Artificial Intelligence in Agriculture and Animal Production - Innovations for Sustainable Food Systems: A Review

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Abstract: - Agriculture science, crop production and Animal production, are faced with unprecedented challenges due to climate change, resource constraints, population growth, and calls for sustainability. Artificial Intelligence (AI) is increasingly being used to enhance productivity, make improved decisions, and reduce environmental impacts. In crop production, AI enables precision agriculture, predictive analysis, and disease identification. In animal agriculture, AI enables tracking of livestock, health monitoring, feed optimization, and supply chain optimization. This article captures the applications of AI in both sectors, identifies advantages and disadvantages, and outlines directions for building resilient food systems.

Keywords: - Artificial Intelligence, Smart Agriculture, IoT, Precision Agriculture, Precision Farming, Machine Learning, Automation, Food Security

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1. Introduction

The world's food systems face unprecedented pressures from climate change, population growth, and resource scarcity. By 2050, the global population is expected to exceed **9.7 billion**, demanding a **70 % increase** in food production (FAO, 2021). ***Artificial Intelligence (AI)*** provides new tools for precision farming, enabling data-driven solutions that increase productivity while minimizing environmental impact. Through predictive analytics, autonomous systems, and smart sensing technologies, AI supports the transition toward more resilient and sustainable food systems.

In this we are trying to present a comprehensive review of these emerging technologies being developed within the context of smart agriculture and smart farming, for the benefit of farmers and consumers. By exploring practical applications and prospects in future, this work aims to provide valuable insights to support sustainable development goals through the application of new technologies.

2. Open Field Smart Agriculture

Smart open field agriculture leverages the advantages of the Internet of Things (IoT), artificial intelligence (AI), and other new technologies to optimize crop production and resource management. IoT refers to the concept of autonomous and automated information exchange between real-world devices, leveraging network technologies such as radio frequency identification (RFID) and wireless sensor networks (WSNs). Some of these devices, called sensors, collect information about their environment (e.g. soil moisture, air temperature and humidity, animal temperature and heart rate), while a second group of these devices, referred to as actuators, take care of performing actions that modify their environment (e.g. performing irrigation, turning air conditioning on or off, adjusting lighting, or issuing notifications to farmers). Finally, a third group of devices provides services for storing and managing sensing data, as well as for making data-based decisions about the actions to be taken by the actuators. In this context, drones and UAVs provide aerial imaging and precision spraying, while satellite imaging offers extensive data on crop health, soil conditions and weather patterns, enabling more informed decision-making.

The most important emerging technologies that, combined with artificial intelligence, contribute to the transformation of the smart open field agriculture sector are:

1. Artificial Intelligence and Machine Learning
2. Drones and UAVs
3. Remote Sensing
4. IoT and Sensor Technology
5. Precision Agriculture

2.1 Artificial Intelligence and Machine Learning

AI and ML technologies offer revolutionary solutions to enhance productivity, sustainability, and profitability in farming practice. These technologies have transformed traditional farming into "smart farming" and have the potential to revolutionize the future of agriculture. Various use cases, such as precision agriculture, where AI-powered drones, satellites, and sensors are employed for real-time monitoring of crops, soil conditions, and water usage. People can understand how AI-driven analytics can optimize irrigation, fertilization, and pest control, resulting in improved yield and resource efficiency.

AI is a key enabler in the transformation of agricultural operations and has led to a revolution in the use and analysis of agricultural data. AI techniques (often supported by ML techniques) are used to process large streams of data received from multiple sources, including IoT devices, drones, and satellites, producing predictive models and actionable insights. [13]. Additionally, these tools can be used to plan land use, crop varieties, coordinate planting schedules, and generate predictions about crop yields and prices. Farmers can harness these results to boost farm productivity.

2.2 Drones and UAVs

Agricultural drones, are the electro-mechanical devices that are used in farming, may assist in increasing crop yield, and monitor its growth, among other things. These drones may be used to spray fertilizers or insecticides across a field in a consistent manner. Aerial mapping will also provide farmers with a bird's eye perspective of their fields, allowing them to swiftly spot pests, soil contamination, and growing conditions and to take corrective actions in the form of the engagement of fertilizers and pesticides. UAVs are becoming more common to meet the rising demands of agriculture for the increasing population. Drones will assist straightforward, efficient, and reliable production with the correct cameras, sensor, and equipment. If the solutions offered for these drones are linked into various machine learning and internet ideas, they can help enhance things even more.

The use of drones in agriculture is extending at a brisk pace in crop production, early warning systems, disaster risk reduction, forestry, fisheries, as well as in wildlife conservation, for example.

Precision farming combines sensor data and imaging with real-time data analytics to improve farm productivity through mapping spatial variability in the field. Data collected through drone sorties provides the much-needed wealth of raw data to activate analytical models for agriculture. In supporting precision farming, drones can do soil health scans, monitor crop health, assist in planning irrigation schedules, apply fertilizers, estimate yield data and provide valuable data for weather analysis. Data collected through drones combined with other data sources and analytic solutions provide actionable information.[12]

2.3 Remote sensing

Remote sensing technologies enhance farmers' monitoring capabilities, offering insights into crop status, soil richness, and weather conditions. Through satellite imagery - which is analyzed using remote sensing algorithms - growers can identify areas with water pressure, gain insights into crop vigor, and estimate harvest times, thus empowering them to manage their holdings more effectively [14].

2.4 IoT and Sensor Technology

IoT allows for real-time monitoring and data collection from various sensors placed throughout the farm. The sensors measure parameters such as soil moisture, temperature, humidity, and crop nutrient levels. For example, soil moisture sensors provide continuous data that can inform accurate irrigation systems that provide the necessary amounts of water to plants, ensuring water conservation and promoting optimal crop growth [15]. At the same time, they reduce the risk of over-irrigation, thus reducing the possibility of nutrients.

2.5 Precision Agriculture

Precision Agriculture (PA) is a whole-farm management approach using information technology, satellite positioning (GNSS) data, remote sensing and proximal data gathering. These technologies have the goal of optimizing returns on inputs whilst potentially reducing environmental impacts. The state-of-the-art of PA on arable land, permanent crops and within dairy farming are reviewed, mainly in the European context, together with some economic aspects of the adoption of PA. Options to address PA adoption are discussed, including measures within the CAP 2014-2020 legislation and the important contribution of advisory services across Europe.[1]

Precision agriculture uses AI to manage multisource information, such as satellite images, soil sensors, and drones. Machine learning algorithms forecast nutrient concentration and drought, in addition to pest outbreaks.

For example, computer vision technology identifies potential diseases in crops such as wheat and corn, allowing for early intervention. Smart irrigation systems using AI cut water use by 30% or more. Crop monitoring using drone technology employs deep learning algorithms that allow them to pinpoint weeds, reducing pesticide use and increasing crop production [7].

3. Precision Livestock Farming (PLF).

Precision livestock farming (PLF) is a new approach that leverages innovative technologies to enhance livestock productivity. With AI and other new emerging technologies, PLF (Precision livestock farming) aims to optimize resource use, improve animal health, and reduce the environmental impact of livestock farming. The main technologies and their applications in precision livestock farming are:

A. Artificial Intelligence
B. Drones and Aerial Monitoring
Γ. IoT and Sensor Technologies
Δ. Automated Feeding and Milking Systems
E. Genomic Technologies

3.1 Artificial Intelligence

Artificial Intelligence (AI) has emerged as a transformative technology in animal science, offering innovative solutions for livestock management, disease detection, genetic improvement, and animal welfare.

Precision Livestock Farming (PLF) involves the use of AI-driven sensors, imaging systems, and data analytics to monitor and manage livestock efficiently. AI-powered wearable devices, such as smart collars, ear tags, and RFID chips, collect real-time data on animal movement, health, and environmental conditions. This information allows farmers to optimize feeding, breeding, and housing conditions to improve productivity and sustainability. For instance, AI-based systems can analyze feeding patterns and adjust nutrition plans to maximize feed efficiency while reducing waste. Similarly, automated milking systems with AI capabilities help monitor milk quality, detect early signs of mastitis, and optimize dairy cow health. [2]

3.2 Drones and Aerial Monitoring

Precision livestock farming uses drones for real-time monitoring, management, and data collection to improve animal health, productivity, and resource efficiency. Drones use sensors like thermal cameras to detect early signs of illness, track herd location, or guide animals with audio cues. They also enable tasks like monitoring pasture health, inspecting infrastructure, and performing tasks that are otherwise time-consuming and labor-intensive, supporting more sustainable and data-driven farming practices.

Additionally, exceptional conditions such as injury of animals can be detected. This is accomplished by obtaining visual or thermal imagery from cameras mounted on the drones and then processing the images using AI algorithms. Drones provide an aerial, bird’s-eye view of the fields, aiding farmers to manage their herds in a more efficient manner; this is especially important for large herds and/or extensive grazing lands [16]. Thermal imaging may also be used to detect heat stress in animals to warrant timely interventions to ensure animal welfare [17].

3.3 IoT and Sensor Technologies

The use of Internet of Things (IoT) technology in the field of animal health monitoring is becoming increasingly popular. IoT-based systems can provide real-time data on various parameters of an animal's health, including body temperature, heart rate, and activity level. This information can be invaluable for farmers, veterinarians, and researchers in identifying and addressing health issues in animals. IoT-based systems can detect subtle changes in an animal's health parameters that may be missed by human observation

However, there are some drawbacks to using IoT technology in animal health monitoring, such as concerns over privacy and security of the data collected. Additionally, the cost of implementing an IoT-based system can be a significant barrier for some farmers or animal owners.

Overall, the use of IoT technology in animal health monitoring has the potential to revolutionize the way we care for and manage animals. With the ability to collect and analyze real-time data on an animal's health parameters, we can better understand and address health issues in animals, leading to improved animal welfare and more efficient management practices.[3]

3.4 Automated Feeding and Milking Systems

Advanced feeding systems such as mixing and feeding robots have been developed to deliver the entire ration to animal groups multiple times a day with accuracy and consistency.

Over recent years, it has become obvious the dairy industry is showing increasing growth in the use of automation, robotics and artificial intelligence (AI) as solutions to many challenges on the farm, particularly as related to labor demands. The challenges created by current labor markets are not the only factors driving a movement toward AI on the farm.

Implementation of AI systems is here to stay. While nothing will replace human presence, involvement and oversight on the farm, developing technologies can help simplify some of the many tasks that have to be managed every day. Automating many of the highly repetitious jobs on the farm may be one answer to some of these challenges.

3.5 Genomic Technologies

Genetic improvement in domesticated animal populations that are used for agricultural production mainly involves selection of males and females that, when mated, are expected to produce progeny that perform better than the average of the current generation. Performance usually includes a combination of multiple characteristics, or traits, most of which are quantitative in nature.[4]

Advancements in genomic technologies allow for the genetic screening and selection of livestock with desirable characteristics, such as resistance to specific diseases, increased growth rates in relation to the conditions in a specific location and enhanced reproductive performance. By integrating genomic data with PLF systems, farmers can make informed decisions about animal breeding, enhancing herd health and productivity.[5]

4. Applications of AI in crop agriculture

- *Precision Agriculture*

AI integrates drones, IoT sensors, and satellite imagery to assess soil health, nutrient levels, and pest outbreaks. Machine Learning Models recommend targeted inputs such as irrigation and fertilizers [6]

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- *Crop Monitoring and Disease Detection*

Computer vision systems analyze plant leaves to detect early symptoms of diseases or nutrient deficiencies. AI-based mobile apps make this accessible to farmers in remote areas.

- *Yield Forecasting and Climate Modeling*

AI-based predictive models estimate yields using weather, soil, and historical data. These insights improve planning and market stability [7].

- *Smart Irrigation*

AI-driven systems optimize irrigation schedules, reducing water consumption while maintaining crop performance [8].

5. Applications of Ai in Animal Production

5.1 *Precision Livestock Farming (PLF)*

AI uses wearable sensors, cameras, and RFID tags to monitor animal health, movement, and productivity in real-time [9].

5.2 Disease Detection and Health Monitoring

Machine learning models analyze animal behavior, feeding patterns, and sound (e.g., coughing in pigs or poultry) to detect illness early, reducing mortality rates.

5.3 Feed Optimization

AI algorithms design balanced rations and predict feed conversion efficiency. This minimizes costs while improving growth rates [10].

5.4 *Breeding and Genetics*

AI supports genomic selection and reproductive technologies, accelerating genetic improvement for disease resistance and productivity [9].

5.5 *Supply Chain and Traceability*

Blockchain integrated with AI ensures traceability of meat, milk, and eggs, enhancing food safety and consumer trust [11].

6. Digital transformation in sustainability

The digital transformation in agriculture and sustainability is a critical driver for reducing inputs, production costs, and ensuring stable production, through the utilization of cutting-edge technologies and specialized expertise.

- *Benefits and Applications*

Resource Optimization: Using sensors, IoT systems, drones, and artificial intelligence (AI), real-time data is collected that allows farmers to monitor environmental conditions, soil moisture, and fertilization needs. Thus, precise irrigation and fertilization can be implemented, reducing water and fertilizer wastage while reducing overall production costs.

Automated Decision-Making: The integration of digital tools allows for the automatic analysis of large volumes of data, facilitating production decisions. This helps to safeguard production, even in times of crisis, making the agricultural sector more resistant.

Enhancing Competitiveness and Sustainability: Through digitalization, producers gain access to personalized advice and services, based on accurate agronomic data. Digitalization also contributes to enhancing food security and competitiveness, creating a comprehensive digital ecosystem.

- *Perspectives*

Digital transformation allows for the creation of an intelligent information system that not only reduces input and production costs but also ensures production stability. Through partnerships between the public and private sectors, solutions are implemented that promote sustainability, enhance production efficiency and make the agri-food sector more sustainable and competitive at national and European level.

The digitalization of agriculture achieves:

- Reduction of inputs and production costs,
- Optimization of the use of natural resources,
- Ensuring stable production,
- Development of innovative, sustainable business models.

This approach is based on the integration of advanced technologies and the use of specialized expertise, creating an integrated, digital ecosystem that guides Greek agriculture towards a more efficient and environmentally friendly future.

7. Challenges and Future Prospects

Despite the many benefits, implementing AI in these areas comes with challenges, including:

- *Cost and Infrastructure:*

The initial investment in high-end systems, as well as the need for reliable connectivity in remote areas, can be obstacles.

- *Training and skills:*

Successful AI integration requires training farmers and ranchers to make the most of the tools available.

- *Data Security:*

Protecting the data collected and processed by AI systems is critical for preventing cyberattacks and ensuring privacy.

With the further evolution of technologies and the support of European and government programs, the effectiveness and adoption of these solutions are expected to improve, leading to a more sustainable and efficient agriculture and livestock farming.

8. Sustainable Food Systems: Conclusions

Food systems and agriculture are at a crossroads, and a profound transformation is needed at all scales, Agroecological and other innovative approaches in agriculture are increasingly praised for their potential contribution to reach these crucial goals.

Globally, our society faces an enormous challenge to feed, house, and provide a healthy life for the growing human population while preserving the environment and natural resources for the benefit of future generations. To meet these challenges, sustainable food production and environmental stewardship are paramount and will require a new approach. The health of humans, animals, and the environment are inextricably linked. This approach can be applied to food safety, sustainable food production, and environmental stewardship by bringing together interdisciplinary teams to address these challenges.

Innovations for sustainable food systems include precision agriculture using sensors and AI for resource optimization, alternative proteins like plant-based, insect, and lab-grown meat, vertical farming in controlled environments, and digital tools for traceability and supply chain efficiency. Other key areas are social and systemic changes, such as promoting plant-based diets, upcycling food waste, creating shorter food supply chains, and fostering community-supported agriculture.

Creating a sustainable food future - simultaneously feeding a more populous world, fostering development and poverty reduction, and mitigating climate change and other environmental damage - presents a set of deeply intertwined challenges. The challenge of sustainably feeding nearly 10 billion people by 2050 is greater than commonly appreciated.

Finally:
Despite the challenges, a sustainable food future is achievable. Regulation and technological innovation will be essential to achieve the most ambitious plans. Innovation in farm management will also be necessary to mitigate emissions. Productivity gains must be linked to protection of carbon-rich ecosystems. Productivity gains are critical. Slowing demand growth is critical too.

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