Agritech, March, 2025, Vol.2(1): 12-15

Mechanization and Automation are the drivers for Future Agriculture

Aruna T N, Pramod Kumar Sahoo, Dilip Kumar Kushwaha, Soumya Krishan V, Swapnaja K Jadhav[1*]

Division of Agricultural Engineering, ICAR-IARI, New Delhi.
[1]ICAR-Central Institute of Agricultural Engineering, Bhopal

swapnaja20kjadhav@gmail.com

Agriculture has significantly transformed over the past few decades, evolving into a highly diversified global sector. It now encompasses a wide range of operations, from small subsistence-based farms to vast industrial-scale holdings. With the world's population projected to reach nearly 10 billion by 2050 (FAO, 2017), the pressure on agricultural systems to meet growing food demands is intensifying. To address these challenges, it is essential to accelerate agricultural production to contribute to overall GDP growth, meet rising food demands, and improve the incomes of those reliant on agriculture.

In the face of limited resources and climate change, increasing agricultural productivity requires a sustainable approach (Jyoti et al., 2019). Higher land productivity, achieved through improved crop yields and multiple cropping, demands additional labor for various farm operations (Kepner et al., 1987). Intensive agriculture, therefore, relies heavily on diverse machinery to save time and labor in the field. Farm machinery is a key driver of agricultural productivity, and the mechanization sector plays a critical role in enhancing farming efficiency (Oduma et al., 2019). Mechanization also ensures the timely execution of operations, which increases both productivity and income. Many farm activities need to be completed within short timeframes to maximize performance and returns (Sahay, 1971).

In recent years, there has been a significant decline in the use of traditional manual, and animal power in agriculture. Indian agriculture, in particular, has witnessed exponential growth in mechanization (Verma and Guru, 2014). The country witnessed phenomenal growth in mechanization by rising food grain productivity from 0.71t/ha to 2.39 t/ha 0.63 t/ha increased linearly with an increase in power availability from 0.3kW/ha in the year 1961-62 to 2.76kW/ha in the year 2020-21 (Singh and Singh, 2021). The use of mechanical power has a positive impact on food grain productivity, which is a critical factor in the transition from food insecurity to self-sufficiency. The adoption of farm machinery and mechanization technology packages has been instrumental in increasing crop intensity and farm production over the past 50 years, demonstrating a positive relationship between farm power availability and agricultural development (Singh and Sahni, 2019). However, with the advent of mechanization, machines like tractors, harvesters, and planters became commonplace, drastically improving productivity and reducing the physical burden on farmers. The significance of these advancements cannot be overstated. As the global population continues to grow, there is increasing pressure on the agricultural sector to produce more food with fewer resources.

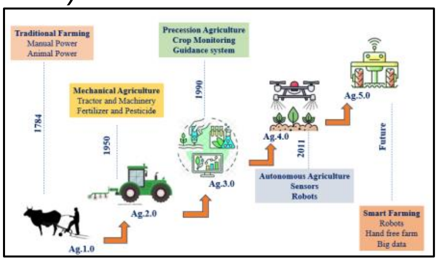
Mechanization is now evolving into automation, incorporating advanced technologies such as robotics, artificial intelligence, and the Internet of Things into farming practices. Automated farming is the process of using machines and technology to automate the process of agriculture (Mahmud et al., 2020). It is also called agricultural robotics and it has become significantly more popular in recent years. These technologies enable precise control over various agricultural processes, leading to better resource management, increased yields, and sustainable farming practices (Bechar and Vigneault, 2016).

Automation in agricultural mechanization is a growing area of research and development, focusing on improving food quality, ensuring operator comfort and safety, enabling precision agrochemical application, conserving energy, and promoting environmental sustainability (Fountas et al., 2020). Mechanization and automation have revolutionized agriculture, transforming it from a labor-intensive into a highly efficient and productive sector (McNulty and Grace,2008).

Mechanization and Automation in Agriculture (Source: AI Created)

Evolution of Agricultural Mechanization from Traditional to Automation

Mechanization and automation have revolutionized agriculture, enhancing efficiency, productivity, and sustainability. The journey began in the late 18th century with basic tools like the plough and seed drill, which made traditional farming faster and less labor-intensive. The advent of steam-powered machinery in the 19th century further accelerated this process, and machines like threshers and harvesters took over some of the most labor-intensive tasks (Anonymous, 2023). The introduction of tractors in the early 20th century was one of the most transformative moments in agricultural mechanization. Tractors revolutionized farming by replacing animals as the primary source of power for plowing, planting, and harvesting. By the mid-20th century, gasoline- and diesel-powered tractors became standard on farms worldwide, significantly reducing the reliance on manual labor and animal power (Anonymous, 2023). Today, tractors are standard worldwide, with India leading in production and export, showcasing the profound impact of mechanization on modern agriculture. The annual compound growth rate of the tractor population from 1950-51 to 2020-21 is 10.584 percent. In 2020-21, the total power available through tractors in the country was 229.53 million kW. Considering the net sown area of 140 Mha, tractor availability increased from one tractor per 16,470 hectares in 1950-51 to one tractor per 16 hectares in 2020-21. Correspondingly, the power availability per hectare from tractors reached 1.64 kW/ha in 2020-21. The export percentage of tractors, relative to domestic sales, varied from 0.29 to 13.56 percent during this period (Kapur et al., 2015; Singh and Singh, 2021).



Evolution trend of agricultural mechanization

The post-World War II period experienced a surge in agricultural productivity known as the Green Revolution. During this time, the use of modern mechanized equipment, along with advances in irrigation, synthetic fertilizers, and high-yield crop varieties, led to dramatic increases in food production. Combines, which could perform multiple tasks like reaping, threshing, and winnowing, became widespread, drastically improving harvesting efficiency. The development of specialized machinery for planting, fertilizing, and pest control further optimized the production process (Hemathilake and Gunathilake. 2022).

As technology advanced, automation began to complement traditional mechanization. In the latter half of the 20th century, the introduction of automated systems designed to perform repetitive tasks, such as irrigation control, milking, and feed distribution. Automation initially focused on reducing labor and improving efficiency in specific areas like livestock management and crop handling (Grift et al., 2008; FAO, 2022). The integration of digital technologies in the late 20th and early 21st centuries marked a new era in agricultural automation. Precision agriculture emerged, driven by advances in GPS technology, sensors, and data analytics. Farmers could now optimize their use of water, fertilizers, and pesticides by applying these resources precisely where and when they were needed. This approach not only reduced input costs but also minimized environmental impact (FAO.2022).

Today, automation in agriculture has progressed even further with the advent of autonomous systems and robotics. Autonomous tractors, drones, and robotic harvesters are now being used to monitor crops, apply inputs, and perform harvesting with minimal human intervention. Artificial intelligence and machine learning are increasingly integrated into these systems, enabling real-time decision-making based on data collected from fields. The Internet of Things has also become central to modern farming, connecting sensors and machinery to streamline operations and improve efficiency (Abbasi et al., 2022; Kolawole et al., 2023).

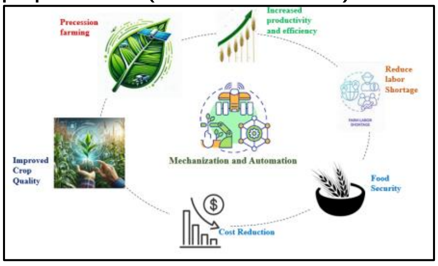
The evolution of mechanization and automation has significantly improved farm productivity. By reducing the resources, labor, and time required to cultivate crops, farmers can produce more food with fewer inputs (FAO, 2022). This is critical as the global population continues to rise and agricultural resources become scarcer. Moreover, automation supports sustainable farming activities by enabling more precise application of resources, reducing waste, and mitigating environmental damage (McNulty and Grace, 2008).

Benefits of Mechanization and Automation in Agriculture

Mechanization and automation in agriculture are essential to address the growing global challenges in food production, resource management, and labor shortages. Mechanization improves the speed and precision of farming operations such as planting, harvesting, irrigation, and spraying. Automation further enhances this by employing robots, sensors, and AI for all-time operation, increasing productivity beyond what human labor can achieve (Fountas et al., 2020). Agriculture faces a critical labor shortage, especially in developed countries (Singh and Singh, 2021). Automated machines and robotics can help to fill this gap by taking over repetitive, labor-intensive tasks, thus ensuring that farms remain operational even with fewer human workers (McNulty and Grace,2008). Automation enables precision farming, where inputs like water, fertilizers, and pesticides are applied with accuracy, minimizing waste and environmental impact. Automated systems use real-time data from

Agritech, March, 2025, Vol.2(1): 12-15

sensors and drones to optimize resource use ((Bechar and Vigneault, 2016). Mechanization and automation contribute to sustainable agriculture by improving resource use efficiency. Technologies like autonomous tractors, smart irrigation systems, and soil sensors help reduce fuel, water, and chemical inputs, mitigating environmental effects. Automated systems can monitor crop health through advanced imaging and data analytics, making adjustments to maintain optimal growing conditions. This leads to better quality produce and higher yields (Subeesh and Mehta, 2021). Although the initial investment in automated systems can be high, long-term cost reductions are realized through savings on labor, fuel, and inputs. Autonomous machines can also reduce operational errors and downtime. With a global population projected to exceed 9.7 billion by 2050, mechanization and automation are vital to increasing food production without expanding the agricultural footprint, contributing to food security for a growing population (Groover. 2024).



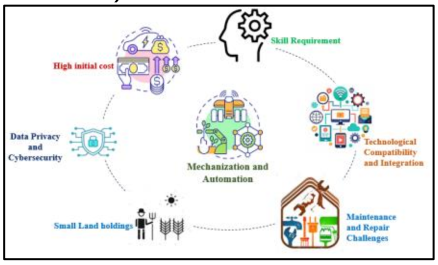
Benefits of Mechanization and Automation in Agriculture

Challenges of adoption of Mechanization and Automation in agriculture

The challenges associated with mechanization and automation in agriculture encompass a range of technical, economic, and social factors (FAO, 2022). The significant costs of purchasing and maintaining advanced agricultural machinery, robotics, and automation systems are difficult to handle, particularly for small and medium-sized farmers (Gustavo et al., 2023). The adoption of automation technologies also necessitates specialized skills in operation, programming, and maintenance. Farmers may need additional training to effectively use these new technologies.

Existing legacy systems on many farms may not easily integrate with new mechanized or automated solutions, posing compatibility challenges across different machinery and platforms (Gustavo et al., 2023; Bazargani and Deemyad. 2024).

Furthermore, automation systems typically rely on robust digital infrastructure, such as reliable internet connectivity and data storage, which may not be available in all farming regions. Advanced automated systems also require sophisticated repair and maintenance, and access to spare parts, trained technicians, and servicing facilities can be limited in rural areas (Wang et al., 2021).



Challenges of Mechanization and Automation in Agriculture

Automation systems often depend on large amounts of farm data for precision farming and decision-making, raising concerns about data privacy and the potential misuse of data by third parties.

Cybersecurity threats also become a concern as farms integrate more digital tools, which are vulnerable to hacking or data breaches (Xing et al., 2021).

Cultural and behavioral changes within farming communities, especially in regions with a history of minimal mechanization, can further hinder the adoption of these advancements.

Future Scope of Mechanization and Automation in Agriculture

In the future, the scope of mechanization and automation in agriculture is expected to significantly expand, potentially mirroring the Hands-Free Farm model (Anonymous, 2023; Hands-Free Hectare, 2024). This vision includes the widespread adoption of advanced technologies such as autonomous machinery, drones, and precision tools that can fully automate farming processes. These innovations will enable the precise application of resources like water, fertilizers, and pesticides, which will enhance efficiency, reduce waste, and improve crop yields. As automation systems evolve, they will address labor shortages by reducing the need for manual labor in tasks such as planting, weeding, and harvesting (Mahmud et al., 2020; Wang et al., 2021). The Hands-Free Farming illustrates how such technologies can revolutionize farming by making operations more sustainable and scalable. Future advancements will likely extend this model, making autonomous farming systems more accessible and adaptable across different agricultural contexts. However, realizing this potential will require overcoming challenges related to investment, job displacement, and the need for new skills and training. Overall, the future of mechanization and automation holds the promise of transforming agriculture into a more efficient, sustainable, and technologically advanced sector.

Conclusion

Mechanization and automation have become essential in driving the future of agriculture, offering innovative solutions to address global challenges in food production, resource management, and labor shortages. As this article has explained, the integration of advanced technologies such as autonomous machinery, robotics, and precision farming has transformed agriculture into a more efficient and productive sector. Despite challenges in adoption, these advancements provide significant opportunities for sustainable farming practices, enabling precise control of agricultural operations while ensuring higher yields and better resource utilization. The future of agriculture lies in fully embracing mechanization and automation to meet the demands of a growing global population.

References

- Abbasi, R., Martinez, P. and Ahmad, R. 2022. The digitization of agricultural industry – a systematic literature review on agriculture 4.0, Smart Agricultural Technology.2.
- Anonymous. 2023. ASPEE. From Hand Tools to Mechanization: The Evolution of Early Agricultural Equipment. https://aspee.com/blog/from-hand-tools-to-mechanization-the-evolution-of-early-agricultural-equipment/
- Anonymous. 2023. Six years of autonomous agriculture - the Hands-Free Farm team look back.https://www.harper-adams.ac.uk/news/207995/six-years-of-autonomous-agriculture--the-hands-free-farm-team-look-back
- Bazargani, K and Deemyad, T. 2024. Automation's Impact on Agriculture: Opportunities, Challenges, and Economic Effects. Robotics. 13 (2). 33.
- Bechar, A. and Vigneault, C. 2017. Agricultural robots for field operations: Concepts and components. Biosystems Engineering, 149, 94-111.
- Chauhan, J., Choudhury, P., Pal, S. and Kunwar. S. 2021. Sustaining national food security and increasing farmers' income through quality seed. The Indian Journal of Agricultural Sciences. 90.
- FAO. 2017. The future of food and agriculture – Trends and challenges. Rome.
- FAO. 2022. The State of Food and Agriculture 2022. Leveraging automation in agriculture for transforming agrifood systems. Rome
- Fountas, S., Mylonas, N., Malounas, I., Rodias, E., Santos, C. and Pekkeriet, E. 2020. Agricultural Robotics for Field Operations. Sensors. 20. 2672.
- Groover, M. P. 2024. Automation. Encyclopedia Britannica. https://www.britannica.com/technology/automation.
- Grift, T., Qin Zhang, Q., Naoshi Kondo, N. and Ting. K.C. 2008. A review of automation and robotics for the bioindustry. Journal of Biomechatronic Engineering, 1(1):37-54
- Gustavo, G., Casagrande, D.E., Cortes, L.P. and Verschae, R. 2023. Why the low adoption of robotics in the farms? Challenges for the establishment of commercial agricultural robots. Smart Agricultural Technology, 3.
- Hands-Free Hectare, Wikipedia, Wikimedia Foundation, 9 July 2024. https://en.wikipedia.org/wiki/Hands_Free_Hectare
- Hemathilake, D.M.K.S. and Gunathilake. D.M.C.C. 2022. Agricultural productivity and food supply to meet increased demands, Editor(s): Rajeev Bhat, Future Foods-Academic Press, 539-553, https://doi.org/10.1016/B978-0-323-91001-9.00016-5.
- Jyoti1, B., Ram Reddy, K.V.S., Sawant, C.P., Pandirwar, A.P., Potdar, R.R. and Randhe, R.D. 2019. Predicting draft requirement of tillage implements using pull type load cell in southern region of Andhra Pradesh, India. International Journal of Current Microbiology and Applied Sciences 9: 606-612.
- Kepner, R.A., Bainer, R. and Barger, E.L. 1987. Textbook of Principle of farm machinery. Third edition. CBS publishers and distributors Pvt. Ltd. New Delhi. India, pp: 3-4.
- Kolawole, E., Abdulrahman, R., Animasaun, A., Kolapo, F. and Ayodele. 2023. Automation in Agricultural and Biosystems Engineering: Automation. Journal of Engineering Research and Reports. 25. 57-65.
- Mahmud, M. S. A., Zainal Abidin, M. S., Abiodun Emmanuel, A., and Hasan, H. S. 2020. Robotics and Automation in Agriculture: Present and Future Applications. Applications of Modelling and Simulation, 4, 130–140
- McNulty, P. and Grace, P. 2009. Agricultural mechanization and automation. Encyclopedia of Life Support Systems, UNESCO, Paris. http://dx.doi.org/10.13140/2.1.4421.9683
- Oduma, O., Oluka, S.I., Nwakuba, N.R. and Ntunde, D.I. 2019. Agricultural field machinery selection and utilization for improved farm operations in South-East Nigeria- A review. Agricultural Engineering 3: 44-58.
- Sahay, J. 1971. Text book of Elements of agricultural engineering. Standard publisher's distributors. New Delhi. India pp: 3-4.
- Singh, S and Singh, S. 2021. Farm Power Availability and its Perspective in Indian Agriculture. RASSA Journal of Science for Society. 3(2): 114-126.
- Subeesh, A. and Mehta, C.R. 2021. Automation and digitization of agriculture using artificial intelligence and Internet of Things. Artificial Intelligence in Agriculture, 5: 278-291.
- Verma, A. and Guru, P.K. 2014. Development and evaluation of cultivator cum seed Drill. Article in Ecology, Environment and Conservation 21: 1359-1364.
- Wang T, Xu X, Wang C, Li Z. and Li D. 2021. From Smart Farming towards Unmanned Farms: A New Mode of Agricultural Production. Agriculture. 2021; 11(2):145.
- Xing. Y., Lei.S., Jianing, C., Mohamed,A.F., Jun, W., Edmond, N and Kai, H. 2021. A Survey on Smart Agriculture: Development Modes, Technologies, and Security and Privacy Challenges. IEEE/CAA Journal of Automation. Sinica, 8(2); 273-302.