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## SMART AGRICULTURE - TECHNICAL AND ECONOMIC FACTORS OF DEVELOPMENT

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**Abstract:** The authors consider the key factors in the development of smart agriculture. These are technical and socio-economic factors. Technical factors are related to scientific and technical progress and innovations. In this connection, agriculture has undergone various historical developments, i.e. the evolution of agricultural techniques. It is a long historical path from manual tools to sophisticated smart technical systems. The development of smart agriculture, however, is strongly influenced by a complex set of economic and social factors, which determine the speed and extent of its implementation. There are many risks to this development path. The authors analyze in detail certain techniques and socio-economic factors of development. In the concluding remarks, they propose a multidisciplinary approach, an integral approach and a systemic approach in the development of this important, modern stage in the development of agriculture and rural development.

**Keywords:** Smart agriculture, Technical factors, Socio-economic factors, Risks, Conditions of development, Future of development

### INTRODUCTION

Smart agriculture is a revolutionary concept that integrates cutting-edge technologies with traditional agricultural knowledge, creating a synergy that has the potential to transform global food production.

In addition, the development of smart agriculture depends on several key socio-economic factors: optimization of production factors; innovation models and commercialization; economic and agrarian policy of the state, investment in research and development, etc.

For the successful development of smart agriculture, it is necessary to integrate technical and economic factors. This integration requires a number of measures and actions of the state's economic policy, agrarian policy, education of young farmers about the possibilities of smart agriculture, development of the information system, etc.

## **MATERIAL AND METHODS**

The material for this paper originates, first of all, from the master's thesis of the first author, which was defended at the Electrical Engineering of the FTN in Novi Sad, which is indicated in the list of references. There are also works published by authors from this field, as well as works by foreign authors.

The method of work is analytical (method of analysis and synthesis), historical method, comparative method, descriptive method, as well as other methods. The results of the research are given in the headings that follow in the paper.

### **HISTORICAL CONTEX AND EVOLUTION OF AGRICULTURAL TECHNIQUES**

The first technological revolution was agriculture itself as the planned cultivation of plants and domestication of animals, which transformed nomadic hunter-gatherers into organized farmers. Since then, there has been a major evolution in agricultural technology from rudimentary hand tools to today's sophisticated smart systems.

The stages of evolution are:

Pre-industrial agricultural technologies, which used mechanical advances and animal power. Early civilizations (Mesopotamia, Egypt, China, America) developed specialized tools such as plows, irrigation systems, and warehouses. These innovations relied on human and animal energy. This energy paradigm would not change significantly until the Industrial Revolution began to transform agriculture in the 18th and 19th centuries;

Mechanical revolution in agriculture (18th-19th century). This period saw the introduction of iron ploughs, mechanical seed drills and early harvesting machines. The introduction of steam power marked a key change in the energy paradigm of agriculture. Steam-powered threshers and tractors at the end of the 19th century represented the first non-biological energy source used in large-scale agriculture, heralding the upcoming electric revolution (the transition from steam to internal combustion engines in agricultural machinery);

Electrification of rural areas (1900-1950). At the beginning of the 20th century, there was a gradual electrification of rural areas in developed countries, introducing the first electrical technologies in agriculture. This process started first in the USA, and then across Europe, although with different timelines and coverage. Electrical infrastructure created the foundations for modern agricultural practices and significantly improved labor productivity;

The Green Revolution: Chemical and Biological Innovations (1950-1970). This period was marked by the development of high-yielding crop varieties, synthetic fertilizers, pesticides, and expanded irrigation systems. These innovations led to dramatic increases in yields, but also increased dependence on irrigation, as well as growing concerns about environmental impact;

The emergence of precision agriculture (1980-1990) was followed by the emergence of several technologies: Global Positioning System (GPS satellites);

Geographic information systems (GIS - computer systems for storage, analysis and visualization of spatial data);

Variable rate technology (VRT - systems capable of changing the rates of application of seeds, fertilizers and pesticides based on field conditions);

Yield monitors (sensors and systems that measure and map crop yields during harvest) (Pejanović et al., 2025b);

Remote sensing (satellite and aerial photography systems that provide data on crop health, soil moisture and other variables in the field);

Precision agriculture primarily focused on site-specific crop management. This approach was a significant departure from the uniform methods of implementing the Green Revolution;

Digital agriculture and application of smart systems (2000-present). The beginning of the 21<sup>st</sup> century saw the emergence of precision agriculture and its evolution into digital agriculture. These included: Development of automated guidance systems (GPS guidance for tractors and equipment);

Wireless sensor networks (monitor conditions on the ground and transmit data wirelessly) (Pejanović, 2025);

Communication between machines (standards like ISOBUS allow machines and tractors to share data and coordinate operations);

Farm management information systems (software platforms integrate multiple data sources for comprehensive farm management);

Advances in remote sensing (satellite imagery and introduction of drone-based sensing systems).

The era of digital agriculture marked the increasing application of electrical engineering in agriculture (Pejanović, 2025).

Smart agriculture (2010-present). Its characteristics will be described in the following text.

## **TECHNICAL FACTORS OF SMART AGRICULTURE**

The latest evolution in agricultural technology - differently called agriculture 4.0, smart agriculture or agriculture 5.0 - represents the convergence of digital agricultural systems with new technologies. Technical elements that enable the development of smart agriculture include:

Sensor technology - the development of hyperspectral sensors that enable precise monitoring of crop conditions, which is one of the foundations of smart agriculture. The

Internet of Things (IoT) represents interconnected sensor networks that monitor every aspect of agricultural production (Pejanović, 2025);

Drones and satellite technology - Space technology is used for crop monitoring and irrigation systems. These systems enable the collection of data on soil conditions, plant development and water needs over large areas with minimal human resources;

Artificial intelligence and machine learning - Neural networks and other machine learning systems enable the interpretation of a significant amount of data collected by sensors, and the making of precise decisions in resource management (Pejanović et al., 2025a). These include advanced algorithms that analyze agricultural data to recognize and predict patterns (Pejanović et al., 2024b);

Robotics and Automation - Autonomous and semi-autonomous systems perform numerous agricultural tasks;

Cloud and Edge Computing - Distributed processing capabilities that bring computing power to agricultural environments;

Blockchain Technology - Secure, transparent systems for agricultural supply chain management.

Starting from this, smart agriculture assumes a systemic approach that integrates these technologies in order to create adaptive, responsive agricultural production systems capable of optimizing the use of resources and achieving positive agricultural production results.

Smart agriculture implies the convergence of agricultural science and practice with advanced information, communication and control technologies. Scientists and practitioners use different terms - smart agriculture, agriculture 4.0, digital agriculture and precision agriculture - to describe aspects of this technological transformation.

Smart agriculture includes, therefore, the application of modern information and communication technologies (ICT) in agriculture in order to increase the quantity and quality of products while optimizing the necessary human work (Villa-Henricksen et al., 2020).

Key components of smart farming systems:

Sensor and monitoring systems (collect data on agricultural processes, environmental conditions and equipment performance using various sensor technologies) (Pejanović et al., 2025b);

Networks for data transmission and communication (these networks enable the transfer of data between sensors, processing systems and actuators) (Pejanović, 2025);

Data processing and analysis systems (these systems transform raw data into useful insights through various computational approaches);

Artificial intelligence and machine learning (advanced algorithms for pattern recognition and prediction) (Pejanović, 2024);

Decision-making and management systems (systems help decision-makers or make autonomous decisions based on processed data);

Actuation and management systems (these systems implement decisions by controlling agricultural equipment and infrastructure).

The interdisciplinary nature of smart agriculture stems from the above. The main disciplines contributing to smart agriculture include:

Agricultural sciences (crop and animal production, soil science, plant pathology); Electrical engineering (sensors, control, energy systems, communications); Computer science (data analysis, artificial intelligence, software development) (Pejanović et al., 2024a); Mechanical engineering (equipment design, robotics, fluid systems); Environmental science (ecosystem impact, sustainability assessment, climate interactions); Economics (cost-benefit analysis, investment planning, risk management); Social sciences (user adoption factors, workforce impacts, community effects). All this requires cooperation and joint work.

Smart agricultural technologies are applied in different agricultural sectors: Crop production - field crops: precision sowing, variable rate fertilization, automated harvesting; Viticulture: microclimate monitoring, selective harvesting, disease prediction; Orchards: automated pruning, selective harvesting, frost protection systems; Livestock production - dairy farming: automated milking systems, individual animal monitoring, nutrition optimization; livestock: precise feeding, health monitoring, environmental control; Aquaculture: water quality monitoring, automated feeding, production optimization; poultry: behavior monitoring, production monitoring, environmental control; Agriculture in a controlled environment - greenhouses (climate control, automated irrigation, additional lighting); Vertical farms (controlled environment, optimal use of resources); Indoor animal production (environmental monitoring and control systems).

There are many challenges in the application of smart agriculture. These challenges simultaneously drive numerous innovations. We will list the most significant challenges: Climate change (change in temperature patterns, change in precipitation patterns, extreme weather events); Lack of resources (water shortages, land constraints, energy challenges); Population growth and food security (increasing demand for food, yield differences and productivity challenges, food losses and waste); Labor challenges (adverse demographics, labor availability and costs, working conditions and safety); Requirements for environmental sustainability (emission of greenhouse gases, impacts on water quality, preservation of biodiversity, health and soil conservation); Compliance with regulations (regulatory frameworks, consumer expectations).

## **SOCIO-ECONOMIC FACTORS OF SMART AGRICULTURE**

The development of smart agriculture does not depend only on technological innovations but is strongly influenced by a complex set of economic and social factors that determine the speed and scope of its implementation (Pejanović, 2013). There are many socio-

economic factors for the development of smart agriculture (Pejanović, 2013): Investment potential and financial instruments - we are talking about the availability of financial resources for investing in new technologies. Without adequate financial instruments and diversification of funding sources, farmers (especially those from less developed countries) face significant obstacles when implementing smart solutions; Economic sustainability and profitability - the application of modern technologies in agriculture requires significant initial investments in inputs (labor and equipment). At the same time, the key is to achieve an optimal relation between invested funds and achieved results; Market structures and access to markets - the existence of functional market structures enables farmers to access not only domestic but also international markets. In addition, the market influences the movement of food prices; In addition to economic factors, social development factors are also important (Pejanović, 2013). This includes demographic changes and age structure (Pejanović, 2013). Older farmers (whose share in rural areas population increases) are more difficult to adopt innovative technology than young ones. Education and knowledge transfer are very important. The social perception of agriculture as an activity and the willingness of the community to accept technological innovations significantly influence the pace at which smart agriculture develops. Namely, in many societies there is resistance to new technologies, partly due to traditional values, partly due to insufficient understanding of the advantages they bring; Development policies and strategies play a key role in creating a favorable environment for the development of smart agriculture. The Agriculture and Rural Development Strategy set the framework for the long-term development of the sector and can significantly speed up or slow down the introduction of smart technologies. Government incentives, including subsidies for the purchase of modern equipment, tax breaks and other financial instruments, can also significantly influence farmers' decisions to invest in smart technologies; Investing in research and development, as well as cooperation between scientific research institutions and agricultural producers, is an important factor in the development and adaptation of smart technologies to local conditions. The development of startup systems in the field of agriculture and support for incubators and science and technology parks can significantly contribute to innovations in this field; Technological prerequisites include digital infrastructure and availability of technologies. The development of digital infrastructure includes access to the Internet in rural areas, as well as equipment for precision agricultural machinery. Availability and affordability include not only the physical availability of equipment, but also the economic affordability that allows farmers of various economic capabilities to implement at least some level of smart solutions; The ecological dimension includes sustainable resource management, adaptation to climate change and renewable energy sources. Smart agriculture contributes to the sustainable management of natural resources through the optimization of the use of water, energy and other inputs. Along with the sustainable management of natural resources, the reduction of the use of pesticides, mineral fertilizers and other agrochemicals, and the ecological disposal of agricultural waste, smart agriculture is an important instrument in the fight against environmental degradation. Adaptation to climate change is possible through smart agriculture. Smart technologies enable better monitoring of weather conditions, more precise planning of agricultural activities and more efficient management of risks associated with climate change. The integration of renewable energy sources into agricultural production is an important aspect of smart agriculture (Pejanović, 2013).

## CONCLUSION

The development of smart agriculture requires a multidisciplinary approach that integrates knowledge from the fields of agriculture, ecology, information technology and social sciences. Smart farming has real potential for more productive and sustainable agricultural production. This requires a holistic approach that takes into account all relevant socio-economic factors. The successful development of smart agriculture involves finding the optimal balance between economic goals and social needs, including food security, rural development and environmental protection. In addition to all that, education at all levels is important, as is the transfer of knowledge and skills. Technical-technological and socio-economic factors therefore play a decisive role in the development of smart agriculture, determining the pace and scope of its implementation. The successful development of smart agriculture requires an integrated approach that takes into account all relevant factors, from innovation and technology to economic incentives and financial instruments, through education, training and demographic trends, to the institutional framework. The future of smart agriculture depends on society's ability to create a favorable environment for its implementation, which implies adequate development policies and strategies, investments in education and research, development of digital infrastructure and incentives for farmers to adopt new technologies. Smart agriculture is not only a technological innovation, but a complex socio-economic phenomenon that requires a systemic approach and cooperation of all relevant actors, including the state, scientific research institutions, agricultural producers and society as a whole. Only through such an integrated approach is it possible to use the full potential of smart agriculture to achieve sustainable food production and rural development.

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