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Agriculture in the face of new digitization technologies

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Abstract. Agriculture plays a vital role in food production, resource utilization, and employment but faces challenges from population growth, climate change, and food shortages. The development of information technology has significantly contributed to the industry's development, and modern technologies such as artificial intelligence, the Internet of Things, computer vision, and machine learning have revolutionized agricultural practices. The

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purpose of this review is to explore the adoption of digital technologies in agriculture, with a specific focus on their application in livestock breeding. Through the examination of current literature and the utilization of various research methods, this review contributes to the existing knowledge in the field. It is established that the latest information tools allow collecting, analysing data, automating tasks and supporting decision-making, which leads to increased agricultural efficiency, resource management and sustainable development. It has been proven that modern technologies play a crucial role in increasing agricultural production, improving the efficiency of livestock and crop production. These technologies include devices and sensors, data analytics and decision support systems, as well as systems for overall farm productivity assessment. Precision technologies in agriculture, thanks to automation, sensors and machine learning, allow farmers to monitor animal health, optimise feed consumption, detect diseases at early stages and increase overall productivity. IT solutions in agriculture facilitate data processing, visualisation and decision-making, leading to lower costs, greater efficiency and improved food security. The study provides practical insights for farmers and other agricultural stakeholders who can benefit from accurate information, real-time monitoring and automated processes through the integration of modern technologies, ultimately improving agricultural practices and sustainability

Keywords: sustainable agriculture; digitalization; precision livestock farming; farm management systems; data-driven farming

INTRODUCTION

Agriculture is a crucial sector in many countries that includes crop production and animal husbandry. It plays a vital role in food production, resource utilization, and employment (Gamage *et al.*, 2023). The current challenges of global agriculture are the ever-increasing world population, climate change, food shortages, and land degradation (Subeesh & Mehta, 2021). Therefore, to improve the agricultural food production chain and ensure its maximum safety, it is necessary to implement systems to support farmers. The development of information technology has contributed to the rapid development of various industries (Mahfuz *et al.*, 2022). Modern information technologies in agriculture are recognized as a significant driver of the industry's development (De Vries *et al.*, 2023). Large-scale farms invest heavily in computerization, improving systematization and management. Access to computers and the internet opens up opportunities for farmers (Mendes *et al.*, 2022). The application of digital technology in agriculture has improved efficiency and quality of agricultural production (Yao & Sun, 2023), leading to increased awareness among farmers about the potential of computer and IT networks in production processes (Javaid *et al.*, 2023).

Computer programs support animal inventory, veterinary treatments, machinery maintenance, health assessment, and nutrition management. Decision support systems aid strategic and tactical decision-making by providing relevant information (Eriksen *et al.*, 2022). Advanced technologies, including automatic control systems and GPS, optimize productivity and resource utilization in crop and animal production. Modern technologies in animal husbandry improve welfare, profitability, food security, and environmental impact reduction (Balasundram *et al.*, 2023). Precision dairy farming (PDF) utilizes technology to monitor various animal production, physiological, and behavioral parameters, including heat detection, animal activity, and milk yield. R. Antanaitis *et al.* (2021) implemented precision breeding technologies to assess heat stress indicators such as humidity and temperature in dairy cattle. The reticulorumen parameters, including temperature, pH, rumination index, and walking activity of cows, were measured using boluses. The comprehensive farm management software solution DelPro by DeLaval Inc. (Tumba, Sweden) was used to analyze these measurements. The findings confirm the significance of employing innovative solutions to evaluate heat stress and its impact on animals.

The purpose of this review article was to present the most essential and current information on the implementation of digitization in agriculture, with particular emphasis on livestock breeding, by examining the use of IT tools in agriculture and exploring relevant literature from databases like Google Scholar, ScienceDirect, and Web of Science. Moreover, the search was narrowed down to 2018-2020. The review aims to contribute to a comprehensive understanding of the advancements and potential of digital technologies in enhancing livestock breeding practices and overall agricultural productivity.

MODERN TECHNOLOGIES FOR ENHANCED AGRICULTURAL PRODUCTION

Agriculture is pivotal in providing food products and raw materials for industries, shaping the natural environment, creating jobs, and contributing to the landscape (Pawlak & Kołodziejczak, 2020). To ensure satisfactory

profits, agriculture must leverage appropriate knowledge and implement modern technologies that enhance farm production, alleviate owners from excessive workloads, safeguard the environment, and ensure food safety (Holzinger *et al.*, 2023). Like other farm sectors, agriculture seeks opportunities to maximize income by adopting modern equipment and software, reducing production costs, determining production direction, and improving decision-making. Modern technologies are also introduced to animal production in order to maximize profit or improve the welfare of farm animals (Bao & Xie, 2022; Racewicz *et al.*, 2021).

IT systems have become an integral and pervasive agribusiness component, seamlessly integrated into every sector's operation (Gabriel & Gandorfer, 2023). Modern technologies used in agriculture include devices and sensors (position determination systems, sensors for the content of soil components, the amount of water in the soil, yield forecasting, environmental, soil preparation for sowing, distribution of fertilizer in the soil), data analysis and decision support systems (standards and protocols used to monitor production, algorithms for data processing and reasoning for individual types of production, easy-to-use software) and general farm performance evaluation systems (Gabriel & Gandorfer, 2023; Saranya *et al.*, 2023; Wakchaure *et al.*, 2023). The devices used in modern agriculture are autonomous tractors, harvesting robots, drones, and sensors that measure and monitor crops. In addition, these devices communicate with each other and collect and exchange data (Adusumalli, 2018). Technologies used in agriculture are divided into guidance systems (hardware systems and software that allow you to drive vehicles and machines in the field), data acquisition technologies (from sensors mounted on machines and stationary on the ground, from detection systems using satellites and aircraft, from data collecting and storing spatial data, e.g., yield maps, soil fertility, vegetation coverage of the substrate, soil water content and from sensors and systems evaluating the welfare of farm animals), as well as executive technologies (software and hardware, e.g., automatically controlled sprayer nozzles, agricultural robots, systems of fertilizer seeders with automatic change of the dose of fertilizers, depending on the information contained in the map of soil fertility) (Sadjadi & Fernández, 2023; Xie *et al.*, 2022; Xu *et al.*, 2022).

Up-to-date and accurate information is most valuable to the modern farmer. Due to the growing world population, the demand for food is growing. For this purpose, precision technology in agriculture is used. Automation can improve agriculture's quality and productivity by reducing errors and early detection of diseases in crops or animals (Shin *et al.*, 2022). IT systems used for decision support require a sufficiently large database and constant data supply to function effectively and achieve desired outcomes. In plant production, the collected data inform about the spatial and temporal variability of plant characteristics and the environment and external conditions, e.g., about the properties of soils, plants, pests, estimated yields, and identification of local variability. The data should also include information on the weather forecast and marketing forecasts. The farmer at each stage of cultivation should be able to locate the place from which the information is provided, properly analyze this data, and use the calculations and information provided (Jones *et al.*, 2022). In animal production, data are collected, e.g., on the milk yield of cows, the physical activity of animals, their health, and consumption of water and fodder. Through proper data management, the farm's production efficiency is increased. Based on the collected information, maps with soil and plant data are created. Then models and application maps are created. Sowing, fertilization, and plant protection are carried out based on the maps. The doses of agents are appropriately specified for each place in the field (Aquilani *et al.*, 2022).

Agriculture stands apart from other industries due to several distinctive characteristics. These include its intimate link with the land, reliance on climatic factors, dependence on the specific needs of cultivated plants and animal husbandry, the time-sensitive nature of economic processes, the influence of seasonal variations, the diversification of production, and the versatility of agricultural products. These unique attributes collectively set agriculture apart and shape its requirements and challenges (Pawlak & Kołodziejczak, 2020). The unique production conditions influence the outcomes and expenses of agriculture. Agricultural production has its own distinct characteristics that set it apart from other sectors of the economy. These conditions, both internal and external, play a crucial role in the operation of agricultural companies. These factors include both natural elements such as soil and climate (including the length of the vegetation period, availability of water resources, average and minimum temperatures, soil fertility, occurrences of floods and droughts, etc.), as well as economic factors (such as price levels, demand, logistics, and transportation conditions, labor availability, costs of raw materials and supplies, etc.). These specific conditions have a decisive impact on agricultural operations, shaping the challenges and opportunities agro-companies face (Sadjadi & Fernández, 2023).

In light of growing global food demand, modern agriculture is significantly benefited by accurate, comprehensive data and precision technology, facilitating early disease detection, efficient resource use, and

enhanced productivity. Unique in its dependence on variable natural and economic factors, the sector's outcomes and challenges are directly influenced by the specific conditions, making the integration of predictive and responsive data analysis critical in navigating its unique complexities.

PRECISION LIVESTOCK FARMING AND CROP PRODUCTION

Due to the integration of computer systems, sensors, and machine learning in agriculture, it is possible to implement precision livestock farming (PLF). It aims to make it easier for breeders to monitor product quality, animal health, or welfare, translating into greater productivity (Džermeikaitė *et al.*, 2023). The concept of precise animal production refers to management issues based on real-time feedback aimed at eliminating the variability disturbing the effectiveness of the process itself (Wang *et al.*, 2023). Computer programs in agriculture can be used for animal inventory, recording information on veterinary treatments and lactation data. Programs for comprehensive maintenance of agricultural machinery and equipment are becoming increasingly common. There are also programs to improve efficiency in animal husbandry, which are designed to assess health, feeding rules, environmental conditions, reproduction, and neonatal mortality (Singh *et al.*, 2022). By using modern technologies, such as sensors, and implementing artificial intelligence to manage animal husbandry, breeders can react faster to diseases that do not yet give visual symptoms. For this purpose, monitoring of animal health parameters, which include movement, feed, and water consumption, is used (Neethirajan, 2020). Then, thanks to software and algorithms, deviations or irregularities are predicted in order to be able to identify and quickly react to possible disease entities.

In addition, it is possible to reduce production costs thanks to such solutions. Several algorithms have been identified for detecting various diseases (Neethirajan, 2020). In the case of mastitis detection, the Bag of Words (BoW) and Gradient Boosted Trees (GBT) algorithms are used, which are aimed at detecting somatic cells in milk and electrical conductivity (Dhoble *et al.*, 2019). The detection of mastitis using automatic devices is easier. There are several devices on the market to detect this disease, e.g., Fossomatic meter (Hillerød, Denmark), Dramiński mastitis detector/Mastitis detector (Olsztyn, Poland), Afimilk mastitis detector (Kibbutz Afikim, Israel). They are based on the detection of physicochemical and biological changes in milk or udders or on the assessment of milk or blood biomarkers associated with mastitis (Džermeikaitė *et al.*, 2023). To detect lameness, animal limb movement is assessed, along with imaging, using the Fog computing, Classification, and regressive tree (CART) XGBoost algorithm (Coşkun *et al.*, 2023; Kavlak *et al.*, 2023). Swine flu, on the other hand, is assessed using the Optical flow algorithm by measuring animals' mobility and direction (Neethirajan, 2020). Balanced feeds and optimal nutrition are key to ensuring farm productivity. RGB-D cameras and algorithms such as TDIDT (Top-Down Induction of Decision Trees algorithm), ENET (Elastic-Net algorithm), SSD (Single Shot MultiBox Detector), ARIMA (Auto-Regressive Integrated Moving Average) are used to help farmers estimate their animals' feed and water consumption. This is to assist farmers by allowing them to assess feed expenditure according to the needs of the animals, as well as to estimate the performance of the animals (Neethirajan, 2020). Animal husbandry uses digitization in the form of sensors and accelerometers to monitor animal health (Lemmens *et al.*, 2023). Furthermore, by using image processing and machine learning techniques, it is possible to detect heat in cows early. This involves analyzing the behavior of the animals under examination, presenting a significant solution in the realm of precision farming (Myat Noe *et al.*, 2023). Automation of the milking system (AMS) is also used, which is based on digital devices installed in the milking parlors, which record and collect data on the amount of milk obtained and allow for the analysis and selection of the appropriate amount and type of feed separately for each animal. In addition, during the AMS, the teats of the animals are cleaned by the milking robot, which additionally attaches the milking cups (Hansen *et al.*, 2020). Moreover, the use of automation of milking systems allows farmers to be provided with information on milk yield, milk quality, as well as animal activity (Lemmens *et al.*, 2023). Using biosensors, it is possible to manage herd reproduction. Using, among others, DeLaval Herd Navigator (DeLaval Inc., Tumba, Sweden) it is possible to analyze progesterone contained in cow's milk, but also this program is able to confirm pregnancy in cows, detect early embryo losses, as well as determine the optimal time for insemination of cattle) (Džermeikaitė *et al.*, 2023). In addition to programs for animal production, there are many programs for crop production that can be used for crop rotation by registering crops, planning fieldwork (from sowing or planting to applying fertilization and plant protection products), and managing the machinery park. An additional advantage of using computer programs in agriculture is the possibility of filling out applications for subsidies from the European Union. The European Union launched the Horizon 2020 project 'Internet of Farm & Food' (IoF2020)', which aimed to accelerate technological progress and the use of digital techniques in

agriculture (Klerkx *et al.*, 2019). Also, the Digital Europe program (2021-2027) launched by the EU aims to bring digital technologies closer to companies and present agriculture as a sector where technology development is highly desirable (Sadjadi & Fernández, 2023).

Many agricultural enterprises use various IT solutions that improve their functioning. The basic role of computer programs is to process a huge amount of data and then visualize them in a form that speeds up and facilitates the decision-making process (Sadjadi & Fernández, 2023). Among the most frequently appearing software on the market, the following can be distinguished: systems for processing and then storing information in database systems (e.g. all Internet and applications integrated with the database), systems for communication with external devices connected directly or indirectly to the computer (e.g. an application communicating with GPS) and systems used to communicate with the outside world (e.g. a web browser) (Balasundram *et al.*, 2023).

Decisions of different scopes (strategic, tactical, and operational) are frequently made on farms. The precision of these decisions relies on the knowledge and experience of the farmer, but additional accurate and detailed information can enhance decision-making (Robert *et al.*, 2016). However, acquiring more precise data is often limited by time and cost constraints. Certain information emerges only through the processing of extensive datasets. The processing itself is not time-consuming; the primary challenge for IT tools lies in the time required to input the data into the system. By automating data acquisition processes, this barrier can be reduced (Zhu, 2022). To facilitate accurate decision-making, one approach is to utilize tools that aid in the decision-making process. Decision support systems are employed to gather, process, and present information to users, enabling them to make informed decisions. These systems are commonly utilized at the strategic or tactical level and assist in various stages of the decision-making process. By combining traditional management skills with precision farming technologies, decision support systems enable users to make optimal decisions for their production systems. The availability of an increasing number of programs of this nature further enhances decision-making capabilities in agriculture (Yao & Sun, 2023).

New technologies used in the production system bring many benefits to the production processes. Sensors on agricultural machines and vehicles are able to measure the values of many parameters, and the user has the ability to create various combinations based on measurement values (e.g. machine performance, size of cultivated area, fuel consumption, amount of funds used per unit area) (Abbasi *et al.*, 2022). One of the most important technological achievements in agriculture is automatic control systems. The combined use of automatic section control and GPS allows the machine to be located and the size of the cultivated area to be recorded, in addition, if the machine moves over a previously cultivated area, the system automatically switches off the relevant sections to avoid overlapping treatments (Subeesh & Mehta, 2021). Very often the fields are not the same everywhere, especially in large fields. Often, the borders of crops differ from the borders of plots on cadastral maps. Using modern technologies such as agricultural robots, artificial intelligence, as well as unmanned aerial vehicles (UAV), it is possible to set boundaries based on satellite images, and virtual boundaries are visible to machines (Bacco *et al.*, 2019). Sensors placed in combines can provide information not only on the yield but also on grain moisture (Xu *et al.*, 2019). Information on cultivated acreage and soil mineral content is combined to create field maps, making it possible to control fertilizer doses as needed. When working with a sprayer, positioning allows you to adjust the right amount of plant protection products, which reduces their excessive consumption and reduces the cost of the treatment (Mikula *et al.*, 2020).

The use of modern technologies into animal husbandry is related to the development of ICT technologies, including computer technology and digital technologies, as well as the development of microprocessor chemical, optical, and biophysical sensors, and biomarkers. The use of digitization in farm management has a breakthrough effect, automating many processes, reducing expenses and waste, while increasing the efficiency of farms, which translates into economic profits (Džermeikaitė *et al.*, 2023). Moreover, thanks to the implementation of IT solutions in agriculture, it ensures increased food security and food security, improved animal welfare, increased work safety, as well as reduced environmental impact and counteracting climate change (Zorić *et al.*, 2023). Physically, they translate into reduced fuel consumption (by 10%), reduced costs of crop protection (by 30%), time of agrotechnical treatments (by 6%), and service in animal husbandry (by 40%). As a result of the use of precision farming, fertilization costs may be reduced, and the use of precise animal production in animal nutrition will reduce its cost (Vrchota *et al.*, 2022). The specificity of the issues to be solved, the sensors used, the products obtained, and the approach to animals encourages the use of a species approach. In the case of cows and fatteners, individual monitoring and management are used, while in the rearing of other species, they are treated in groups. Currently, the most advanced technological

solutions in animal production are used in the production of dairy cattle, which in combination with breeding programs constitute commonly functioning systems of integral animal husbandry (e.g. AfiFarm). As part of the systems offered for dairy cattle, there are pedometers and accelerometers (mounted on the limbs or neck of the cow), whose original function was to detect heat by intensifying physical activity. Modern devices can also determine changes in body temperature, pH, monitor the intensity of food intake, chewing and digestion, water consumption, animal activity and the number of breaths (Džermeikaitė *et al.*, 2023). By analyzing volatile organic compounds, it is possible to assess metabolic processes and detect their disorders by analyzing the breath, sweat, and saliva of animals. This technique is employed to test for bovine tuberculosis, brucellosis, or ketoacidosis in cattle. Additionally, the measurement of animal sweat can serve as an indicator of physical stress. Infrared thermography (IRT) is another method utilized for diagnosing and assessing pain in animals, as well as detecting thermal abnormalities. Through IRT, fluctuations in body temperature can be identified, along with conditions such as lameness in horses, mastitis in sheep, and inflammations or infections (Džermeikaitė *et al.*, 2023). Out of concern for the well-being of cows and their health, thanks to the use of automatic feeding systems (e.g. Vector, Optimat T4, Trioliet B. V., Jeantil), it is possible to feed animals individually. These systems are fully automatic (from the automatic collection of the feed material to the dispenser to its delivery to the feed table), but they also have the ability to control feed portions so that the amount in each place is the same (Mahfuz *et al.*, 2022). Real-time information on digestion processes is provided by rumen pH sensors, which also allow for measuring its temperature (e.g. eCow, SmaXtec), which directly translates into the quick diagnosis of metabolic diseases such as acidosis or ketosis. Infrared sensors and cameras are also available to identify mastitis and abomasal displacement. In dairy cattle breeding with the use of milking systems, milk monitoring is used – real-time analysis of milking, e.g. protein, fat, lactose, and somatic cell count. Milk with incorrect parameters can be redirected to another tank, and the measurement results are transferred to the software, creating a much more accurate database than the one from trial milking (Schori & Münger, 2022).

In pig farming, as in dairy cattle, individual feeding systems are used, equipped with electronic feed stations (EFS). The system is based on the use of EFS and individual RFI transponders for pig identification, combined with automatic weighing machines. It is possible to use it both in bedding and slatted systems. The advantages of using this system include lower feed consumption, higher body weight gains, and 30% less nitrogen and phosphorus excreted into the environment. Similar solutions are being tested for broiler chickens, turkeys, and laying hens (Mahfuz *et al.*, 2022). Self-weighing and separating systems are highly favored by pig farmers as they allow for the individual identification of each animal and redirecting them to specific sectors based on their weight. This enables the segregation of heavier animals to sectors with feed containing lower protein and energy concentrations, while lighter animals are directed to sectors with feed rich in protein and energy. Measurement methods rely mainly on obtaining image data of animals, which are processed by appropriate software (Chen *et al.*, 2023). Automatic weighing systems (e.g. Flockman) are used in the rearing of slaughtered poultry, which allows obtaining information, e.g. on growth and feed utilization. Modern technologies in animal production are also used in the management of natural fertilizers or in controlling the microclimate of farm premises (Havelka *et al.*, 2022).

The integration of computer systems, sensors, and machine learning in agriculture enables precision livestock farming and the detection of various diseases, leading to improved productivity, animal welfare.

CONCLUSIONS

Agriculture plays a key role in providing food, resources, employment, and the environment. The effective use of systems in farm management brings numerous benefits, including better monitoring of information, improvement of economic indicators, improvement of data quality on the farm. The implementation of modern sensor-based technologies such as artificial intelligence, the Internet of Things and computer vision has significantly improved farm management, efficiency, and resource utilization in agriculture. These technologies enable data collection, analysis, task automation and decision support, leading to better resource management, sustainability and animal welfare, disease prevention, and soil properties, environmental conditions, and weather. The integration of sensor technology and digital solutions in agriculture has further improved productivity, profitability, food security and environmental sustainability. By harnessing the potential of digital technologies and sensors, future research could focus on improving existing technologies, exploring innovative solutions, and addressing socio-economic issues and adoption challenges. Areas include advances in artificial intelligence and machine learning for smart decision making, development of advanced IoT systems for precise monitoring and control, and exploration of emerging technologies such as robotics. Through research in these areas, the benefits of digital and sensor technologies can be fully exploited, ensuring a more sustainable and productive future for the agricultural industry.

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CONFLICT OF INTEREST

None.

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Анотація. Сільське господарство відіграє життєво важливу роль у виробництві продуктів харчування, використанні ресурсів та забезпеченні зайнятості, але стикається з проблемами, пов'язаними зі зростанням населення, зміною клімату та нестачею продовольства. Розвиток інформаційних технологій зробив значний внесок у розвиток галузі, а сучасні технології, такі як штучний інтелект, інтернет речей, комп'ютерний зір і машинне навчання, зробили революцію в сільськогосподарській практиці. Мета цього огляду - дослідити впровадження цифрових технологій у сільському господарстві з особливим акцентом на їх застосування у тваринництві. Завдяки вивченню сучасної літератури та використанню різних методів дослідження, цей огляд робить внесок в існуючі знання в цій галузі. Встановлено, що новітні інформаційні інструменти дозволяють збирати, аналізувати дані, автоматизувати завдання та підтримувати прийняття рішень, що призводить до підвищення ефективності сільского господарства, управління ресурсами та сталого розвитку. Доведено, що сучасні технології відіграють вирішальну роль у збільшенні сільськогосподарського виробництва, підвищенні ефективності тваринництва та рослинництва. Ці технології включають пристрої та датчики, системи аналізу даних та підтримки прийняття рішень, а також системи загальної оцінки продуктивності фермерських господарств. Точні технології в сільському господарстві, завдяки автоматизації, датчикам і машинному навчанню, дозволяють фермерам стежити за здоров'ям тварин, оптимізувати споживання кормів, виявляти хвороби на ранніх стадіях і підвищувати загальну продуктивність. IT-рішення в сільському господарстві полегшують обробку даних, візуалізацію та прийняття рішень, що призводить до зниження витрат, підвищення ефективності та покращення продовольчої безпеки. Дослідження надає практичну інформацію для фермерів та інших учасників сільськогосподарської галузі, які можуть отримати вигоду від точної інформації, моніторингу в режимі реального часу та автоматизованих процесів шляхом інтеграції сучасних технологій, що в кінцевому підсумку покращує сільськогосподарські практики та стійкість

Ключові слова: стале сільське господарство; діджиталізація; точне тваринництво; системи управління фермами; кероване даними сільське господарство