Agtech in focus: Agriculture is driving slowly toward autonomous machines

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Summary

Autonomous machines[1] are a potential game changer in crop farming, boosting productivity, precision, and ease of operations, but bringing them successfully to the market implies a long road. Although some robots have the same functionality as tractors, we do not expect the conventional tractor to be replaced anytime soon. The global agricultural machinery industry is currently focusing on innovating specific stages of the crop production cycle and gradually developing autonomous capabilities across field operations.

At present, the global agtech landscape is fragmented, with many startups and various autonomous machines tailored for specific field tasks, but acquisitions and partnerships offer the industry a way forward and a means to provide more integrated solutions that can be distributed effectively among farmers.

However, safety regulations are a key precondition for wider commercialization of autonomous machines. While market fragmentation and an underdeveloped distribution network also pose limitations, the primary reason for the delayed uptake is regulatory uncertainty. Industry standards and legal frameworks are currently under development and expected to be in place in the next few years. Though regulations will vary across regions, the core issues to be addressed are applicable across the globe. To explore these issues, we examine the regulatory environment in the EU and what it means for the industry.

Autonomous machines are a potential game changer in agricultural fields… in the long term

Nowadays, advances in farming productivity come from technological innovations and digitalization rather than increased machine size and horsepower. Automation enables machines to work faster and more precisely with fewer inputs (water, fertilizers, crop protection, energy), thereby making farming operations more sustainable. Furthermore, driverless machines can partly replace increasingly scarce labor and improve working conditions on farms. The potential gains are huge, both for farmers and the wider society. But the adoption of autonomous machines like agricultural robots and autonomous tractors will take time, as farmers need proof of their value and benefits.

[1] Autonomous machines refer to robots and autonomous tractors operating in agricultural fields without a driver or direct supervision.

The journey toward machine automation began in the 1990s with the introduction of navigation systems (e.g., GPS). Guidance and autosteering systems marked a major step toward autonomous driving – though, notably, wider adoption of positioning technology took more than a decade as the technology became more reliable and affordable. To cultivate significant crop areas, many farmers nowadays use autosteering system support, which provides optimized machine routing, reduced fuel use, and increased crop yields.[2] Autosteering, however, is only the first step toward autonomous machines, which should be able to work without a human operator or on-site supervisor. These machines must be capable of stand-alone diagnosis, decision-making, or task performance in changing environments. Several stages of technology developments must be performed before full autonomy is achieved (if ever) (see Figure 1).

Figure 1: Automation pathway of agricultural machinery

Source: CNH – CASE IH 2016, RaboResearch 2024

Autonomous machines need to bring productivity gains

Unlike road vehicles, which have the sole task of driving, agricultural machinery performs multiple operations throughout the crop production cycle. To justify the hefty cost of technology development, autonomous machines should be more effective in tasks such as tilling, sowing, plant treatment, and crop harvesting compared to their conventional peers. They must provide measurable improvements in productivity in order to convince farmers to purchase them. These value drivers can be found in two main directions:

Firstly, autonomous machines that can drive without an operator or immediate supervision will extend the machine's working hours, especially when skilled tractor drivers become increasingly scarce. In addition, field operations can be lengthy and tedious, so freeing operators from the duty of sitting in the cabin will improve working conditions. Technically, autonomous machines can work as long as the fuel tank or battery capacity allows, which can provide 24-hour mode. Of course, the size of the field is a limitation, as machines are currently set to operate autonomously only within field boundaries.

Secondly, enhanced data-driven precision and fleet-management capabilities can potentially result in lower operational costs or higher yields. Utilizing digital features embedded in autonomous machinery across the whole production cycle can step up field productivity, like following planting lines in harvesting. Gains can also be derived from automating the coordination of multiple machines used in a field operation, so-called platooning. A current example is the management of the tractor from the harvester cabin during harvesting.

[2] Productivity gains made via application guidance and autosteering systems result from reducing overlap and minimizing gaps in field operations. Soitinaho, R., Oksanen, T. (2021). Guidance, Auto-Steering Systems and Control. In: Karkee, M., Zhang, Q. (eds) Fundamentals of Agricultural and Field Robotics. Agriculture Automation and Control. Springer, Cham. https://doi.org/10.1007/978-3-030-70400-1_10

Incremental technology development, rather than revolution

Although autonomous machines are a potential game changer in field operations, they will not change field operations overnight. As with the adoption of autosteering technology, building understanding and market acceptance among potential users will take time. Autonomous features are going through incremental developments in each field task, consequently connecting those capabilities in a digital ecosystem of services. In this way, farmers are given the flexibility to navigate the course of technology advancement according to their specific needs. It also allows the agricultural machinery industry to market innovations in an impactful and economically rewarding manner.

OEMs' automation pathway is long and bumpy

Original equipment manufacturers (OEMs) have been on the automation pathway for nearly three decades. However, the vision of fully autonomous tractors only recently became part of the industry's strategies. In 2016, CNH Industrial introduced its concept, which set the basic definitions and stages of machine automation illustrated in figure 1. Between 2021 and 2023, several OEMs, like John Deere, CNH (via CASE IH and New Holland), Kubota, Yanmar, CLAAS, and the startup Monarch Tractor, launched concepts and prototypes of autonomous tractors. From a technical perspective, the capabilities of autonomous tractors are available, but very few models are available on the market. Notably, commercially available models like Monarch and Yamar are in the lower horsepower range (e.g., around 100 hp), where the safety risks are limited.

OEMs have sound reasons to postpone broad commercialization of autonomous tractors:

- **Safety regulations** are a major issue (see Box 1). Manufacturers are still hesitant to introduce autonomous tractors due to their potential legal liability in case of an accident. The regulatory framework is still evolving to catch up with technological innovations like autonomous tractors. The absence of widely accepted certification and insurance policies also prevents OEMs from selling fully autonomous models.
- **Cyber security** and even concerns about malicious misuse are subject to regulation too, especially in the European domain. This is highly relevant for autonomous machines, as they are usually connected to online platforms and collect loads of data.
- **The business model** is challenging. The high investment costs of innovation need to pay off for both OEMs and end users (e.g., farmers). Normally, companies offer novel capabilities as an option (e.g., retrofit) before adding them to the standard set of machine functions (e.g., factory fit).

In the last three years, the leading OEMs have strengthened their autonomous technology capabilities via acquisitions and joint ventures, investing mainly in artificial intelligence and robotics. It is clear that the continuing innovation in field operations is the ultimate priority of OEMs, rather than autonomous tractors specifically. Their strategy is to offer a diverse portfolio of precision ag solutions for direct productivity gains in each stage of the production cycle.

Box 1: European regulation to harmonize the safety requirements of autonomous agricultural machines

The regulation of autonomous agricultural machines is still evolving in Europe, and it is crucial for the wider commercialization of autonomous machines in the region.

Both global industry standards and legislation around autonomous farming equipment are still a work in progress. The EU regulatory framework is expected to be in place no earlier than 2027. Its complexity puts a high burden on established OEMs and agricultural robot startups. This inevitably adds to the costs of machine development and commercialization.

The regulatory framework needs to address various issues, including safety in machinery design and use, cybersecurity, and liability.

From an EU perspective, autonomous tractors are covered by the Mother Regulation, and agricultural robots fall under the Machinery Regulation.

Article 35 of the Mother Regulation (Regulation EU 167/2013) specifically covers new technologies or concepts like autonomous tractors and provides OEMs with a specific but burdensome procedure to grant type-approval for autonomous use. It works on a case-by-case basis and can take three years.

The newly adopted Machine Regulation (Regulation EU 2023/1230) introduces three important requirements for agricultural robots:[3]

a. **A supervisory function** in each agricultural robot that sends alerts of risks to a supervisor, who can stop, restart, or bring the robot to a safe position.
b. **A physical-border or obstacle-detection system,** so the robot can travel safely in a defined working area.
c. **Risk-assessment capability** in machines that use machine learning or artificial intelligence (AI).

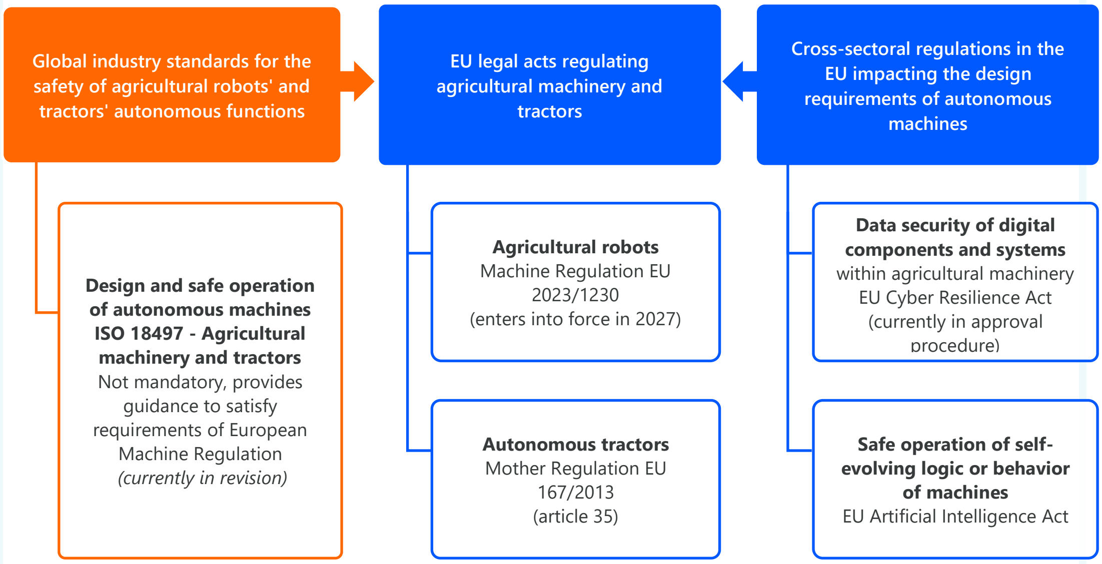
The Machine Regulation will enter into force in January 2027.

Global industry standards are needed, as OEMs are developing machines that can be used across various regions. The agriculture machinery industry highly anticipates the revision of ISO 18497, which is a standard that deals with the safety of the autonomous functions of tractors and robots. Although it is not mandatory, this global standard is intended to become an EU standard (EN ISO 18497) as well, and compliance will give presumption of conformity with EU regulations. The global standard is expected to be in place at the beginning of 2025.

EU cybersecurity and AI regulations will impact the development of autonomous machines. On top of the core legislation, OEMs need to comply with safety requirements for digital components and for self-evolving capabilities, like AI and machine learning, which are embedded in autonomous vehicles (see Figure 2).

[3] Agricultural robots are referred to as "autonomous mobile machinery" in the EU Machine Regulation.

Figure 2: European regulatory framework on agricultural robots and autonomous tractors

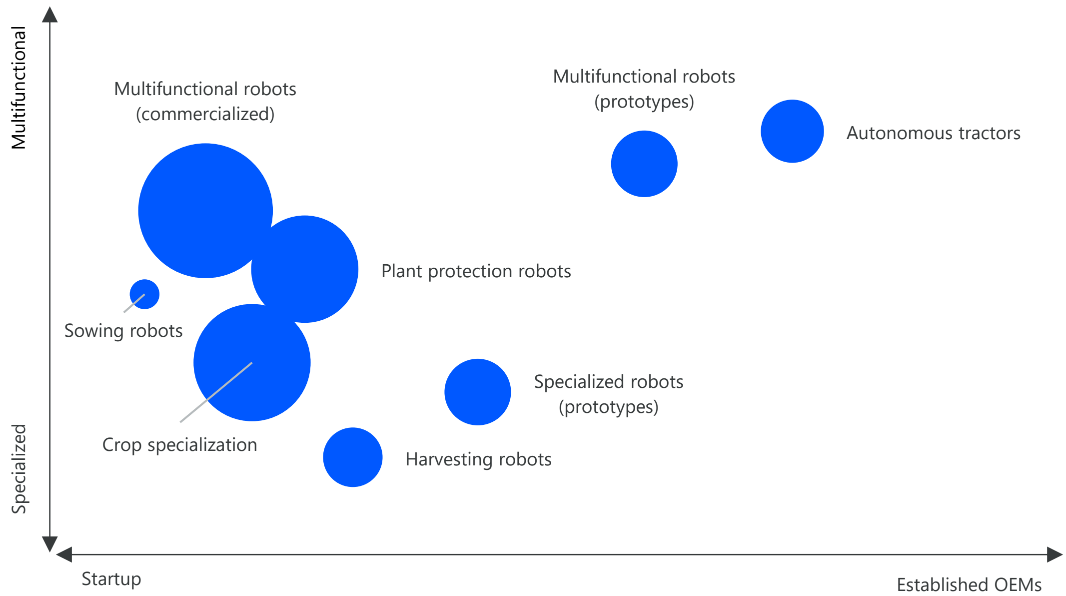


Source: CEMA, European Agricultural Machinery Association 2024

The extremely diverse playing field of agricultural robots is set to change

Despite 25 years of development, the agricultural robot industry is still in its infancy. The number of companies is still growing, and the playing field is very diverse, fragmented, and populated by various types of companies, ranging from startups to major OEMs and from specialized to multifunctional (see Figure 3). Given the currently crowded and competitive playing field, the industry will inevitably consolidate once the market matures. The question is whether new players will be able to challenge the large traditional manufacturers.

Figure 3: Global landscape of autonomous machine models by company type and scale, 2024



Note: The review includes 104 models of autonomous machines. The graph shows the distribution of agricultural robots and autonomous tractor models according to company scale (x-axis: startups vs. OEMs) and type (y-axis: specialized vs. multifunctional).
Source: Rabobank based on various public sources 2024

With startups dominating the agricultural robot landscape, consolidation looms

In the agtech domain, the initial development of a solution often stems from exploring technological applications rather than from farmer demand. As such, technology startups utilizing advanced digital technologies have created a significant number of robotic solutions. Currently, 87% of commercialized agricultural robots are owned by their developers (startups and scaleups), while the remainder has been acquired by agricultural equipment manufacturers. Given the crowded landscape, consolidation is expected. More acquisitions by OEMs is a logical pathway, but farm input companies are also a potential destination for agricultural robots, particularly for plant protection robotic solutions. Collaboration agreements between technology companies and equipment manufacturers are also a way for further market penetration of agricultural robots.

Agricultural robots cannot do everything (yet); specialization per task or crop is the common approach

As agricultural robots cannot do everything in the field, at least not yet, developers focus on optimizing the performance of specific tasks. The majority of robots specialize in crop protection activities (especially weeding), following the global trend of more responsible use of chemicals.

Soil tilling is a common task for robots too, as it is lengthy and tedious. However, soil cultivation often requires greater power, which significantly limits the use cases for robots in tilling. Notably, several of the newer multifunctional robots have greater power to address this challenge, which has provoked positive interest among arable farmers. Farmers in regions with larger fields and low population density, like Australia, Canada, and eastern Europe, are more open to these robotic solutions.

The specificity of crop cultivation often requires equipment to be versatile. Currently, many robotic solutions are designed to operate in certain crop fields – most commonly, vineyards and orchards. These labor-intensive production systems will benefit from automation and smaller, maneuverable equipment, which corresponds with the characteristics of robots. Other current "robot domains" include horticulture crops, like strawberries and asparagus, where labor-intensity and relatively high crop values drive investments in automation.

Will smarter implements challenge the traditional chain of command in farming equipment?

In recent years, several European equipment manufacturers launched multifunctional agricultural robot projects – for example, Krone and LEMKEN, Eidam Landtechnik, Horsch (all from Germany) and Kuhn (France). These manufacturers will design their robots to enable smarter application of agricultural implements, such as plows, harrows, cultivators, seeders, hoes, and other tools, that can be managed by software. Normally, tractor manufacturers steer the development of precision-farming capabilities, but these European producers of attached equipment are trying to change this pattern. The guiding principles of these European robotic projects are that the farming process should set the pace of the pulling vehicle (e.g., a tractor or agricultural robot) and that farmers should be free to combine equipment with tractors or robots, no matter the brand – the so-called "plug and play" function. This principle can only be put into practice by applying an open-source digital model using a standardized language between the equipment's sensors and controllers. One example, the Combined Powers project from Krone and LEMKEN, uses agrirouter, an open platform that allows the free exchange of data between machinery and agricultural software applications from different manufacturers.

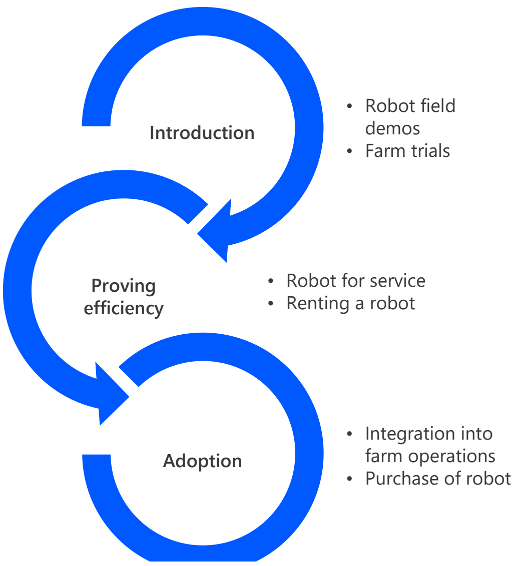
These European equipment manufacturers base the design of their agricultural robots on the assumption that European farmers will increasingly use lighter but smarter equipment, in alignment with the principles of regenerative agriculture. Companies aim to offer more data-driven operation with higher productivity and lower input use and soil compaction.

Notably, the above-mentioned projects are still in the prototype phase and will need at least five years to reach commercialization. However, they bear a high potential to step up the precision-farming capabilities of European agricultural equipment and make them accessible to more end users via open-source software.

Wider adoption of robots depends on effective distribution strategies

Along with the emergence of new players, more startups, and smaller players in the fairly consolidated agricultural machinery industry, new commercialization and payment models are arising. Bank loans and leasing are currently the main ways farmers finance the purchase of equipment, but for robots and other automation solutions, renting and subscription models are more common (see figure 4).

Figure 4: Robots' distribution cycle



Source: Rabobank based on public sources, 2024

The agricultural robot market is still in the early phase of commercialization, and companies are testing various strategies for placing robots on the market. Conventional distribution channels via machinery dealers and leasing companies are not yet available for agricultural robot companies, as production numbers are too small for leasing companies to enter that segment. Additionally, farmers interested in a purchase are still limited in number, as the business case is not proven yet.

Currently, the primary approach for marketing robots is via renting or subscription, often directly from the developer or via a local distributor. Often, local distributors also offer contract services in order to expand use cases and to build trust in the technology.

Agtech service providers offer a more effective distribution outlet for robots that specialize in tasks like spraying or seeding. Distributors of various digital services have the know-how to handle the specific software of the robots and their management platforms. Moreover, they already operate within the networks of innovative farmers, who are expected to be the early adopters of agricultural robots.

Agricultural cooperatives can play an important role in the adoption of agricultural robots in Europe, especially for plant protection. Co-ops have ambitious sustainability goals, including reduced pesticide application, and operate within wide farmer-member networks. For example, the Dutch cooperative Agrifirm provides smart spraying services to its members using Ecorobotics, while the German sugar cooperative Südzucker is testing FarmDroid.

In conclusion

Agricultural machinery is becoming increasingly intelligent, but robots are not yet taking over the fields. The primary reason for the delayed uptake is uncertainty about safety regulations. Companies must prove safety in design and in use before rolling out their products to the market.

In a broader context, the complexity of open-field operations necessitates an evolutionary approach of incremental technology development, rather than disruptive revolutionary solutions. Providing farmers the flexibility to choose their speed and scope of innovation is a crucial aspect of the industry's approach. Meanwhile, we anticipate consolidation and collaboration within the agricultural robot segment, which is still in the early phase of commercialization.

Robots won't replace the tractor anytime soon, due to its reliability and versatility of use cases. Agricultural robots can serve as an efficient addition on large-scale arable farms, reducing drivers' hours in the cabin. Specific tasks in labor-intensive orchards and vineyards are also suitable terrain for robotic solutions, even today.

For wider adoption, agricultural robots will need a more fully developed distribution network. For the time being, service and renting contracts, rather than purchase, will be the major distribution model for robots.

Imprint

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