: an order of magnitude higher yield per hectare; 10 times less water per unit of output is required; 5 times less fertilizer per unit of production; increased protection against diseases; no crop damage; and much more. The ratio of capital and operational costs an essential decision in the choice of technology. The more complex the technology, the more expensive it is. At present, hydroponics occupy a strong position, the main advantage of which is the simplicity of technical implementation, which makes it easier to control, operate, repair, cheaper to repair and replace components, and much more. Hydroponics does not cause crop loss if a failure occurs in the water supply system (Kozai et al. 2015).

In comparison with traditional hydroponics, aeroponics does not require any liquid or solid medium for growing plants (Kozai et al. 2020). Alternatively, a liquid solution of nutrients produces dust in the air chambers where the root portion of the plant is put through the nozzles. Of course, aeroponics is the most sustainable cultivation technology without the use of soil, since it uses up to 90% less water than the most effective conventional hydroponic systems and, most importantly, does not require replacing the nutrient medium. Aeroponics does not require additional aeration (the effect is absent when the roots are suffocating), there is no need for cleaning after using the nutrient solution (if correctly calculated, it is entirely absorbed by the roots). Aeroponics optimizes greater air access for more successful plant growth, unlike substrate methods. The plant in the aeroponic apparatus has 100% access to CO_2, which contributes to the accelerated growth of the plant. In addition, the absence of a nutrient medium requires aeroponic systems to follow a vertical structure that further saves energy as gravity naturally absorbs excess fluid.

In contrast, conventional horizontal hydroponic systems often require water pumps to control the excess solution. Water that circulates in hydroponics gives additional weight, which is reflected as a contribution to the material consumption of the structure (Table 9.1). Therefore, hydroponics is usually used in single-shelf technology (Benke and Tomkins 2017; Goddek et al. 2019a, b).

In general, hydroponics occupies a leading position in the city-farming market, which is estimated at $ 2 billion. Aeroponic systems have not received widespread use, since it requires more complicated calculations, more subtle and time-consuming settings, and therefore, more qualified maintenance personnel. Still, they are beginning to attract considerable attention. In the next 5 years, experts predict a faster growth of aeroponics, aerohydroponics, and aquaponics technologies because they are more economical and efficient than hydroponics systems (Battaglia 2017; Sidorenkov et al. 2017; Mytton-Mills 2018).

Automated vertical farms intend to transform the world of agriculture, and this is not surprising because advanced hydroponics and aeroponics technologies bypass

Fig. 9.15 The essence of "Hyponics" is aeroponics and computer technology (https://auto-grow.ru/assets/images/tickets/1776/cbafba0f04887c9b575327efc8bfc894d82bcd0c.pdf)

conventional crops are pioneers in change. There are many companies creating farms the size of a standard shipping container. Such farms can be used by novice entrepreneurs for the restaurant business because, in this way, it is possible to save on the transportation of plants and serve only fresh products on the table.

The "Hyponics" is an example of high technology. It is the most progressive subspecies of aerohydroponics, which appeared relatively recently due to the improvement of classical hydroponic methods. Today there are already melons, from one vine of which more than 90 fruits weighing 1.2 kg are collected, and a cucumber tree, giving 3000 cucumbers, and 6-m sugarcane. In 3 months, up to 4000 fruits ripen on this beautiful tomato. From one melon vine, the Japanese harvest 90 fruits with an average weight of 1.2 kg. And their "cucumber-tree" gives more than 3000 fruits. Natural sugarcane, instead of 2–3 m, almost two times faster than under normal conditions, grows to 6 m. They become even that papaya growth was not worse than in the tropics, although it does not grow in the Japanese climate.

The inventor of "Hyponics," Shigeo Nozawa, president of Kyowa, spent 20 years experimenting. The essence of this method is the use of aeroponics and computer technology (Fig. 9.15). The mixture is continuously circulating, feeding plants only with those substances that it needs, precisely in this period of development, and their concentration is several times higher than the plant could get from the soil (Hydropon East Magazine 2012).

Special equipment creates optimal temperature, humidity, and other characteristics, increasing the speed of development, and the ripening of fruits increases by 3–4 times. It took 1000 experiments and many years of painstaking work to develop nutritional compounds for each culture. The company keeps in strict confidence its solution formulas. It is known that no stimulants, hormonal, and other drugs that artificially accelerate growth are not used in them. The fruits grown on Hyponics are not inferior in quality to ordinary fruits and no danger or side effects for humans. According to the employees of the Japanese company Kyowa, using "Hyponics," you can grow any plant. An example of this is cucumber bush, which gives more than 3000 fruits, or a melon vine, with which up to 90 fruits are harvested with an average weight of 1.2 kg. A sugarcane reached 6 m in height, while in natural conditions, it does not grow more than 2–3 m; they began to grow tropical papaya in the Haydon way, as well as pumpkins in various colors and tobacco (Division of Hyponica 2020).

9.5.3 LED Lighting Systems

Currently, LEDs have no alternative. However, the LEDs have not reached the limit of their capabilities and are in the process of constant updating. LEDs have several unique advantages and many disadvantages.

LED is a semiconductor light source containing one or several crystals of the Crystals to be in one body with a lens. The lens forms the light flux. The LED has the main feature: the light that LED emits is in a narrow range of the spectrum. The range of radiation of the LED depends on the chemical composition of semiconductors.

The principle of operation of the LED based on electrical luminescence: cold emission occurs when the LED electric current flows. The electric current in the LED passes through the p-n junction in the forward direction, charge carriers of the semiconductor (electrons and holes) recombine with the emission of photons. Semiconductor materials have different efficiency, which emits light during the recombination. Semiconductors with different wavelengths create the LEDs from UV to mid-IR. LEDs have directional radiation through a plastic lens covering the LED chip.

All semiconductors are light-emitting diodes, currents of fear because the resistivity of semiconductors depends on temperature. The resistance of semiconductor decreases if the temperature rises, and there is an avalanche process which increases the electric current. The LED will burn if the electric current will increase. The lifetime of LEDs depends on temperature, while the quality of light depends on the lifetime of the LED. Illumination decreases with time, and labor is the aging (degradation) of the lamp.

The beautiful life of a typical LED lamp is 5000–100,000 h. Other manufacturers indicate more modest numbers, only 35,000 h. The lifetime of LED is the time that the device operates until the moment of failure, and this is not the final breakdown, a drop in performance below a certain level. Some manufacturers believe this threshold the reduction of the luminous flux by 30% of the nominal value, the other 50%. These data generally are not reported in promotional materials and in the documentation for luminaires that do not allow the buyer to make the right choice (Nikiforov 2015; Sun et al. 2017).

Developments in the LED market are developing very quickly. The LEDs that did not meet expectations, removed from production, and start a new, better one. Testing of the LED is carried out in extreme conditions (current strength and the temperature of the crystal are at the limit of acceptable values) within a relatively short period. The results of the tests extrapolated independence on a longer time interval for normal operating conditions (Liu et al. 2016).

Individual single LED is not used directly. The LED is part of a lighting unit (lamp, reflector), which produces the assembly of a LED matrix. The LED light has lighting equipment: driver block power supply, stabilizer. Manufacturers of lighting devices used to indicate the lifetime of the LEDs under normal conditions. The real power supply system cannot provide normal conditions. In the power system, there is always some voltage drop, voltage fluctuations, harmonics, etc. LED lights still work less of a lifespan that the manufacturer promises. The lifetime of the LED lamp depends on the driver (pulsed power supply) and secondary optics. The heat-dissipating system in LED lighting uses a ribbed aluminum radiator (Nikiforov 2005). Lenses on the secondary optics in LED lamps are usually made of plastic, which over time, becomes cloudy. The reflectors are mostly made of plastic, coated with a thin layer of metal. Here it may have the effect of tarnishing the metal surface. These problems are solved by the use of modern materials and the sealing of the luminary (Nikiforov 2009; Nikiforov 2012).

LEDs have many advantages relative to other light sources. The power of LEDs is the efficiency of conversion of electricity to light. Modern commercial LEDs have the indicator light output 170 LM/W, industrial 110 LM/W, and every year they improve.

LED lighting system effectively adjusts light modes in the spectral composition and intensity. Other light sources are not flexible regulation of the light conditions. The LED lighting system provides energy savings on lighting (not only material things but also environmental safety). Every kilowatt of energy that saves the LED reduces the combustion of fossil fuels, harmful emissions in the air, and no need to build new power stations, electric networks, and infrastructure. LED lamps have the advantage of simple disposal in comparison with other lights.

Technologies that grow plants and use LEDs in an artificial microclimate have a promising future. One of them is the opportunity to obtain a certified organic product and raw materials, year-round to grow crops of high productivity, to abandon herbicides and pesticides, and to reduce environmental pressure on natural resources and more.

The practical implementation of the lighting plants with LEDs in a synthetic controlled microclimate is faced with many difficulties (Horibe et al. 2018; Kozai et al. 2019; Kozai 2019). We were discussing the unresolved question, such as the effective range of optical energy for plant growth. The range for adequate growth and development of plants varies across crops, types, varieties, hybrids, according to the vegetation periods. The range should change depending on the vegetative period of plant development, changes of microclimate parameters, and other settings. Currently, there is no understanding based on what position the action of light fields; there is no clear theory, which can be used to reasonably select the optimal parameters of a bright environment for artificial microclimate (Donskoy et al. 2019; Klyuchka et al. 2019a, b; Klyuchka and Lukyanov 2019).

Spectrum is only one of the characteristics of the light environment and light environment is part of an artificial microclimate. An adjustable parametric climate, as habitat for plants, is a complex multifactorial object for the simulation (Klyuchka et al. 2018a, b). The plant as a research object can be divided into vegetative part and root part. The vegetative part of the plant responds to crucial factors: light, temperature, humidity, and gas composition of the air. The root part of the plant responds to the water temperature, water acidity (pH), the concentration of salts, oxygen content, and conductivity. Both plant parts are interdependent and react to internal changes with each other. Every single unit of these factors is a tool to encourage, influence, impact on plants. There are dynamics at the time of the processes. An essential biological element is the progressive growth and development of plants, the changes in the environment under the action of the life processes of plants (Li et al. 2018; Klyuchka et al. 2019a, b; Klyuchka and Lukyanov 2019).

Currently, there is no understanding based on what position the action of light fields; there is no clear theory, which can be used to reasonably select the optimal parameters of a bright environment for artificial microclimate.

Problems that associate artificial light microclimate and photobiological processes of plants impact on modern greenhouse technology. Modernization of greenhouse production takes place only at the level of individual systems. It makes a slight win for reducing energy consumption. The breakthrough could provide the studies that establish a definite relationship between microclimate parameters of internal processes in plants. The research will give an accurate prediction of the operation of the cultivation of greenhouse plants, increasing the productivity of plants, to obtain the specific biochemical composition of plant materials in conditions of artificial microclimate. Research is aimed at building the biotech systems to a new level, the so-called CPS. CPS is physical and engineered systems whose operations are monitored, coordinated, and integrate computing and communication core. Cyber-physical processes require dynamic-programming in real-time (Kozai et al. 2020; Niu et al. 2020; Takagaki et al. 2020).

9.5.4 Researches on LED Lighting Systems in Greenhouse

Electrical energy passes through several stages in the power supply system, such as generation, transmission, distribution, and consumption. The lighting system is a consumer of electrical energy, that is, part of the power supply system. The lighting system also creates a light environment for plants in greenhouses. The lighting system is an intermediary between the power supply system and the lighting environment for plants. The quality of electrical energy determines the quality of the artificial microclimate in greenhouses. The task of the quality of electric power is not unique. Consumers of electric energy must use electrical equipment that does not violate the operating mode of the entire network or consumers of electric energy should use additional material to eliminate negative phenomena. The negative aspects of the power supply system are as follows: the state of the network from a variable load schedule, reactive power, voltage drop or surge, asymmetry of the network, non-sinusoidal shape of the current and voltage curves, and more.

The energy component in the cost structure in the production of greenhouses (according to various sources) approaches 45% and can increase up to 65% depending on the climate. An event that reduces the consumption of electrical energy

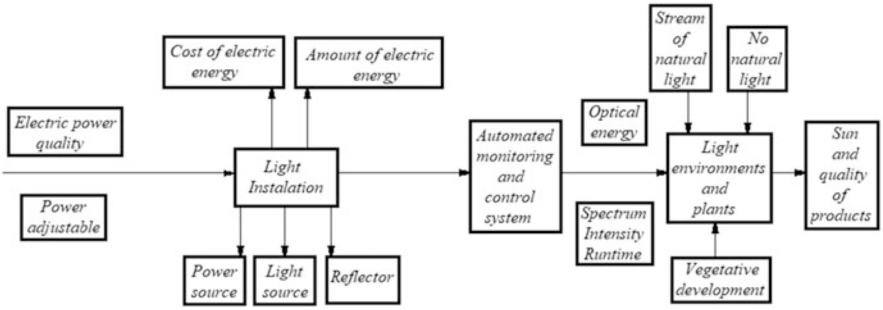

Fig. 9.16 A conceptual model of the organization of the light environment in a biotechnological system

is called energy-saving. For example, reducing the use of electric power for lighting is the replacement of gas-discharge light sources with LED light sources. Figure 9.16 shows the primary factors that affect the light environment of greenhouses.

An analysis of the literature found that the parameters and modes of electric lighting networks of greenhouses have several specific properties. The main feature is a weak correlation between load curves and reactive power. The reason for this property is associated with a significant degree of uncertainty about the operation of lighting electrical networks. Weather and climatic conditions (excess or lack of sunlight) create work uncertainty. The reason for this property limits the possibility of using traditional methods of voltage regulation and reactive power compensation in networks using batteries of statistical capacitors.

The conceptual model provides an analysis of factors that affect the light environment of the greenhouse (Fig. 9.16). The conceptual model illustrates a complex objective. The conceptual model is formed by functional modeling. Functional modeling consists of breaking the object under study into functional blocks. Function blocks detect points in the functional diagram. The aspects of the functional diagram are characterized by the optimization criterion and the main process parameters. The choice of lighting installation depends on several groups of factors:

- Economic factors: the amount of equipment used, electricity consumption, and electricity tariff;
- Power supply factors: power quality and power loss; equipment used for power control and voltage regulation;
- Factors that influence the choice of a light source according to light, technical and electrical, operational parameters;
- Factors that relate to the choice of schemes for switching on the lighting system, lighting equipment;
- Factors that influence the choice of an automation system, control, measurement, registration, control, dimming (adaptive dynamic lighting);
- Factors that influence the choice of lighting method (constant, variable, pulsed, multi-spectral, and others). The choice significantly affects the spatial distribution

of the light flux with a directivity gradient determined by the duration of the exposure in terms of intensity and spectral composition of optical energy.

We analyzed the existing methods and technical means of controlling the operating modes of electric networks of industrial greenhouses. An analysis of previous studies indicates a low power factor and the need for reactive power compensation in lighting electrical systems of greenhouses. It shows the absence of recommended means of automatic control regulation in lighting networks. Some scientists propose the use of phase-switching boost transformers. This device has the advantages of magnetic and semiconductor technology in combination with connecting secondary windings to various phases of the supply network, which allows a relatively simple and effective way to solve the problems of voltage regulation and compensation of reactive power. Booster transformer can create a large number of combinations of modules and phases of additional EMF. This property makes it possible to control the voltage and reactive power modes, and as a result, control the parameters of the electric lighting networks in the conditions of weak correlation of the responsive power load graphs.

Another problem with lighting electrical networks is a large proportion of nonlinear loads exceeding the linear component. The nonlinear load is the source of higher harmonics in the electrical grid. Sources of nonlinear load are electric drives with electronic speed converters, air conditioning, and ventilation systems, single-phase consumers, high-pressure discharge lamps with electronic ballasts. Sources of nonlinear load are office equipment part of an automated control system, tracking, control: computers, servers, uninterruptible power supplies, LED light sources. In the future, the problem of nonlinear loads will only grow and increase.

Non-linear load distorts the shape of the current and voltage curves. Deformation of the shape of the current and voltage curves affects the reduction of the power factor of electrical equipment; for prolonged heating and to increase losses in the network; to rapid aging of insulation; to reduce the useful life; to the false triggering of the microprocessor relay protection system. Some scientists note the malfunctioning of measuring devices and monitoring devices. Problems for greenhouse enterprises increase capital costs for the replacement of electrical equipment and additional operating expenses.

Currently, scientists are developing organizational and technical measures to improve the reliability of the power supply system and the quality of electricity. LED lamps and single-phase power supplies are energy-saving technologies, but the main types of distorting loads in the electric network depend on LED equipment. Therefore, the problem is not trivial; the method of optimal design for lighting systems, which allows obtaining new structures of lighting networks. New arrangements of lighting networks should solve the problem of a rational configuration of electrical equipment for lighting networks of greenhouses to create an adjustable lighting environment for plants.

Thus, the potential for optimizing and improving the artificial lighting system for plants can be realized in the following areas:

- The power supply for lighting systems is important for a lighting system. The quality of power supply cannot be ignored; operational indicators of light sources depend on it; therefore, the characteristics of the light environment in which the plants are forced to be. The quality of the power supply determines the pulsation and duration of the entire lighting system.
- The electrical connection diagram is the main point in the design of lighting systems. A factor that takes into account the location of the light source relative to the plants in the volume of the greenhouse affects the intensity of the light environment, the number of necessary lighting devices, and energy consumption.
- To focus on the spatial redistribution of optical energy through various lighting methods (variable, pulsed, multi-spectral, and other lighting methods), which reduce the number of equipment in use, thereby reducing the load on the entire power supply system.
- Automated control systems use the principle of the consistency interdependence of the microclimate subsystems (innovative information and software technologies).
- Information and software technologies for the development of the concept of biotechnological feedback using methods of functional diagnostics of the physiological activity of plants.

9.6 Modern Vertical Greenhouses of the Third Level

Vertical greenhouses of the third level of constructive and technical implementation have a reasonably broad interpretation and, in a sense, they use “classical” greenhouse technologies: soilless plant growing, artificial light sources, automation of microclimate systems, and much more. The difference is that vertical greenhouses need to solve the issue of integration in the urban environment, to use a minimum area due to the multi-level design of technological surfaces. And also use closed process cycles. And so the estate, the success of a particular greenhouse depends on a combination of many individual factors. The analysis of vertical greenhouses among themselves, as well as vertical greenhouses in comparison with the “classical” greenhouse technologies, can be found in large numbers in the English-language scientific literature.

A study on the concept of a vertical farm optimization model, with excellent increasing conditions in a managed environment, improved energy, and waste flow, automation systems as well as modular system applications, was published in January 2017 (Final Report Vertical Farm 2.0 2015). The study Vertical Farm 2.0 (VF 2.0, Fig. 9.17) is the product of a parallel engineering (CE) workshop at the German Aerospace Center (DLR) in Bremen, together with the Association for Vertical Agriculture (AFV).

The purpose of the report was to develop a basic functional scenario in all areas from design, technical equipment, technological process, logistics process, and more. The VF 2.0 module has four development levels (2 for leafy greens and 2 for grape growing). On the ground floor, there is a center for processing, sorting,

Fig. 9.17 Basic functional model of the vertical greenhouse VF 2.0 (http://www.fao.org/3/a-i4904e.pdf%20Accessed%2013%20Feb%202020)

and storage of finished plant products. The project was provided by the possibility of adding a level of a roof greenhouse for expanding the production. Each cultivation module is designed as autonomously as possible as an independent unit, independently of other modules.

The following technologies were taken as the base model: hydroponics on a multi-rack installation, LED lighting system, varieties of lettuce, and tomatoes were selected. Conventional agricultural technologies were made in the calculation. Automated technology Nutrient Film Technique (NFT) (which is used by the American company AeroFarms) was chosen for the production of plants. The plant's lighting system and air management system cover almost 98% of the energy requirement (Table 9.2). Reducing energy costs is the main objective of reducing manufacturing costs. Vertical farms become a safe, economically feasible, and environmentally efficient way of generating a substantial amount of food for people in large cities.

The process design involves greenhouse development, the climate control system components, the power supply system element (NDS), and the structure itself. Unit inputs include seeds, electricity (light and heat/cooling), carbon dioxide, and nutrient irrigation water (Klyuchka et al. 2020). Reversible standards are water coming from the drain or wastewater vapor and excess heat in the air management system (AMS). The final results obtained through the crop are waste (uneatable material) and product (eatable material). Separate chapters include a detailed analysis of lighting requirements, climatic conditions. Each subsystem is associated with a part of the overall process.

Table 9.2 Total energy consumption per subsystem on the baseline scenario

Subsystem/relevant area	Yearly energy demand [kWh]	Distribution of energy use (%)	Chapter reference
Illumination system	12,152,463	69.9	7
Air management system	4,853,038	27.9	8
Nutrient delivery system	69,739	0.4	6
Plant health monitoring system	106,872	0.6	9
Horticulture operations	36,500	0.2	5
Growth floors core area	24,094	0.1	11
Ground floor core	15,067	0.1	11
Ground floor working area	125,008	0.7	11
Total	17,382,422		

The concept of the vegetative and generative stage, where most structures are linked either through the associated components or through the object itself, is a good example. The primary aim of this analysis is to evaluate the total value of VF. A well-designed roadmap of the information is necessary to achieve this goal regarding essential aspects in each subsystem to avoid bottlenecks that can potentially slow down the process of both design and operation.

The aim of the basic modules VF 2.0 is to achieve the most efficient yield, food quality standards, and protection, rather than the maximum return at the optimum cost. According to a study (Zeidler et al. 2013), waste disposal within the program would require high costs, which will minimize the effectiveness of the project. The device will use the currently available heat and water recovery technologies. Recycling of purified water for plants will be carried out. The heat from the LED lamps is removed from the production facilities and transported to other parts of the building using a heat pump. A tank can be created to store this energy for future applications.

Despite considerable experience in growing plants under artificial lighting, there is currently no single view of the optimal intensity (power) of illumination, the spectral composition of radiation, a dose of plant irradiation, photoperiod, etc. In almost every case, a peculiar lighting system is created that best meets the physiological needs of the cultivated plant. This direction is at the stage of formation and development.

The concept of the base module VF 2.0 uses artificial lighting. Designers admitted, based on the opinion of optimistic scientists, that the optimal light spectrum and photoperiod (Sabzalian et al. 2014; Kozai et al. 2015) maximize the yield of plant products. The model chosen is the Heliospectra Light Bar V101G-L which is configured for water cooling and designed explicitly for VF applications. It generates a spectrum of light precisely designed to enhance photosynthesis.

The result of the initial project of the VF 2.0 module was the construction of a real building measuring 75 × 35 meters, which is a particular starting point for further research and implementation of the most promising innovative technologies that city farming needs so much. The experiment is currently ongoing, and the results for a functioning VF 2.0 base model have not been published.

9.7 Vertical Farm 2.0

The final report, VF 2.0 on the design of a functionally and economically feasible vertical farm, as an innovative technology for sustainable agriculture, gave an ambiguous assessment and some conflicting conclusions. The purpose of the report was the demonstration of how realistic it is to implement this project in the current economic situation. Of course, in the project, the calculation was carried out both for capital and operational costs for equipment, so the warranty period is given for quite a long 30 years. A long-term warranty does not require the cheapest machine, which offers a guarantee of high reliability and fast high-quality repairs. At the same time, an extended warranty period provides for the modernization of gradual re-equipment of production with the advent of new technologies.

Moreover, in practice, multi-level vertical greenhouses have demonstrated economic success in Japan and Singapore, for example, where products are merchandised in a different retail segment at a slightly higher price than the EU or US markets.

The killer's criterion in this equation is not the technology itself, but the restrictions on reducing the cost of electricity and labor, which make up the majority of operating expenses, probably increasing these costs several times per 1 m^2. VF 2.0 needs additional expenditure without any difference in the production of a net economic benefit relative to regular plant food. This attempt exposes a fractured plan to address the crucial problems of food production today.

Another conclusion is that urban vertical greenhouses should demonstrate the full range of the most advanced agricultural technology in a controlled environment (CEA), which implements the principles of a closed cycle. The VF 2.0 report conducted a comparative analysis of a multi-layer growing system with large-scale thermal air masses in a greenhouse in terms of using recycling systems. For example, in an air movement control system combined with precise touch control of air quality, the VF 2.0 manufacturer gives a clear advantage in optimizing environmental parameters. There are several HVAC solutions in terms of climate control applications by creating overlapping sensor technologies to create multiple data points.

Automation using technology would be the most logical development direction to reduce labor costs. The report emphasized that any technology has an adaptation period when testing and debugging take place after installation. The period of transition to full production capacity may be delayed due to weak bottlenecks in technology not taken into account. It would be appropriate automation with the help of artificial intelligence (AI), which can be of great importance in the role of an advanced, informed expert, without spending years on the training of personnel and highly skilled specialists. The potential for machine learning and personalized feedback from sensors is essential and can further lead to the production of automated VF 2.0.

The concept, when it comes to the design project of the vertical greenhouse VF 2.0, is very inventive and unique, with such a mix of experts from various fields and young entrepreneurs. As a result, the AVF has no precedent in the agriculture of foreign organizations representing this form of operation and membership.

Existing typical agricultural organizations tend to focus primarily on the rural, regional representation of farmers or on the form of organization of production, which focuses mostly on national issues or, at best, on particular supply chains. Searching for versions to different types of organizations or networks that specialize in technologies of this size, AVF is the only foreign association with 300 members from both sides of the CEA and beyond. Therefore, AVF needs to be sure that this is the impetus for the development of innovative solutions in the field of food production. This project has the distinctive character of AVF, which supports new food production on a large scale and with high energy in this expanding market. Based on these efforts, the framework for the next step was successfully laid to begin work on the design of the new VF 3.0 base model.

Concepts related to the incorporation of vertical greenhouses in the city reflect valid information that is debated in small academic communities. Such principles (such as CPUL) and the underlying theories have not yet entered the general public consciousness or the political discourse; they have not yet reached the mainstream or do not reflect the opinion of the majority. The difference between existing standards and the concept of vertical greenhouses is the most critical obstacle to more extensive transformation and system integration-now and in the future. Global work is needed at all levels of state, scientific, educational, public, and so on.

Generally speaking, the understanding of new goods and innovations is critical for further implementation. Innovation, such as vertical greenhouses, depends on its social acceptability, especially in the early stages (Specht et al. 2016). “Acceptance” is defined as “the process or fact of receiving something as adequate, valid or appropriate” (Oxford Dictionary Acceptance 2014). Therefore, one of the specific goals of such research is to analyze people’s attitudes to certain new technologies, especially those associated with risks. The widespread occurrence of risks and low public acceptance of innovations in biotechnology, energy production, GMOs, carbon capture, and storage, as well as precision farming, organic farming, and conservation agriculture is perceived. As for vertical greenhouses, concerns are raised about integration, the use of public resources, accessibility, technical complexity, and aesthetics of vertical greenhouse projects. Perceived risks are associated with possible low-quality products and potential health risks associated with urban pollution. Finally, the ecological and economic balance is being questioned (Kozai et al. 2019; Kozai 2019; Kozai et al. 2020; Niu et al. 2020).

Another type of potential threat applies to the implemented or suggested production. The crucial factor in this context is the stakeholder belief that the technologies used in vertical greenhouses (i.e., soil-free cultivation technologies) are unnecessarily complicated. This tool primarily relates to more technologically sophisticated systems, such as autonomous, automated, closed vertical greenhouse systems. This tool refers mainly to more technically advanced systems, such as independent, automatic, closed vertical greenhouse systems. The use of soilless cultivation or methods that use synergies between urban agriculture and buildings (for example, by combining heat, water cycles, waste, etc.) is also covered by this tool. Since sophisticated technologies are associated with high costs, it can be assumed that the technology of vertical greenhouses can contribute to higher property prices and, thus, change the surroundings.

The perceived high complexity and high operating costs of vertical greenhouses also pose the perceived risk of pursuing large enterprises as a profitable but unsustainable business. For example, vertical greenhouses are managed for profit without integrating social or other functions. This category of risks is directly related to the search for specialists who could design, implement a technical project, and maintain the technical part separately and separately greenhouse plants, and much more.

The development of vertical greenhouse technologies is associated with a diverse set of risks, according to many stakeholders. The main threats were related to urban integration of vertical greenhouses, the production system, the food itself, the environmental balance, and economic indicators. However, it has been shown that there are many risks associated with a lack of expertise, non-integrative policy-making, inadequate transfer of research findings to the general public, and a lack of ongoing demonstration projects (Kozai 2013, 2018; Kozai et al. 2019, 2020). Also, comparing the results in the available literature that current practice and market data negate some of the perceived risks. Further research should focus on the creation, dissemination, and dissemination of new data to raise awareness and knowledge through pilot and demonstration projects (He et al. 2019; Fang and Chung 2019; Paponov et al. 2020).

The German Center for Research and Innovation in Tokyo (DWIH Tokyo), together with the French Embassy in Japan and the Japanese Agency for Science and Technology (JST) invited 16 speakers from Germany, France, and Japan to Tokyo to discuss how artificial intelligence can help solve environmental problems. More than 150 participants took part in the one-day event. The panelists came up with four different points of view. At the first meeting, they presented the experience of developing policies about environmental issues and the digital transition process and their relationship to each country's national policies. Speakers emphasized the enormous potential of AI to promote more resilient societies, especially in the energy and mobility sectors. However, they also indicated a need to realize this potential. It is necessary to change the attitude of the population (Udaltsova et al. 2015; Niu et al. 2020). The second session discussed the use of artificial intelligence in agriculture and land use. Agriculture is one of the main factors contributing to global warming, and demand will grow as the world's population grows. Artificial intelligence applications such as robotic tractors or drones to test crop growth can significantly increase productivity and labor efficiency, and natural resource management will reduce greenhouse gas emissions. It was emphasized that environmental benefits must be economically attractive, which is still not always the case.

The third session brought artificial intelligence from rural areas to cities under the theme of applying artificial intelligence to Smart Cities. Thanks to AI, the mobility of connected, autonomous, typical, and electrical (CASE) can soon become a reality, and people will be able to use applications to compare the costs of various routes, for example, with a car-sharing service with independent driving. AI can also be used in "smart buildings" that are looking for ways to reduce energy consumption independently. However, the innovative systems that lay the foundation for smart cities vary widely between countries. It is also reflected in the question of who owns the enormous amounts of data processed in a smart city that affects personal data, legal business data, and government data. It was noted that Japan and Europe share similar positions regarding data privacy.

In the last session, examples of already used AI applications in the field of environmental protection were presented. For example, a demonstration project of a virtual power plant (VPP), implemented jointly by a German and Japanese company, the use of AI for climate service products, AI for studying the impact of climate change on ocean resources, and machine learning in the context of environmental hazard monitoring. Throughout the conference, the importance of the international and intersectoral exchange of AI and climate change issues has become apparent. Both transitions (digital and environmental) will occur at the global level and will affect almost all walks of life.

It is a vivid illustration of promising areas in all spheres of human life, including AgTech vertical greenhouses.

9.8 Research and Development Toward Greenhouse Agro-Technology

AgTech is an industry that grows plants in an artificial microclimate and has many prospects for the future. AgTech receives a certified organic product, allows high productivity all year long, eliminates the need for herbicides, pesticides, and reduces environmental stress on natural resources. Generally, it is attractive for investment. The practical implementation of the technology faces many difficulties in growing plants in an artificially controlled microclimate.

The biologist studies the processes of plant physiology at the level of molecules, cells, tissues, at the level of an individual organ, the whole organism (phylogenesis). Scientists with biological education direct their eyes to the internal processes of plant systems, and they ignore the technical component of the experiment. Biologists cannot make the right choice of a light source for many factors: light, technical, electrical, photometric, and other characteristics.

Engineers simulate the artificial environment in which greenhouse plants are forced to be. Scientists with technical education are aimed at the implementation of various electrical technologies, engineering systems, devices, process automation, instrumentation, and the use of information technology. Engineers do not genuinely understand the features of a biological object. Engineers research the development of specific analysis methods:

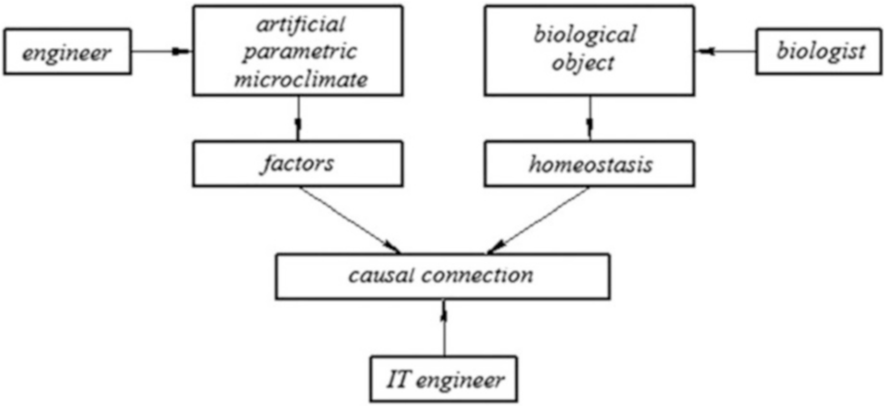

Fig. 9.18 Biotechnological system model

- Methods of analysis of electrical technologies which are methods of stimulating plants and seeds with fields of various nature: optical, laser, electric, magnetic, electromagnetic, acoustic and other areas,
- Methods of analysis of engineering systems that create an artificial microclimate and are a way of influencing plants,
- Analysis methods of instrumentation, which is an indirect tool for assessing the effectiveness of impact on plants.

An engineer strives to create an artificial microclimate with stable parameters that vary in a particular range. At first glance, the task is quite simple and is to create a favorable living environment. To assess the effectiveness of microclimate systems, engineers choose to increase the productivity of photosynthesis. However, the daily intensity of photosynthesis depends on many factors: on the environment, on the state of the plant at a given time, on the internal biological rhythm during the day. Engineers conclude the single results of increasing the productivity of photosynthesis. Plant physiology experts emphasize that photosynthesis productivity does not always correlate with overall plant productivity (Chikov 1997; Chikov et al. 2012).

Information technology experts are trying to unite biologists and engineers. Information technology specialists are trying to establish a connection between various systems: biological, technical, information. Information technology specialists solve specific analytical problems of a practical application: collecting information and processing results. The next part of the paper is the interpretation of the results and the determination of the causal relationship.

The model of the biotechnological system of artificial microclimate (Fig. 9.18) contains several studied objects:

- Parametric artificial microclimate as a technical complex system with many heterogeneous components;
- Plants like a complex living system;

- Information control and measurement system that establishes the relationship between the microclimate and the process of growing plants.

We conducted an analytical study on scientific works (231 scientific articles) that study the effect of LED lighting systems on plants in an artificial microclimate. The experiments are organized by scientific laboratories and production sites at various levels. The question that currently has no solution and causes discussion: the effective spectrum of optical energy for plant growth. An analysis of scientific research methodologies does not provide a universal and accurate answer. The lighting spectrum varies by plant cultures, varieties, hybrids, and by vegetative periods of development. The spectrum is part of an adjustable microclimate. The spectrum efficiency varies depending on temperature changes, on the gas composition of the air, the formation, and quality of the nutrient solution for the roots and other factors.

Currently, there is no sense: what is the basis of the position of the action of light fields of different spectra. There is no theory with the help of which it is possible to substantiate the choice of optimal parameters of the light-medium for an artificial microclimate. There are no criteria for assessing the effectiveness (the same for all) of the processes of plant growth and development. Scientific research methods need serious revision.

At present, the norm is accepted as optimal for plants separately for each element of the light-medium: norm in the spectrum, the norm in intensity, the norm in time of exposure. The patterns of the individual parts of the light-medium are chosen empirically (random nature), according to the reference and scientific literature on the results of past experiments on various crops and plant varieties. There is no information about the optimal ratios (proportions) between the elements of the light-medium inside the whole norm. The optimal norms are not the same for different rates (different dimensions) of the aspects of the light-medium. The ratio of the light environment elements is an independent factor that forms the light habitat of plants. Currently, this approach is poorly researched and not practiced. The problem in which it is necessary to find the optimal ratio of the elements of the light-medium is a more complex and time-consuming task.

Our hypothesis is as follows. The ratio of the elements of the light-medium (spectrum, intensity, exposure time) within the whole norm is a separate acting factor that affects all structural and service systems of plants.

A significant advantage of LED lighting modules over other lighting systems is the simple technical implementation of the control of optical energy by spectrum, by intensity, by duration. The exposure dose during the operation of the light installation is determined as the product of the intensity "E" on the exposure time "τ": $H = E \times \tau$. Thus, the same exposure dose can be obtained at different depths and exposure times. The LED lighting system provides a unique opportunity to use the power of the LED, which is an individual value and can vary. The power of the LED is regulated through changes in current and is determined according to Ohm's law: $P = I \times U$, where "I" is the current strength, and "U" is the voltage of the LED. A monochromatic LED of a particular spectrum determines the level of the experiment, where the intensity and time of exposure vary.

Efficiency criteria are the length of the roots and the length of the seedlings. A crucial qualitative indicator of the development of the seedling is the proportional ratio of the root length to the length of the seedling, thus harmonizing the development. The mass of seedlings gives indirect information about the leaf area of the seedling and the diameter of the stem. The graph is formed according to the results of an experiment from a family of transfer characteristics, which are the dependencies of the relative increase in parameters on exposure doses for various ratios of the elements of the light-medium. The analysis is carried out according to the graph of the curve family. The choice is made relative to the level of increase to determine the exposure dose. The dose level of exposure is determined based on two conditions. In the first condition, the level of exposure should be significant, or the relative increase in the parameter under study should be higher than the relative error of its determination. In the second condition, the line of the significant level must cross as many transfer characteristics as possible so that the corresponding spectral sensitivity curve consists of a more substantial number of points. Each monochromatic LED's definition with a different wavelength and exposure doses can increase germination and primary parameters of germination. On the graph of the transfer characteristics, draw a horizontal line for the selected level of growth and, at the initial intersection with the transfer characteristic for a given wavelength, determine the exposure dose. Analysis of all levels of research will allow you to create a "light recipe." The results are generated and accumulated in the database in the control and measuring climate control system.

We want to highlight several aspects that are not taken into account in many scientific studies.

9.8.1 Parametric Artificial Microclimate

We will show an ideal model for a biotechnological system for growing plants. As an object of study, the plant can be divided into vegetative and root parts. The vegetative part of the plant responds to the primary factors: light, temperature, humidity, gas composition of the air. The root part of the plant responds to water temperature, water acidity (or pH), salt concentration, oxygen content, and electrical conductivity. Both parts of the plants are interdependent and react to each other's internal changes.

The main factors of the microclimate interact with background factors: pressure, fluctuations in parameters, and so on. Each individual of these factors is an instrument of influence on plants. Thus, we create for each element a separate microclimate system: a control system for the light environment, a temperature control system, a humidity control system, a carbon dioxide concentration control system, and a power supply system.

At first glance, the task is simple: each microclimate system forms an optimal controlled parameter. But such a concept contradicts the common goal of the entire closed biotechnological system of plant growing: increasing the productivity of a biological object for the lowest energy costs. A biotechnological system that has many various components is determined by the "direction of the goal" of this system. In other words, we can organize a complex structure of individual elements, but the functionality of a complex system determines the relationship between these elements.

All factors interact with each other; therefore, it is necessary to take into account the dynamics of ongoing processes. The dynamics of the processes are stable, periodic, or oscillatory. For example, the work of light sources increases the temperature and humidity of the environment. As a result, the transpiration process in plants increases. Another example, the balance between carbon dioxide and oxygen is not stable due to the vital activity of plants. Another factor: uniform distribution of parameters in the volume of the artificial system. Uniform distribution of parameters provides circulation (speed of air, heat, humidity, gas, nutrient solution). An essential biological factor, such as the progressive growth and development of plants, is a change in the habitat under the influence of vital plant processes. Daily fluctuations in the process of photosynthesis and biological rhythms of all internal procedures of plants depend on optimal environmental conditions and will always be present.

The use of optical energy of a specific spectrum for the intensification of plant growth demonstrates positive experience. However, the practice of their application reveals that the biological effect is lower than expected and is unstable. This fact can be explained by the fact that technological, biological, and engineering issues are created for lighting systems that are isolated and not deep enough.

Thus, the scientific idea is as follows. The optimal ratio of the characteristics of the controlled light environment (spectrum, intensity, exposure time), which stimulates or inhibits the development of plant seeds during germination, is characterized by the functional spectral sensitivity of the seeds. Patterns provide the basis for creating a synthetic spectrum of LED arrays and make the optimal selection of the characteristics of the light-medium for a given culture. Models provide an idea of how to control the process of seed germination, which will increase germination, reduce germination time, and improve the quality of commodity seedlings of medicinal and green crops.

9.8.2 Plants as a Complex Living System

The plant plays two roles in scientific research. The first role threatens the plant as an object of study. That is, we are interested in variability, plasticity, adaptation of the living system, the law of irritability. In the second role, the plant as an assessment of the quality of the effectiveness of the technical system, to obtain a crop of high productivity with specific attributes of biochemical composition. We note: an artificial microclimate for plants is created through a long chain of experiments using the "trial and error" method.

The plant as a biological object is plastic, and the plant adapts to any proposed conditions to realize its genetic potential. The biological curve of plants clearly shows that any factor can pass from a positively stimulating to a limiting factor of both low and high intensity. It has been established that the range of positive effects of microclimate factors is quite narrow, unstable, and depends on other environmental factors. And here lies the tremendous potential for improving the efficiency of greenhouse production.

We must consider concepts such as ontogenesis and morphogenesis. Ontogenesis is the development of an individual organism, while the general laws of morphogenesis relate to the formation and differentiation of organs and tissues. Morphogenesis events (stable patterns) are embedded in ontogenesis events (individual development). The problem is to separate the personal characteristics of plants, seeds and highlight the models of morphogenesis of a particular crop and variety. Therefore, a qualitative research result should be based on a large sample of events. The flow of information from the many ongoing researches is not clear. In the future, we must learn to compare, evaluate the microclimate parameters with the parameters of the functional state of plants for a qualitative assessment of the cause–effect relationship. Scientists must obtain information, store, process, interpret, and apply in practice, as well as repeatedly verify the reproducibility of experiments and establish a pattern.

An artificial microclimate, as a habitat for plants, is a complex multifactorial object for modeling. The specific features of the artificial microclimate are reflected in the subjective individual reaction of plants. The potential of plants is difficult to assess with the advent of ever new varieties and hybrids that are obtained using biotechnology methods. We concluded that the properties of plants deprive the versatility of the parameters of the artificial microclimate. Each plant needs a particular personal environment for artificial microclimate.

9.8.3 Information Control and Measuring System

Information technology should bring together biologists and engineers to solve specific analytical problems of a practical application. Artificial microclimate creates a habitat for a biological object using engineering equipment, which is structured into separate subsystems of lighting, heating, air conditioning, ventilation, watering, power, gas composition, and more. The microclimate subsystems are served by automated control systems through instrumentation to coordinate work.

The empirical models describing biomass growth due to photosynthesis productivity depending on many factors have disadvantages. In essence, they require a large number of scientific multifactor experiments. The organization of multivariate analyses is a process that involves a lot of time, money, and high accuracy. The determination of the best parameters of a light source is carried out using various methods, including both mathematical (calculation methods for determining optical energy by quantity and quality) and physiological (by analyzing the reaction of plants to the lighting spectrum) methods (Nikiforov 2018; Good et al. 2019). But none of the methods can be adopted unambiguously since the reproducibility of scientific research and the quality of the predictability of the result remain very low.

Biotechnological systems for growing plants in an artificial microclimate are among the complex systems. Such complex systems include biological and technical objects with the presence of many components that are combined by a single technological process. Biotechnological systems require organized management. Control methods for closed technical systems are practically transferred to complex biotechnological systems of artificial microclimate.

A task that solves the problem of increasing the efficiency of the management process requires management based on a context-sensitive language. Currently, several insurmountable contradictions interfere with organizing the management of complex systems in a context-sensitive style. This circumstance forces us to use problem-oriented words that are close to nature, with further formalization following the requirements of the technical base of its presentation.

The control problem is related to the concept of biotechnological feedback. Biotechnological feedback is a combination of signal and structural information exchange between the components of a complex system. The idea of biotechnological feedback requires some extraordinary approaches to understanding the management of a complex system. In this case, it is necessary to take into account the features of components with fundamentally different properties. Management in technical systems is usually organized according to judgments based on mathematical modeling. The construction of a technical system with biological components imposes restrictions on the entire system, both of a technical nature and many other limitations. Evaluation of the biological part in a complex system raises the question of the appropriateness of applying a control action at any given time. Now the problems of the biotechnological system are being solved by increasing the complexity of the whole system by creating new subsystems and not established new connections.

An analysis of the work showed that the control problem boils down to isolating the physical signal with subsequent actions at the signal feedback level. The specificity of the biological component is found in a functional state, which is a reaction to past actions of the system, or as consequences of delayed response. Thus, an operational state does not make sense without a comparative analysis of possible functional states in the context of environmental monitoring in an artificial microclimate. An indicator of the assessment of the habitat is plants, on which all changes are reflected. Biotechnological feedback is a source for the formation of databases in a biotechnological system. Management boils down to the need for decision making through the use of systems with databases (knowledge). Biotechnological feedback is an unknown unexplored topic for the practical application of methods that provide an integrated assessment of the quality of the environment regarding the functional state of plants.

Currently, microscopy and analytical methods remain quite popular, which destroys the object as a result of taking a biological sample for analysis. These methods are aimed at assessing the performance of specific plant organs, which are not an integral assessment of the functional state of a biological object. In the last 10 years, studies of functional diagnostic methods have spread in practice. Functional diagnostics is an objective assessment that detects deviations from the norm based on measurements of physical, chemical, or other objective indicators using instrumental or laboratory research methods. An accurate estimate of the environment in an artificial microclimate and the plant's functional state obtains reproducible results. It establishes laws and patterns that can be applied to a wide range of plant objects. Signals of various functional origins can significantly improve the accuracy of early diagnosis, and therefore quickly record the change in the operational state of a biological purpose. Thus, functional diagnostics as the basis of biotechnological feedback is an indicator of the adaptive capabilities of plants through signs of mutual relations between various components of the system.

Currently, there are many methods related to the concepts of the functional state of a biological object (express diagnostics) for assessing the holistic image of plants: the radiography, the method of slow induction of chlorophyll fluorescence, hyperspectral analysis, phenotyping (pattern recognition), the method of acoustic response, technique determination of electric biopotential, electrography, and other methods. But microscopy and analytical methods remain quite popular, which destroys the object as a result of taking a biological sample for analysis. These methods are aimed at assessing the performance of specific plant organs, which are not an integral assessment of the functional state of a biological object. In the last 10 years, methods of functional diagnostics have spread in the practice of research. Functional diagnostics is an objective assessment that detects deviations from the norm based on measurements of physical, chemical, or other objective indicators using instrumental or laboratory research methods. An accurate evaluation of the environment in an artificial microclimate and the functional state of the plant obtains reproducible results and establishes the legality to be applied to a wide range of plant objects. Signals of various functional origins can significantly improve the accuracy of early diagnosis, and therefore quickly record the change in the functional state of a biological purpose. Thus, functional diagnostics as the basis of biotechnological feedback is an indicator of the adaptive capabilities of plants through signs of mutual relations between various components of the system.

The lack of understanding of the internal processes associated with the creation of an artificial microclimate and its effect on plant photobiological processes is reflected in current high-level greenhouse technologies. Modernization of greenhouse production occurs only at the level of individual systems, which makes a slight gain in terms of reducing the energy intensity of the process of growing greenhouse plants, increasing plant productivity, obtaining a particular biochemical composition of plant materials. A breakthrough can provide research to establish an unambiguous relationship between microclimate parameters and internal processes in plants. Based on these studies, biotechnological systems of a new level, the so-called CPS, can be built. CPS is physical and engineering systems whose operations are controlled, coordinated, and integrated by the computing and communication core. Cyber-physical processes will require dynamic self-programming in real-time.

The uniqueness of the situation at the moment is as follows:

- Lack of specialists who combine biological knowledge, technical knowledge, and knowledge of information technology.

- Lack of a simple understanding of the effect of controlled light on the internal processes of plants, including the impact of stimulating the process of germination of plant seeds.
- LED technology is developing rapidly. LED light sources make it possible to form a light-medium by spectral properties in the range from near IR to near UV with sufficient radiation intensity. At the same time, the efficiency of LED sources is continuously increasing. The research spectrum should cover LED not only light sources, but also LED power sources and the quality of the power supply system. LED lighting systems await further development.
- Microprocessor control systems allow you to effectively manage and monitor all parameters of the artificial microclimate and light environment. Precise control systems for plant growth dynamics await further development.
- Methods for determining the functional state of plants in the process of plant development make it possible to assess the influence of stimulating factors through real-time assessment of the functional activity of seeds. Analysis of the process of seed germination can be carried out without waiting for the appearance of external phenotypic characters. Methods for determining the functional state of plants are aimed at finding an integral parameter that is a consolidator of all other influences and factors. The essential indicator tracks the impact of all elements of artificial microclimate. The control and measuring system regularly sends data that is generated, analyzed, and creates a greenhouse operation system. Methods for determining the functional state of plants are waiting for further development and practical application.

9.9 Policies and Legal Framework Toward Greenhouse Agro-Technology

The goal of the AgTech greenhouse agricultural technology policy is to create such institutional conditions that will allow us to form a competitive product and enhance the competitiveness of agricultural enterprises. The main instrument of such a policy should be the digital economy. The digital economy is an adaptive cyber-physical system of systems. The digital economy allows at every moment the most rational use of the resources at its disposal for the fullest possible satisfaction of the needs of its participants. The core elements of the digital economy are constantly transforming integrated product and service systems (PSS).

The European Union (EU) Commission is a prime example of addressing climate and environmental issues (Brussels, December 11, 2019). The EU is trying to create an industrial strategy within the framework of the European Green Deal project to solve the double problem of green and digital transformation. The principal objective of the new political program will be to stimulate the development of leading markets for a climate-neutral in the EU and beyond. The new project should unite citizens in all their diversity, with national, regional, local authorities, civil society, and industry, working closely with EU institutions and advisory bodies. Digital technology is an essential tool for achieving the sustainable development goals of

The European Green Deal. The Commission aims to examine measures to ensure that digital technologies, such as artificial intelligence, 5G, cloud, and peripheral computing, and the Internet of things, can accelerate and maximize the impact of policies to combat climate change and protect the environment. The practice of the EU Commission has no precedent in the scale of the work done and in the number of countries that are united by one goal.

The European Green Deal project was the result of past work. A group of scientists from three international institutes held more than 20 months of various kinds of events: 18 official negotiations, bilateral meetings, and meetings of working groups of interested parties, after which an agreement was drawn up on June 28, 2017. The new organic regulation is EU regulation 2018/848. In 2017, organic regulation was finally agreed upon after one of the longest stages of debate and negotiation that the EU has seen. The European Council said that over the next 10 years, the commission would assess the compatibility of this practice with the principles of organic production. The commission will be able to use the results of the analysis, after which the commission will be able to submit an appropriate legislative proposal.

Organic food research in the USA has been underway for over 20 years. The USA National Organic Standards Board (NOSB), on November 1, 2017, decided that hydroponic and container greenhouses would be eligible for organic certification. The Straits Times (June 25, 2019) reported that Sky Greens, an island city, the vertical farm, was awarded the world's first national standard for organic vegetables grown in urban settings. The equivalence rules between organic in the USA and the EU have been controversial. All US and EU trade agreements now have another area in which manufacturing differences exist.

Thus, scientific research in the field of AgTech should develop in parallel with the development of concepts such as organic food products, functional food products, and the status of vertical farms at the level of international standards. AgTech standards will provide a fundamental foundation for building policies to address climate and environmental issues.

9.10 Conclusion

The evolution of greenhouse production is at the beginning of the journey, we must hurry. Over the next 50 years, scientists predict rapid climate change. Scientists estimate that when the air temperature rises for every 1 °C, 10% of agricultural land will be lost. Governments will face enormous challenges in the future related to safe food and water supply. Vertical farming can be potentially useful to increase food production and promote sustainable urban management.

Thus, we believe that there are no terrible greenhouse technologies. An essential factor in the success of technology is external conditions: the technological and intellectual level of the country; a unique way of thinking to combine technical and biological systems; non-standard methods of research and design of closed systems.

9.11 Future Roadmap Toward Greenhouse Agro-Technology and Sustainability

An optimistic forecast is provided by a parallel engineering workshop (CE) at the German Aerospace Center (DLR) in Bremen, together with the Association for Vertical Agriculture (AVF) (Final Report Vertical Farm 2.0 2015). The workshop brought together experts from around the world to share their experience and knowledge in collaboration. The seminar aimed to develop a basic functional scenario in all areas for design, technical equipment, technological process, logistics process, and more. Searching for equivalents of new types of organizations or platforms specializing in innovations of this scale, AVF is currently the only international organization with 300 members from all sides of CEA and beyond.

An analysis of the conclusions that scientists gave at the events could be the basis of the roadmap of the future on the path to agricultural greenhouse technologies and sustainable development:

- A vertical farming project can be seen as a model for simulating future projects. The main objective of the project is to formulate a criterion for comparing technologies and a methodology for assessing the effectiveness of agricultural technologies.
- The project plays the role of a platform on which the most advanced technologies were introduced or, for comparison, several different techniques.
- The project must have an open information platform with the same projects in different countries. An open-source concept would contribute to the accumulation of data for analysis and the search for patterns.
- The project should be developed continuously in the framework of the digital economy, logistics, business projects, and much more.
- The project should solve problems that are related to the issues of big data, artificial intelligence, robotics, and much more.

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