NEW ERA AGRICULTURE MAGAZINE

Agriculture 4.0: Evolution, Challenges and Future Prospects

Tanvitha P [1]*, M. Rama Devy[2]

Abstract: -

Agriculture 4.0 marks a major shift toward technology driven farming through the integration of IoT, artificial intelligence, automation, robotics and data analytics. It connects all stages of agricultural production using real time data to improve efficiency, productivity and sustainability. The evolution from Agriculture 1.0 to 4.0 reflects a transition from manual and mechanized farming to intelligent, automated systems. While Agriculture 4.0 offers benefits such as optimized input use, improved yields and reduced environmental impact, it also faces challenges related to device durability, energy limitations and data quality. Ensuring reliable, FAIR compliant data is essential for effective decision support systems. Future developments including 5G-enabled smart farms, autonomous systems, genomics and circular bioeconomy approaches are expected to further strengthen sustainable and resilient agricultural systems.

Introduction:

Agriculture 4.0, also known as the next phase of technology-driven farming, offers a way out with the integration of data, automation and smart decision making, it promises a new future for both smallholders and agri-entrepreneurs. It uses technologies like sensors, data analytics, automation and AI to enhance agricultural processes, making them smarter, faster and more efficient, unlike previous revolutions that focused on machinery or chemicals (Wolfert *et al.*, 2017), this one connects every stage, from seed to harvest through real time data driven systems.

Smart sensors now do much more than

Tanvitha P [1]*, M. Rama Devy[2]

Department of Agricultural extension education

[1]Ph.D. Scholar, Department of Agricultural Extension Education,

[2]Professor &Head Department of Agricultura Extension Education

Agricultural College, Bapatla

just tracking activities, they continuously collect valuable data about farm workers, crops and products. Agriculture 4.0 marks a major shift in how farming is done, turning traditional farms into smart, connected systems. With modern equipment, digitally linked tractors and intelligent machinery, farmers can work more efficiently, produce better-quality food and protect the environment at the same time (Ali, B *e tal.*, 2023*)*.

Evolution of Agriculture from 1.0 to 4.0

Agriculture 1.0 The Manual Labor Era, from hunting and gathering to settled agriculture, which was started about 10,000 BCE and was characterized by the domestication of plants and animals. Simple equipment, physical and animal labour and a heavy reliance on the sun and rain were characteristic features of agriculture 1.0.

Farmers relied on their knowledge of the land, weather patterns and traditional agricultural methods passed down from father to son. This period was characterized by subsistence farming, in which families produced just enough food to feed themselves.

Agriculture 2.0, also known as the era of mechanization, began during the 18th-19th centuries with the Industrial Revolution, introducing tractors and harvesters that boosted productivity by replacing manual labour. Chemical fertilizers and pesticides emerged later, drastically increasing yields but raising environmental concerns like soil degradation. Post World war-II factory conversions from wartime production accelerated these changes, alongside seed and breed improvements.

Agriculture 3.0, also known as precision agriculture, marked a shift toward technology driven farming aimed at improving efficiency and productivity. Advanced tools such as GPS, remote sensing and Geographic Information Systems (GIS) were incorporated into agricultural practices to gather detailed information on soil characteristics, crop condition and weather variability. This information enabled the creation of accurate field maps and supported site-specific application of inputs like fertilizers, pesticides, and irrigation water. As a result, resources were used more efficiently, waste was reduced, and negative environmental impacts were minimized.

Agriculture 4.0 signifies the current phase of digital transformation in agriculture. It is defined by the integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), robotics and big data analytics. In this stage, farming systems are becoming highly automated, with robots carrying out activities including planting, weed control and harvesting. IoT-based sensors continuously track key parameters of farm operations, ranging from soil moisture levels to the health status of livestock. Meanwhile, AI-driven tools process large volumes of data to support informed decision-making and to forecast future trends and outcomes.

The targeted and accurate use of agricultural inputs substantially reduces resource wastage and lowers environmental impacts. In addition, significant contributions come from advances in plant breeding, which focus on developing crop varieties that require fewer inputs while maintaining high yields and showing greater resistance to environmental stresses.

Challenges

At the device level, deploying IoT systems in real agricultural fields is challenging because field conditions are harsh and unpredictable. Edge devices are exposed to heavy rainfall, extreme temperatures, high humidity, strong winds, dust and damage from wildlife such as rodents and birds, which can affect their performance and lifespan. Therefore, devices must be designed with strong, weather-resistant casings that protect internal components without affecting their functionality. Another major challenge is energy limitation, as wireless sensors rely on batteries and are often placed in remote or difficult-to-access locations.

Agriculture 4.0 depends on high-quality data to generate meaningful outcomes. Data quality includes intrinsic accuracy and consistency, contextual relevance, clear representation and secure accessibility. These dimensions align with FAIR data principles, which are essential for maximizing scientific value, enabling scalable AI-based decision support systems and improving the reliability and trustworthiness of Agriculture 4.0 solutions.(Araújo, S. O *e tal* .,)

Future Prospects of agriculture 4.0

The future of agriculture is expected to be shaped by the deeper integration of advanced digital and biological technologies. The convergence of 5G connectivity with artificial intelligence will enable faster data transmission, supporting real-time monitoring, precise control and timely decision-making across farm operations. Autonomous farming systems are likely to expand, with robotics and AI enabling fully automated farms capable of operating continuously with minimal human intervention.

At the same time, vertical and urban farming systems supported by smart technologies are gaining importance in cities, helping to ensure food security while reducing pressure on rural land and water resources. Advances in genomics and biotechnology will further contribute by developing climate-resilient,high-yielding crop varieties capable of withstanding environmental stresses. In addition, the concept of a circular bioeconomy is expected to play a crucial role, focusing on the conversion of agricultural waste into bio-based products, thereby promoting resource efficiency and moving toward zero-waste, sustainable farming systems.

Reference

1. Ali, B., Zakeri, A., Llieva, A., & Iliev, O. (2023). Reshaping of the Future Farming: From Industry 4.0 Toward Agriculture 4.0. *American Journal of Applied Scientific Research*, *2*, 64.
2. Araújo, S. O., Peres, R. S., Barata, J., Lidon, F., & Ramalho, J. C. (2021). Characterising the agriculture 4.0 landscape—emerging trends, challenges and opportunities. *Agronomy*, *11*(4), 667.
3. Lima, G. C., Figueiredo, F. L., Barbieri, A. E., & Seki, J. (2021). Agro 4.0: Enabling agriculture digital transformation through IoT. *Revista Ciência Agronômica*, *51*, e20207771
4. Liu, Y., Ma, X., Shu, L., Hancke, G. P., & Abu-Mahfouz, A. M. (2020). From industry 4.0 to agriculture 4.0: Current status, enabling technologies, and research challenges. *IEEE transactions on industrial informatics*, *17*(6), 4322-4334.
5. The Evolution of Agriculture: From 1.0 to 4.0. (n.d.). Linea Professionale. Retrieved from https://professionale.saissementi.it/en/news/english-the-evolution-of-agriculture-from-1-0-to-4-0/
6. Trendov, N., Varas, S., & Zeng, M. *Jun. 2018. Digital Technologies in Agriculture and Rural Areas: Status Report. Food and Agriculture Organization of the United Nations, Rome*.
7. Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big data in smart farming–a review. *Agricultural systems*, *153*, 69-80.