Precision and Smart Agriculture – the Present and the Future

'European Agricultural Fund for Rural Development: Europe investing in rural areas'.
The project co-financed from the European Union funds under Scheme II of the Technical Assistance measure 'Polish Rural Network' of the Rural Development Programme for 2014–2020.
The Managing Authority of the Rural Development Programme for 2014–2020 – the Minister of Agriculture and Rural Development.
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Scholar Publishing House
Warsaw 2023

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ISBN 978-83-67450-63-8
doi 10.7366/9788367450638

The monograph titled *Precision and Smart Agriculture – the Present and the Future* was prepared as part of the project: European Green Deal – Opportunities and Challenges for Polish Agriculture. ‘European Agricultural Fund for Rural Development: Europe investing in rural areas’. The project co-financed from the European Union funds under Scheme II of the Technical Assistance measure ‘Polish Rural Network’ of the Rural Development Programme for 2014–2020.
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Publication commissioned by the FDPA and issued by Scholar Publishing House, ul. Oboźna 1, 00-340 Warszawa,
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This publication provides a synopsis of the multi-author study entitled Precision and Smart Agriculture – the Present and the Future, published following the scientific conference organised by the Foundation for the Development of Polish Agriculture in Toruń on 24–25 May 2023. The conference was funded by the Action Plan of the National Rural Network for 2014–2020 and the Operational Programme for 2022–2023. The monograph has six chapters, which are expanded versions of the papers delivered at the seminar, and an addendum with supplementary materials.

The monograph summarises the impact of the components and instruments of the broadly understood technological revolution on the developments in genetic engineering, animal husbandry, and plant production technologies. It comprises six chapters, each dedicated to a separate area of agricultural production.

The first chapter, titled "Precise Animal Farming", discusses the application of smart agriculture tools in animal husbandry.

The notion of precision livestock farming (PLF) refers to the aspects of management based on real-time feedback aimed at eliminating variability that can disrupt the efficiency of the production process. Precision livestock farming, together with precision agriculture (PA), represents elements of smart agriculture (SA). The use of precision production in animal husbandry has been made possible by the development of digital technologies as well as microprocessor optical, biophysical, and chemical sensors to monitor the animals, animal products, and the breeders' supporting equipment.

The main benefits of the PLF include increased productivity, lower operating and labour costs, better profitability and food security, improved food safety and animal welfare, improved labour safety, higher product quality, lower consumption of energy and raw materials. Due to the advantages of the PLF and PA, they were found to be useful in helping to achieve the European Green Deal (EGD) objectives. Wide-scale monitoring of many elements in the environment and animal reactions, available in many systems of precise herd management, or dedicated tools for disease detection, can instantly provide information on subclinical health hazards; this, alongside improved animal welfare, can help eliminate the use of antibiotics. Precise feeding and automated systems for the maintenance of farm animals can help reduce environmental impacts and counteract climate change.

Some of the solutions, especially those related to the ventilation of premises, facilitate better adaptation to the climate anomalies already being observed. Other advantages of PLF and PA solutions are translated into such tangible changes as reduced fuel consumption (by 10%), lower crop protection costs (by 30%), reduced time needed for agrotechnical measures (by 6%), and less time required for tending livestock (by 40%). The use of PLF measures in animal nutrition can reduce its cost by up to 25% and increase feed digestibility to 70%.

However, alongside the benefits and popularity of the PLF, its limitations ought to be mentioned. First and foremost is the high cost of capital expenditure needed for precise farming installations, which makes such investment uneconomic for extensive and semi-subsistence farms. For this reason, the PLF tends to be targeted at large herds. Another limitation lies in the breeders' capacity to absorb new knowledge and apply new technologies, as many of them were educated in an era when the level of technological development was much lower. The last but not least impediment is the low 5G network coverage in rural areas, which can effectively debilitate the PLF systems or cause serious errors in their operation.

PLF measures offer individual nutrition for herded livestock. For this to happen, every single animal needs to be correctly identified and have its dietary requirements defined in terms of the animal's subsistence and production needs. Therefore, individual feeding typically represents one of the components of herd management systems.

Electronic feed stations that enable feeding to be wholly individualised and introduced in the 1990s for sows and dairy cows, today, find applications in other technological groups and species, albeit in a slightly modified formula. Precision feeding, such as electronic sow feeding (ESF) for weaners or fattening pigs in the Exafan or intelligent precision feeding (IPF) systems, requires the use of at least two different feeds with different levels of net energy and amino acids with standardised digestibility. The level of nutrition is flexible and depends only on the speed of weight gain. One clear advantage of these systems is lower feed uptake (by 30%), higher weight gain, reduced nitrogen (N) and phosphorus (P) volumes discharged into the environment (by 40%), and lower greenhouse gas (GHG) emissions (by 6%).

Similar solutions are being tested for broiler chickens, turkeys, and laying hens, with automatic weighing and separating systems being especially popular with pig breeders. Similarly, automated layer systems for poultry weighing not only can be used for obtaining information on weight gain or feed consumption but can also be connected with ventilation controllers to tailor the microclimate to the needs of the growing animals (Flockman).

Traditional weighing scales are no longer needed to measure body mass, since there are many commercial systems on the market that determine the animal's weight based on 3D camera recordings (Weight Detect, eYeScan, Pigwei, OptiScan, GroStat, and WUGGL). Visual systems and image processing technologies above all enable mathematical modelling to be used for monitoring reactions associated with animal health and welfare, and have other practical applications. For instance, the Smart Farm assistant offers flock management for many types of poultry and enables early alerts as well as production planning to be made solely based on the analysis of images and data gleaned from the standard equipment. Self-propelled robots are also increasingly finding their way into poultry houses (FLOX, Spoutnic NAV, Octopus XO, or ChickenBoy).

As regards cattle, and dairy cows in particular, there is a whole range of solutions that facilitate feeding, herd management, heat detection, calving, grazing, etc. The multitude of integrated systemic solutions in place can truly render this sector of production maintenance-free. Owing to the size of the animals, they can be relatively easily fitted out with various kinds of equipment and devices. Contemporary pedometers, accelerometers, tags, and ear tags can also help determine the ratios of specific types of behaviour, changes in body temperature, intensification of rumination and digestion, or even the uptake of feed and water, and the number of breaths (e.g., Fullwood, Afimilk, SCR, ITIN-HOCH).

Other new technologies in precision production include measures enabling the detection of lameness as well as mastitis, also using special ear tags for cows (Smartbow). This can be done using boluses, i.e., rumen pH sensors, that can also measure an animal's temperature (eCow, SmaXtec). Calving sensors are another type of device that is endogenous in nature.

A game-changing breakthrough came with the application of the first-ever milking robot in the Netherlands in 1992. While there were only 2,200 such systems installed across the globe by 2003, today their number is estimated to be around 50,000.

PLF solutions are also present in classical grazing. Stationary sensors to monitor the pace of grass growth and drones with similar software are already available on the market, and the first autonomous grass harvesting machines are already on offer (Exos). The pasture's biomass is also appraised on the basis of commercial satellite imagery. Together with a commercial "electronic shepherd" system (CSIRO, eSheperd, Agersen) using acoustic or electric stimuli to alert the animals that they are approaching a fence, or even virtual fencing, these solutions form an automated system for grazing control.

There is good reason for dubbing smart agriculture "the third green revolution", which is taking place before our very eyes. Just as with any other investment, the PLF requires a stable market situation and production profitability, both being rare commodities in recent years. What will certainly pose a challenge to precision animal production will be the integration of different solutions, technologies, and databases functioning within farms, as well as the communication between them. Even now, some of the PLF servicing and processing of the accumulated data is done in what is called the "cloud" made available by the equipment provider.

In summary, it can be concluded that precision agriculture has been a part of agricultural policies both at national and EU levels, in order to safeguard food security and the attainment of the climate goals. Given the above, the development and integration of the PLF and SA, indicates the evolution of agriculture in an era of global digitisation.

The chapter "Precise Soil Cultivation and Monitoring Systems" discusses contemporary solutions for integrated soil cultivation systems, based on three segments: measuring, executive, and control. These segments underpin the modern approach to maintaining an adequate soil culture that enables its yield potential to be preserved. In 2022, the population of the globe exceeded eight billion people. Some researchers predict that food production will have to grow by 70% in order to feed the Earth's population in 2050. Given the fact that in developed countries the use of farmland is already close to its maximum productivity, the needed solutions might be sought in optimising the available resources for agricultural production.

The main hindrances to optimising agricultural production include the considerable pace of change in crop requirements during the vegetation period as well as dissimilar environmental conditions. This necessitates the use of technological resources enabling an individual approach to the requirements of every plant. If the optimal possible conditions for plant growth are to be maintained, the diagnostic and executive elements need to continue operating on an ongoing basis in relation to individual plants. The discussed systemic solutions comprise three segments: a system for data collection; a system for analysis and prediction, and operational elements. Although each of the segments represents an autonomous technological solution, synergies in soil cultivation can only be obtained if they are fully integrated.

Soil cultivation is an essential activity that helps improve the yields of all crop plants. Cultivation measures ought to enable the plants to intake and convert the maximum possible amount of chemical compounds present in their environment into more complex structures such as proteins, polysaccharides, and lignins, in effect producing higher yields.

These changes are driven by the need to ensure constant access to solar energy and carriers of soil nutrients to crop plants, and limiting the competition from other plants. In each such case, different strategies were formulated over the years to create optimum environmental conditions for plant cultivation. In addition to the factors listed above, there appeared the notions of conservation and regenerative agriculture, i.e., types of cultivation that aim not only to increase the yield but also to improve the soil structure.

The introduction of adequate soil cultivation requires sound knowledge about its condition and adequate tools for its cultivation. Agriculture is currently undergoing a transition associated with a dynamic introduction of technologies enabling a fast transfer of the measurement and control data in basic production processes.

The technologies being introduced in agriculture, focused on collecting and processing data relevant to how production processes are progressing, are described in cloud applications using several related notions such as Agriculture 4.0, Digital Agriculture or Smart Agriculture. The ongoing automation of measurements in agriculture, where the remote exchange of data collected from fields is a continuous process, also results in increased requirements concerning fast access to such data and the associated issue of the baud rates in the databuses that cannot handle such huge volumes of data.

The chapter also discusses the main types of sensors and related solutions used to obtain geolocation data on crop and soil parameters, and the real-time data transfer to other segments of the system.

Allowing widespread access to Global Navigation Satellite System (GNSS) signals and reducing data transmission costs by GSM networks with their simultaneous full accessibility provided a stimulus to introduce automated elements to the farm machinery. An important factor concerning automation in farm machinery is determining the machine's (or rather its operational component's) exact location in the field. This is done using GNSS positioning data from different providers (GPS, Glonass, Galileo). Since the satellites move on different orbits, in many cases it is useful to combine signals from several providers to maintain the continuity of signal positioning.

Placing a GNSS receiver on a tractor allows its position to be actively monitored, but provides no information on the position of use of a given tool. As the GNSS positioning systems became more precise and the control systems were enhanced, machines and devices with autonomous, active adjustment of the working elements' position.

The operational segment is discussed on the basis of semi-automatic structures or autonomous robots fitted out with active elements for conducting cultivation and conservation works. Several structural solutions for field robots are outlined, with a special emphasis on their power supply systems as well as health and safety measures. Modern solutions in operational elements that can align with robots and be used for soil cultivation are also discussed.

The chapter also outlines the architecture that integrates various components of smart agriculture to ensure access to real-time data. Most manufacturers of robots or autonomous agricultural platforms offer electric-powered, self-driving vehicles. It is a practical solution as it enables the use of a single (electric) system to power both the autonomous platform and the components mounted on the robot.

The electric power transmission system is noted for the easy operation of its extremely precise computer controls, good adaptation to the environment, uncomplicated maintenance, and high reliability. Electric propulsion generates forces and momentum using different electric motors to power operational elements directly or via mechanical transmission, so as to enable the robot to make many different moves. In designing the platforms for mobile farming robots, direct current (DC) powered motors are preferred due to their good start-up and speed control characteristics, smooth speed control, high overload capacity, and low impact of electromagnetic interference. If the platform is powered by a combustion engine, then an additional electric system or a hydrostatic system is installed to power the devices.

The use of hydraulic technology has effectively increased the degree of automation and helped popularise agricultural machinery. It also enables many diverse applications, including technical support for farming machines such as control, propulsion, and steering. Hydraulic propulsion mechanisms include hydraulic cylinders for linear motion, hydraulic motors for rotary motion, and tilt engines for tilting motion, which, together with oil tanks, oil pumps, control valves, and control circuits, form the hydraulic propulsion system. It is heavier than the electric one and requires more careful handling.

Farming robots are equipped with operational elements (power source, controller, robotic arm, end effector), devices for monitoring the environment (radar, camera) as well as other supplementary elements. The performance of farming robots depends not only on the working capacity of their individual components but also on the possible coordination between their systems. Most field robots have four systems to ensure their smooth and sturdy operation: a set of sensors and magnitude converters, a set of actuators, data processing and transmission systems, and local or cloud-based data analysis systems.

Solutions supported by external computers can operate in situations when there is a need for greater computer power or when the inference process requires data to be collected from several autonomous units. Cloud computing enables access to cloud-based services (computing, storage, etc.), increasingly incorporating Big Data technologies. Many such technologies have already found applications in agriculture and are expected to also have a presence in future systems where robots will be used on a mass scale.

The introduction of new solutions into crop cultivation is being made possible thanks to the rapid development of new measurement systems and high-speed data transmission. Although today farming robots can replace humans in simple agricultural production, they still fail to meet the requirements of complex operations in multifaceted economic processes. As robotics develops and image processing technologies become more and more advanced, studies of autonomous farming robots operating in structurally complex farmland are starting to enjoy wide currency.

The chapter "Precise Mineral Fertilisation" discusses the applications of contemporary precision farming technologies in mineral fertilisation. Such fertilisation is the primary agrotechnical measure aimed at fulfilling plants' nutritional needs. If mineral fertilisers are improperly or excessively used and not fully absorbed by plants, they will remain in the soil until they are washed away with precipitation into water reservoirs. Excessive fertilisation will permanently disrupt the equilibrium in the nutrient content, ultimately leading to considerable losses in crop yields.

A rational use of mineral fertilisers is advocated because of the economic and ecological aspects arising from the applicable legislation (EGD). Technical solutions and technologies offered by precision agriculture can help reduce mineral fertilisation. One such technology is known as the Variable Rate Application (VRA) and is based on a compact system using data from GPS modules, digital maps, and digital data from soil samples. The use of the VRA technology in mineral fertilising requires fertiliser spreaders fitted out with controllers and actuators enabling automated changes in the fertiliser quantities fed from the hopper onto the spreader discs.

Precision fertilisation also requires specific data resources for identifying soil properties, nutrient content, and plants' nutrient demand needed to obtain the desired yields. Such measures include yield size measurement, soil electromagnetic scanning, soil samples, and satellite or drone remote sensing.

Fertiliser doses that are optimal for plants can be determined if the soil's physical and chemical properties are known, as they affect the soil's biological properties, understood as the diversity and activity of its life forms.

Although soil physical and chemical properties can be examined using soil samples, testing the electric properties of the material under investigation is faster. Hence, a popular precision agriculture method is measuring soil electrical conductivity (EC), a value that is closely correlated with soil salinity and humidity. The EC values also help assess soil texture, organic matter content, and acidity (pH). The soil's EC is typically measured based on electrical resistivity or electromagnetic induction, with conductometers, i.e., devices measuring such values, which can be contact or contact-free.

The data gathered using soil scanners help identify field areas that show the greatest nutrient abundance or deficit. Other sources of data include yield maps from combine and forage harvesters.

Crop yield mapping is a major component of precision agriculture. Multiannual maps represent an excellent source of information on cropping variations in a given field; they help identify the areas with better and weaker crops, thus allowing for their in-depth analyses at a later stage. As the next step, yield maps can be used to prepare maps of fertiliser application and seed usage.

The yield maps obtained from the combine and forage harvesters help find the differences between the given field's individual fragments and analyse the consequences of the tillage activities in detail. Alongside the maps showing soil electric conductivity, the yield maps provide indications for making soil samples.

Fertilisation in precision farming relies on the accurate identification of spatial differences in the content of assimilable nutrients by increasing the number of collected soil samples. Based on the results of assigning the nutrients' availability to abundance classes (threshold values), soil abundance maps, and fertiliser application maps are prepared (so-called application maps).

Precision agriculture uses the zonal method for collecting soil samples, whereby the field is divided into zones based on the soil properties or actual yields. The zones are delineated using

GPS navigation; the method in question requires information on the field properties, on which basis the zones for collecting the soil samples are identified. To this end, the soil EC values can be used as a valid source of information.

The first step in the sample collection procedure is preparing a map of the fields where such samples will be collected. Then, grids are added onto the map – in this way, the fields are divided into zones also known as rasters. Each such raster is assigned an identification number, together with the soil sample collected from it.

Soil samples are collected by an automated vehicle-mounted device with an extractor that makes a puncture 30 cm deep. Then the operator visits all the collection sites in the field, led there by a homing device. Every aggregate sample is put into a plastic bag or other packaging, with a detailed description of the exact field and site it was collected from.

At the final stage of the process, the collected material is delivered to a chemical-agricultural station. In the station's laboratory, the soil samples are dried, ground, and chemically analysed in accordance with the applicable regulations.

The test results obtained from the chemical and agricultural station, supplemented by additional information (such as electromagnetic conductivity, cropping history, and plants' condition) are processed using special balancing methods whereby the nutrient discharge (with the crops, loss of soil nutrients) is compared with their uptake (organic fertilisers, precrop residue, the release of soil nutrients, etc.). Based on such data, detailed maps showing the content of individual nutrients in the soil are prepared. Finally, digital application maps are created to be used in the terminals controlling the operation of fertiliser spreaders.

Precision fertilisation requires machines with an automated regulation of fertiliser quantities and width of the spreading based on GPS data. Currently, many spreader and sprayer manufacturers offer as an extra option of electrical control of the seed (fertiliser) quantities using satellite navigation. In the VRA technology, the system of variable fertiliser application consists of a field computer fitted out with software and GPS, coupled with the spreader's computer.

Mineral fertilisation is a basic tillage activity. Both ecological and economic considerations obligate farmers to reduce fertiliser use. One way to do this is to use variable fertiliser quantities on individual field zones with varying crop productivity arising from variable soil properties, topographic features, etc. Applying variable fertiliser quantities is made possible by precision agriculture.

Practice demonstrates that precision fertilisation generates savings in the form of reduced fertiliser use and fewer differences in the crop yields.

A Summary

The chapter titled “AI Applications in Agriculture” discusses several terms associated with a broad application of artificial intelligence (AI) in agriculture. In recent years, agriculture has seen a genuine revolution driven by the introduction of new data collection technologies. For many years, agricultural production has rested mainly on observations and conclusions made by farmers themselves, while agrotechnical recommendations pertained to some general activities related to the protection of crops and livestock.

For example, wheat sowing dates were calculated by finding the average of trials conducted for many years in the given areas. The resultant recommended sowing dates were formulated on the basis of many overlapping factors, such as soil temperature, humidity, structure, and many others. This, however, may cause problems due to the considerable input of labour required to collect data from a large number of sensors.

Together with the introduction of remote data transmission systems measuring technologies began to be used outside laboratories. The term Internet of Things (IoT) appeared, to describe structural elements as self-standing computer systems linked to data transmission networks. In other words, these elements were granted a subjective status, by being assigned a MAC address, i.e., a unique network identifier.

Concerning agriculture, the IoT enables the transmission of measurement results from a large number of sensors to be automated, in a process which could affect every branch of agricultural production, while generating huge volumes of data. It is estimated that in 2018, 250,000 households representing 10% to 15% of all US households used IoT solutions. Many recent studies indicate that, if used, precise measurement techniques transmitting real-time data can help increase production by as much as 70% compared to the agricultural output today.

The reams of data generated by sensors call for technologies that will allow for their efficient processing and garnering of useful knowledge. Overwhelming the recipients with raw data leads to information chaos that prevents any on-the-ground activities from being commenced. Therefore, technologies enabling data analysis and decision-making need to be devised.

By and large, it can be said that the notion of intelligence refers to the ability to adapt to the changing conditions. Nowadays, it is AI that is becoming increasingly popular and is a hotly debated issue, including various emotional perspectives.

The main idea behind the efforts to develop AI is to create a system that will work similarly to the human brain. The technology is driven by attempts to create algorithms capable of providing answers to specific questions on how the human brain thinks, learns, makes judgments, and collaborates in problem-solving.

Due to the degree of the universality of its algorithms and its potential uses, AI is typically divided into three categories. The first is known as artificial general intelligence (AGI), or strong

AI. It comprises machines that are capable of accomplishing every intellectual task that can be done by humans. Examples of AGI uses include agricultural or companion robots.

Another group includes algorithms that allow operations at the narrow intelligence level (ANI) and is also known as weak AI. Such narrow-intelligence algorithms can surpass humans in performing specific tasks but are not capable of using their skills in other tasks, such as driving or creating works of art.

The last category, artificial superintelligence (ASI), is as yet in the sphere of research; the term refers to algorithms whose intellectual capabilities will be beyond the power of the human mind.

The process whereby AI systems acquire knowledge is called machine learning. AI is a broader concept referring to a set of computational techniques. However, state-of-the-art AI solutions are based on the use of machine learning algorithms.

Supervised learning is probably one most readily associated with the notion of AI. In it, the computer algorithm receives specific training data, consisting of paired input and output data. Another common machine learning method is unsupervised learning, whereby the computer receives unstructured data. The data entered into the system do not specify how the result relates to the input data. Unsupervised learning is used for disclosing yet unknown interrelationships between the data.

Semi-supervised learning is a step between supervised and unsupervised learning. Many datasets have noisy, incorrect labels or no labels at all, which means that the inputs and outputs are incorrectly paired or not paired at all.

Reinforcement learning is learning by the trial and error method, whereby the computer programme is instructed to attain a specific objective in a dynamic environment. The programme learns by undertaking multiple activities, measuring the feedback from such activities and improving its behavioural policy through iteration.

Deep learning is a subfield of machine learning which develops algorithms using multilayer neural networks, mathematical structures loosely inspired by biological neural networks and how they are triggered.

The chatbot known as ChatGPT (Chat Generative Pre-training Transformer – ChatGPT) is a tool based on the GPT-3 model and launched on 30 November 2022. Its main function is to facilitate access to information and perform tasks defined by humans by providing them with useful and accurate answers to their queries.

ChatGPT is considered a game changer for several reasons, one of them being the model's size. With 175 billion parameters, the GPT is one of the largest language models ever devised. It renders ChatGPT one of the most powerful models capable of generating human-emulated text and performing an array of tasks involving natural language processing.

It is also highly rated due to its capacity to produce high-quality text that is congruous and similar to text produced by humans. GPT-3 can create answers to prompt notes that are hardly distinguishable from those written by humans; it can also perform many diverse tasks based on natural language processing without having to resort to task-specific training data.

Even though ChatGPT is a powerful language-generating tool, it is not perfect and at times can produce answers that are not logically congruent. This is due to the limitations in its ability to grasp the context, insufficient knowledge or lack of knowledge about the world, or its excessive reliance on statistical patterns, among other factors.

AI can soon revolutionise agriculture and facilitate more efficient plant production, effective monitoring and crop forecasting. One limitation to the potential use of AI tools in agriculture is the absence of accurate and standardised measurements in farms. Since agriculture in particular is a sector where considerable volumes of data are incomplete or noisy, there is a need to develop methods that will be capable of working effectively with large, yet incomplete datasets.

The chapter titled “Genetic Engineering in Plant Cultivation and Animal Husbandry”, discusses genetic engineering technologies that help improve productivity thanks to the application of novel solutions compliant with sustainable development concepts.

According to the most frequently used definition, biotechnology is the provision of goods and services with the use of biological methods. Biotechnology is a science with a high degree of applicability that integrates knowledge and developments from disciplines such as general biology, applied biology, synthetic biology, and that uses engineering, bioengineering as well as genetic engineering technologies and techniques.

Biotechnology can be divided into traditional and modern branches. Traditional biotechnology involves the use of live organisms in such biotechnological processes as brewing, silage or dairy production. It also includes processes that involve selection methods of crop plants (crop yield) and domestic animals (disease resistance) that are specifically targeted for their utility. The application of genetic engineering techniques is doubtless a more precise alternative as they enable one gene or a group of genes to be modified or directly transferred between related or unrelated organisms in a much shorter period.

There has been an ongoing dispute concerning the classification of organisms produced using biotechnological methods. Cisgenesis involves the transmission of a specific gene(s) between sexually compatible organisms. Intragenesis denotes a modification of the DNA sequence within a single species or the use of techniques to silence the target gene, while transgenesis refers to the process of the gene(s) transmission between phylogenetically distant that are not capable of natural plant crossbreeding.

Methods enabling genome editing and engaging for these specific nucleases include Zinc Finger Nucleases (ZFN), Transcription Activator-Like Effector (TALEN) nucleases, and meganucleases. Genetic modification processes were rapidly accelerated as a result of genome editing techniques being revolutionised and the adaptation of CRISPR, a protective bacterial mechanism, for genetic engineering purposes.

The recent trends in global agriculture notably include the production of a sufficient amount of food to satisfy the needs of the growing human population, improving the living conditions of the population whose lives are directly linked with agriculture, and sustainable development based on the protection and conservation of the environment and natural resources. Given the latest technological advances in biotechnology, we can safely conclude that there exist sufficient ways and possibilities to modify live organisms (microorganisms, plants, and animals) to cater to the needs arising from the trends outlined above.

Biotechnology is a science with a utilitarian mission, and the degree to which it can be employed to address the needs of smart, modern agriculture depends solely on the degree of acceptance of its proposed solutions on the part of the general public, as well as on the legal and organisational determinants. Given the main assumptions of the European Commission's Farm to Fork (F2F) strategy, the aim of which is to attain climate neutrality by 2050 and develop the EU's present food production system into a sustainable model, biotechnology could propose such genetic modifications that will support:

1. The supply of inexpensive food of full nutritional quality, while promoting a healthy and balanced diet;
2. Limiting the pesticide and fertiliser use;
3. Reducing food loss and wastage through waste management and other measures;
4. Developing methods to identify food fraud attempts in the supply chain;
5. Improving animal welfare.

Among the principal directions of plant modifications that could find applications related to attaining the goals set in the EGD and are already applied in plant production across the world, is the introduction of genes which induce herbicide tolerance (HT), insect resistance (IR), abiotic stress tolerance (ST), disease resistance (fungal, bacterial, viral), in addition to the modification of qualitative and quantitative properties, and biofortification.

The application of biotechnology in the modification of animals is similarly well documented. Despite a plethora of commercially available products of animal origin, the main emphasis is placed on its applications in biomedicine. As regards precise animal husbandry, genetic engineering techniques are used to make industrial products or consumer articles (genetically modified fibres), enhance the quantitative manufacturing, and qualitative food properties, build up disease resistance, and increase feed use efficiency. Optimising animal production while maintaining a high level of animal welfare is one of the goals enshrined in the sustainable agriculture strategy.

Even though EU officials have confirmed that products made with the use of New Genomic Techniques (NGT) have the potential to support a more sustainable food system under the EGD, neither the present legal framework nor the society's attitude suggests that such products could find any application in the near future.

The chapter titled "Opportunities for Implementing Precise Agriculture Measures via the CAP Strategic Plan for 2023–2027 Interventions and Other Public Policies" offers information on the algorithms and procedures for implementing precision agriculture elements in the area governed by agricultural policies. The materials presented here are intended to provide information on the development strategies of the agricultural sector given the sector's current economic policy determinants, i.e., a sphere that complements the work related to precision agriculture in the strategic aspects.

Global trends reveal the bourgeoning of investments in the sector of farming technologies, including smart farming (smart agriculture) technologies, and their integral component – precision agriculture (precision farming). The digitisation of agriculture and automation of farm processes are becoming a necessity due to the growing problem of labour shortage in agriculture. Having in mind the ambitious goals of the F2F strategy to reduce the use of chemical PPPs and restrict nutrient losses through better nutrient management, support for digital solutions is essential.

For this reason, the EU's Member States need to give special consideration to the overarching goal in their CAP Strategic Plans for 2023–2027, which is to modernise the agricultural sector by promoting the transfer of knowledge, innovation, and digitisation in farming and rural areas, and offering incentives to apply such novel solutions.

The Strategic Plan for the Common Agricultural Policy 2023–2027 prepared by Poland describes the strategy for the development of digital technologies in farming and rural areas and outlines the strategy indicating how such technologies may be used to improve the efficiency and effectiveness of the Strategic Plan interventions.

The major issues associated with digitisation in farming and rural areas include among others:

- promoting the development and modernisation of information and communication technology (ICT) infrastructure in rural areas and the development of digital telecom infrastructure;
- development of human resources in rural areas based on broadband Internet networks;
- modernisation in agriculture aimed to adapt state-of-the-art technologies, also in automation and digitisation;

- creating and implementing innovative applications and ICT open platforms to enable online advisory services, supporting agricultural producers, and encouraging users to engage in active collaboration (including transfer of knowledge);
- digital education of children, youth, and adults, also in the field of cybersecurity.

The Strategic Plan's interventions that are expected to directly or indirectly facilitate meeting these needs include:

- investments in farms aimed to enhance their competitive edge;
- investments aimed to improve cattle's and pigs' welfare;
- investments contributing to the environment as well as climate protection and conservation;
- sectoral interventions – fruit and vegetables, e.g., under "Improvement of the Infrastructure for Planning and Organising Production, Adapting Production to Qualitative and Quantitative Demand, Optimising Production Costs and Return on Investment, and Stabilising the Prices of Fruit and Vegetable Producers" and "Research and Development";
- infrastructure in rural areas and implementation of the smart villages concept;
- cooperation between the EIP Operational Groups;
- LEADER Local Action Groups.

Initiatives to facilitate the digitisation of agriculture and rural areas are also being implemented outside the CAP. Such instruments will include the national Recovery and Resilience Facility and Cohesion Fund payments, mainly under the Digital Europe Programme, and national funding as part of the Broadband Fund.

Activities aimed to foster the development of digitisation in agriculture will be pursued based on the results of Horizon 2020 and Horizon Europe projects. In addition to those, in making their decisions, farmers in Poland can make use of public data addressed to farmers and made available by the Polish Institute of Meteorology and Water Management – National Research Institute (Pol. Instytut Meteorologii i Gospodarki Wodnej – PIB) or the Drought Monitoring System for Agriculture, which takes into account the climate-related water balance and spatial variability of soil conditions. Yet another instrument is eDWIN, the Online Platform for Advisory and Decision Support in Integrated Plant Protection.

The agricultural sector and rural areas are crucial components in ensuring food security. However, due to changes taking place in the natural environment and climate conditions, the sector is facing the daunting challenges in either adapting to them or curbing their negative impacts. This can be done thanks to precise agriculture solutions and their implementation, and is expected to produce greater yields, limit the use of water, and industrial means of production; it is also consistent with the EGD assumptions. A major part of the process is played by CAP instruments, research funding under Horizon Europe, and initiatives launched by domestic R&D institutions.

A Summary

Poland has developed a set of key issues needed to promote digitisation in agriculture and rural areas. Notably, these include fostering the expansion and modernisation of ICT infrastructure in rural areas, development of digital telecom infrastructure, as well as creation and implementation of innovative applications and open-access ICT platforms that will facilitate online advisory support to agricultural producers and encourage users to engage in active collaboration (including knowledge transfer).

The development of precision agriculture will also enable the adaptation of the farming sector in making structural changes, especially given the labour market limitations. Nonetheless, it needs to be underlined that the use of such technologies will require farmers to acquire new skills, which will have to be preceded by a relevant needs assessment.

We hope that the present monograph will acquaint the readers with the complex matter of new technologies and their applications in agriculture.

The Foundation for the Development of Polish Agriculture (FDPA) is a nongovernmental organisation with traditions dating back 35 years. Our mission is to support the sustainable development of rural areas, in particular, enterprise and the creation of jobs outside agriculture, and to ensure equal opportunities for women, the unemployed, and young people. To this end, as one of the most active and largest loan funds in Poland, we engage in loan activities and services fostering the development of small rural enterprises.

We take part in local development programmes, community initiatives, information, and education schemes. We also publish respected studies and specialist reports such as the biannual report on the state of Poland's rural areas (latest edition: *Polska wieś 2022. Raport o stanie wsi*) and numerous publications to promote the sustainable development of rural areas that deal with issues such as adaptation to climate change and effective resource management.

Since 2009, we have regularly organised a competition entitled Rural Poland – the Legacy and the Future for scientific and popular-science works on agriculture and rural areas and those that promote their history and cultural heritage. We initiated debates held as part of the cyclical event entitled Rural Poland in the 21st Century. We have also organised many international, domestic and local projects addressed to rural residents, farmers, local governments, agricultural advisory centres, public institutions as well as small and medium-sized enterprises.

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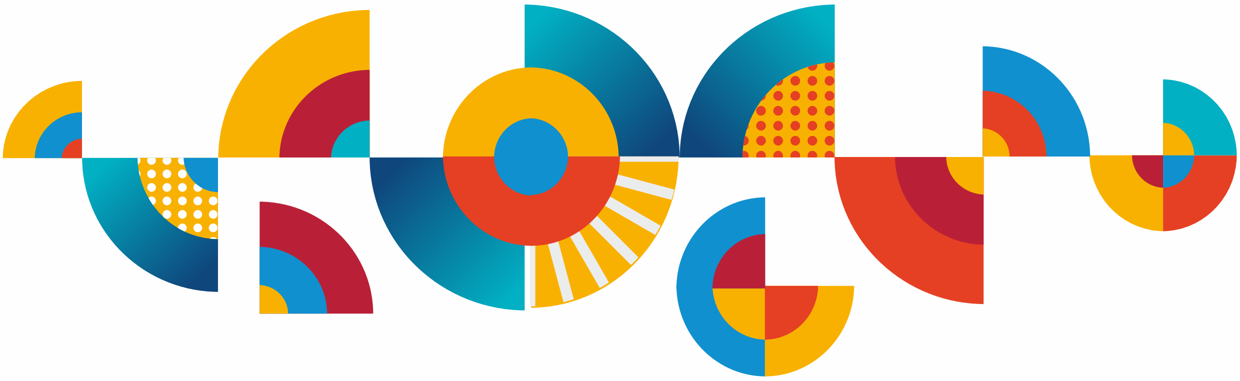
The monograph discusses many aspects of precision agriculture, including animal production, fertilisation, soil cultivation, genetic engineering in plant production and animal husbandry, AI solutions for agriculture, and financing measures. […] Practitioners in animal and plant production will certainly find the publication useful.

Prof. Roman Niżnikowski

Precise and smart agriculture is doubtless the only path whereby the nutritional needs of the growing global population can be met. […] Animal feed grown in vertical farms is already available on the market, as are vegetables grown solely in LED lighting. Currently, more and more farms in Poland are making use of satellite mapping, GNSS positioning, animal microchipping and product tagging, robotic weeders and milking robots. The 4.0 Revolution is taking place before our very eyes.

Dr Jacek Walczak

The monograph is the fifth and last volume compiled as part of a project titled *European Green Deal – Opportunities and Challenges for Polish Agriculture*, administered by the Foundation for the Development of Polish Agriculture (FDPA). The papers included here were originally presented at seminars focused on formulating guidelines for the implementation of the EU's new scheme, European Green Deal (EGD), through farming practices aimed at enhancing opportunities for the development of Polish agriculture.



ISBN 978-83-67450-63-8