The transformative role of artificial intelligence in agriculture

As the strength, duration, and complexity of stress increase, it becomes harder to recognize the symptoms of plants, thus making the challenge more difficult. The combined effects of abiotic stress or the interactions between abiotic and biotic stress factors make the symptoms unrecognizable. Symptoms could be interpreted as severe effects of abiotic or biotic stressors. When climate change is considered, the combined effects of plant diseases or insects with abiotic stressors have become more realistic. As we predicted earlier, more virulent plant pathogens or more aggressive insects would appear in the future, and insect mobility might increase along with population growth. Current climate change scenarios predict that global temperatures and droughts will increase in the coming decades, and interactions between abiotic and biotic stressors will become more intertwined and complex. According to the Food and Agricultural Organization of the United Nations, the population will likely increase by 2 billion by the year 2050. As global populations grow, pest outbreaks would threaten our food security. Therefore, we need to find rapid, accurate, and reliable methods to recognize plant symptoms and improve decision-making and mitigate risks. The etiology behind these symptoms should be based on reliable evidence.

We need to highlight the rapidly expanding role of artificial intelligence (AI) in precision agriculture and its transformative potential in disease recognition, food security, and sustainable crop management. As the global population continues to grow, the demand for efficient, resilient, and environmentally responsible agricultural systems has never been greater. Since we cannot increase agricultural areas, let alone that they are decreasing, we need much more sophisticated equipment and agricultural systems to achieve maximum crop yield per unit area. Therefore, AI offers innovative solutions to reshape modern farming practices and enable data-driven decision-making at unprecedented levels. AI in agriculture refers to the use of advanced computational techniques such as machine learning, computer vision, robotics, predictive analytics, and image processing to optimize agricultural productivity and sustainability.

Traditionally, farming has relied heavily on experience, observation, and manual labour in large areas. However, with the integration of AI, agriculture is evolving into a highly precise, efficient, and technologically advanced sector, often referred to as "smart farming" or "precision agriculture," across small or large agricultural areas. One of the most significant applications of AI in agriculture is crop monitoring and disease detection, even in small-scale farms or greenhouses.

Using image analysis and deep learning models, such as those based on YOLO (You Only Look Once) architectures, farmers can identify plant diseases, nutrient deficiencies, and stress conditions (e.g., drought or salinity) at very early stages. For example, AI systems can analyze leaf images to detect symptoms of fungal infections such as Zymoseptoria tritici in wheat or Alternaria in tomato plants. By training the machine to recognize the symptoms resulting from abiotic stress factors such as drought, salinity, or heavy metal stress, as well as biotic stress agents, it is possible to detect these stressors at early stages; therefore, we could reduce yield losses and minimize the use of chemical pesticides or compounds.

Another important application is precision irrigation and resource management. AI systems can integrate data from soil sensors, weather forecasts, and satellite images to determine the optimal amount of water needed by crops at specific growth stages. This not only conserves water, especially in arid regions such as southeastern Türkiye, but also enhances crop productivity. Similarly, AI-driven nutrient and disease management systems can recommend precise fertilizer and pesticide applications, thereby reducing environmental pollution and improving soil health.

AI can also play a crucial role in yield prediction and crop modeling. By analyzing historical data, climate patterns, and real-time field conditions, machine learning algorithms can predict crop yields with high accuracy for future years. These predictions are valuable for farmers, policymakers, and supply chain stakeholders, enabling better planning and risk management. For instance, AI models can forecast how environmental factors such as temperature increases, drought, or cold days under climate change scenarios may influence the spread of plant pathogens or the productivity of crops like wheat, maize, and other crops. In addition, robotics and automation powered by AI are revolutionizing farm operations. For example, farmers are increasingly using autonomous tractors, drones, harvesting robots, and weed-removing robots to perform tasks such as planting, spraying, monitoring, and harvesting. Drones equipped with multispectral cameras can quickly survey large agricultural fields, identifying crop health variability and guiding targeted interventions. This reduces labour costs and increases operational efficiency, particularly in large-scale farming systems.

AI is also contributing significantly to plant breeding and genetic improvement. By analyzing genomic data and phenotypic traits, AI can accelerate the identification of desirable characteristics such as drought tolerance, disease resistance, and salinity tolerance. This is particularly important in the context of global climate change, where crops must adapt to increasingly harsh environmental conditions. Advanced AI tools can shorten breeding cycles and enhance the development of resilient crop varieties. Furthermore, AI-driven decision support systems can increase the reliability of the scientific findings. Mobile applications and cloud-based platforms can provide real-time recommendations on planting dates, pest control strategies, irrigation schedules, and marketing trends. These tools are especially beneficial for smallholder farmers, who may lack access to traditional agricultural extension services.

We could look at the pros and cons of AI to be more realistic. Precision farming and higher productivity, early disease and stress detection, resource optimization, automation and labour reduction, better decision-making, early yield detection, and environmental sustainability could be counted as pros. For example, autonomous tractors use AI to plough fields, plant seeds, apply fertilizers with precision, and minimize human labour and energy costs, which would be reflected in prices. AI-driven drones perform aerial surveys and detect soil health, and weeding robots equipped with AI-powered sensors can distinguish between crops and weeds, reducing the frequency of herbicide applications and promoting eco-friendly farming practices.

In contrast, cons of AI in agriculture could be counted as a high initial cost, especially for small farms; technical complexity; data dependency; limited accessibility in rural areas; maintenance and reliability issues; job displacement, especially for young generations; privacy and data concerns, such as misuse of data; and too much involvement of technology, e.g., farmers may always depend too much on AI even for trivial decisions. It is important to note that many AI models developed in high-income countries are used in low- and middle-income countries. The results from those countries could be misleading and may not help with decision-making. For example, AI-powered tools for detecting crop diseases trained on European or North American data might lead to misdiagnoses or ineffective recommendations for much poorer countries. So, the help will never reach its destination.

Despite its disadvantages and limitations, the adoption of AI in agriculture presents a unique opportunity for farmers and scientists to develop their skills. Essential investment and collaborative research are necessary to fully realize the benefits of AI in agriculture and minimize its negative aspects. We should urgently consider accessibility, cost reduction, farmer training, and infrastructure development. Large farms can invest in fully autonomous agricultural machinery; however, smallholder farmers struggle with high costs and maintenance challenges. To maximize the benefits of AI-driven farm management in developing countries-, and small farms, policymakers should promote digital literacy and expand cloud infrastructure in rural areas. Since agriculture is labour-intensive, we need automation throughout the cropping season to monitor crop health. We can utilize satellite images and weather data to monitor crop health in real-time. AI and machine learning technologies can help forecast the weather, estimate crop yield, and prices.

Before we conclude our letter, we need to explain the terminology and its uses in AI tools. One of the common terminologies with AI is machine learning (ML). This most common terminology is used in crop improvement, crop health monitoring, and disease and pest infestation estimation. The algorithm used in ML is used to analyze large volumes of data on weather patterns, crop and soil monitoring, disease estimation, etc. It is a programming language written in Python. With this learning program, farmers can estimate projected data based on solid evidence. Since the agricultural sector faces multiple risks and uncertainties due to changing climatic conditions and marketing trends, farmers can only judge the potential value of their crops or the impact of incoming stressors based on their experience; however, they may still face too much variation. With ML, they could make estimations on firm evidence. Again, approximately 570 million smallholder farmers are unaware of this opportunity. Since we cannot bring their businesses under a single company, we can unite them in decision-making by introducing this system. So, the crop production and disease management could be maintained safely. Internet of Things (IoT) is another term. Real-time data from IoT devices, such as soil moisture, air temperature, and crop health monitoring systems, can generate predictions that help optimize farming operations. The combination of ML-powered software and IoT allows more precise control over irrigation, fertilization, and pest management. Drones, another device, can be used to collect data on crops, including soil health and water levels. Additionally, these remote sensing platforms can help reduce the use of pesticides, saving time and money compared to traditional methods. Chatbots can also serve as a convenient interface for accessing crop information. It works with AI platforms and provides farmers with smart ideas for their crops and management. Robots are used in smart farming tasks such as weed control, harvesting, and fertigation. With the help of these tools, regression and Bayesian models on crop production and pest management estimation, clustering (similar characters can be grouped to give smart ideas, which can be useful for identifying which plants are more likely to survive in certain stress conditions), and artificial neural networks (ANN) are made. ANN can be suitable for identifying complex data patterns that are too complex for humans to discern. With the help of ANN, we can develop new crop strains that are more resistant to pests and diseases.

In conclusion, AI is poised to revolutionize agriculture by enhancing productivity, improving sustainability, and enabling more informed decision-making. Its applications, from disease detection and precision farming to robotics and climate modeling offer vast areas in agriculture. Although AI has made remarkable improvements in the agricultural sector, it still has a relatively low impact on farmers and scientists compared to other sectors such as medicine and social media. One of the main reasons is that people in this field hesitate to adopt high-tech machine learning solutions, largely due to their limited educational background and approach. However, as we move toward a future characterized by increasing environmental challenges and food demand, the integration of AI into agricultural systems will be essential and crucial. Policymakers, researchers, and farmers must work together to ensure that these technologies are accessible, affordable, and tailored to local needs. AI-invested agricultural sectors receive significant attention, with an expected annual growth rate of 25%. By 2050, AI-based tools in agriculture will reach 85% in developing countries and 95% in developed countries. In terms of AI tool adoption, developing countries are expected to follow developed countries by 10 years until 2040, then narrow the gap to approximately 5 years by 2050.

Additionally, AI-based nanosensing mechanisms and smart sensors are being continuously developed to enable rapid detection of pathogens and abiotic stress, as well as pathogen identification. Policymakers and investors in AI businesses should develop more user-friendly systems and teach AI with minimal training. One should remember that AI systems compatible with existing agricultural workflows are more likely to be accepted. For example, if farmers are happy to operate their farms without AI, it is very difficult to persuade them to adopt AI-based agricultural systems. Therefore, recommendations in favor of AI remain a great challenge. Thus, AI developers and policymakers should be well-trained to adopt AI in agriculture. To close the gap between developed and developing countries, international collaboration can play a crucial role in the transfer of AI.

We hope this letter provides valuable insight into the transformative role of AI in agriculture and encourages further exploration and investment in this promising field.

Useful sources:

https://www. fao.org

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