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THE SIGNIFICANCE AND ROLE OF USING INNOVATIVE TECHNOLOGIES IN MODERN AGRICULTURAL PRODUCTION

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Abstract. In order to succeed to feed the global population in upcoming period, additionally pressed by climate change, or economic shocks and environmental issues, agriculture is forced to be based on innovation and improved technologies. Furthermore, although it mainly works with living organisms and complex chemical processes, it rapidly becomes a part of a digital world. So, current agri-food production ensures food safety and security by the wider use of various drones, robots, sensors, software packages, IoT, etc., enabling business optimization, sustainability and profitability. On other side, in some segments, operating with advanced mechanization, equipment and technology requires specific skills and knowledges form farmers, exposing the user-friendly approach as certain challenge for contemporary science and practice.

Keywords: *Agriculture, innovations, digitalization, technological step forward.*

Introduction

Agriculture is closely linked to the fourth industrial revolution that could be underlined as „smart revolution" (Rose, Chilvers, 2018; Zambon et al., 2019). Currently, agriculture is in certain socio-economic transition trying to relay on benefits offered by previous technological step forward, i.e. digitalization. Overmastering the new technological processes and alternatives have provided upgraded and completely new products and services used in agriculture affecting the important professional transformations, i.e.

advanced interactivity between human capital at one side, and used technology and equipment at other side (Sima et al., 2020; Kalitanyi, Goldman, 2021).

So after „green revolution“ in previous century, or searching for intensive increase in agricultural output at global level, through the impact of modern mechanical engineering, chemistry, or bio-engineering (development of mechanization and equipment, implementation of various irrigation systems, use of improved complex fertilizers' formula, or creation of resilient plant varieties and breeds in laboratories, etc.), (Radović, Jeločnik, 2021), there come to painful sobering primarily caused by environmental and climate change issues, while introducing the „smart farming" concept that will enable overall sustainability to available natural resources and entire agriculture and processing industry throughout the operation under the big data, IoT and clean technologies, complete digitalization and automatization, use of renewables, etc. (Wolfert et al., 2017; Navarro et al., 2020). So current civilization enters and will live in the era of agriculture 4.0 and digital revolution, in strivings to protect the planet Earth from further degradation but also to feed overall population (Zhai et al., 2020; Javaid et al., 2022).

Agriculture 4.0 enables the fusion of contemporary information technology with common agricultural methods. Entering the new era leads to smart and modern agriculture that uses advanced technology to improve the efficiency and productivity of agricultural processes, but respecting the nature and environmental challenges (Lezoche et al., 2020; Sharma et al., 2022). By itself, generally concept 4.0 is underlying the use of Internet and information and communication technologies (ICT), while it brings significant efficiency to production processes not only in industry, but also in other economic sectors, especially in agriculture (Aricioglu et al., 2020). Concept gradually changes commonly practiced agriculture into its modern forms, relying on innovation and advanced technologies, such are artificial intelligence (AI), robotics, the use of drones and machine learning (Dayioglu, Turker, 2021).

Today's conditions for performing agricultural production impose the application of modern technologies as the main solution towards the occurred complex changes. Induced technological progress, in recent decades also involves traditional agriculture, which starts to rely heavily on innovative technology. Implementation of contemporary technologies was additionally accelerated by constancy and intensity in climate changes and environmental pollution, which have drastically increased over the last 100 years, while from market requirements that underline the imperative on food safety (Subić et al., 2017; Arora, 2019; Marina et al., 2024).

In general, global agricultural policies currently are supporting development and implementation of modern technologies, as they tend to be much more productive than traditionally used one (majority of them have already utilize the maximal productive limits, jeopardizing the profitability potential of additional investments in self-development. So, development based on innovation represents high-priority task for entities involved in agriculture (Bannikova et al., 2021).

Application of mentioned systems is reflecting in advanced production cycles, underlaying the sustainability and better efficiency. Innovative solutions in agriculture can be underlined by common term "Precision Agriculture". Many authors have been defined the concept of precision agriculture in different ways, but in essence it represents management strategy under different advanced ICTs, as well as the use of huge datasets from various fields of agriculture for further analysis and decision making. In this way, a more rational use of available resources such are water, soil, fertilizers, pesticides, seeds, energy and labor is enabled. On „smart" strategy-based plant and animal production reduces the losses in water, energy and nutrients, while leads to decrease in negative impact on environment (Sishodia et al., 2020; Khanal et al., 2020; Masi et al., 2022; Dimitrijević, 2023). The paper involves usually required scientific structure. The introduction describes background of observed topic – development of smart agriculture. Subheading methodology explains all used methods and data required for the research. Section turned to results and discussion presents the development of innovative technologies used in modern agriculture, as well as the significance and role of applying these technologies. Besides it underlines possible improvements that can be achieved through their implementation in performed production processes at farms. Further, specific conclusions are provided, along with possibilities for the future use of innovative technologies.

Methodological Framework

Performed research encompasses few for social sciences common methods, such are desktop research (intensive literature and data research), or deduction, analysis and synthesis that enables better understanding of observed topic and forming of adequate conclusions. Above all, used methods have been supported theoretical perception and understanding of impact of "Agriculture 4.0" to current society, identifying certain trends, technological gaps, and top issues.

Paper writing involved combination of globally available scientific literature sources and professional facts, in order to introspect the significance, role and impact of innovations and new technologies use to sustainability of agriculture and food production.

The main goal of the paper is to highlight and make closer the significance and the role of "Smart Agriculture", i.e. the contemporary agricultural practices based on innovative technologies, digitalization and frequent knowledge transfer from academic community and innovation centers to producers.

Results with Discussion

In essence of progress is innovation, while the core of agriculture is turned to survival of humanity. Survival is generally equalized with smart development of agriculture. Basically, innovations are recognized as a locomotive of agricultural development some seven decades ago, while marking constant modernization of agriculture, i.e. technical and technological improvement, was set as global priority. This was set due to few characteristics of respond of agriculture to innovation, as in long run: it will yield much more than the value of invested in initial innovation, or, almost each innovation in agriculture lead to additional decreasing in manual labor use, or, innovations could be usually implemented just after competition of pre-required structural changes in overall economy and society (innovations are usually tested and transferred from other sectors, they force overall infrastructural equipping, etc.), or, smart progress of overall economy will induce rise in incomes and consumption, requiring in one moment development of agriculture, or food import (Papanek, 1954).

Previously, the role of innovations in agriculture has been primarily the combat for enough food for feeding the increased global population. Of course, it was science- based sector at that time. Meanwhile, the significance of innovations in agriculture rise to redefinition of several industrial policies, as it implies unification of many mutually different hi-tech sectors, as are bio and nano-technology, petro-chemistry, genetic engineering, ITC, renewable energy, digitalization, aeronautics, etc., how the current agriculture spreads its battlefield to environmental and health issues, climate changes, or prevention of economic and energy shocks, etc. (Njegovan, Jeločnik, 2013; Subić, Jeločnik, 2023).

Focusing to digitalization as a part of smart farming, it tends to enable rational use of available natural resources, capital, labor, and energy, in line to environmental and climate requirements (Nastić et al., 2023). At micro level, innovations should also support agriculturalists to adequately respond to several issues related to used technology and production system, way of organizing logistic and marketing, or adapting to local environment, etc. (Jeločnik et al., 2024).

There are several technological achievements incorporated in smart agriculture in last few decades. Most of them generally better suits to crop than animal production. Some of key aspects considers the use of GPS, sensors, drones and satellite images.

GPS (Global Positioning System) technology is used to perform precise navigation in equipment appliance based on previously developed highly precise maps (Ali, 2020; Kostić, 2021). Systems are currently increasingly in use, primarily due to easy handling, technical precision and economic affordability even to smaller agricultural producers. The main advantage of GPS is obtaining the reliable information in real time, while its processing enables maximal utilization of the most productive agricultural areas. Besides, they are able to work in any condition that could affect increase in productivity in growing any crop (Pandey et al., 2021).

Application of sensors in agriculture could be diverse, while they are expected to provide a wide range of information, such are: soil moisture, climatic parameters (air temperature and relative humidity), crop condition, nutrient level, or some other parameters that enable easier decision-making (Oparnica et al., 2017, Subic et al., 2017). In modern agriculture, sensors are becoming an indispensable part of the system due to their ability to improve efficiency and sustainability of production (Martos et al., 2021). Applying the full automation and robots in agriculture is based on the use of information collected by different types of sensors.

Satellite images are usually free of charge, while have high temporal resolution (sometimes throughout the whole year), (Nguyen et al., 2020). Also, these images are characterized by lower spatial resolution compared to images obtained by drones or proximal sensors, but they are very important for the development of sustainable solutions due the fact they enable a global overview and consideration (Marszalek et al., 2022). Images supports advanced crop optimization, as offers real-time and complex data related to grown crops, cultivated land, and climate conditions (Weraikat et al., 2024).

The use of drones for monitoring the crops' growing began experimentally during the beginning of 21st century (Mulla, 2013). These modern technical systems equipped with innovative technological solutions offer new ways to monitor and manage agricultural activities, while to improve the efficiency and productivity of agricultural production

(Marina et al., 2023). Drones currently used in agriculture are upgraded usually with different types of sensors, as are multispectral, hyperspectral, thermal and RGB cameras. These upgrades enable precise monitoring of land complex and accurate determination of plant health condition (Lin et al., 2021).

Intelligent systems make possible forecasting complex, usually unknown demands emerged from environment. Smart Agriculture seeks for and offers complete solutions for AI use and automation in the agricultural sector. In developed countries, agriculture and food industry are still facing the challenges turned to demands for increase the productivity, or produced volume of food, as well as to creation of job opportunities for people settled in economically weak and rural areas. Economic trends and rapid changes in business environment also affect the agricultural sector. Some previously performed researches show that there is a huge need for the use of ICT in solving the top problems, while increase the productivity and marketing in agriculture. However, the interest for ICT use in agriculture is far from fully exploited. Introducing the ICT in rural space and agriculture keeps much slower compared to other economic sectors (Milovanović, 2014).

Some key concerns and facts that links the use of new technologies (digitalization) and agriculture at global could be seen on Diagram 1.

Industrialization and development of ICT sector open up the new possibilities for rise in overall economy and continuous advancing in the digital sector. Current development characterizes accelerated progress of new technologies used in agriculture. Technologies such as the Internet, IoT, or robotics are serving as key directions of the fourth industrial revolution, that has significant impact to agriculture as well (Castaneda Miranda, Castano Meneses, 2020). This is well describing by fact that technology based on Internet of Things (IoT) used in agro-food complex has been achieved a growth up to 16% within the period 2017-2022. (Morio et al., 2017). Experts foresee long-term effects by the use of information technologies in agro-food industry, which will be manifested throughout the savings in used resources and materials, as well as costs' optimization (Vladisavljević et al., 2019). Due to growth of agricultural output, there is required revision of production management system used in rural space. Several studies prove that the advancing in digital technology initiates better efficiency in close economic sectors. Momentarily, implementation of digitalities in agriculture could be seen as one of the key ways for improving the efficiency of management, while advancing the sectors' development (Abbasi et al., 2022).

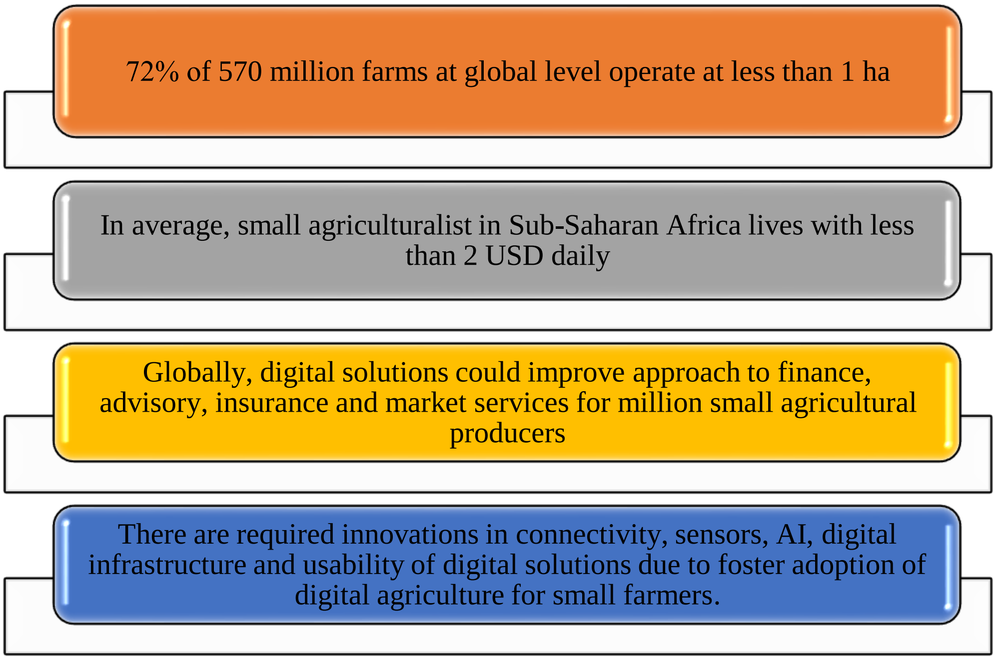

Diagram 1. Key concerns in agriculture related to digitalization (Chandra, Collis, 2021.)

The concept of smart agriculture could be seen as integrated approach to the management of agricultural activities, turned to securing of infrastructure required for the use of modern technologies in food industry. This approach involves using big data, computing services and IoT to monitor, automate and analyze agricultural processes. Also known as precision agriculture, smart agriculture involves software-controlled systems supported by sensor technology. The growing importance of mentioned concept arise from increase in world's population, the higher demand for yields growth, need for more efficient use of available natural resources, advancement in ICT, as well as the large need for climate-sustainable models of agricultural production (Mishra, 2022).

In the most cases, agriculture has played a key role in social and economic development of underdeveloped countries. There are mainly in focus the issues of food security and food safety, i.e. the well-being of population through the maximized productivity and improved food quality. So, improving agriculture in certain country is significant challenge, due to increase in demand for food, or avoiding the problems of hunger and malnutrition (Aker, 2011). The complexity of mentioned issue is additionally underlined by expectation of sustainable growth of agriculture. In current circumstances, farmers are facing the decrease in profit margins, while there comes to increase in costs of input, such are fertilizers and energy, or products' prices have remained stable or even decreased.

IoT is leading technological approach within the smart agriculture, enabling the exchange of datasets between implemented sensors and used devices. Mentioned technology provides adding value to information through automated processing, analyzing and access, making possible quick, while cost-effective management under the agricultural holding. IoT also enables real-time supervision of weeds, pests or diseases occurrence, accidental weather and soil conditions (Boursianis et al., 2022; Dhanaraju et al., 2022).

IoT contributes to rational use of natural resources and inputs. Their application in agriculture provides monitoring and management under different parameters in operational and open environment, using heterogeneous automated components. IoT technologies secures that agriculture in economic sense acts to be simpler to manage, possible for making real-time decisions, decreasing uncertainty, inefficiency, and shallowing environmental footprint.

Among the implemented solutions so far, there could be singled out the systems for pest control, planting, or replacement of heavy tractors that initiates reduction of soil compaction, as well as systems for precise fertigation. Applying IoT to supervise water consumption due to optimal plant growth, as well as to define soil moisture or nutrient content, represents the usual application of IoT technology in agriculture (Zhang et al., 2017; Vladisavljević et al., 2019).

The application of high technologies and automation has been increasingly occurred in livestock production. IoT enables the monitoring of the physical condition and behavior of animals via advanced sensor systems. Good example is "Connected cow" system, developed by the IT company "Fujitsu". System uses sensors placed on animals towards continuous monitoring different health and production parameters. Animal activity data is automatically collected, analyzed and transmitted in real time. Processes such as milking the cows, or feeding the animals are also constantly monitored. Certain animal diseases could be detected in early stage, due to monitoring of changes in physical activity of animals, as reduced moving usually indicates health problems. System significantly contributes in improving the animal health and welfare, or efficiency of livestock production, while reducing the overall costs (Klein, 2017; Nawandar, Satpute, 2019; Katemboh et al., 2020; Koszela et al., 2021).

Information systems and neural networks enable the analysis of large number of data, contributing the improvement of farm business efficiency. The core challenges of farmers are currently the maximization of incomes and costs reduction, while keeping the high products quality in changing production environment. In this context, agricultural enterprises usually create information database enabling continuous exchange of data between analytical and administrative structure of business entity. Mentioned base has crucial importance for the development of IoT in agriculture (Gazquez et al., 2016; Issad et al., 2019).

Use of IoT technologies significantly changes the ways in management and organization of agricultural production. The introduction of Big Data technology, drones and self-driving vehicles, or different sensors, transform the traditional farms into the "smart farms". Obtained technological step forward enables optimization of performed production processes, better management under production resources, while increase the overall productivity in agriculture (Kumar et al., 2022). General level of intensity in mobile internet connection at global level could be considered in the Diagram 2.

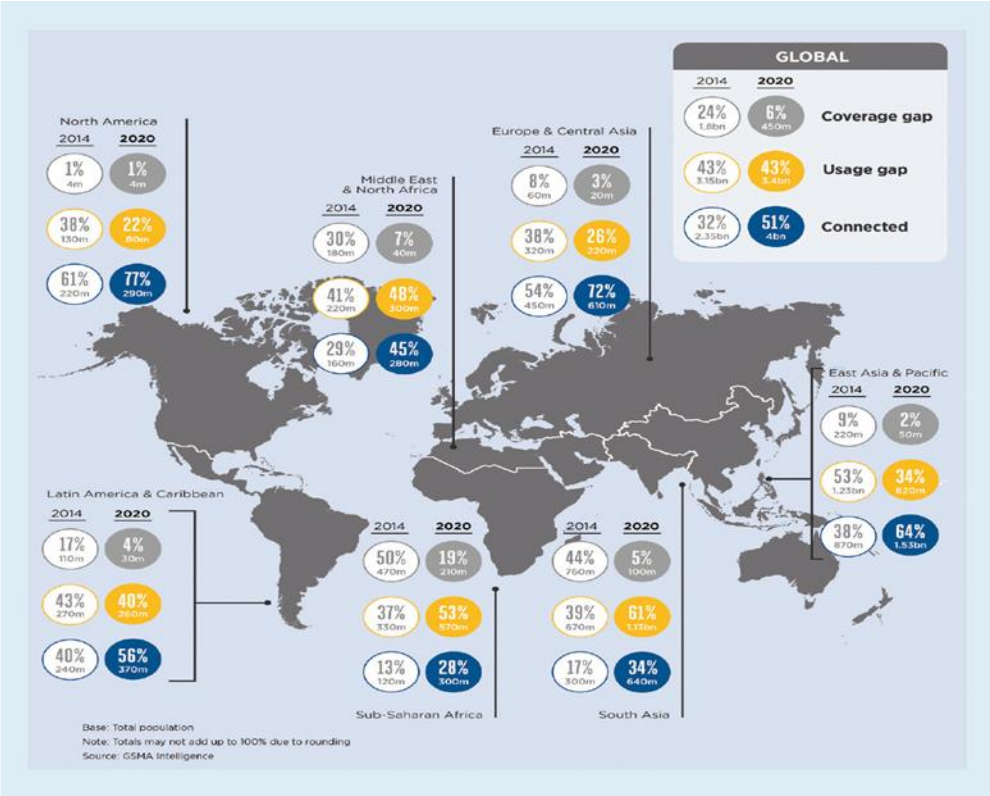

Diagram 2. Linking the mobile internet per global regions in 2020. (GSMA, 2020.)

The use of drones in various economic sectors is growing rapidly. The increase is particularly prominent in agriculture. Some estimations show that the market for drones used in agricultural production is expected to grow from 1.2 billion USD in 2019. to 4.8 billion USD in 2024. (Mukhamediev et al., 2021). From area monitoring to providing security, the use of drones will be more widespread at the farms in upcoming years. Information collected by drones on farms, mainly used for decision-making, are just a part of broader concept known as "precision agriculture". Nowadays, use of drones has already become a key factor in performing large-scale precision agriculture activities in crop production. Field data collected by drones are allowing the farmers to optimally plan planting and treatment activities, due to yields' maximization. Some research points out that precision agriculture systems can significantly increase crop yields, what represents excellent improvement in an industry characterized by low gross margins, such is agriculture (Raj et al., 2022).

Way how the drone application is successfully integrated into agricultural practice represent the monitoring of crops' health status. So, the drones equipped with specialized imaging gadgets that could follow the Normalized Difference Vegetation Index (NDVI), indicate the state of plant health according to crops' color. Mentioned technology allows continuous monitoring of crop growth, enabling quick intervention if any health issue occur (Hama et al., 2021).

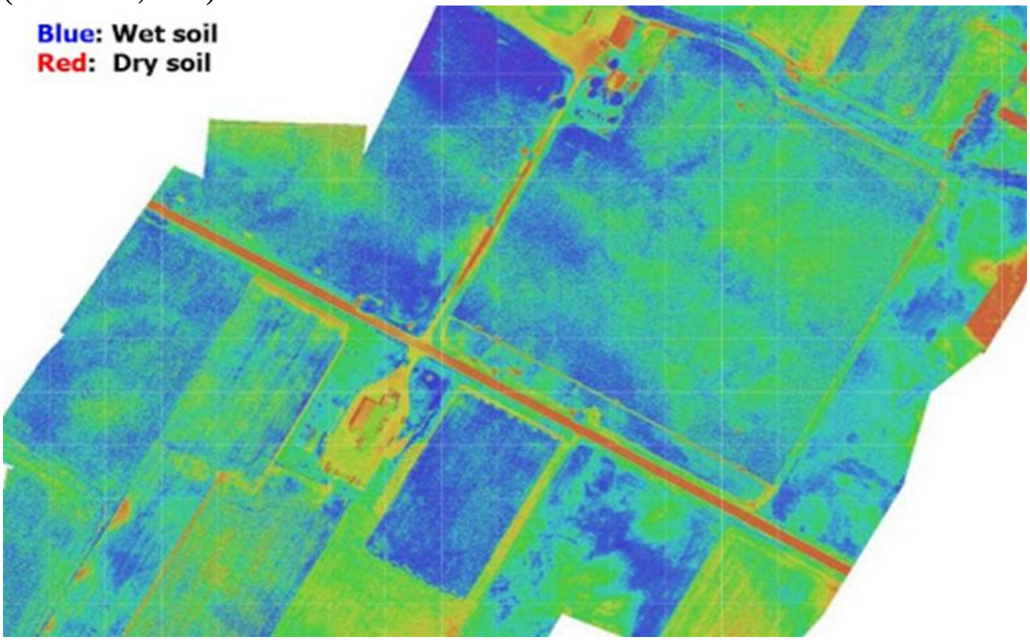

Diagram 3. Real-time monitoring of soil condition due to the level of soil humidity (Croptracker, 2024.)

Drones that use conventional cameras are also being used to monitor crop health. Although many farmers have already used satellite imagery to monitor crop growth, their density and color, access to these kinds of data is usually too expensive and less efficient compared to more precise imagery obtained by drones (as drones fly closer to the fields, the impact of cloudy weather and unfavorable light conditions is much lower than to satellite imaging, while they offer images with precision to couple mm). High precision enables detection of gaps in planted areas, allowing replanting if necessary. It also provides quick detection and further treatment of disease or pest issues. Terrain monitoring by drones is also used to assess the soil health, as well as field conditions. Drones enable accurate mapping of fields, including elevation data, allowing detection of any irregularities at the land parcels. Field elevation information is highly required in determining drainage patterns, while identifying wet and dry areas, enabling use of more efficient irrigation methods (Diagram 3.). Additionally, some enterprises that provide services by agricultural drones, offer possibility to monitor nitrogen level in soil by the use of advanced sensors or leaf of the crop, enabling precise fertilization and elimination of spots with weak crops' growth, while improving the soil health in long-run (McNeil, Snow, 2016; Muraru et al., 2019; Abbas et al., 2023; Rocha et al., 2023; Jalajamony et al., 2023).

Treatment with pesticides by the drones is already widespread in Southeast Asia, while in South Korea over the 30% of spraying treatments with pesticides is done by drones. Sprayer drones are particularly useful in hard-to-reach fields such are steep areas at higher altitudes. They are much effective by conventional ground sprayer, substituting the workers and cutting the labor and inputs costs, while reducing the general health risks. These drones are managed by highly precise software applications, possible to target predefined small land areas (Onler et al., 2023; Kovalev et al., 2024).

Conclusion

In line to deep review of available scientific literature, it could be concluded that the application of new technologies and digitization have a huge impact on all sectors of economy, including the agriculture. Although in other sectors of economy, modern technology, such as IoT, robotics, complete automation of production line, drones, software packages, etc. are applied much more, their increasing use is also noticeable in agriculture.

The application of innovative technologies in modern agricultural production can significantly enhance efficiency and sustainability in several key ways. Precision agriculture utilizes sensors and satellite technologies to monitor soil and crop conditions in real time, enabling farmers to optimize resources and inputs use, such as water and fertilizers, thereby reducing costs and increasing yields (e.g. drones can capture images of fields to identify areas needing additional attention or inputs).

The introduction of robots and automated systems in processes like planting, harvesting, and packaging can greatly reduce the reliance on manual labor while increasing the speed and accuracy of operations. This not only lowers labor costs but also minimizes the risk of human mistakes, leading to better outcomes. Additionally, machine learning and data analytics can assist farmers in making informed decisions based on historical and current data. Predictive models can help determine the optimal timing for planting or harvesting, thus enhancing yields and reducing losses. Furthermore, innovative technologies facilitate the implementation of sustainable practices, such as precision irrigation and integrated pest management, which lessen the environmental impact and contribute to the conservation of natural resources—essential for the long-term sustainability of agricultural production. Digital platforms also enable farmers to connect directly with consumers and markets, reducing distribution costs and increasing profitability. This direct link allows producers to better understand consumer needs and tailor their products accordingly.

In conclusion, innovative technologies have the potential to transform agriculture by enabling better resource utilization, increasing productivity and sustainability, and strengthening the market position of producers. The key challenge remains ensuring adequate education and training for working with these technologies, so that their benefits can be maximized. Through continuous innovation and improvement, agriculture can become more resilient and capable of addressing the challenges posed by global population growth and climate change.

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