PLANT SCIENCE TODAY
Vol 13(sp1): 01–09
https://doi.org/10.14719/pst.9063

eISSN 2348-1900

REVIEW ARTICLE

Agri-robotics in smallholder agriculture: A comprehensive review of recent efficient and affordable technologies

Vipin Tanwar[1*], Rakesh Kumar[1*], Neetu Sharma[1], Raju Gupta[2], Bhim Singh[1], Vivek Bhagat[1], Gagandeep Kaur[3], Ranjana Mankotia[1], Vikalp Ranjan[1] & Shivam[1]

[1]Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu 180 009, Jammu & Kashmir, India
[2]Krishi Vigyan Kendra, R.S. Pura, Jammu 181 102, Jammu & Kashmir, India
[3]Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana 141 004, Punjab, India

*Correspondence email - tanwarvipin098@gmail.com; sharmark77ag@gmail.com

Received: 24 April 2025; Accepted: 04 November 2025; Available online: Version 1.0: 12 January 2026

Cite this article: Vipin T, Rakesh K, Neetu S, Raju G, Bhim S, Vivek B, Gagandeep K, Ranjana M, Vikalp R, Shivam. Agri-robotics in smallholder agriculture: A comprehensive review of recent efficient and affordable technologies. Plant Science Today. 2026;13(sp1):01–09. https://doi.org/10.14719/pst.9063

Abstract

This review emphasizes how agri-robotics is transforming small-scale farming by solving issues related to labour shortages, inefficiency in conventional methods and the growing need for sustainable agricultural practices. The study examines various agri-robots suitable for near future adoption on small-scale farms. Examples include IARI's seeding robot for precise planting, the Smart Core robot for automatic soil sampling and the Evo robot for advanced weeding. Additionally, it covers the tomato plucker robot developed by Octaneaon, a duck robot for weeding in paddy fields and agricultural drones utilized for targeted spraying and crop monitoring. These robots are demonstrating clear enhancements in operational efficiency, crop yields and optimal resource utilization. Their applications include autonomous seeding, intelligent irrigation, multi-functional harvesting and soil sampling, all of which contribute to enhanced precision agriculture. Government initiatives like Sub-Mission on Agricultural Mechanization (SMAM), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Custom Hiring Centers (CHCs) and the Namo Drone Didi (NDD) scheme provide both financial and technical assistance, accelerating the adoption of these technologies. Experimental research indicates that drone-assisted herbicide application results in improved weed control effectiveness, increased yield and that diesel-powered robots are more energy-efficient. The drip irrigation systems utilizing soil moisture sensors as an automated irrigation method have better water use efficiency. This paper concludes that government policies, research findings and user-friendly innovations make agri-robots suitable for small-scale farmers and foster sustainable agricultural practices.

Keywords: agricultural drones; agri-robotics; automated irrigation; precision agriculture; small scale farmers

Introduction

India is an agricultural nation that has long relied on its natural resources. The world's population is currently close to 8.1 billion in 2025 and by 2050, it is projected to reach around 10 billion. To meet the world's food requirements, the agriculture sector's current food production must increase by approximately 55 % (1). Harvesting fragile fruits and controlling intra-row weeds are only two of the numerous challenging field activities involved in crop cultivation. Additionally, there is a labour shortage in the agriculture industry in many nations since most workers prefer to relocate to metropolitan areas for high-paying occupations (2, 3). As a result, there is a greater need for agri-robotics to meet the nation's huge population's food needs. In addition, these technologies improve crop quality, ensure sustainability and save time (4). Furthermore, reducing post-harvest losses and enhancing value addition in agricultural products requires consistent supply of high-quality raw materials-something agri-robots can help achieve.

Agricultural field operations are highly complex and traditional methods often face multiple challenges-creating opportunities for robotic solutions. These technologies assist in the data collection and the automated management of various agricultural chores, enabling farmers to make better decisions and save money on labour, inputs and variable expenses. However, the stability of agricultural production and sustainability are also maintained by the development of robotics and sensing technologies. Therefore, the micro-dose of fertilizer is essential to the sustainable production of food grains, as it maximizes returns for impoverished farmers and minimize waste (5). As robotics engineer George Kontor of Carnegie Mellon University in Pittsburgh, Pennsylvania, notes, "intelligent robots can replace costly systems and become feasible for small and marginal farmers". From the field level to the advanced industrial level, the employment of robots and smart farming technologies facilitates the completion of a variety of activities. The various operations such as precision seeding (6-8), automatic target-specific weed control (9, 10), drone spraying, automated irrigation (11), automatic paddy harvesting (12, 13), fruit harvesting (14, 15) and other agricultural operations are among their capabilities.

High purchase costs, operational challenges, limited adoption and a strong reliance on conventional methods are the primary barriers preventing small and marginal farmers from embracing agricultural robotics. The first of these difficulties is that buying a single robot for a specific field activity is expensive and farmers are unable to operate the robots in their fields. Furthermore, farmers do not trust robots to work in their fields. Due to all these obstacles, small and marginal farmers are not using robots to labour in their fields. The scientific and commercial agricultural robotic systems used in a variety of field operations are covered in this review paper. The objectives are to present an overview of the functions of agri-robots, assess their applications in agriculture and evaluate their economic feasibility for small and marginal farmers.

Agri-robots

The term “robot” originates from the Czech word *robota*, meaning “forced labour”. A robot is a human-made mechanical system that typically operates via remote control or through autonomous functions, often using electromagnetic signals. Agricultural robots are used for tasks such as weeding, harvesting, seeding, irrigation, spraying and precision (smart) irrigation. These machines can operate either autonomously or under remote control. Automated robots are generally employed by large-scale farmers or plantation owners cultivating single crops over extensive areas, whereas remote-controlled robots are more affordable and can be purchased by small and marginal farmers for use on smaller holdings.

Working of robots

An agri-robot is a gadget that is primarily made to carry out multiple tasks in the agricultural industry, either autonomously or with the aid of remote controls and pre-programmed instructions. “Primary sources of power” is misleading-sensors, actuators and control systems are *components*, not *power sources*. The sensors are the robot's first functional components, primarily using infrared radiation to detect obstacles and boundaries. Additionally, this aids in the collection of environmental data using cameras, microphones, temperature sensors and ultrasonic sensors, which give the robotic system the real-time data. The control system, typically built around microcontrollers such as Arduino or Raspberry Pi, processes this sensory data to make decisions-such as whether the robot should move forward, stop or turn. Actuators carry out the remaining tasks by assisting in the movement of the robotic components in a particular direction with the aid of pneumatic cylinders or hydraulic systems. This mostly serves to move the robot in accordance with the task at hand. To carry out various functions, the actuators are mostly attached with end-effectors, which primarily mimic the wrist, elbow, fingers and other components of the human arm. The end-effectors are the last connected part to the cropping field. Once a task is completed, the communication module sends a completion signal via Wi-Fi, Bluetooth or voice-recognition interfaces.

Robots used by small scale farmers in agriculture

Seeding robot by IARI

To improve the accuracy and efficiency of seed sowing in agriculture, the Indian Agricultural Research Institute (IARI) created the Robotic Precision Planter as shown in Fig. 1. This self-sufficient system performs tasks such as seed placement, soil preparation and post-sowing operations with minimal human intervention. The Robotic Precision Planter seeks to increase crop yields, lower labour costs and advance sustainable farming methods by automating the planting process. It is a useful instrument for contemporary agriculture because of its accuracy and effectiveness. Sensing devices, ultrasonic and infrared sensors, actuators, microprocessors, stepper motors, servomotors and communication and data processing units are some of its components (16-18). An agricultural robot equipped with sensors and vision technology has been used for seed planting and trials on paddy and maize seed sowing have demonstrated its practical utility (19, 20).

Fig. 1. Seeding robot by IARI.

Smart core robot for soil sampling

The Smart Core Robot is an advanced system designed to automate soil sampling in agricultural fields (Fig. 2). For farmers and academics to evaluate soil health, nitrogen levels and other elements that affect crop growth, soil sampling is an essential duty. The goal of this robot is to simplify this procedure and increase its accuracy and efficiency. It analyses a variety of soil parameters, including pH, moisture content, temperature, nutrient content, texture, compaction and organic matter. This robot assists in the autonomous assessment of grapevine composition, yield, soil moisture and vegetative development (21, 22).

Fig. 2. Smart core robot for sampling soil.

Evo robot for weeding

The Evo Weeding Robot is designed to autonomously detect and remove weeds from crop fields, reducing the need for labour-intensive conventional methods (Fig. 3). It seeks to replace labour-intensive, conventional weeding techniques with an automated system that boosts productivity, uses less chemicals and encourages environmentally friendly farming methods. These robots detect and remove weeds without harming crops by utilizing state-of-the-art technology including machine vision, artificial intelligence and precision mechanics. In addition to removing weeds using a controlled device, this aids in the automated identification and discrimination of crops and weeds (23-26).

A comparative study evaluated different types of robots for weed control, selecting the optimal option for farmers based on yield and energy efficiency. As shown in Table 1, the most effective technique in this case is inter-row loosening using a diesel-powered

Fig. 3. Evo robot for weeding.

Table 1. Comparative studies of different types of robots in sugar beet production

Parameters	Diesel robot	Electric robot
Fuel/energy use	5.19 L/ha	3 kWh/ha
Working speed	5 km/hr	1 km/hr
Sugar beet yield	65.2 t/ha	65.2 t/ha
Total energy consumption	26671 MJ/ha	29615 MJ/ha
Energy productivity	2.41 kg/MJ	2.20 kg/MJ
Net energy gain	171879 MJ/ha	171879 MJ/ha
Greenhouse gas emission	4471 kg CO_2eq/ha	4693 kg CO_2eq/ha
Greenhouse gas emission ratio	5.80	5.56

robot. Compared with diesel-powered robots, automated robots have the same input energy but produce less and have a lower energy efficiency ratio, but electric robots are far slower, have higher input energy and have a lower efficiency ratio. Overall diesel-powered robots demonstrated lower energy consumption, higher productivity and greater energy efficiency.

Tomato plucker by Octaneon

As shown in Fig. 4, the Octaneon Tomato Plucker is a harvesting robot equipped with multiple fruit-picking arms (27, 28). This cutting-edge agricultural robot was created to automate the tomato harvesting procedure (29-31). The robot, created by Octaneon, is intended to increase productivity, lower labour expenses and guarantee a superior harvest. Using advanced technologies such as robotics, machine learning and artificial intelligence (AI), the system can detect and selectively pick ripe tomatoes without damaging the fruit or plants (32, 33).

Duck robot for paddy weeding

As shown in Fig. 5, the duck robot for paddy weeding is an innovative agricultural solution that uses robotic mechanisms to mimic the behaviour of ducks traditionally employed in rice fields. This robot, which combines biological and robotic processes, imitates the behavior of ducks, which are typically used to manage weeds in rice fields. It tackles the problems with conventional weeding techniques, like a lack of workers, pesticide damage to the environment and ineffective weed control. By lowering the environmental impact of farming and promoting precision agriculture techniques, this robot offers a viable, economical and effective substitute for sustaining healthy paddy fields.

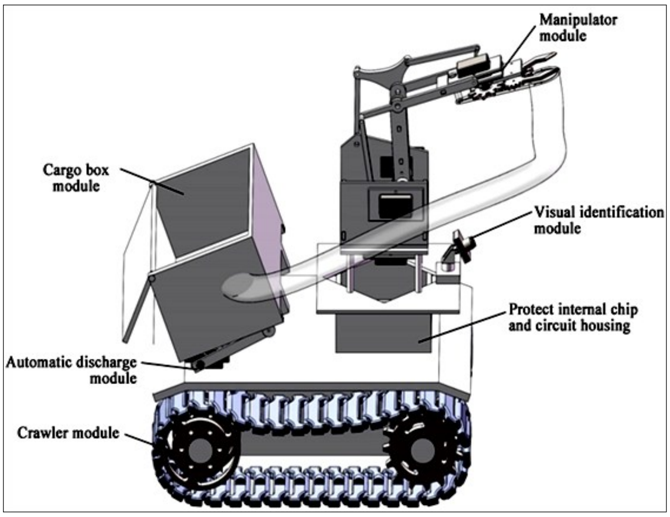


Fig. 4. Tomato plucker by Octaneon.

Fig. 5. Duck robot for paddy weeding.

Agricultural drones

As shown in Fig. 6, agricultural drones or Unmanned Aerial Vehicles (UAVs), are equipped with sensors, cameras and other technologies to monitor, manage and optimise farming operations. By giving farmers access to real-time data, boosting crop management and increasing overall productivity, these are completely changing the agricultural sector. They can swiftly cover vast areas and offer insights that were previously only achievable with satellite images or manual labour, but at a cheaper cost and with greater precision (34, 35).

Fig. 6. Agricultural drones.

Application of agri-robotics in agriculture

Autonomous precision seeding

Agri-robots are primarily used to plant seeds autonomously and precisely, utilizing cutting-edge technologies such as GPS, sensors and machine learning to guarantee ideal seed placement, depth and spacing. Precision agriculture, which uses automation and data-driven insights to improve agricultural production and sustainability, is a burgeoning trend that includes these robotic devices. For instance, the field is ploughed and seeded by the driverless tractors as it has field efficiency of approximately 74 % compared to 45 % for conventional operation. Also, it has more accuracy of travelling in straight and takes less time to complete work (36).

Micro-spraying by robots

The comparison of UAVs and Knapsack sprayer for the efficiency, time saving and money saving and better control of weeds in the cropping field as shown in Table 2. These little autonomous robots are used in agriculture to precisely apply pesticides, fungicides, herbicides and fertilizer. These robots are designed to operate in a very effective and ecologically friendly way, reducing waste and the impact on the environment by instantly spraying minute amounts of the treatment onto the plants or areas that need it. In Barnyard millet and Rice the UAVs and Knapsack spraying of herbicide pretilachlor at pre-emergence in which UAVs spray results in saving of 20 times more water and 25 % of herbicide as well. In the 5-min spray test workers utilize a backpack spray to spray 150 plants with 1000 mL of solution, whereas UAVs spray 100 plants on their own with 200 mL of solution (37).

Multi-talented robots for harvesting

These are the most sophisticated harvesting robots, capable of carrying out a variety of crop-harvesting duties. These autonomous and effective robots can do a variety of tasks, including sorting, picking or chopping crops, identifying ripe products and even packing. Multi-talented harvesting robots' main benefit is their capacity to simplify the harvesting process by integrating many tasks into a single robotic system, which lowers labour costs, boosts productivity and guarantees that crops are gathered at their best quality. For instance, using an algorithm method, the robot can detect carrots with 93 % accuracy in 4 sec and cantaloupe with 95 % accuracy in 2 sec (38). Also, the robot KrushiBot came in price of Rs. 50000-100000 which is used to for tasks like pesticide spraying and monitoring crop health. The other robot FFRobotics Harvester came in price range of 30-40 lakhs which work for 20 hr/day and harvest 9000 fruits/hr which was using artificial lighting for night harvesting of fruits. These both robots used for apple, strawberries, tomatoes, chillies, etc.

Low-cost soil monitoring robots

These self-sufficient, compact and affordable robots are designed to collect and evaluate soil data, providing farmers with up-to-date information on temperature, moisture content, soil health and other critical parameters. These robots are anticipated to be a cost-effective choice for small and medium-sized farms as well as larger companies looking to reduce costs while still enjoying the advantages of precision agriculture. For instance, the ground robot measured crop and soil data with an insertion probe and camera (39).

Smart irrigation

A comparison of robotic and conventional agricultural practices in term of efficiency and resource use as presented in Table 2. It describes the application of cutting-edge techniques and technology to maximize water consumption in landscapes, gardens and agricultural fields. To minimize water waste, improve crop health and increase overall irrigation efficiency, it makes use of sensors, data analytics and automation to make sure that plants get the proper amount of water at the correct time. For instance, the tomato crop's smart irrigation system, which combines automated soil moisture sensor-based drip irrigation with conventional drip irrigation, yields more, uses more water efficiently and uses less water than conventional drip irrigation (40).

In Fig. 7, the most effective technique in this figure was drip irrigation based on soil moisture sensors, which offers the maximum water use efficiency. This is because time-based, volume-based and conventional drip irrigation systems do not measure soil moisture; instead, they irrigate according to a schedule, which causes water to be lost through evaporation and infiltration and not entirely utilized by the plants. Nevertheless, drip irrigation based on tensiometers determines the amount of water needed based on the tension in the soil micropores, which is an imprecise technique of determining soil moisture. However, by calculating the entire volumetric water need, soil moisture sensors precisely monitor soil moisture and automatically irrigate at the right time and amount (40). The soil moisture sensor-based drip irrigation is not suitable for all crops without adjustment as different crops have different root depths, water requirements and soil moisture thresholds in which the different calibration requirement for each crop. Also, the different potential issues came in these automated irrigation sensors as

Table 2. Comparative performance of robotic and conventional agricultural practices in terms of efficiency, yield and resource use

S.No.	Type of robotic comparison	Reason	References
1	Soil moisture sensor based automated drip irrigation and conventional drip irrigation	The automated method provides highest yield, water use efficiency, benefit cost ratio and lowest water requirement while conventional method require labour and more wastage of water	(40)
2	Agricultural drone and knapsack sprayer	In this the drone spray of pre-emergence Pretilachlor @500 g/ha with spray fluid of 40 L/ha provide best result comparable with the knapsack sprayer with spray fluid of 500 L/ha with no phytotoxic effect as well. The drone spray saves 20 times more water and provide high weed control efficiency as well	(45)
3	Automated robotic and conventional inter-row loosening	In this comparison the automated robot is energy efficient, require less input energy and give higher yield in comparison with conventional method	(46)
4	Robotic and conventional rotary tiller	In this comparison is basis on working efficiency and accuracy in which the working efficiency of robot is 1.8 times more than conventional operation and high accuracy due to more accuracy of straightness of travelling and takes less time to complete work	(47)
5	Robotic and conventional soil puddler	In this the comparison is based on operating capacity, accuracy, number of puddling. The robot operation can done maximum tillage in only 2 times tillage while other conventional operations take more than 2 times tillage for maximum puddling	(47)

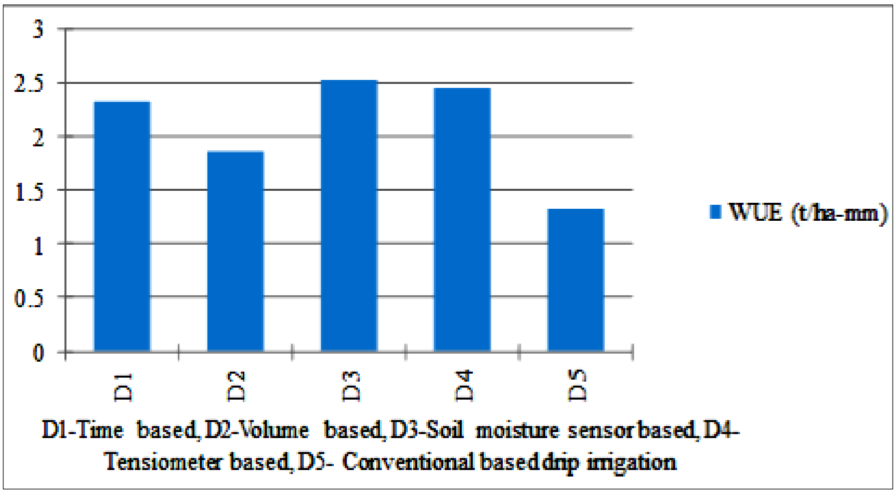


Fig. 7. Comparative analysis of different types of drip irrigation methods with water use efficiency.

maintenance of sensors is very important as sensors can corrode, clog lose proper soil contact which make the error in providing values. Additionally, calibration drift can also occur due to change in soil properties, temperature fluctuations, aging of electronics which causes the error in providing values.

Weed control by Agricultural drones

As shown in Table 3 and 4, the experiment was laid in Randomized Block Design with three replication in which the variable doses of herbicide were sprayed with knapsack sprayer in a spray fluid of 500 L/ha, the first three treatments of T1, T2 and T3 received drone spraying of pre-emergence pretilachlor @500 g/ha at different spray fluids of 40, 50 and 60 L/ha (Fig. 8). In this case, the spray fluid of 40 L/ha with drone gives better results than other spray fluids of 50, 60 and 500 L/ha, which also saves water and it also results in higher weed control efficiency when compared to other treatments at 15, 30 and 45 days after transplanting. In this regard the drone spray at 40 L/ha with 500 g/ha of pretilachlor has 80 % more yield and 22 % better weed control (41). This treatment has yield of net income of Rs. 27441 MJ/ha, B:C ratio of 2.0 and achieved highest output energy (Rs. 79160 MJ/ha).

Performance comparison of diesel and electric weed control robot

A comparative evaluation of robotic weed management systems revealed clear differences in energy use, productivity and operational efficiency among different power sources (Fig. 9). Diesel-powered robots showed higher working speed and field efficiency, resulting in improved productivity and lower total energy consumption per unit area. In contrast, electric robots, despite having comparable input energy, operated at slower speeds, which reduced their energy efficiency ratio and field capacity. Diesel-powered systems also demonstrated better adaptability to field conditions and sustained performance during extended operations. The analysis further indicated higher net energy gains and improved overall efficiency for diesel-powered robots. Overall, diesel-powered robotic systems were found to be more suitable for intensive weed management under field conditions (42).

Government initiatives towards small scale farmers

The several initiatives were taken by the government to help the farmers to improve the productivity, saving time and money. In this the global development in agro-robotics and corresponding Indian government initiatives are summarized in Table 5 and that are:

Table 3. Effect of drone herbicide dose and spray fluid on yield attributes and yield parameters in irrigated Barnyard millet

Treatments	Productive tillers/m^2	No. of grains/ear head	Ear head length (cm)	Ear head weight (g)	Test weight (g)
DS of PE pretilachlor @500 g/ha with SF of 40 L/ha	180	1642	21.9	8.9	3.6
DS of PE pretilachlor @500 g/ha with SF of 50 L/ha	168	1533	21.1	8.1	3.6
DS of PE pretilachlor @500 g/ha with SF of 60 L/ha	135	1302	17.1	6.6	3.5
DS of PE pretilachlor @375 g/ha with SF of 40 L/ha	151	1412	18.7	7.3	3.5
DS of PE pretilachlor @375 g/ha with SF of 50 L/ha	133	1291	17.0	6.6	3.5
DS of PE pretilachlor @375 g/ha with SF of 60 L/ha	117	1167	15.0	5.8	3.4
MS of PE pretilachlor @375 g/ha with SF of 375 L/ha	165	1530	20.7	7.9	3.6
MS of PE pretilachlor @375 g/ha with SF of 500 L/ha	132	1278	17.0	6.5	3.5
Weedy check	99	1059	13.1	5.1	3.4
SEd	5	51	0.7	0.3	0.1
CD (P = 0.05)	11	108	1.5	0.6	NS

Table 4. Effect of drone herbicide dose and spray fluid on weed control efficiency in irrigated Barnyard millet

Treatments	Weed control efficiency (%)		
	At 15 DAT	At 30 DAT	At 45 DAT
DS of PE pretilachlor @500 g/ha with SF of 40 L/ha	91.9	89.2	82.8
DS of PE pretilachlor @500 g/ha with SF of 50 L/ha	89.4	86.1	78.3
DS of PE pretilachlor @500 g/ha with SF of 60 L/ha	79.5	76.4	67.4
DS of PE pretilachlor @375 g/ha with SF of 40 L/ha	85.4	81.3	73.0
DS of PE pretilachlor @375 g/ha with SF of 50 L/ha	78.5	74.4	66.6
DS of PE pretilachlor @375 g/ha with SF of 60 L/ha	70.6	63.7	50.8
MS of PE pretilachlor @375 g/ha with SF of 375 L/ha	88.4	85.8	78.1
MS of PE pretilachlor @375 g/ha with SF of 500 L/ha	77.9	73.2	63.1
Weedy check	-	-	-

DAT: days after transplanting.

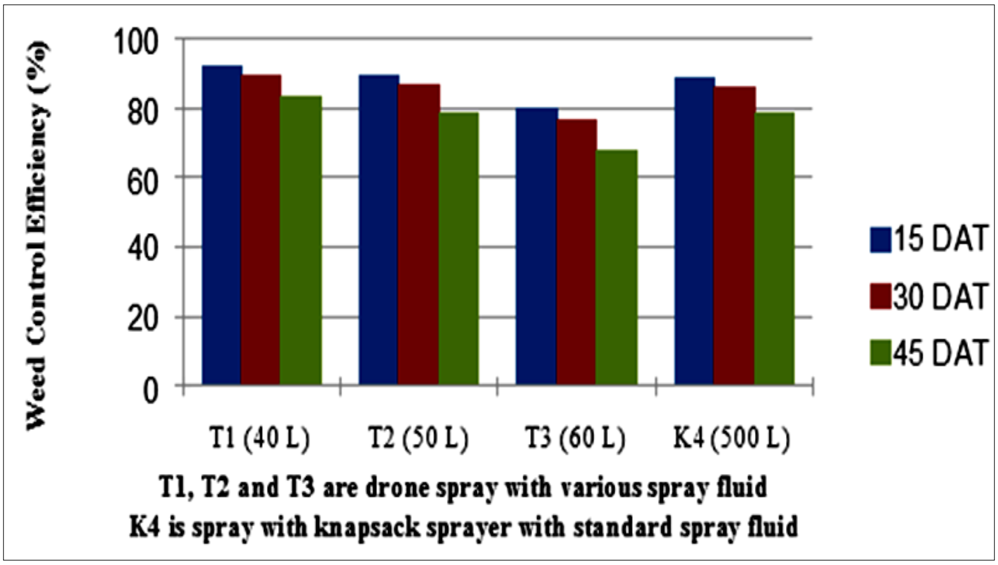
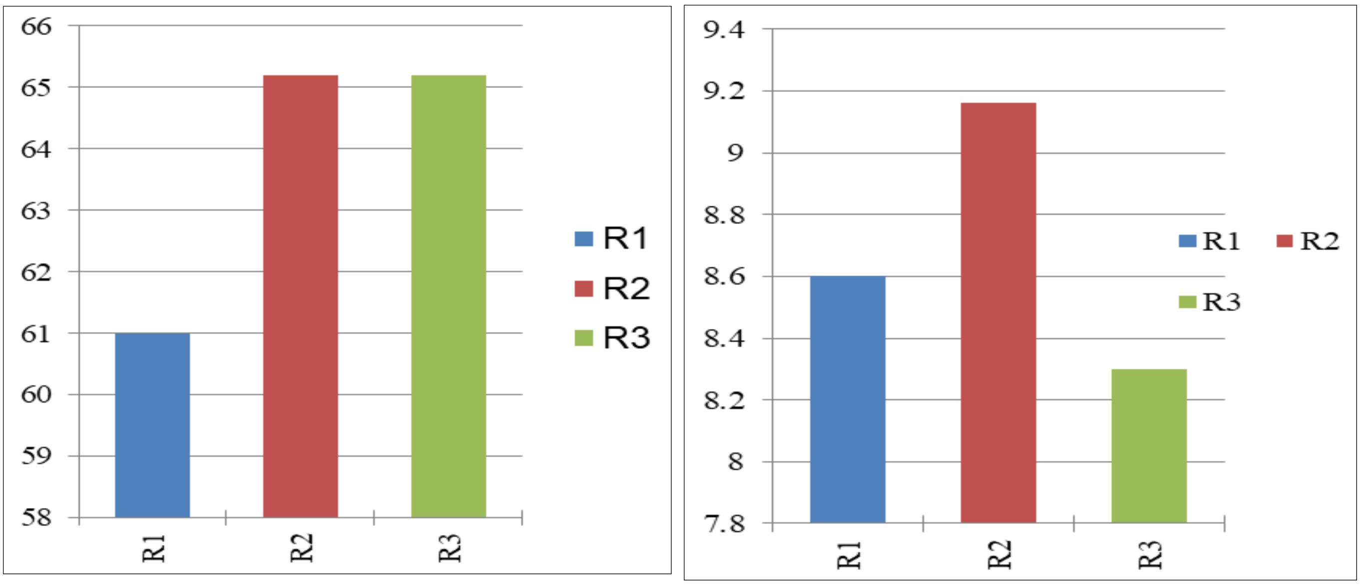


Fig. 8. Comparative studies of different volumes of spray fluid through drone with knapsack spray.



R1-Automated robot, R2–Diesel powered robot, R3–Electric robot **R1-Automated robot, R2–Diesel powered robot, R3–Electric robot**

Fig. 9. Comparative analysis of different types of robots with their yield and energy efficiency ratio.

Table 5. The global development in agro-robotics and initiatives taken by Indian government to support agro-robotics

Global developments in agro-robotics	Indian government initiatives
Autonomous tractors and driverless machinery (John Deere, Kubota AI powered tractors)	Sub-Mission on Agricultural Mechanization (SMAM) – provides subsidies for farm machinery and promotes adoption of advanced tools.
Drone based spraying and crop monitoring (widely used in USA, China, Japan)	Namo Drone Didi Scheme - promotes use of drones in spraying, mapping and women empowerment through drone operation
Multi-crop harvesting robots (Strawberry, Apples and other fruits in Europe and USA)	Pradhan Mantri Matsaya Sampada Yojana (PMMSY) – encourages mechanization and technology adoption in horticulture
IoT-Enabled Smart Irrigation Robots (Israel, Australia)	Pradhan Mantri Krishi Sinchai Yojana (PMKSY) – focuses on "more crop per drop" by using automation and precision irrigation
Swarm robotics for large scale planting and weeding (UK, USA)	Digital Agriculture Mission (2025) – supports AI, Drones, Robotics for scaling Indian Agriculture

Sub-Mission on Agricultural Mechanization (SMAM): This scheme is launched by the Ministry of Agriculture and Farmers Welfare in the year of 2014-15 to increase the reach of farm mechanization for small scale and marginal farmers.

Eligibility: It is for all farmers, Self-help groups (SHGs), cooperative society, Farmer producer organizations (FPOs), entrepreneurs, etc.

Subsidy: This program provides subsidy on newly developed equipment, modern machinery which provides 50 % subsidy for SC, ST, small, marginal and women farmers and 40 % for other farmers.

Funding: In this 60 % funding is provided by Central Government and 40 % by the State Government.

Under SMAM, funds amount of Rs. 141.39 crores released towards drone promotion. In this 263 agri-drones have been procured by 193 institutions of ICAR across the country. The 263 personnel from these institutions have undergone drone pilot training (43).

Pradhan Mantri Krishi Sinchai Yojana (PMKSY): This scheme is launched by the Ministry of Agriculture and Farmers Welfare in the year of 2015-16 to improve the water use efficiency through micro irrigation, precision farming technologies and robotic system for precise water management. The scheme motto is "Har Khet ko Pani" and "Per Drop More Crop".

Subsidy: The government provides a subsidy of 55 % for small and marginal farmers and 45 % for other farmers. In J&K, the maximum subsidy for installing micro-irrigation system is Rs. 93750/ha.

Funding: In this 60 % funding is provided by Central Government and 40 % by the state government. In North-East and Himalayan States, the cost share is 90 % and 10 % by Center and State government.

In this scheme, the farmers benefitted of Jammu & Kashmir are 23,681 in2022-23 and 52,132 in 2024-25 with total area of 1090 ha area under micro-irrigation (44).

Custom Hiring Centers (CHC) Scheme: The Government of India has established these centers to provide the farm machinery and equipment to small and marginal farmers on a rental basis. These are mainly formed to help the modern agriculture practices are affordable and accessible.

Subsidy: To encourage the adoption of Drone technology in agriculture, FPOs can receive 75 % of drone cost with maximum limit of 7.5 lakhs. The individual farmers including SCs, STs, small, marginal and women can receive 50 % of drone cost with maximum limit 5 lakhs.

Funding: For opening of CHCs at the village level, the project up to 10lacs got financial assistance 80 % to the other states and 95 % to the North-Eastern states by the Government.

In this scheme, 44607 CHCs with 139319 agricultural machineries for renting out are registered on mobile app in which total of 114461 farmers are registered on this mobile app named CHC App (45).

Namo Drone Didi (NDD) Scheme: It is launched in 2023 by the Government of India aimed to empowering women-led Self-help Groups by provide the drone technology for agricultural services.

Funding: This scheme has an outlay of Rs.1261 crore from the period 2023-26 by targeting the distribution of 15000 drones to selected SHGs.

Subsidy: The scheme provides 80 % subsidy on drone costs up to 8 lakhs and 20 % can be financed through loans under Agriculture Infrastructure Fund.

Training: The 15 days training programs are also provided for SHGs members to ensure proper handling and operations.

For 2024-25, the target is to distribute the drones to 3090 to the selected SHGs (46).

Challenges & Limitation

High initial and maintenance cost

The cost of purchasing agri-robots is very high for small and medium -scale farmers. These are not in the range of the normal person. Also, the regular servicing, software updates and part replacements are also very expensive.

Increase of unemployment

There is also an increase of unemployment of the labour who are unskilled. The person who not having the knowledge of driving the robots must face the unemployment in the future. Although there is increase of employment for the skilful labour.

High energy consumption

It refers to the significant amount of power required to operate agricultural robots effectively. These robots often rely on advanced technologies, such as sensors, artificial intelligence, GPS and heavy-duty mechanical components, which demand substantial energy input.

Technical complexity

Farmers and operators need training to handle, maintain and troubleshoot the agri-robots. A lack of skilled personnel in rural areas to provide support for advanced systems is a significant limitation.

Lack of decision-making power

Lack of decision-making power in the context of agri-robots refers to the limitations of robots in independently making accurate and context-sensitive decisions. This limitation can hinder their effectiveness in dynamic and unpredictable farming environments.

Limited adaptability

Different crops, soil types and farm layouts require specific robotic adaptations, increasing complexity. These often struggle in extreme weather conditions like heavy rain, snow, or dust storms. The navigation in uneven or densely planted fields can be challenging for many robots.

Conclusion

The integration of agri-bots with the small farms has the potential to revolutionize traditional farming practices. This technology can significantly reduce labour costs and enhance productivity and increase the effectiveness of sowing, weeding and harvesting. To make agribots available to small-scale farmers, several issues will come which consists of high initial costs, lack of technological knowledge and small landholding sizes must be resolved. To maximize benefits, governments, research institutions and private companies should focus on developing cost-effective, easy-to-use robotic solutions for small scale farms. Farmers can embrace these technologies with the support of cooperative-based machinery sharing arrangements, training programs and financial assistance. In the long run, agri-robots have the potential to empower small farmers, addressing labour shortages and climate change issues while improving agriculture's sustainability, efficiency and profitability.

Acknowledgements

The authors are grateful to Mr. Sumit Bura for his constant guidance and expertise.

Authors' contributions

VT carried out the research part of the paper. RK carried out the corrections. NS participated in the modification. RG and BS participated in the sequence alignment. VB participated in the table's arrangements. GK and RM helped in the rearrangement of the subheadings and finishing. VR helped in arranging the subtopics. S helped in searching relevant data. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. King A. Technology: The future of agriculture. Nature. 2017;544:521. https://doi.org/10.1038/544S21a
2. Billingsley J, Oetomo D, Reid J. Agricultural robotics [TC spotlight]. IEEE Robot Autom Mag. 2009;16(4):16. https://doi.org/10.1109/MRA.2009.934829
3. Oetomo D, Billingsley J. Special issue on agricultural robotics. Intell Serv Robot. 2010;3(4):207–8. https://doi.org/10.1007/s11370-010-0079-y
4. Kondo N, Nishitsuji Y, Ling PP, Ting KC. Visual feedback guided robotic cherry tomato harvesting. Trans ASAE. 1996;39(6):2331–8. https://doi.org/10.13031/2013.27744
5. Åstrand B, Baerveldt AJ. An agricultural mobile robot with vision-based perception for mechanical weed control. Auton Robots. 2002;13(1):21–35. https://doi.org/10.1023/A:1015674004201
6. Camara BS, Camara F, Berthe A, Oswald A. Micro-dosing of fertilizer-a technology for farmers' needs and resources. Int J Agri Sci. 2013;3 (5):387–99.
7. Divya CH, Ramakrishna H, Praveena G. Review article: Seeding and fertilization using an automated robot. Int J Curr Res. 2013;5(3):461–6.
8. Sunitha KA, Suraj GS, Sowrya PN, Atchyut Sriram G, Shreyas D, Srinivas T. Agricultural robots designed for seeding mechanism. Front Automob Mech Eng. 2017;197:1–6. https://doi.org/10.1088/1757-899X/197/1/012043
9. Chikowo R, Faloya V, Petit S, Munier-Jolain NM. Integrated weed management systems allow reduced reliance on herbicides and long-term weed control. Agric Ecosyst Environ. 2009;132(3–4):237–42. https://doi.org/10.1016/j.agee.2009.04.009
10. Wu X, Aravechia S, Lottes P, Stachniss C, Pradalier C. Robotic weed control using automated weeds and crop classification. J Field Robot. 2020;37:322–40. https://doi.org/10.1002/rob.21938
11. Bodunde OP, Adie UC, Ikumapayi OM, Akinyoola JO, Aderoba AA. Architectural design and performance evaluation of a ZigBee technology-based adaptive sprinkler irrigation robot. Comput Electron Agric. 2019;160:168–78. https://doi.org/10.1016/j.compag.2019.03.021
12. Bac CW, Roorda T, Reshef R, Berman S, Hemming J, van Henten EJ. Analysis of a motion planning problem for sweet-pepper harvesting in a dense obstacle environment. Biosyst Eng. 2016;146:85–97. https://doi.org/10.1016/j.biosystemseng.2015.07.004
13. Fue KG, Porter WM, Barnes EM, Rains GC. An extensive review of mobile agricultural robotics for field operations: Focus on cotton harvesting. Agric Eng. 2020;2(150):174. https://doi.org/10.3390/agriengineering2010010
14. Li Z, Miao F, Yang Z, Chai P, Yang S. Factors affecting human hand grasp type in tomato fruit-picking: A statistical investigation for ergonomic development of harvesting robot. Comput Electron Agric. 2019;157:90–7. https://doi.org/10.1016/j.compag.2018.12.047
15. Williams HAM, Jones MH, Nejati M, Seabright MJ, Bell J, Penhall ND, et al. Robotic kiwifruit harvesting using machine vision, convolutional neural networks and robotic arms. Biosyst Eng. 2019;181:140–56. https://doi.org/10.1016/j.biosystemseng.2019.03.007
16. Kumar P, Ashok G. Design and fabrication of smart seed sowing robot. Mater Today Proc. 2020;39:354–8. https://doi.org/10.1016/j.matpr.2020.07.432
17. Jayakrishna PVS, Reddy MS, Sai NJ, Susheel N, Peeyush KP. Autonomous seed sowing agricultural robot. In: 2018 International Conference on Advances in Computing, Communications and Informatics (ICACCI). IEEE; 2018. p. 2332–6. https://doi.org/10.1109/ICACCI.2018.8554622
18. Nagdeve T, Jangde P, Tandulkar H, Dhara S, Ukani N, Chakole S. Design of automated seed sowing robot for BT cotton seed. In: 2020 Second International Conference on Inventive Research in Computing Applications (ICIRCA). IEEE; 2020. p. 303–7. https://doi.org/10.1109/ICIRCA48905.2020.9183259
19. Santhi PV, Kapileswar N, Chenchela VKR, Prasad CHVS. Sensor and vision based autonomous AGRIBOT for sowing seeds. In: 2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS). IEEE; 2018. p. 242–5. https://doi.org/10.1109/ICECDS.2017.8389873
20. Indian Agricultural Research Institute. Annual report. New Delhi: IARI; 2018. p. 83.
21. Saiz V, Rovira F, Millot C. Performance improvement of a vineyard robot through its mechanical design. In: 2017 ASABE Annual International Meeting. Paper No: 1701120; 2017.
22. Xu E, Hou BM, JiaNa BI, Shen ZG, Wang B. Smart agriculture based on internet of things. In: International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST). IEEE; 2021. p. 157–62.
23. Tillett ND, Hague T, Grundy AC, Dedousis AP. Mechanical within-row weed control for transplanted crops using computer vision. Biosyst Eng. 2008;99:171–8. https://doi.org/10.1016/j.biosystemseng.2007.09.026
24. Åstrand B, Baerveldt AJ. An agricultural mobile robot with vision-based perception for mechanical weed control. Auton Robots. 2002;13:21–35. https://doi.org/10.1023/A:1015674004201
25. Cloutier DC, Van der Weide RY, Peruzzi A, Leblanc ML. Mechanical weed management. In: Non-chemical weed management: principles, concepts and technology; 2007. p. 111–34. https://doi.org/10.1079/9781845932909.0111
26. Griepentrog HW, Nørremark M, Nielsen J. Autonomous intra-row rotor weeding based on GPS. In: Proceeding of CIGR World Congress Agricultural Engineering for a Better World. Bonn, Germany; 3rd–7th September 2006. p. 2–6.
27. Silwal A, Davidson JR, Karkee M, Mo C, Zhang Q, Lewis K. Design, integration and field evaluation of a robotic apple harvester. J Field Robot. 2017;34(2):1140–55. https://doi.org/10.1002/rob.21715
28. Li T, Qiu Q, Zhao CJ, Xie F. Task planning of multi-arm harvesting robots for high-density dwarf orchard. Trans CSAE. 2021;37(2):1–10.
29. Peng Y, Liu J, Hie M, Shan H, He M, Hou GY. Research progress of urban dual-arm humanoid grape harvesting robot. In: 2021 IEEE 11th Annual International Conference on CYBER Technology in Automation, Control and Intelligent Systems (CYBER). Paper No: 459. IEEE; 2021. https://doi.org/10.1109/CYBER53097.2021.9588266
30. Zhao Y, Gong L, Liu C, Huan Y. Dual-arm robot design and testing for harvesting tomato in greenhouse. IFAC-PapersOnLine. 2016;49 (16):161–5. https://doi.org/10.1016/j.ifacol.2016.10.030
31. Ling X, Zhao YS, Gong L, Liu CL, Wang T. Dual-arm cooperation and implementing for robotic harvesting tomato using binocular vision. Robot Auton Syst. 2019;114:134–43. https://doi.org/10.1016/j.robot.2019.01.019
32. Wang Z. Robot obstacle avoidance and navigation control algorithm research based on multisensory information fusion. In: Proceeding of 11th International Conference on Intelligent Computation Technology and Automation (ICICTA). IEEE; 2018. p. 351–4. https://doi.org/10.1109/ICICTA.2018.00086
33. Blok PM, van Boheemen K, van Evert FK, IJsselmuiden J, Kim G. Robot navigation in orchards with localization based on particle filter and Kalman filter. Comput Electron Agric. 2019;157:261–9. https://doi.org/10.1016/j.compag.2018.12.046

34. Kumar S, Shivani J, Mishra J, Kumar S, Bharati R. Efficacy of pre- and post-emergence herbicides on complex weed flora in direct-seeded rice (*Oryza sativa*) in the eastern plains. Indian J Agric Sci. 2018;88(3):387–92. https://doi.org/10.56093/ijas.v88i3.78502

35. Paul RAI, Arthanari PM, Pazhanivelan S, Kavitha R, Djanaguiraman M. Drone-based herbicide application for energy saving, higher weed control and economics in direct-seeded rice (*Oryza sativa*). Indian J Agric Sci. 2023;93(7):704–9. https://doi.org/10.56093/ijas.v93i7.137859

36. Ganesh MI. The ironies of autonomy. Humanit Soc Sci Commun. 2020;7(1):1–10. https://doi.org/10.1057/s41599-020-00646-0

37. Subramaniam R, Hajjaj SSH, Gsangaya KR, Sultan MTH, Mail MF, Hua LS. Redesigning dispenser component to enhance performance crop-dusting agriculture drones. Mater Today Proc. 2023;81:166–72. https://doi.org/10.1016/j.matpr.2021.03.015

38. Raja V, Bhaskaran B, Nagaraj K, Sampathkumar J, Senthilkumar S. Agricultural harvesting using integrated robot system. Indones J Electr Eng Comput Sci. 2022;25:152. https://doi.org/10.11591/ijeecs.v25.i1.pp152-158

39. Linford J, Haghshenas-Jaryani M. A ground robotic system for crops and soil monitoring and data collection in New Mexico chile pepper farms. Discov Agric. 2024;2(1):1–26. https://doi.org/10.1007/s44279-024-00113-3

40. Nagarajan K, Ramanathan SP, Thiyagarajan G, Panneerselvam S. Optimization of irrigation scheduling under different types of automated drip irrigation system for tomato. Int J Curr Microbiol Appl Sci. 2020;9(7):3315–9. https://doi.org/10.20546/ijcmas.2020.907.387

41. Jeyaprakash P, Ramesh T, Vallal Kannan S. Optimization of herbicide dose and spray fluid for drone-based weed management in irrigated barnyard millet. Appl Ecol Environ Res. 2024;22(6):6173–86. https://doi.org/10.15666/aeer/2206_61736186

42. Bručienė I, Aleliūnas D, Šarauskis E, Romaneckas K. Influence of mechanical and intelligent robotic weed control methods on energy efficiency and environment in organic sugar beet production. Agriculture. 2021;11(5):449. https://doi.org/10.3390/agriculture11050449

43. Press Information Bureau (PIB). Sub-Mission on Agricultural Mechanization; 2023.

44. Ministry of Agriculture and Farmers Welfare (MoA & FW). Pradhan Mantri Krishi Sinchayee Yojana; 2023.

45. Ministry of Agriculture and Farmers Welfare (MoA & FW). Mechanization and Technology; 2020.

46. Press Information Bureau (PIB). Namo Didi Drone Scheme; 2024.

47. Matsuo Y, Yukumoto O, Yamamoto S, Noguchi N, Hara Y. Enhanced adaptability of tilling robot (2nd report) - Execution of various operations by tilling robot. JARQ. 2013;47(2):153–64. https://doi.org/10.6090/jarq.47.153

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.