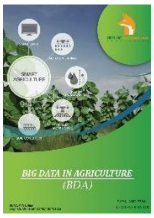
ZIBELINE INTERNATIONAL™
PUBLISHING
ISSN: 2682-7786 (Online)
CODEN: BDAIDR

Big Data in Agriculture (BDA)

DOI: http://doi.org/10.26480/bda.01.2026.18.27



REVIEW ARTICLE

BIOINSPIRED ROBOTIC SYSTEMS FOR PRECISION AND SUSTAINABLE AGRICULTURE: TRENDS, APPLICATIONS, AND CHALLENGES

Isak Karabegović

Academy of Science and Arts of Bosnia and Herzegovina, 71000 Sarajevo, Bosnia and Herzegovina.
**Corresponding Author email: isak1910@hotmail.com*

ARTICLE DETAILS

Article History:

Received 20 August 2025
Revised 28 September 2025
Accepted 22 October 2025
Available online 24 November 2025

ABSTRACT

This paper explores the role of bioinspired robotic systems in advancing precision and sustainable agriculture, emphasizing their potential to transform traditional farming practices through innovative designs inspired by biological systems. Bioinspired approaches draw upon mechanisms found in plants, insects, and animals to enhance adaptability, efficiency, and ecological compatibility. Recent developments include soft robotic grippers that handle delicate fruits without causing mechanical damage, autonomous drones for targeted spraying and monitoring, and sensor technologies inspired by natural systems that improve perception and decision-making in complex agricultural environments. These technologies contribute to greater precision in resource use, reduced reliance on pesticides and water, and improved overall sustainability of agricultural operations.In addition to benefits, the paper examines significant challenges that limit the broader adoption of bioinspired robotics. These include high development and implementation costs, difficulties in scaling prototypes into commercially viable systems, and the need for specialized environments or infrastructure. Furthermore, the complexity of integrating these robotic systems with existing agricultural practices presents barriers, especially for small and medium-sized farms with limited technical capacity.The paper concludes by identifying future research directions that could accelerate the adoption of bioinspired robots. These include the use of biodegradable materials to minimize environmental impact, the development of biohybrid systems that merge biological and mechanical components, and the expansion of applications in urban and vertical farming contexts. Together, these pathways highlight the potential of bioinspired robotic systems to support a transition toward more resilient, efficient, and sustainable food production systems.

KEYWORDS

bioinspired robotics, precision agriculture, sustainable agriculture, smart farming, soft robots, autonomous systems.

1. INTRODUCTION

Modern agriculture stands at a crossroads. On one side, it must meet rising global food demand; projections estimate that, by 2050, food production needs to increase by at least 70 %. On the other, it must contend with the profound effects of climate change, degradation of ecosystems, labor shortages, and the imperative of minimizing environmental footprints (Hammond et al., 2023; Chellapurath et al., 2023; Karabegović et al., 2020). The tension between these demands calls for resilient, efficient, and innovative solutions—enter bioinspired robotics within the paradigm of precision and sustainable agriculture.Sustainable agriculture aims to enhance productivity while preserving biodiversity, maintaining soil health, and reducing chemical inputs. Precision agriculture employs technologies like sensors, GPS, data analytics, and Internet of Things tools to ensure inputs—water, fertilizers, pesticides—are used precisely where needed, thereby reducing waste and environmental impact. Bioinspired robotics draws from natural systems—plants, animals, microorganisms—to inform robotic design, actuation, sensing, and control (Kondoyanni et al., 2022; Karabegović, 2022). Soft robots mimic plant and animal flexibility for safe interaction, while novel actuation mechanisms echo biological motion and adaptability (Sarker et al., 2024; Deng and Li, 2025). This synergy enables robots that are efficient, adaptive, and gentle—qualities vital for handling delicate crops, navigating variable terrains, and operating in uncontrolled outdoor conditions.

1.1 Global Challenges Driving Innovation

1.1.1 Climate Change & Environmental Stressors

Agricultural systems face intensifying climate extremes—droughts, floods, shifting seasons—that destabilize yields and strain resources. Sustainable and precision methods propose solutions: targeted irrigation, soil health monitoring, and greenhouse gas reduction (Chellapurath et al., 2023). Bioinspired robots augment these by offering adaptive functions that respond in real time to environmental cues—such as moisture levels, temperature fluctuations, and plant stress signals.

1.1.2 Labor Shortages

Many agricultural regions struggle with recruiting sufficient workforce for seasonal and labor-intensive tasks like hand-harvesting. Autonomous platforms—robots capable of perception, decision-making, and manipulation—offer continuity and efficiency. For example, a robotic system using conditional GANs for fruit detection in vertical farming can reliably pick strawberries with minimal human input. Soft robotic

Quick Response Code	Access this article online	
	Website: www.bigdatainagriculture.com.my	**DOI:** 10.26480/bda.01.2026.18.27

Cite The Article:Isak Karabegović (2026). Bioinspired Robotic Systems For Precision And Sustainable Agriculture: Trends, Applications, And Challenges. *Big Data In Agriculture (BDA)*, 8(1): 18-27

grippers amplify this by minimizing damage to delicate produce (Kondoyanni et al., 2022; Wang et al., 2023).

1.1.3 Food Security & Sustainability

As global population grows, sustainable intensification of agriculture is crucial. Innovations like bioinspired soft grippers allow for selective harvesting, reducing waste and preserving crop quality. Swarm robotics—ensembles of simple units operating collaboratively—can enable scalable, distributed tasks such as weeding, pest monitoring, and precision seeding.

1.1.4 Environmental Impact & Ecosystem Balance

Excessive use of agrochemicals and monocultures threaten soil health and biodiversity. Precision application systems, guided by bioinspired sensors, enable reduced input and localized interventions. Nonetheless, concerns about long-term ecological impact—such as disruption to pollinators—must be addressed proactively (Chellapurath et al., 2023; Kondoyanni et al., 2022; Karabegović and Banjanović-Mehmedović, 2021).

1.2 Technological Trends and Innovations

1.2.1 Soft Robotics and Adaptive Actuation

Advances in soft robotics enable robots with multiple degrees of freedom and material compliance for safe plant interaction . Bioinspired actuation methods involving hydrogels, shape-memory materials, and artificial muscles allow robots to adapt dynamically to complex agricultural environments (Deng and Li, 2025; Wang et al., 2024).

1.2.2 Perception-Action Loops Inspired by Biology

In vertical farms, robots using GAN-based synthetic data approaches can detect ripe produce and actuate harvesting in unpredictable canopies (Wang et al., 2023). The Passive Motion Paradigm—modeled after neural control of movement—enables smoother, goal-oriented manipulation with minimal damage.

1.2.3 Swarm Robotics and Modular Platforms

Swarm robots and modular systems present flexible, scalable ways to conduct tasks like pest control, distributed monitoring, and precision input application across large or heterogeneous fields (Kondoyanni et al., 2022; Galin and Meshcheryakov, 2019).

1.2.4 Biohybrid and Smart Materials

Emerging biohybrid systems integrate living tissues—such as muscle cells or neurons—with robotic frameworks for enhanced responsiveness . Similarly, material systems that emulate osmotic or hygroscopic shape changes (as in plant structures) offer novel actuation possibilities (Gao et al., 2021; Karabegović and Karabegović, 2019).

1.2.5 Aerial-Ground Collaborative Systems

Integrated UAV–UGV systems enable real-time field monitoring and targeted intervention: drones survey crop health and weeds, while ground units carry out precise actions like selective spraying or mechanical weeding (Pretto et al., 2019).

1.2.6 Conservation-aligned Design

Bioinspired robots designed for environmental conservation—minimizing disturbance, matching camouflage, and preserving ecosystems—offer insights valuable for agricultural applications where habitat sensitivity is crucial (Webster-Wood et al., 2022).

1.2.7 Why This Integration Matters

The intersection of bioinspired robotics with precision and sustainable agriculture opens new pathways (Fountas et al., 2022):

- *Resource Efficiency*: Robots that sense and respond like plants can optimize water, nutrient, and pesticide use.
- *Minimal Crop Damage*: Soft, adaptive manipulators reduce waste and improve post-harvest quality.
- *Resilience and Adaptability*: Systems can adjust to varying crop architectures, environmental conditions, and unpredictable terrains.
- *Labor Independence:* Autonomous harvesting and monitoring counteract labor shortages and support continuous production.
- *Ecosystem Respect*: Designs inspired by biology can align with ecological processes rather than uproot them.

2. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

2.1 Definition and Principles of Bioinspired Robotics

Bioinspired robotics is an interdisciplinary field that leverages biological systems—from plants, animals, and microorganisms—as models for robotic design, actuation, sensing, and control. This approach seeks to create robots that are adaptive, energy-efficient, flexible, and environmentally compatible (Karabegović et al., 2024). By mimicking natural behaviors such as peristaltic motion, tentacle-like grasping, or biomechanical sensing, these robots can interact delicately with sensitive crops and navigate complex environments with minimal damage. In agriculture, such systems enable gentle manipulation, precision harvesting, and robust environmental sensing that conventional rigid robots cannot achieve.

2.2 Trends in Implementation of Service Robots in Agriculture

The last decade has produced significant advances in the deployment of service robots across agricultural domains. The current landscape includes diverse applications ranging from automated harvesting and precision spraying to crop monitoring and soil analysis, as Figure 1 shows.

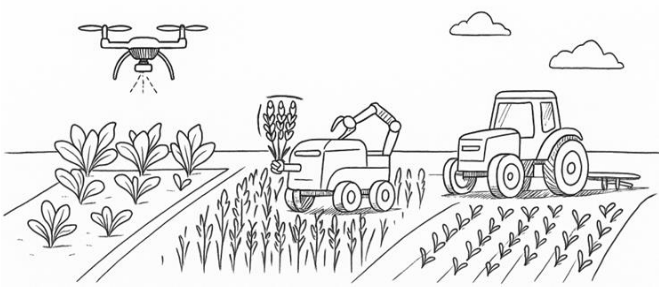
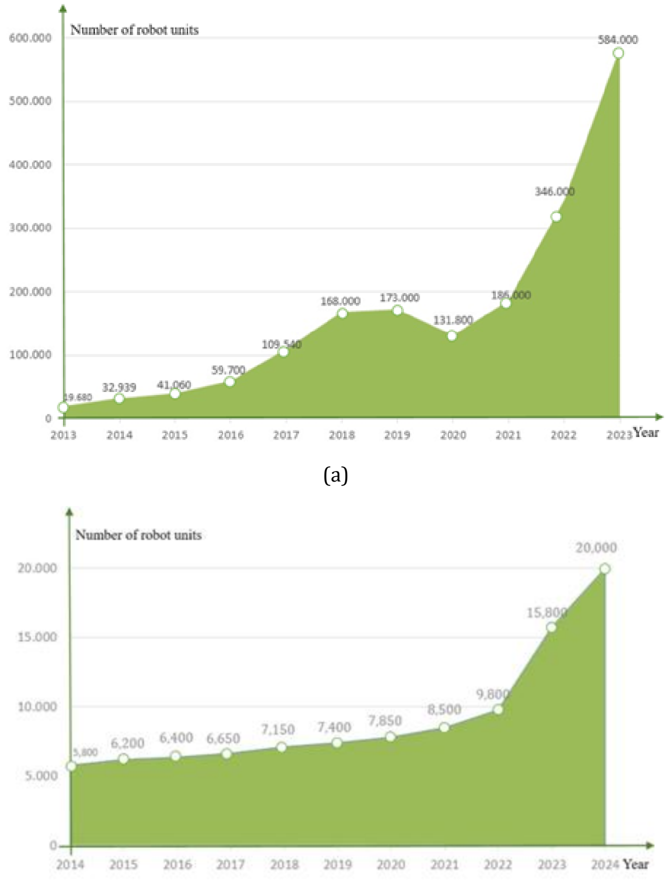


Figure 1: Bioinspired Robotic Systems for Precision and Bustainable Agriculture

These systems not only enhance productivity but also reduce dependency on manual labor, addressing critical shortages in many regions. Moreover, the integration of artificial intelligence and machine learning has enabled robots to adapt to complex and dynamic agricultural environments. Sustainability goals further drive innovation, as service robots contribute to resource efficiency and minimize ecological impact. Together, these trends illustrate a shift toward more resilient, technology-driven farming practices that align with the demands of global food security and environmental stewardship. To provide a clearer overview of these developments, Figure 2a presents the overall trend in the adoption of service robots for professional use (2013–2023), while Figure 2b highlights their specific implementation in agriculture (2013–2024), illustrating both steady and accelerated growth of these technologies (International Federation of Robotics (IFR), 2014; International Federation of Robotics (IFR), 2025; International Federation of Robotics (IFR), 2014; International Federation of Robotics (IFR), 2018; International Federation of Robotics (IFR), 2020; International Federation of Robotics (IFR), 2023; IFR: Frankfurt Am Main, Germany, 2023). The data, as illustrated in Figure 2a, reveal a clear upward trend in the adoption of service robots for professional use between 2013 and 2023. Installations increased from 19,680 units in 2013 to 584,000 units in 2023, representing more than a twentyfold growth over the decade. After steady growth until 2019, a decline occurred in 2020 (131,800 units), largely associated with the global disruptions caused by the COVID-19 pandemic. However, from 2021 onwards, the trend recovered rapidly, reaching record levels in 2022 and 2023, which demonstrates a strong expansion and growing confidence in service robot technologies. This trajectory confirms that service robots have become a key driver of technological transformation across multiple sectors.



(a)

(b)

Figure 2 : Trends in the Adoption of Service Robots: a) Overall adoption of service robots for professional use (2013–2023), b) Adoption of service robots in agriculture (2013–2024)

The data, as shown in Figure 2b, illustrate a steady increase in the use of service robots in agriculture over the past eleven years. Installations grew from 5,400 units in 2013 to 20,000 units in 2024, representing nearly a fourfold growth. From 2013 to 2021, the rise was gradual and moderate, while a stronger acceleration can be observed from 2022 onwards. A particularly sharp increase occurred in 2023 and 2024, reflecting the growing demand for automation and digitalization of agricultural processes. These figures clearly demonstrate that robotics is becoming a key driver of modernization and sustainability in agriculture. The range of applications for service robots in agriculture is extensive, encompassing robots for milking cows, soil cultivation, drones for various agricultural tasks, grass-cutting robots, weeding robots, harvesting robots, monitoring robots, and more. Figure 3 illustrates the trend of increasing implementation of service robots in agriculture.

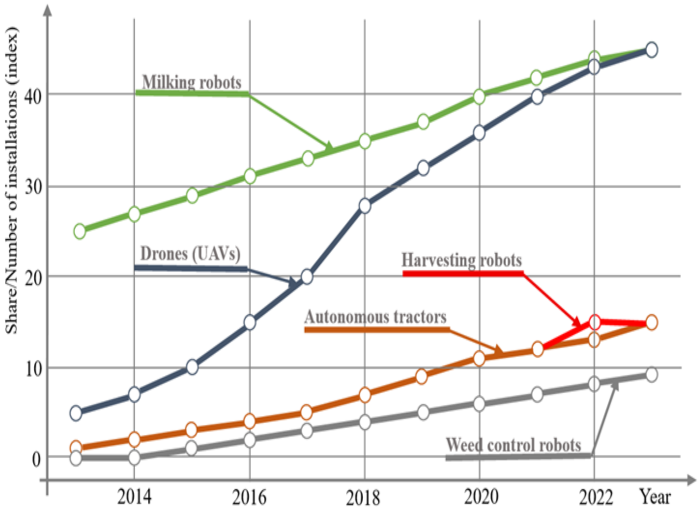


Figure 3: Growth trend in the implementation of service robots by category in agriculture, 2013–2023, worldwide.

The figure illustrates the adoption trends of various service robots in agriculture from 2013 to 2023 (International Federation of Robotics (IFR), 2014; International Federation of Robotics (IFR), 2025; International Federation of Robotics (IFR), 2014; International Federation of Robotics (IFR), 2018; International Federation of Robotics (IFR), 2020; International Federation of Robotics (IFR), 2023; IFR: Frankfurt Am Main, Germany, 2023). Milking robots show a consistently high adoption rate, starting at around 30 (index) in 2013 and steadily increasing to over 40 by 2023, indicating their widespread and stable use. Drones (UAVs) exhibit rapid growth, especially after 2016, rising from approximately 5 to 40 (index) by 2023, reflecting their increasing role in precision farming and aerial monitoring. Harvesting robots and autonomous tractors show moderate adoption, with both steadily rising after 2015, though harvesting robots experience a slight plateau around 2022. Weed control robots have the lowest adoption rates, increasing gradually from below 5 to around 12 (index) by 2023, indicating emerging but still limited implementation. Overall, the trends highlight that technologies like milking robots and drones are leading the digital transformation in agriculture, while autonomous machinery and specialized robots are gradually expanding as the sector adapts to automation. These patterns emphasize both the diversity of robotic solutions and the differential pace of adoption across agricultural tasks.

2.2.1 Drones and Sensing Systems

In the last five years, drones equipped with sensing systems have become central to precision agriculture. Their integration with multispectral, thermal, and RGB cameras enables real-time crop monitoring, soil analysis, and site-specific resource optimization. Drones have become a central component of precision agriculture, supporting spraying, crop monitoring, and multispectral sensing (Rehman et al., 2019). Their application is illustrated in Figure 4.

Figure 4: Examples of agricultural drones in field operations

Compared to traditional scouting, UAVs provide high-resolution spatial data that allow early detection of plant stress, targeted irrigation, and variable-rate fertilization (Tsouros, et al., 2019). Modern workflows combine automated mission planning, on-board data preprocessing, and cloud-based analytics. Multispectral indices such as NDVI and NDRE are widely used to assess crop vigor, while thermal imaging identifies water stress and irrigation inefficiencies (Nebiker et al., 2016). More advanced systems integrate LiDAR for canopy structure mapping, supporting yield estimation in orchards and vineyards. Importantly, these aerial data layers are increasingly fused with ground-based sensors and weather models, improving diagnostic accuracy and reducing false positives . Trends between 2021 and 2025 reveal a shift from RGB-only payloads to multispectral and thermal packages, with endurance extending to 40 minutes per flight and widespread adoption of edge AI for weed/crop classification (Liakos et al., 2018). Integration with variable-rate technology has enabled closed-loop management systems where drone data directly inform sprayers and irrigation units. Despite rapid progress, challenges remain. UAV-derived indices require calibration with ground truth, while weather and regulatory constraints limit scalability. Smaller farms often depend on external service providers due to skill gaps and costs. Nonetheless, economic benefits are evident: input savings, reduced environmental impact, and compliance with sustainability standards have driven broader adoption. Looking forward, further regulatory flexibility for beyond visual line-of-sight (BVLOS) flights and standardization of data formats are expected to expand the impact of drones and sensing systems in agriculture (Tsouros, et al., 2019; Liakos et al., 2018).

Table 1: Trends in the use of drones and sensing systems in agriculture (2021–2025)

Year	Sensor payloads	Flight endurance	Adoption level
2021	Mostly RGB, pilot multispectral	20–25 min	Low (early adopters)
2022	Multispectral expands, first thermal	25–30 min	Moderate
2023	Multispectral common, thermal emerging	30–35 min	Growing adoption
2024	Multispectral + thermal mainstream	35–40 min	High in specialty crops
2025	Multispectral + thermal standard, LiDAR pilots	40–45 min	High, broader acreage

As shown in Table 1, drone adoption has shifted from low pilot projects with simple RGB cameras in 2021 to mainstream use of multispectral and thermal payloads by 2025 (Rehman et al., 2019; Tsouros et al., 2019; Nebiker et al., 2016). Flight endurance and integration with advanced sensing technologies have steadily improved, driving broader adoption across different crop systems.

2.2.2 Autonomous Harvesting Robots

In the last decade, autonomous harvesting robots have evolved into one of the most promising applications of agricultural robotics. Equipped with machine vision, AI-based perception, and adaptive grippers, these robots are designed to detect ripeness, localize fruits or vegetables, and execute precision harvesting without damaging crops. Their use has become particularly widespread in high-value crops such as strawberries, tomatoes, apples, and peppers, where labor shortages and high harvesting costs have accelerated the demand for automation (Bac et al., 2017; Li et al., 2024). Figure 5 illustrates examples of harvesting robots in field operations (Future Farming, 2022; Agence de presse APEI, 2022; Mallport, 2024).

Figure 5: Examples of autonomous harvesting robots in agriculture

Compared to manual harvesting, autonomous systems offer continuous operation, labor cost reduction, and the potential for improved product consistency. Advanced perception technologies integrate RGB-D cameras, hyperspectral sensors, and convolutional neural networks (CNNs) to distinguish between ripe and unripe fruits even under variable lighting (Silwal et al., 2017). Gripping technologies have also advanced from rigid mechanical end-effectors to soft robotic grippers and vacuum-based systems, reducing the risk of fruit bruising (Navas et al., 2021). Recent workflows emphasize a fusion of perception, path planning, and motion optimization, enabling robots to adapt to complex environments such as dense foliage. Integration with Internet of Things (IoT) platforms and cloud-based farm management systems allows real-time yield estimation and operational monitoring . Importantly, autonomous harvesters are increasingly designed as modular units that can be mounted on mobile platforms or drones for multi-functional tasks, from pruning to spraying. Despite these advances, challenges remain. Harvesting robots must cope with occlusions, variable fruit positions, and dynamic outdoor conditions such as wind or lighting variability. Economic barriers are also notable, as initial investment costs remain high for small and medium-sized farms (Bac et al., 2017; Li et al., 2024). Nevertheless, trends from 2021 to 2025 show increasing adoption, improved speed of fruit recognition and picking, and wider commercial deployment, particularly in developed agricultural markets.

Table 2: Trends in the adoption of autonomous harvesting robots (2021–2025)

Year	Perception systems	Picking speed	Adoption level
2021	RGB + simple vision	1–2 fruits/min	Low (experimental trials)
2022	RGB-D + basic AI	2–3 fruits/min	Moderate
2023	AI + CNN recognition	3–4 fruits/min	Growing adoption
2024	AI + hyperspectral + soft grippers	4–5 fruits/min	High in specialty crops
2025	AI + multi-sensor fusion + fleet operation	5–6 fruits/min	High, broader commercial use

As shown in Table 2, harvesting robots have steadily advanced in perception, gripping technology, and operational speed, resulting in broader commercial adoption (The Business Research Company, 2025). By 2025, multi-sensor fusion and integration with fleet management systems are expected to enable large-scale deployment across different crop types.

2.2.3 Self-driving Tractors and Modular Ground Vehicles

Self-driving tractors and modular ground vehicles have become a cornerstone of modern smart farming, combining autonomous navigation, precision control, and modular attachments for multiple agricultural tasks. These vehicles leverage GNSS-based guidance, LiDAR, radar, and computer vision to operate autonomously in various field conditions, including uneven terrain and dense crop layouts (Bechar and Vigneault, 2016; Karabegović and Banjanović-Mehmedović, 2021; Wei et al., 2024). Figure 6 illustrates examples of autonomous tractors and modular ground vehicles in field operations (First Furrow Staff, 2016; Olha. (n.d.); Mike, 2016).

Figure 6: Examples of autonomous tractors and modular ground vehicles in agriculture

Compared to conventional tractors, autonomous systems allow for continuous operation, optimized fuel consumption, and reduced soil compaction. Modular designs enable single platforms to perform plowing, seeding, spraying, and fertilization through interchangeable attachments, increasing operational flexibility and cost-effectiveness (). Advanced perception systems integrate GNSS corrections, obstacle detection sensors, and AI-driven path planning algorithms to maintain precision even under challenging conditions, such as low visibility or overlapping crop rows.

Integration with farm management platforms enables closed-loop operations, where data from crop sensors, drones, and weather stations guide real-time adjustments in vehicle speed, spraying rates, and seeding density. Emerging trends also include swarm coordination of multiple modular vehicles, enabling collaborative field operations for large-scale farms (Wei et al., 2024; Shamshiri et al., 2018).

Challenges remain in regulatory approval, cybersecurity, and high initial investment costs. Terrain variability, weather, and unstructured field conditions still require robust AI algorithms and sensor fusion to ensure safe and reliable autonomous operation. Despite these hurdles, adoption continues to grow due to labor shortages, increasing efficiency demands, and environmental sustainability incentives.

Table 3: Trends in autonomous tractors and modular ground vehicles (2021–2025)

Year	Autonomy level	Operational tasks	Adoption level
2021	Assisted GPS	Seeding, limited spraying	Low (pilot projects)
2022	Partial autonomy	Seeding, spraying, fertilization	Moderate
2023	Conditional autonomy	Multi-tasking modular platforms	Growing adoption
2024	High autonomy	Modular multi-task fleets	High in commercial farms
2025	Full autonomy + swarm operation	Large-scale coordinated operations	High, expanding adoption

As shown in Table 3, the evolution of autonomous tractors and modular ground vehicles has progressed from basic GPS-assisted systems to fully autonomous platforms capable of multi-task operations and coordinated fleet management (Mordor Intelligence, 2025; Research and Markets, 2023). By 2025, widespread adoption across commercial farms is expected, particularly in regions with labor shortages and precision agriculture initiatives.

2.2.4 Weeding and Pest Control Robots

Autonomous weeding and pest control robots have become increasingly important for sustainable agriculture, reducing reliance on chemical herbicides and pesticides while improving crop yield and environmental outcomes. These robots combine computer vision, AI-based object recognition, and precise actuation systems to identify and remove weeds or target pests at a plant-level scale (Slaughter et al., 2008; Ghobadpour et al., 2022). Figure 7 illustrates examples of weeding and pest control robots in field operations (Le Betteravier, 2021; Wurst, A.X., 2020; Buzzworthy. (n.d.).

Figure 7: Examples of autonomous weeding and pest control robots

Compared to conventional mechanical or chemical methods, these systems offer targeted interventions, minimizing crop damage and reducing input costs. Vision systems typically employ RGB, multispectral, or hyperspectral cameras to differentiate between crops and weeds, while AI algorithms guide robotic arms, mechanical cutters, or micro-sprayers to selectively remove weeds or apply localized pesticide doses. Modern robots integrate GPS and RTK-based navigation with real-time perception for precise field operations. Some systems utilize swarm robotics concepts, allowing multiple units to collaborate across large areas, optimizing coverage and efficiency. Integration with farm management software further enables adaptive scheduling, tracking of pest outbreaks, and data-driven decision-making (Ghobadpour et al., 2022; Duckett et al., 2018). Challenges include variable lighting, occlusion by crop foliage, and uneven terrain, which can reduce detection accuracy. High initial costs and maintenance requirements also limit adoption, particularly for small-scale farms. Despite these hurdles, adoption is increasing, driven by regulatory pressure to reduce chemical inputs, labor shortages, and growing emphasis on environmentally friendly farming practices. Trends in autonomous weeding and pest control robots (Table 4) are synthesized from recent literature (Wang et al., 2025; Xu et al., 2025; Lytridis and Pachidis, 2024).

Table 4: Trends in autonomous weeding and pest control robots (2021–2025)

Year	Sensing & AI	Actuation type	Adoption level
2021	RGB cameras + basic AI	Mechanical weeding	Low (experimental)
2022	RGB-D + object recognition	Mechanical & spot spraying	Moderate
2023	Multispectral + CNN-based AI	Robotic arms, micro-sprayers	Growing adoption
2024	Hyperspectral + advanced AI	Multi-functional weeding & pest control	High in specialty crops
2025	Multi-sensor fusion + swarm operation	Fully autonomous selective removal	High, expanding commercial use

As shown in Table 4, autonomous weeding and pest control robots have evolved from basic RGB-guided mechanical systems to multi-sensor, AI-driven platforms capable of precise, selective interventions. By 2025, swarm coordination and multi-sensor fusion are expected to enable large-scale deployment, reducing herbicide and pesticide usage while enhancing crop productivity.

2.2.5 Swarm Robotics

Swarm robotics represents a novel approach to agricultural automation, inspired by collective behavior observed in social insects. Multiple small, autonomous robots work collaboratively to perform tasks such as planting, harvesting, weeding, and environmental monitoring, enabling scalability and redundancy while maintaining flexibility in complex field conditions (Brambilla et al., 2013; Karabegović and Doleček, 2012; Calderón-Arce et al., 2022). Figure 8 illustrates examples of swarm robotics applications in agriculture (Editorial, 2022; Toon, 2020; Armananta, 2024).

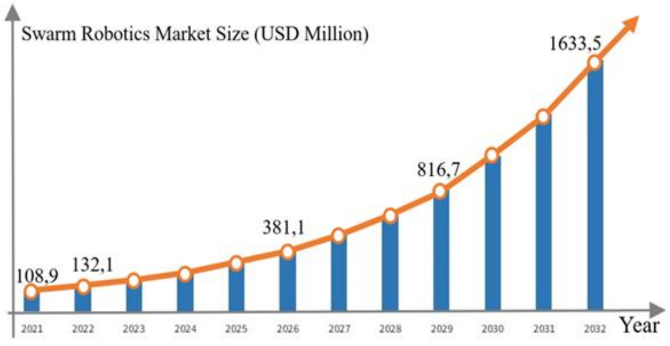
Figure 8: Examples of swarm robotics in agricultural operations

Compared to single large autonomous machines, swarm systems offer advantages in adaptability, fault tolerance, and cost-effectiveness. Each unit is equipped with local sensors, communication modules, and AI-based decision-making algorithms that allow robots to coordinate in real time. Swarm strategies include distributed task allocation, path planning, and obstacle avoidance, often guided by a central farm management system for higher-level oversight (Su et al., 2021). Recent developments integrate aerial drones and ground robots in hybrid swarms, enabling multi-layer monitoring and precision interventions across large fields. Swarm robotics also facilitates high-frequency data collection, improving crop health monitoring, pest detection, and yield estimation. The modular and scalable nature of these systems allows farms to adjust the number of active units according to workload, crop type, or environmental conditions. Challenges remain in communication reliability, energy management, and interoperability of heterogeneous robots. Regulatory frameworks and standardization for swarm operations are still evolving, limiting widespread commercial adoption. Nevertheless, trends from 2021 to 2025 indicate growing research adoption, pilot deployments in specialty crops, and early commercial implementations in large-scale agriculture.

Table 5: Trends in swarm robotics adoption in agriculture (2021–2025)

Year	Robot type & autonomy	Applications	Adoption level
2021	Ground-only simple robots	Experimental monitoring & weeding	Low (research trials)
2022	Ground robots with limited communication	Localized harvesting & pest control	Moderate
2023	Multi-robot coordination	Precision weeding, monitoring	Growing adoption
2024	Hybrid swarm (drones + ground)	Multi-task collaborative operations	High in pilot farms
2025	Fully integrated swarms	Large-scale coordinated operations	High, early commercial use

As shown in Table 5, swarm robotics in agriculture has progressed from simple experimental setups to hybrid multi-robot systems capable of coordinated operations (Albiero et al., 2021; Li et al., 2022). By 2025, the use of swarms is expected to enable efficient, scalable, and adaptive solutions for large farms while supporting precision agriculture initiatives. North America dominates the global swarm robotics market. The region has a strong ecosystem of technology companies, research institutions, and startups focused on developing and deploying swarm robotics solutions, and the investment trend in swarm robotics in the USA is shown in Figure 9 (Global Market Insights. 2023).



Source:https://www.gminsights.com/

Figure 9: U.S Swarm Robotics Market Size u periodu 2021-2032, (USD Million)

In the US, robotics swarms across industries, including agriculture, logistics, defense and healthcare. Precision agriculture is a major driver of growth, with a swarm of robotics being used for tasks such as crop monitoring, planting and harvesting.

2.2.6 Livestock Management Robots

Autonomous livestock management robots are transforming animal husbandry by automating routine tasks such as feeding, milking, monitoring health, and cleaning. These systems combine robotics, sensor networks, and AI-driven analytics to optimize animal welfare, productivity, and operational efficiency (Banhazi et al., 2012). Figure 10 illustrates examples of livestock management robots in farm operations (Gulec, 2023; Downs, 2025; Jornal Campo Soberano. (n.d.).

Figure 10: Examples of livestock management robots in farm operations

Compared to traditional manual husbandry, autonomous robots offer continuous monitoring, precise feeding, and early detection of health issues such as lameness, mastitis, or abnormal behavior. Vision systems, thermal cameras, RFID tracking, and wearable sensors enable real-time assessment of individual animals, providing actionable insights to farm managers (Rutten et al., 2013). Robotic milking systems are a key example, allowing cows to be milked on demand while recording yield, milk composition, and animal activity. Integration with farm management platforms facilitates data-driven decision-making for herd nutrition, breeding, and disease management. Emerging trends include modular mobile robots capable of performing multiple tasks, autonomous cleaning systems, and AI algorithms predicting health risks or feed optimization strategies. These technologies reduce labor requirements, enhance animal welfare, and support sustainable livestock production. Challenges include high initial costs, maintenance requirements, and the need for robust AI capable of operating in dynamic farm environments. Additionally, regulatory considerations for animal safety and data privacy must be addressed. Despite these hurdles, adoption has steadily increased, particularly in large-scale dairy and pig farms, due to labor shortages and the economic benefits of automation.

Table 6: Trends in livestock management robots (2021–2025)

Year	Robot type & functionality	Key applications	Adoption level
2021	Robotic milking only	Milking, basic monitoring	Low (early adopters)
2022	Milking + feeding automation	Feeding, milking, monitoring	Moderate
2023	Multi-task mobile robots	Milking, feeding, cleaning	Growing adoption
2024	AI-assisted monitoring + robotics	Health monitoring, disease detection	High in large-scale farms
2025	Fully integrated herd management systems	All-in-one automation, predictive analytics	High, expanding adoption

As shown in Table 6, livestock management robots have evolved from single-task robotic milking systems to fully integrated herd management platforms (Salfer et al., 2021; Steeneveld et al., 2021). By 2025, these systems are expected to support large-scale, data-driven, and sustainable livestock operations.

3. TECHNOLOGICAL SOLUTIONS

3.1 Bioinspired Manipulators (e.g., Hand-like or Tentacle-inspired Grippers)

Bioinspired manipulators harness the mechanics of natural organisms to achieve adaptive, gentle, and effective gripping, which is crucial for handling delicate agricultural produce. Soft grippers are at the forefront of this innovation, as their compliant silicone-based materials allow deformation around varied geometries, thereby minimizing damage to fruits and vegetables such as apples or mushrooms. Research further highlights that silicone elastomer grippers are cost-effective and safe for biological interactions, though many still rely on relatively simple open-loop control systems (Enrique et al., 2021). Advancements include tendon-driven soft grippers designed with finite element analysis (FEA), which have demonstrated payloads of up to 7 kg, with capacity for lifting objects of 27 kg—highlighting efficiency relative to weight.Additive manufacturing further enhances this field, as novel 3D-printed adaptive grippers made from polylactic acid (PLA) and thermoplastic polyurethane (TPU) can be inexpensively integrated into standard robotic arms, supporting scalability and versatility (Wired, 2017). Overall, bioinspired manipulators provide gentle interaction with crops, material efficiency, and low-cost adaptability. However, significant challenges remain in terms of control sophistication, scalability, cost accessibility, and design standardization.

3.2 Autonomous Mobile Platforms Inspired by Animal Locomotion

Bioinspiration extends beyond manipulators into locomotion, with animal-like movement providing adaptability and resilience for unstructured agricultural terrains. A prominent example is LAURON, a hexapod robot inspired by stick insects and developed in Germany, which employs multiple joints and neural-network-based control to traverse rough surfaces with high stability. Although not designed specifically for agriculture, its principles can be adapted to future mobile platforms.

Another important case is SwagBot, an autonomous herding robot developed in Australia. Equipped with sensors and machine learning algorithms, SwagBot assesses pasture health and directs cattle for optimized grazing, thereby preventing soil degradation. Likewise, Georgia Tech's Tarzan robot, inspired by sloths, demonstrated an energy-efficient approach to field monitoring by hanging from overhead wires to capture crop data (Wired, 2017). These examples show that bioinspired locomotion offers robust mobility in uneven terrain, minimal disturbance of crops and soil, and real-time adaptability to changing field conditions.

3.3 Sensor Systems and AI Algorithms for Resource Optimization (Water, Energy, Fertilizer)

The intelligent management of agricultural inputs such as water, nutrients, and energy is vital for sustainable farming. Modern sensor systems provide real-time monitoring capabilities to optimize resource usage. Leaf sensors, such as the SG-1000, can detect plant turgor pressure and water stress prior to wilting, reducing irrigation needs by up to 50%. Nanosensors based on advanced nanomaterials like graphene and zinc oxide detect soil nutrients, pH, and pathogens, thereby improving fertilizer precision and soil health. Additionally, IoT-supported soil probes, such as the Teralytic system, measure moisture, salinity, and nutrient levels at different depths, enabling farmers to make data-driven adjustments throughout the growing season. These systems, when cloud-connected, allow comprehensive monitoring of field conditions and timely intervention (Business Insider. 2025).

3.4 AI and Algorithmic Control

Artificial intelligence (AI) and algorithmic control are increasingly applied in precision agriculture to enhance efficiency, sustainability, and adaptability. Predictive irrigation systems that combine IoT-enabled sensors with machine learning models such as multilayer perceptrons (MLPs), support vector machines (SVMs), and k-nearest neighbors (k-NN) have achieved irrigation accuracy levels near 99%, with water and energy savings of up to 27% and 57%, respectively. Similarly, IoT- and AI-based smart irrigation systems using ESP32 microcontrollers and long short-term memory (LSTM) models enable automatic, scalable decision-making. These platforms conserve water, increase labor productivity, and offer mobile-based monitoring for flexibility in farm operations . Beyond irrigation, edge AI has advanced pest detection technologies. Embedded neural networks inside traps identify infestations in real time, while energy-harvesting systems ensure sustainable low-power operation. Collectively, these solutions enable precise, data-driven application of agricultural resources tailored to real-time conditions, support resilience against environmental variability, and provide energy-efficient, scalable innovations. Nevertheless, challenges in connectivity, cost, and farmer training remain central barriers to widespread adoption (Wired, 2017; Kunt, 2025; Albanese et al., 2021).

4. CASE STUDIES AND APPLICATIONS

4.1 Examples from EU Projects

4.1.1 agROBOfood

The EU project agROBOfood, funded under Horizon 2020 with a budget of approximately €16 million, has been designed to create an innovation ecosystem supporting the adoption of robotics in the agro-industrial sector across Europe. Through Digital Innovation Hubs (DIHs), the project connects researchers, startups, and companies to jointly develop and demonstrate robotic solutions with practical value for the agri-food sector (Eurecat Centre Tecnològic, 2020).

Demonstration solutions include:

- Automated fruit harvesting, optimized for timing, with reduced labor costs.
- A greenhouse cucumber-harvesting robot capable of assessing fruit ripeness and autonomously harvesting.
- Drone systems for vineyard monitoring.
- Cold-storage palletizers capable of operating without human presence, increasing efficiency and safety (FIRAteam. 2021; Communications, 2022).

DIHs further facilitate the diffusion of these solutions through open calls and regional clusters, enabling deployment across diverse agro-environments (Agenso, 2022).

4.1.2 RHEA

The RHEA project (FP7) aimed to implement a new generation of autonomous robots—both aerial and terrestrial—for efficient weed management using chemical, mechanical, and thermal methods. It covered a variety of crops, including wheat, strawberries, and olives, with the ambition of reducing pesticide use by up to 75% while improving crop quality and worker safety (RHEA Project, 2015; CORDIS, 2017).

Achievements of RHEA include:

- Field testing of robots in wheat, maize, and olive plantations.
- Cooperative operation between unmanned aerial vehicles (UAVs) and ground mobile units (GMUs) for precise spraying tasks.
- Development of safety protocols and modular control systems.
- Socioeconomic contributions, including reduction of chemical residues, improved occupational safety, fewer accidents, and job creation for highly skilled professionals in rural areas (CORDIS, 2017).

4.2 Commercial Solutions

4.2.1 Strawberry Harvesting Robots

Commercial robotic platforms for fruit harvesting increasingly rely on bioinspired manipulators, often designed with tentacle-like or hand-like grippers to minimize fruit damage. These systems improve harvest speed and reduce reliance on seasonal labor. Although specific commercial names are not always disclosed, prototypes and market-ready models demonstrate substantial potential in high-value crops such as strawberries (AgFunderNews, 2023).

4.2.2 Autonomous Niche-task Platforms

Other commercial robots are designed for selective harvesting and greenhouse operations, where environmental control simplifies deployment. These robots typically integrate advanced sensors, AI-based vision, and soft end-effectors to optimize efficiency and reduce waste, especially in specialized crops requiring delicate handling (FreshPlaza, 2024).

4.3 Synthesis and Significance

The reviewed initiatives highlight three major pathways:

- agROBOfood has created a robust testing and scaling platform for robotic technologies in real agro-environments, supporting SMEs through DIH structures and funding.
- RHEA exemplifies pioneering deployment of heterogeneous robot fleets for reducing pesticide use, enhancing safety, and strengthening rural economies.
- Commercial harvesting robots for strawberries illustrate tangible applications of bioinspired robotics to improve efficiency, product quality, and sustainability.

Together, these streams suggest that bioinspired robotics is no longer merely a research trend but a practical reality, with interoperable systems and scalable platforms already operating in agricultural production.

5. DISCUSSION

Bioinspired robotic systems in precision agriculture represent a rapidly evolving technological field that merges robotics, artificial intelligence, and biological principles to address sustainability challenges. Their development offers clear advantages but also faces notable barriers that will shape their adoption.

5.1 Advantages

Key advantages include sustainability and resource efficiency. By mimicking natural processes—such as swarm coordination or root-like water exploration—robots can optimize inputs and minimize waste (Mockshell and Kamanda, 2018; Albiero et al., 2022). They also enhance operational efficiency, enabling precise planting, harvesting, and irrigation with reduced labor dependence. For example, bioinspired grippers minimize fruit damage during strawberry harvesting, while root- and ant-inspired irrigation robots deliver water precisely to crops (Elfferich et al., 2022; Mateos Matilla et al., 2021). Furthermore, these systems reduce pesticide and water consumption by targeting only affected plants, aligning with sustainability goals and reducing farmer costs (Sklar et al., 2022).

5.2 Limitations

Despite these benefits, challenges persist. High costs of design, deployment, and maintenance hinder accessibility, especially for smallholders (Technology in Society, 2023). Many robots are optimized for standardized environments, limiting adaptability to diverse terrains and crops . Additionally, the technological complexity of AI-driven systems requires skilled operation and constant calibration, creating a gap between experimental prototypes and robust, everyday solutions (Sklar et al., 2022; Monteiro, 2024).

5.3 Future Perspectives

The future of bioinspired robotics will likely depend on advances in soft robotics and AI-based interpretation of biological signals, which may improve adaptability and predictive crop management (Monteiro, 2024). Lowering costs through modular design and mass production, alongside supportive policies and subsidies, will be essential for widespread use. However, the socioeconomic implications—including labor displacement and unequal access—must also be addressed through inclusive policies and participatory approaches with farmers.

5.4 Concluding Remarks

In summary, bioinspired robotic systems hold great promise for sustainability, efficiency, and resource conservation in agriculture. Yet, their affordability, adaptability, and ease of use remain central barriers. Addressing these challenges will determine whether such systems evolve from research prototypes into a cornerstone of future sustainable agriculture.

6. CONCLUSION

The integration of bioinspired robotic systems into agriculture represents a transformative shift in food production, combining technological innovation with principles of sustainability and efficiency. These systems offer the potential to optimize resource use, reduce reliance on chemicals and water, and improve overall productivity, while adapting to diverse environmental and operational conditions. At the same time, economic, technical, and organizational challenges continue to limit their widespread adoption. Future development is likely to focus on enhancing autonomy and resilience. Incorporating renewable energy sources, such as solar or wind harvesting, could allow robots to operate for extended periods in remote or resource-limited settings, while also supporting broader environmental goals. Similarly, the integration of intelligent decision-making, enabled by advanced sensors and adaptive algorithms, can transform robots from tools that simply perform tasks into systems capable of dynamic, context-aware actions across complex agricultural landscapes. Another important direction involves the application of bioinspired robotics in non-traditional farming environments, including vertical and urban agriculture. Flexible and adaptive robots can navigate confined or multi-layered spaces, monitor crop growth, manage pollination, and optimize resource application, thereby enhancing local food production while reducing transportation impacts and environmental footprint. Achieving these advances will require interdisciplinary collaboration among engineers, biologists, agronomists, and policymakers. Addressing economic constraints through modular design, standardization, and supportive policy frameworks is essential to ensure access for both large-scale and smallholder operations. Equally important is the consideration of social and labor implications, ensuring that technological innovation contributes to inclusive, resilient, and sustainable agricultural systems. In summary, bioinspired robotic systems offer a strategic pathway for aligning productivity with ecological stewardship. By combining adaptability, intelligence, and sustainable energy use, these technologies have the potential to redefine agricultural practice in the 21st century, demonstrating that technological progress and environmental responsibility can be mutually reinforcing objectives.

REFERENCES

Abioye, E.A., Hensel, O., Esau, T.J., Elijah, O., Abidin, M.S.Z., Ayobami, A.S., Yerima, O., Nasirahmadi, A., 2022. Precision Irrigation Management Using Machine Learning and Digital Farming Solutions. AgriEngineering 4, Pp. 70–103. https://doi.org/10.3390/agriengineering4010006

Agence de presse APEI. 2022. Innovation viticole : quand les robots s'invitent dans les vignes. Actu.fr. https://actu.fr/lifestyle/innovation-viticole-quand-les-robots-s-invitent-dans-les-vignes_53771219.html

Agenso. 2022. Digital Innovation Hubs in agriculture: agROBOfood applications. https://www.agenso.gr

AgFunderNews. 2023. Robotic strawberry pickers: From prototypes to commercialization. AgFunderNews. https://agfundernews.com

Albanese, A., Nardello, M., and Brunelli, D., 2021. Automated pest detection with DNN on the edge for precision agriculture. IEEE Journal on Emerging and Selected Topics in Circuits and Systems, 11 (3), Pp. 458–467. https://doi.org/10.1109/JETCAS.2021.3101740

Albiero, D., Garcia, A.P., Umezu, C.K., and de Paulo, R.L., 2021. Swarm robots in agriculture: Proposing a swarm of small electric robotic tractors as an alternative to heavy tractors [Preprint]. arXiv.

Albiero, D., Garcia, A.P., Umezu, C.K., and de Paulo, R.L., 2022. Swarm robots in mechanized agricultural operations: A review about challenges for research. Computers and Electronics in Agriculture, 193, Pp. 106608. https://doi.org/10.1016/j.compag.2021.106608

Armananta, H., 2024. 10 macam robotik yang ada di pasaran: Inovasi dan teknologi terkini. Top10Bestoday. https://top10bestoday.com/teknologi/10-macam-robotik-yang-ada-di-pasaran/

Bac, C.W., Hemming, J., and van Henten, E.J., 2017. Stem localization of sweet-pepper plants using the support wire as a visual cue. Computers and Electronics in Agriculture, 105, Pp. 111–120.

Banhazi, T.M., Lehr, H., Black, J.L., Crabtree, H., Schofield, P., Tscharke, M., Berckmans, D., 2012. Precision livestock farming: An international review of scientific and commercial aspects. International Journal of Agricultural and Biological Engineering, 5 (3), Pp. 1–9.

Barriers to the adoption of new technologies in rural areas: The case of unmanned aerial vehicles for precision agriculture in India. Technology in Society, 74 (2023), Pp. 102335.

Bechar, A., and Vigneault, C., 2016. Agricultural robots for field operations: Concepts and components. Biosystems Engineering, 149, Pp. 94–111.

Brambilla, M., Ferrante, E., Birattari, M., Dorigo, M., 2013. Swarm robotics: A review from the swarm engineering perspective. Swarm Intelligence, 7 (1), Pp. 1–41. https://doi.org/10.1007/s11721-012-0075-2

Business Insider. 2025. Smart farming technologies: Opportunities and challenges in AI-driven agriculture. Business Insider Research. https://www.businessinsider.com/research/smart-farming-ai-2025

Buzzworthy. (n.d.). This little robot might solve the world's big pesticide problem. https://www.buzzworthy.com/little-robot-against-big-pesticides/

Calderón-Arce, C., Brenes-Torres, J.C., and Solis-Ortega, R., 2022. Swarm Robotics: Simulators, Platforms and Applications Review. Computation, 10 (6), Pp. 80.

Chellapurath, M., Khandelwal, P. C., and Schulz, A.K., 2023. Bioinspired robots can foster nature conservation. Frontiers in Robotics and AI, 10, Article 1145798. https://doi.org/10.3389/frobt.2023.1145798

Communications, B.V., 2022. Robotics in agriculture: Cold-storage automation and beyond. Communications BV Whitepaper. https://www.communicationsbv.com

CORDIS. 2017. RHEA: Robot fleets for highly effective agriculture and forestry management. EU CORDIS Project Results.

Deng, C., and Li, Z., 2025. Review: Advanced drive technologies for bionic soft robots. Journal of Bionic Engineering.

Downs, P.C., 2025. The impact of robotics in livestock feed management. The Ranching Guide. https://theranchingguide.com/the-impact-of-robotics-in-livestock-feed-management/

Duckett, T., Pearson, S., Blackmore, S., and Grieve, B., 2018. Agricultural robotics: The future of robotic agriculture. UK-RAS Network. https://doi.org/10.48550/arXiv.1806.06762

Editorial. 2022. Real-life applications of swarm robots. RoboticsBiz. https://roboticsbiz.com/real-life-applications-of-swarm-robots/

Elfferich, J.F., Dodou, D., and Della Santina, C., 2022. Soft robotic grippers for crop handling or harvesting: A review. IEEE Access, 10, Article 3190863. https://doi.org/10.1109/ACCESS.2022.3190863

Elfferich, J.F., Dodou, D., Santina, C.D., 2022. Soft Robotic Grippers for Crop Handling or Harvesting: A Review, IEEE Access, 10, pp. 75428-75443. https://doi.org/10.1109/ACCESS.2022.3190863

Eurecat Centre Tecnològic. 2020. agROBOfood: Building an innovation ecosystem for agri-food robotics. Eurecat. https://eurecat.org/projects/agrobofood

FIRAteam. 2021. Demonstrations of agricultural robotics at FIRA. FIRA Conference Proceedings. https://fira-agtech.com

First Furrow Staff. 2016. Agriculture technology spotlight: Self-driving tractors. First Furrow. https://www.firstfurrow.com/agriculture-technology-spotlight-self-driving-tractors/

Fountas, S., Espejo García, B., Chitos, A., and Psiroukis, V., 2022. Bio-Inspired Robots and Structures toward Fostering the Modernization of Agriculture. Biomimetics, 769. https://doi.org/10.3390/biomimetics7020069

FreshPlaza. 2024. Autonomous greenhouse robots: Selective harvesting and beyond. FreshPlaza News. https://www.freshplaza.com

Future Farming. 2022. Australian harvesting robot picks apples in seven seconds. Field Robots. https://www.futurefarming.com/tech-in-focus/field-robots/australian-harvesting-robot-picks-apples-in-seven-seconds/

Galin, R., and Meshcheryakov, R., 2019. Automation and robotics in the context of Industry 4.0: The shift to collaborative robots. IOP Conference Series: Materials Science and Engineering, 537 (3), Pp. 032073. https://doi.org/10.1088/1757-899X/537/3/032073

Gao, L., Akhtar, M.U., Yang, F., Ahmad, S., He, J., Lian, Q., Cheng, W., Zhang, J., and Li, D., 2021. Recent progress in engineering functional biohybrid robots actuated by living cells. Acta Biomaterialia, 121, Pp. 29–40. https://doi.org/10.1016/j.actbio.2020.12.002

Ghobadpour, A., Monsalve, G., Cardenas, A., and Mousazadeh, H., 2022. Off-Road Electric Vehicles and Autonomous Robots in Agricultural Sector: Trends, Challenges, and Opportunities. Vehicles, 4 (3), 843–864. https://doi.org/10.3390/vehicles4030047

Global Market Insights. 2023. Swarm robotics market – By end use & forecast, 2021–2032 (Report ID: GMI6847). https://www.gminsights.com/industry-analysis/swarm-robotics-market

Gulec, F., 2023. The role of artificial intelligence in livestock farming with MilkingCloud: Smart farm management. LinkedIn. https://www.linkedin.com/pulse/role-artificial-intelligence-livestock-farming-smart-farm-gulec--kncdc/

Hammond, M., Cichella, V., and Lamuta, C., 2023. Bioinspired soft robotics: State of the art, challenges, and future directions. Current Robotics Reports, 4 (3), Pp. 65–80. https://doi.org/10.1007/s43154 023 00102 2

IFR, "World Robotics Report: 'All-Time High' with Half a Million Robots Installed in one Year," IFR International Federation of Robotics.https://ifr.org/ifr-press-releases/news/wr-report-all-time-highwith- half-a-million-robots-installed, (accessed on 25 August 2025).

International Federation of Robotics (IFR). 2014. World Robotics 2014 – Service Robots. IFR: Frankfurt Am Main, Germany, 2014. https://ifr.org, (accessed on 24 August 2025).

International Federation of Robotics (IFR). 2014. World Robotics 2014 – Service Robots. IFR: Frankfurt Am Main, Germany, 2014. https://ifr.org, (accessed on 25 August 2025).

International Federation of Robotics (IFR). 2018. World Robotics 2018 – Service Robots. IFR: Frankfurt Am Main, Germany, 2018. https://ifr.org, (accessed on 26 August 2025).

International Federation of Robotics (IFR). 2020. World Robotics 2018 – Service Robots. IFR: Frankfurt Am Main, Germany, 2020. https://ifr.org, (accessed on 26 August 2025).

International Federation of Robotics (IFR). 2023. World Robotics 2018 – Service Robots. IFR: Frankfurt Am Main, Germany, 2023. https://ifr.org, (accessed on 28 August 2025).

International Federation of Robotics (IFR). 2024. World Robotics 2018 – Service Robots. IFR: Frankfurt Am Main, Germany, 2024. https://ifr.org, (accessed on 28 August 2025).

Jornal Campo Soberano. (n.d.). Engorda de bezerro: 5 segredos para um crescimento explosivo! Jornal Campo Soberano. https://jornal.camposoberano.com.br/engorda-de-bezerro-2/#google_vignette

Karabegović I., Banjanović-Mehmedović L.,(Ed.) 2021. SERVICE ROBOTS: Advances in Research and Application , NOVA Science Publisher, New York, USA, pp.205-243. https://novapublishers.com/

Karabegović, I., Karabegović, E., 2019. The Role of Collaborative Service Robots in the Implementation of Industry 4.0, International Journal of Robotics and Automation Technology, 6, PP. 40-46.

Karabegović, I., 2022. Sensory Technology is One of the Basic Technologies of Industry 4.0 and the Fourth Industrial Revolution, ACTA Technica Corviniensis – Bulletin of Engineering, Tome XV [2022] | Fascicule, 4, PP. 33-39.http://acta.fih.upt.ro

Karabegović, I., Banjanović-Mehmedović, L. (Eds)., 2021. Service Robots: Advances in Research and Application, NOVA Science Publisher, New York, USA, USA. https://novapublishers.com/shop/service-robots-advances-in-research-and-applications/

Karabegović, I., Doleček, V., 2012. Servisni roboti (Service Robots), Društvo za robotiku u Bosni i Hercegovini, Bihać. ISBN 978-9958-9262-3-5, pp.81-114.

Karabegović, I., Kovačević, A., Banjanović-Mehmedović, L., 2020. Integration Industry 4.0 in Business and Manufacturing; IGI Global: Hershey, PA, USA.

Karabegović, I., Mahmić, M., Karabegović, E., Husak, E., 2024. Advanced Robotics as the Drive of Innovation: The Role of the Implementation of Advanced Robotics in Industry 4.0. In: Karabegovic, I., Kovačević, A., Mandzuka, S. (eds) New Technologies, Development and Application VII. NT 2024. Lecture Notes in Networks and Systems, vol 1069. Springer, Cham. https://doi.org/10.1007/978-3-031-66268-3_1

Kondoyanni, M., Loukatos, D., Maraveas, C., Drosos, C., Arvanitis, K.G., 2022. Bio-Inspired Robots and Structures toward Fostering the Modernization of Agriculture. Biomimetics, 7, 69. https://doi.org/10.3390/ biomimetics7020069

Kunt, R., 2025. IoT and AI-based irrigation systems using ESP32 and LSTM models for sustainable agriculture. arXiv preprint arXiv:2501.04567. https://arxiv.org/abs/2501.04567

Le Betteravier. 2021. Robots tackle weeding. https://www.lebetteravier.fr/2021/04/27/les-robots-sattaquent-au-desherbage/

Li, X., 2022. A review on multirobot systems in agriculture: Status, challenges, and future directions. Computers and Electronics in Agriculture, 202, Pp. 107336.

Li, X., Ma, N., Han, Y., Yang, S., Zheng, S., 2024. AHPPEBot: Autonomous robot for tomato harvesting based on phenotyping and pose estimation. arXiv. https://doi.org/10.48550/arXiv.2405.06959

Liakos, K.G., Busato, P., Moshou, D., Pearson, S., Bochtis, D., 2018. Machine learning in agriculture: A review. Sensors, 18 (8), Pp. 2674.

Lytridis, C., and Pachidis, T., 2024. Recent Advances in Agricultural Robots for Automated Weeding. AgriEngineering, 6 (3), Pp. 3279-3296. https://doi.org/10.3390/agriengineering6030187

Mallport. 2024. Innovation in harvesting: AI-powered raspberry robot revolutionizes UK agriculture. https://mallport.co.uk/news/innovation-in-harvesting-ai-powered-raspberry-robot-revolutionizes-uk-agriculture/

Mateos Matilla, D., Lozano Murciaiego, A., Jiménez-Bravo, D.M., Sales Mendes, A., and Leithardt, V.R.Q., 2021. Low-cost edge computing devices and novel user interfaces for monitoring pivot irrigation systems based on Internet of Things and LoRaWAN technologies. Biosystems Engineering. Advance online publication.

Mike. 2016. Case IH autonomous farming tractor concept is the future of farming. Mikeshouts. https://mikeshouts.com/case-ih-autonomous-farming-tractor-concept-is-the-future-of-farming/

Mockshell, J., and Kamanda, J., 2018. Beyond the agroecological and sustainable agricultural intensification debate: Is blended sustainability the way forward? International Journal of Agricultural Sustainability, 16 (2), Pp. 127–149. https://doi.org/10.1080/14735903.2017.131509

Monteiro, R.M., 2024. Visuo-dynamic self-modelling of soft robotic systems. Frontiers in Robotics and AI, 11, Pp. 1403733. https://doi.org/10.3389/frobt.2024.1403733

Mordor Intelligence. 2025. Global autonomous tractors market size & share analysis – growth trends & forecasts (2025–2030). Mordor Intelligence.Retrieved from:https://www.mordorintelligence.com/industry-reports/global-autonomous-tractors-market

Navas, E., Fernández, R., and Fernández, J., 2021. Soft grippers for automatic crop harvesting: A review. Sensors, 21 (8), Pp. 2689.

Nebiker, S., Lack, N., Abächerli, M., and Läderach, S., 2016. Light-weight multispectral UAV sensors and their capabilities for predicting grain yield and detecting plant diseases. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLI-B1, Pp. 963–970. XXIII ISPRS Congress, 12–19 July 2016, Prague, Czech Republic. https://doi.org/10.5194/isprs-archives-XLI-B1-963-2016

Olha. (n.d.). Agro robots are tending to fields: New technologies in farming and agribusiness, generative AI [Stock photo]. Adobe Stock. https://stock.adobe.com/de/images/agro-robots-are-tending-to-fields-new-technologies-in-farming-and-agribusiness-generative-ai/653914938

Pretto, A., Aravecchia, S., Burgard, W., Chebrolu, N., Dornhege, C., Falck, T., Fleckenstein, F., Fontenla, A., Imperoli, M., Khanna, R., Liebisch, F., Lottes, P., Milioto, A., Nardi, D., Nardi, S., Pfeifer, J., Popović, M., Potena, C., Pradalier, C., Rothacker-Feder, E., Nieto, J., 2019. Building an aerial-ground robotics system for precision farming: An adaptable solution (arXiv preprint arXiv:1911.03098). arXiv. Retrieved from https://arxiv.org/abs/1911.03

Rehman, T.U., Mahmud, M.S., Chang, Y.K., Jin, J., and Shin, J., 2019. Current and future applications of statistical machine learning algorithms for agricultural machine vision systems. Computers and Electronics in Agriculture, 156, Pp. 585–605.

Research and Markets. 2023. Global autonomous agriculture equipment market report 2023: Increasing focus toward sustainability bolsters sector. GlobeNewswire.

Retrieved from: https://www.globenewswire.com/news-release/2023/04/12/2645168/28124/en/Global-Autonomous-Agriculture-Equipment-Market-Report-2023-Increasing-Focus-toward-Sustainability-Bolsters-Sector.html

RHEA Project. 2015. Robot fleets for highly effective agriculture and forestry management (RHEA). RHEA Official Report. https://rhea-project.eu

Rutten, C.J., Velthuis, A.G.J., Steeneveld, W., Hogeveen, H., 2013. Invited review: Sensors to support health management on dairy farms. Journal of Dairy Science, 96 (4), Pp. 1928–1952.

Salfer, J.A., and Endres, M.I., 2021. Adoption of automated milking systems and impacts on dairy herd management. Animal, 15 (1), Pp. 100014.

Sarker, A., Ul Islam, T., and Islam, M.R., 2024. A review on recent trends of bioinspired soft robotics: Actuators, control methods, materials selection, sensors, challenges, and future prospects. Advanced Intelligent Systems, Pp. 2400414. https://doi.org/10.1002/aisy.202400414

Shamshiri, R.R., Weltzien, C., Hameed, I.A., Yule, I.J., Grift, T.E., Balasundram, S.K., Chowdhary, G., 2018. Research and development in agricultural robotics: A perspective of digital farming. International Journal of Agricultural and Biological Engineering, 11 (4), Pp. 1–14. https://doi.org/10.25165/j.ijabe.20181104.4278

Silwal, A., Davidson, J.R., Karkee, M., Mo, C., Zhang, Q., and Lewis, K., 2017. Design, integration, and field evaluation of a robotic apple harvester. Journal of Field Robotics, 34 (6), Pp. 1140–1159. https://doi.org/10.1002/rob.21715

Sklar, E., Das, G., and Gao, J., 2022. Robotics and autonomous systems for net zero agriculture. Current Robotics Reports, 3 (1), Pp. 57–64. https://doi.org/10.1007/s43154-022-00077-6

Slaughter, D. C., Giles, D. K., & Downey, D. (2008). Autonomous robotic weed control systems: A review. Computers and Electronics in Agriculture, 61 (1), Pp. 63–78. https://doi.org/10.1016/j.compag.2007.05.008

Steeneveld, W., Tauer, L.W., Hogeveen, H., Oude Lansink, A.G.J.M., 2021. Economic comparison of dairy farms with an automatic milking system and a conventional milking system. Journal of Dairy Science, 104 (1), Pp. 52–67. https://doi.org/10.3168/jds.2020-18616

Su, D., Kong, H., Qiao, Y., and Sukkarieh, S., 2021. Data augmentation for deep learning based semantic segmentation and crop-weed classification in agricultural robotics. Computers and Electronics in Agriculture, 190, Pp. 106418. https://doi.org/10.1016/j.compag.2021.106418

The Business Research Company. 2025. Harvesting robot market trends report 2025 and insights. https://www.thebusinessresearchcompany.com/report/harvesting-robot-global-market-report

Toon, J., 2020. Sloth robot is a very cute way to boost conservation. Futurity. https://www.futurity.org/slothbot-conservation-robot-2388952/

Tsouros, D.C., Bibi, S., and Sarigiannidis, P.G., 2019. A review on UAV-based applications for precision agriculture. Information, 10 (11), Pp. 349.

Wang, C., Song, C., Xu, T., and Jiang, R., 2025. Precision weeding in agriculture: A comprehensive review of intelligent laser robots leveraging deep learning techniques. Agriculture, 15 (11), Pp. 1213.

Wang, F., Urquizo, R.C., Roberts, P., 2023. Biologically inspired robotic perception-action for soft fruit harvesting in vertical growing environments. Precision Agric, 24, Pp. 1072–1096.

Wang, Y., Wang, Y., Mushtaq, R.T., Wei, Q., 2024. Advancements in Soft Robotics: A Comprehensive Review on Actuation Methods, Materials, and Applications. Polymers, 16, Pp. 1087. https://doi.org/10.3390/polym1608108

Webster-Wood, V.A., Guix, M., Xu, N. W., Behkam, B., Sato, H., Sánchez, S., Shimizu, M., and Parker, K.K., 2022. Biohybrid robots: recent progress, challenges, and perspectives. Bioinspiration and Biomimetics, 18 (1), Pp. 015001. https://doi.org/10.1088/1748-3190/ac9c3b

Wei, W., Xiao, M., Duan, W., Wang, H., Zhu, Y., Zhai, C., and Geng, G., 2024. Research Progress on Autonomous Operation Technology for Agricultural Equipment in Large Fields. Agriculture, 14 (9), Pp. 1473.

Wired. 2017. A sloth-inspired robot could monitor crops while hanging overhead. Wired Magazine. https://www.wired.com/story/sloth-inspired-robot

Wurst, A.X., 2020. Un robot autonome pour le semis et le sarclage. UFA Revue. https://www.ufarevue.ch/fre/technique-agricole/un-robot-autonome-pour-le-semis-et-le-sarclage

Xu, H., Li,T., Hou,X., 2025. Key technologies and research progress of intelligent weeding robots. Weed Science, 73 (e25), Pp, 265–278. https://doi.org/10.1017/wsc.2024.95

Cite The Article:Isak Karabegović (2026). Bioinspired Robotic Systems For Precision And Sustainable Agriculture: Trends, Applications, And Challenges. *Big Data In Agriculture (BDA)*, 8(1): 18-27.