Creating closed technobioecosystems (synergotron class) as a modern direction of using digital technologies for the development of Agrarian Science and solving tasks of the agrarian-industrial complex of Russia

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Abstract. In the historical perspective, systems for growing food plants have changed in accordance with the development of the technological structures of humanity. The transition from growing plants in open ground with practically unregulated natural conditions to semi-enclosed (industrial greenhouses, vertical farms, phytotech complexes) with an increase in the proportion of controlled microclimatic parameters allowed to achieve an increase in plant productivity. The logic of further social development leads to an understanding of the need to create and use closed technobioecosystems of the synergotron class for food production with a high content of biologically active substances and to save production resources. The paper presents a review of the history of the development of views and concepts of using biological and technical knowledge in the Agrarian Science and production with the purpose to improve the efficiency of agricultural production of open and protected soils, as well as the emergence of new approaches associated with the creation of closed technobioecosystems of the synergotron class based on developing digital technologies applied to agricultural science and innovative agricultural production.

In the last decades of the twentieth century and in the twenty-first century, with the growth of scientific and technological progress, socio-economic conditions change, the degradation of natural systems continues, ensuring the possibility of human existence itself. And this is the period when a person could look inside the atom, discover the laws of genetics, see the structure of the human brain, the structure of the universe, and reveal other secrets.

The development of scientific knowledge in the field of agriculture and crop production is closely related to the development of the human mind, the emergence of a practical request for new ideas in the field of growing plants. The gradual transition from a descriptive approach to biology and plant growing technology to an experimental one has made it possible to achieve significant success in improving crop productivity.
The culture of the field always went hand in hand with the culture of man.” Starting from collecting (gathering wild edible plants), people gradually moved to the selection and cultivation of useful plants near their homes. The logic of further development led to the creation of farming systems, initially primitive systems (slash-and-burn, forest-field, fallow, and shifting), then more complex (steam, steam-fired, grass, etc.) [5].

The next major step was the idea to grow plants in protected ground (shelters, hothouses, greenhouses), i.e. to manage a large number of microclimatic parameters than is possible in open ground.

Since the 30s of the 20th century, hydroponics has been commercialized. This is a method of growing plants, in which various substrates are used instead of natural soil, such soil substitutes (gravel, crushed stone, expanded clay, mineral wool, coconut fiber, etc.). Currently, hydroponic cultivation of vegetables is the main method of greenhouse production. A little later, there are aeroponic installations for growing plants in a substrate-free environment, but aeroponics has not yet received wide practical application [6].

Along with the development of greenhouse production, a search is underway for new approaches to food production. By the end of the twentieth century, in connection with the development of modern technologies, a new paradigm of agricultural production appeared, which is called “vertical farms, or vertical pharring”. A vertical farm is the generic name of a highly automated agro-industrial complex, located in a specially designed high-rise building, as well as the name of the building itself. The main difference between vertical farms from traditional greenhouses and livestock farms is the vertical multi-tiered placement of plantations and an intensive approach to the use of the territory [3]. According to another definition, vertical farms are automated complexes with artificial lighting, heating and air conditioning, closed water circulation and sterile air. Plants in them are placed on numerous tiers, as a result of which the planting area is ten times larger than the area of a building [7].

The report of the University “Higher School of Economics” notes that “the widespread use of super-intensive robotic crop production, in which crop dependence on weather conditions and the need for large areas of farmland will disappear, will raise the level of human food security to a fundamentally new level. Megapolis, settlements in the Far North and in deserts will be self-sufficient in food due to local agro-complexes using synthetic nutrient solutions instead of soil” [7]. According to specialists of the Higher School of Economics (Russia), in developed countries by 2025, vertical farms will become commonplace for the city. By 2040, the cost of one project of such a farm can reach up to 2 billion dollars. And the market will be estimated at a value of about 1-2 trillion dollars. Vertical trusses are, in fact, real industrial facilities, which are also quite energy-intensive [7].

Vertical eco-farms is a new trend in the field of ecological agriculture. It is assumed that such eco-farms will be energy independent due to the use of solar and wind energy and, as a result, completely autonomous. Vertical agrofarms will equip with a system for collecting and purifying water, processing carbon dioxide and waste. This will make it possible to use another source of free energy – biogas. They will have ultra-light and flexible modular designs [12]. Vertical farming will help protect crop production from climate stress and solve the problem of seasonal production of agricultural products. In addition, traditional crop production is faced with the problem of high losses in the stages of product promotion from producer to consumer, while vertical production is focused on food production in areas close to consumption [4].

The concept of “city-farming” is closely related to the concept of “vertical farm.” Today, most people in the world live in cities. According to UN forecasts, already 86% of all residents of developed countries will live in them by 2050. And the number of fertile lands is decreasing every year, in a couple of decades the resources will no longer be enough, making it harder and harder to provide megacities with fresh products. Therefore, many governments are adopting special programs to prevent this problem. This is a global trend; this approach provides tremendous savings on logistics and resources, which is very important for overpopulated territories. Reducing costs reduces the cost of production, not to mention the fact that people get the opportunity to eat fresh vegetables and greens.
that have not traveled thousands of kilometers to get to the table to the buyer [8]. It should be particularly noted that vertical farms are initially planned as an element of the urban environment, and consideration of the architectural features of the city-farms is one of the important tasks of urban planning of the future [4, 3].

1. The concept of vertical farms, the idea of vertical cultivation in plants in urban environments was proposed in 1999 by Professor Dickson Despommier (Columbia University) [13]. According to prof. Despommier, land suitable for agriculture is less due to desertification and global warming. Further, he believes, it will only get worse. After all, the population is growing, and global warming is intensifying. According to the calculations of prof. Despommier, in order to feed at least 8 billion people, it is required to plow up 100 million hectares, which is equal to the area of Brazil’s farmland. The first official scientific report on the prospects for the development of vertical agriculture was made by Karl Schroeder in July 2007. The speaker emphasized, “If the population of the Toronto area is, say, 3 million people, then sixty large buildings — the city of farms — can feed the entire city” [2].

2. In Russia, the introduction of the ideology of vertical and city pharming is currently not taking place actively enough in comparison with the developed countries of the world. The most developed is the concept of phytotech complexes created by the staff of the Federal State Budget Scientific Institution “Agrophysical Research Institute” (St. Petersburg) [10]. The Institute’s specialists believe that, along with the development of traditional greenhouse structures of protected ground, it is necessary to develop and widely use automated systems for intensive resource-saving production of high-quality plant products under artificial lighting (phytotech complexes), located as close as possible to the places of consumption. Phytotech complexes are an aggregate of energy-efficient vegetative-irradiation equipment with methods of directional formation of light and root-borne media implemented in it to optimize plant growth and development, as well as resource-saving technologies for continuous production of plant products and engineering and measuring equipment for monitoring the physiological state of plants and microclimate control. It is possible to create as a mini-tech-engineering complex with an area of several tens of meters, and increase them to large complexes [9].

Thus, the general patterns of development of agricultural production and increase the productivity of agricultural crops lead to an understanding of the need for a gradual transition to closed and semi-closed systems with a controlled microclimate. Growing plants in the open field is an example of an open, open-loop system, with a practically unregulated plant habitat. Plant growth, development and yield are almost entirely dependent on unpredictable weather conditions. Industrial greenhouses and traditional city – farms are an example of a semi-closed system, where the possibilities of environmental management are greatly expanded. Practice has shown that even the creation of a similar, partially closed agroecosystem makes it possible to achieve a significant increase in yield and a decrease in dependence on external factors that are difficult to regulate. In developed countries, the cultivation of vegetable crops is gradually moving from open ground to greenhouses (protected ground). Further logical analysis shows the need to move to the next stage, which is the creation of closed systems.

No matter how generally progressive the transition to greenhouse production, practice has shown the negative aspects of this method. Even without regard to high energy consumption and energy losses, one should pay attention to the quality of the products. In greenhouse conditions, a favorable environment is created (a kind of incubator) for the development of pests and plant diseases, which have to be fought with the constant use of pesticides. In turn, the frequent use of any group of pesticides leads to the emergence of resistant forms (strains) of microorganisms, which makes it necessary to increase the dose of pesticides and use new ones. And so in a circle. It is well known that medical safety standards (for example, MPCs of toxicants in agricultural products) for greenhouse vegetables are significantly less stringent than for open ground products. Sometimes this situation is explained by the fact that the degradation (decomposition) of pesticides and other toxicants to the safe
components in greenhouse conditions goes faster than in open ground. Nevertheless, the issue of quality and safety of greenhouse products remains open.

Another point that is often ignored is the steady deterioration in the health of workers in greenhouse factories, despite constant precautions and medical examinations. High humidity, poor ventilation, residual quantities of pesticides and other chemical agents, and other factors of greenhouses are potentially dangerous to humans.

The problems of greenhouse production, as well as the classical model of vertical pharming, are largely associated with the violation of the biological rules of functioning of the controlled agroecosystem. The lack of closure of the system does not allow to sufficiently regulate the environmental parameters for growing plants, so some of the resources are wasted. It is difficult to ensure, for example, that the optimum temperature and humidity of the air is maintained; overheating of plants often happens. The waste problem is quite acute, for example, an unused mineral nutrient solution is usually discharged into the environment, polluting it, and clean water is needed for replacement. The transpiration moisture is not used at all; it is tens and hundreds of times higher than the phytomass of cultivated plants. That is, in most cases there is no recycling and waste-free production.

Thus, within the framework of the well-known approaches, the old paradigm of the development of society and scientific research, the resources and opportunities for acquiring new knowledge and technologies are almost exhausted.

Today comes the understanding of the need to move to the noospheric stage of development of human consciousness on planet Earth. “... Now we have a unique opportunity to be the creators of the new world, and not spectators. To do this, we need not only an understanding of the processes taking place, but also the determination to actively change in the minds and in real life”, as noted by the participants of the International Scientific and Practical Online Conference “Noosphere - the Planet of Mind” [1]. Today, this direction is implemented in the megaproject “Great Contribution of the Continents – A Strategic Model of the Cosmic-Planet Integration of the Planet Earth in the Noosphere”, which is developed by a group of the leading scientists under the auspices of UNESCO.

One of the practical steps in this direction is the development of the “Institute for Strategies for the Development” of a new paradigm in the field of food production, environmental management and scientific research in plant growing and agriculture [11]. Understanding the complexity of this task, both theoretical and practical, its components, at the first stage, the institute focused on developing and creating a practical tool for managing plant growth and development factors, taking into account the synergistic effect of interaction and interaction of such factors. A device (“synergotron”) was created, which can rightly be attributed to a new class of closed-type digital devices for growing plants and conducting research in the field of crop production. Obviously, for the first time, special attention in the development of the device was paid precisely to the principle of the system’s closure, which allows creating a programmatically controlled plant habitat regardless of the season, taking into account feedbacks, while saving material and technical resources.

In a synergotron, the principle of modularity (scalability) is implemented. Therefore, it is possible to create systems on a single principle for growing plants of various sizes, from closed micro-installations in the kitchen conditions of a city apartment to large “factory of plants” that satisfy the food needs of a large group of people. Synergotrons for research can also be assembled in the necessary volume for each specific case, from experimental mini-installations for solving a specific scientific task to a large multi-functional experimental complex.

The principle of modularity also allows, in particular, to substantially block the pathways for the spread of disease sources and plant pests. In modern greenhouses, a source of phytopathogens that appeared in one place quickly spreads over the entire area of the greenhouse and damages the plants. In modular synergotrons with sanitary treatment of the internal space, this is excluded. Foci of infection are easily localized.

The problem of the health of the workers of the “factory of plants” is also solved. Unlike greenhouses or classic vertical city farms, staff is not directly located in the plant growing area. In
other words, a synergotron is a closed system controlled by software, which practically does not require human access inside the working chamber.

A comparative analysis of the technical characteristics of a synergotron and its closest analogues show the advantage of the proposed device for a complex of factors. The principal novelty of a synergotron consists in combining the principles of digital program management (including the formation of expert systems of artificial intelligence and the development of a specialized programming language), the possibility of creating a software-controlled environment, activating factors enhancing the biological potential of plants (biological feedback) and modularity, which allows to create installations of different scales on a single principle, from small room installations to industrial plants for growing plants. Ensuring the closure of the system makes it possible to most accurately regulate microclimatic conditions.

The special significance of a synergotron also lies in the fact that it can be used not only for growing plants, but also for carrying out in-depth scientific research in physiology, genetics, and plant growing. The possibilities of conducting a wide range of tests in a synergotron are connected with the possibility of creating a program-controlled environment and the possibility of activating the biological potential of plants through the use of digital technologies.

Being a digital device, a synergotron not only provides differentiated modes of growing plants in the full cycle of ontogenesis, but also allows the electronic recording of these modes, as well as recording the response (reaction) of plants to the impact of a particular factor. As a result, there is an accumulation of information on the reactions of the biological system to certain types of effects. The information is summarized by the artificial intelligence systems of a synergotron and can ultimately serve as a kind of electronic expert on plant growing systems and give hints to the experimenter.

In addition to speeding up the research process itself, it becomes possible to apply mathematical methods for recording and formalizing data, which makes it easier to solve information exchange problems. The expression of the results of an experiment in the form of a formula or a mathematical model simplifies the understanding of the process by different researchers and makes it possible to unify the knowledge gained.

Of great importance is a programming language designed specifically for a synergotron, designed to control this device, transfer, and accumulate information. This language is easily accessible to experts of agronomic profile.

One of the basic principles of managing the growth and development of plants in the closed system of a synergotron is the creation of methods for directed change and activation of the internal biological capabilities of plants by creating favorable conditions for growth and development in relation to the features of each phenophase using special measures to activate the production process of plants.

One of the main reasons for the low productivity of plants in the open field is (at the level of plant physiology) that plant cells and the plant organism in general have to spend a large amount of nutrients synthesized during photosynthesis to adapt or combat adverse climatic conditions. Thus, the potentially high productivity of photosynthesis of plants in practice is used inefficiently, with low efficiency. If plants create favorable and regulated soil and climatic conditions taking into account natural daily fluctuations in a number of parameters, then the energy directed for these purposes will certainly work to increase the yield and quality of the grown products (accumulation of biologically valuable compounds).

Another way of activation is the creation of a set of parameters in which photosynthesis and the production process of plants in general begin to function in a mode of increased intensity (activation by light pulses, temperature gradients, etc.).

The third method of activation is the use of plant growth regulators, in particular, acting at the cellular level and increasing the intensity of plant metabolism. For example, the use of innovative nanoscale compounds of silicon [14, 15, 17].

The novelty of a synergotron compared to its counterparts lies in the fact that for the first time a tool was created for a holistic, integrated effect on the factors activating the plant growth, and these factors are managed in software mode with the ability to simulate daily and hourly changes.
In general, we can confidently talk about an innovative universal multifunctional research and production complex of a closed type with information processing function, which allows one to create intelligent crop systems (self-learning neural networks). This level of obtaining scientific knowledge is fundamentally different from that achieved in modern agrarian science and corresponds to the sixth technological order.

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