ROBOTIC SOLUTIONS IN SUNFLOWER CULTIVATION FOR AN INCREASED SUSTAINABILITY IN RURAL AREAS OF THE WESTERN PLAIN OF ROMANIA

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RESEARCH ARTICLE

Abstract

As the global demand for food production continues to increase, there is a pressing need to explore sustainable solutions that can accelerate innovation in agriculture. One such solution is Farming 4.0, which incorporates cutting-edge technologies like the Internet of Things (IoT), Artificial Intelligence (AI), Big Data analytics, Cloud Computing, renewable energy sources, modernized battery technologies, and agricultural robotics.

Farming 4.0 aims to revolutionize farming methods by adopting precision techniques to increase efficiency and productivity while minimizing resource waste and maximizing crop yields. This transformation is a significant shift in the agricultural sector, offering a more sustainable and efficient approach to meet the rising demands of the global food market.

Within this context, autonomous tractors and agricultural machinery, battery-centric energy solutions, and the integration of robotic and drone technologies for agricultural applications are some of the pivotal technological breakthroughs. Additionally, direct communication among agricultural machinery and centralized data storage in Cloud-based software applications drive Farming 4.0's operational advancements.

The primary objective of this article is to investigate the prospective applications of agricultural robotics in sunflower cultivation across the Western Plains of Romania. The selection criteria for the recommended robots are meticulously tailored to meet the region's unique characteristics, with a distinctive emphasis on organic farming methodologies. Additionally, the study provides a concise analysis of the advancements made in agricultural robotics.

Keywords: robots for agriculture, Farming 4.0, IoT, precision agriculture, drones.
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INTRODUCTION

In recent years, the integration of robotic technologies and artificial intelligence (AI) in the agricultural industry has emerged as a promising avenue for enhancing sustainability and productivity. Particularly in sunflower cultivation, cutting-edge robotic solutions hold significant potential to revolutionize traditional agricultural methods and mitigate sustainability challenges in rural areas.

The global population has experienced exponential growth, surpassing 8 billion in mid-November 2022 from an estimated 2.5 billion in 1950. This staggering increase, adding 1 billion people since 2010 and 2 billion since 1998, underscores the pressing need for innovative approaches to address food security and environmental degradation concerns (United Nations, 2022). Regulatory bodies such as the European Union (EU), the Food and Agriculture Organization (FAO), and the United States of America (USA) have recognized this imperative, taking substantial strides in crafting legislative frameworks to govern the implementation of AI and robotics in agriculture. Despite the rapid population growth witnessed over the past century, the rate of increase has notably decelerated since the 1960s, primarily attributed to declining fertility rates. The global population is projected to reach around 8.5 billion by 2030 and add 1.18 billion in the subsequent two decades, reaching 9.7 billion by 2050 (United Nations, 2022). This gradual growth trajectory underscores the importance of leveraging technological innovations like AI and robotics to enhance agricultural sustainability and address the evolving needs of a growing population.

EU legislation regarding AI and robotics is grounded in fostering innovation while ensuring ethical and responsible technological deployment. The enactment of the European Commission's AI Act in 2021 represents a landmark achievement, establishing a comprehensive regulatory framework geared towards promoting transparency, accountability, and the development of human-

centric AI systems (European Commission, 2021). This legislative framework encompasses critical areas such as data privacy, algorithmic transparency, and liability frameworks for AI-related incidents, providing robust guidelines for the integration of AI-enabled robotic solutions in agriculture.

Subsequently, on March 13, 2024, the European Parliament issued a legislative resolution aimed at regulating the AI Act, envisioning the establishment of a unified legal framework within the EU governing the development, market introduction, deployment, and utilization of AI systems (European Parliament, 2024). This regulatory endeavor prioritizes safeguarding health, safety, and fundamental rights, with a concerted emphasis on enhancing AI literacy and fostering voluntary codes of conduct among pertinent stakeholders.

The FAO, renowned for its expertise in food and agriculture, has actively explored the potential applications of AI and robotics in agricultural development. Initiatives such as "Agriculture 4.0 Agricultural Robotics and Automated Equipment for Sustainable Crop Production" (FAO, 2020), "Digital Agriculture in Action: Artificial Intelligence for Agriculture" (FAO, 2021) and "Digital Technologies in Agriculture and Rural Areas" (FAO, 2019) highlight the FAO's recognition of the transformative impact of these technologies on agricultural sustainability, productivity, and resilience. By advocating for responsible adoption, the FAO aims to address pressing global challenges, including climate change, food insecurity, and rural poverty.

In the United States, legislative efforts have emphasized innovation and regulatory oversight, with federal agencies and initiatives such as the Select Committee on AI and the National Science and Technology Council (NSTC) instrumental in supporting research and development in agricultural robotics, an example being the “National Artificial Intelligence Research and Development Strategic Plan” (NSTC, 2023). The "Robotic Process Automation (RPA) Policy" issued by the US Department of Agriculture (USDA, 2022) further underscores this commitment, providing a framework for the effective and secure implementation of RPA across the organization. In conjunction with the abovementioned policy, it's essential to acknowledge the broader role of robotics and artificial intelligence (AI) in agriculture. While the RPA policy focuses on administrative automation, incorporating robotics and AI in farming can potentially transform agricultural operations significantly.

An overarching challenge within contemporary robotics resides in the intricate integration of artificial intelligence (AI) to bolster autonomy and fortify adaptability when facing unforeseen and unprogrammed scenarios. This entails not only imbuing robotic systems with the capacity to autonomously navigate and execute tasks but also endowing them with the cognitive flexibility to effectively respond to dynamic and unpredictable environments. Achieving this seamless fusion of AI within robotic frameworks necessitates overcoming complexities associated with real-time decision-making, context comprehension, and the synthesis of diverse sensory inputs to navigate novel situations with agility and efficacy.

Research and innovation in digitalization for agriculture and rural areas are crucial for revolutionizing farming practices and ensuring sustainability. Digital and data technologies offer opportunities to enhance precision, efficiency, and environmental performance, enabling data-driven decisions and attracting younger generations to the sector.

In the EU, significant efforts have been made to advance digital transformation through initiatives like Horizon 2020 and Horizon Europe (European Commission, 2020). Successful implementations highlight the potential of digital solutions in agriculture, aiming to boost rural economies and enhance connectivity. Overall, research and innovation in digitalization are essential for driving sustainable development and addressing the challenges farming communities face.

In light of these legislative advancements, this study explores using robotic solutions in sunflower cultivation to bolster sustainability across rural regions of the Western Plain of Romania. By scrutinizing the regulatory framework and benchmark practices globally, this research provides comprehensive insights to policymakers, stakeholders, and practitioners regarding the potential and obstacles in embracing AI-enabled robotics in agricultural settings. Through rigorous empirical analysis and insightful case studies, this study aims to enrich the ongoing dialogue surrounding the prudent and sustainable deployment of AI and robotics in agriculture, primarily focusing on fortifying rural livelihoods and bolstering environmental resilience.

MATERIAL AND METHOD

The research was commenced with an exhaustive investigation of the global agricultural robotics market to identify optimal solutions conducive to organic sunflower cultivation in the Western Plain of Romania. Companies such as AGXEED, AGROINTELLI, and Naïo Technologies from the Netherlands, Denmark, and France, respectively, were meticulously examined for their multifunctional robotics offerings, encompassing models such as AGXEED's AgBot 5.115T2 and AgBot 2.055W4, AGROINTELLI's ROBOTTI LR, and Naïo Technologies' Orio and Oz, proficient in executing diverse tasks ranging from soil preparation to weeding and early-stage plant management. Moreover, specialized solutions focusing on chemical-free weed control were explored from Pixelfarming and Ekobot, while companies like Field Robotics, Monarch, Sitia's TREKTOR and Amos underwent evaluation for their autonomous tractor solutions. In this context, we also explored the capabilities of the H.S.S. AgBot 2.055W3 + CF2000-AB and Jacto's Arbus 4000 JAV for the fertilization process, alongside the Small Robot Co's Tom v4 and DJI's Mavic 3M drone for the process of crop monitoring. Noteworthy was the innovative all-in-one solution from NEXAT, engineered to oversee all aspects of sunflower cultivation. The study also considered emerging projects such as Ecorobotix's AVO spraying robot, Nexus's weeding solutions, and Bluewhite company's autonomous tractor endeavor. Furthermore, attention was devoted to solutions facilitating data collection, exemplified by TERRA-MEPP's TerraSentia robot, and Digital workbench's Tipard 350, with the aim of enhancing precision agriculture practices. This comprehensive inquiry facilitated the identification and selection of the most promising agricultural robotics solutions tailored to the specific requisites of sustainable and organic sunflower cultivation in the Western Plain of Romania.

Concurrently with the selection process of agricultural robots, an exhaustive exploration was conducted into sustainability policies within the agricultural domain, with a specific focus on the European Union (EU). This analysis encompassed the development of a sustainable bioenergy policy tailored for the EU post-2020, emphasizing the critical necessity of promoting the efficient and sustainable utilization of organic biomass resources for bioenergy production. Key considerations within this policy formulation included the delineation of climate and energy targets (CEMA, 2016).

Furthermore, the Position Paper on EU Carbon Farming by CEMA underscored the pivotal role of intelligent agricultural machinery in bolstering organic carbon farming methodologies, advocating for policy measures and technology adoption to facilitate sustainable organic sunflower cultivation (CEMA, 2024). Additionally, in pursuit of attaining self-sufficient energy and mitigating carbon emissions, the designated cultivation farm has instituted a biogas generator that harnesses organic waste generated onsite, with the produced biogas serving dual purposes: fuel for electricity generation and power for high-capacity agricultural machinery, notably for crop transportation to reception bases. In alignment with these sustainability objectives, all farm infrastructure will be outfitted with a photovoltaic panel system for energy generation, complemented by energy storage capabilities, thus further fortifying sustainable practices within the agricultural framework.

RESULTS AND DISCUSSIONS

In this section, we undertake a comprehensive examination of the pragmatic implications and contextual intricacies associated with the integration of robotic solutions within the framework of sunflower cultivation practices, with a specific emphasis on the agrarian landscapes of the Western Plain of Romania. The chapter unfolds as a multifaceted inquiry into the diverse dimensions of robotic interventions spanning distinct phases of sunflower cultivation and is characterized by a rigorous analysis of their technical specifications, operational nuances, and ecological implications, thereby offering profound insights into the transformative potential of robotics in agricultural systems.

Robots for Soil Preparation

Beginning with soil preparation, our investigation commenced by examining the solutions provided by AGXEED, particularly through the implementation of the AgBot 5.115T2.

The AgBot 5.115T2 from AGXEED (https://www.agxeed.com/oursolutions/agbot-n5-115t2/) features a 4.1 L 4-stroke Deutz Diesel Engine, compliant with stage 5 standards, boasting 115 kW/156 hp and a maximum torque

of 610 Nm, with an electric drive train with battery capacity of 30 kWh and a speed range from 0-13.5 km/h, a 350 l diesel tank and 30 l AdBlue tank, a 85 l/min at 210 bar hydraulic pump, up to 4 double-acting proportional spool valves, three-point rear linkage cat 3 and 8 t maximum lift capacity at hooks, three-point front linkage cat 2 (hooks cat 3) and 3 t maximum lift capacity at hooks, optional load sensing, optional electric driven PTO (up to 100 kW)+/-1200 rpm) completely variable in adjustment, optional high voltage connectors (up to 100 kW and 700 V). The AgBot 5.115T2 boasts dimensions of 2695 mm in minimal length, 2000 mm in height, and 3855 mm in total length with the hitch at 90 degrees, weighing in at 7.8 tons when empty. This versatile robot is equipped for soil preparation tasks, offering multiple configurations and implements from companies such as AMAZONE. It can utilize a 3 m digger, costing on average between €10,000 to €30,000 or more, running at a speed of 3.5 km/h and a depth of 30 cm, consuming approximately 22 liters of fuel per hour. Alternatively, it can employ a 3 m front knife roller (price ranging from €2,000 to €5,000 or more) and a 3 m 3-row cultivator (price ranging from €10,000 to €30,000 or more), achieving speeds of up to 10 km/h and operating at a depth of 15 cm. Furthermore, for seedbed preparation, the AgBot 5.115T2 can effectively utilize a 4 m spring tine cultivator, costing on average between €15,000 to €40,000 or more, operating at a speed of 11 km/h. Moreover, the AgBot 5.115T2 stands out with its remarkable field productivity of up to 10 hectares per day, operating at an autonomy level of 4 (high driving automation). Notably, its electric drive train facilitates quick charging, with a charging time of 4-6 hours, ensuring continuous efficiency in agricultural operations. The price of the AgBot 5.115T2 varies depending on the configuration, starting at €320,000+. As of the end of 2023, there were 50+ operational units, with initial sales being done primarily in the Netherlands, Germany, France, and the UK (Figure 1).

Another similar robot from AGXEED is the AgBot 2.055W4 (https://www.agxeed.com/our-solutions/agbot-2-055w4/), boasts a 2.9 L 4-stroke Deutz Diesel Engine, stage 5 compliant, with 55 kW/75 hp and a maximum torque of 300 Nm, with electric drive train with a speed range from 0-13.5 km/h, a 220 l diesel tank, a 85 l/min at 210 bar hydraulic pump, up to 3 double-acting proportional spool valves, three point rear linkage cat 2 (hooks cat 3) and 4 t maximum lift capacity at hooks, three point front linkage cat 2 and 1.5 t maximum lift capacity at hooks, optional load sensing, optional electric driven PTO (up to 55 kW and 700 V) completely variable in adjustment, optional high voltage connectors (up to 55 kW and 700 V).

Figure 1 **AGXEED's AgBot 5.115T2 multipurposed agricultural robot** (https://www.agxeed.com/)

The AgBot 2.055W4 exhibits dimensions of 3850 mm in length, 1500 mm in height, a minimum width of 1800 mm, a wheelbase of 2400 mm, and an empty weight of 3.2 tons. This robotic system is adept at soil preparation tasks, offering various capabilities and implements from companies such as AMAZONE. It can effectively employ a 160 cm bed spader, costing on average between €5,000 to €15,000 or more, operating at a speed of 5 km/h, with a power take-off (PTO) speed of 540 rpm, consuming approximately 4 liters of fuel per hour. Additionally, for seedbed preparation, the AgBot 2.055W4 can utilize a 3 m rotary harrow, costing on average between €10,000 to €25,000 or more, operating at speeds of up to 7 km/h, with a fuel consumption rate of 6.5 liters per hour. The AgBot 2.055W4 boasts an impressive operational capacity, capable of running for up to 20 hours at 75 % capacity, at an autonomy of level 4 (high driving automation). Priced at €190,000, this advanced agricultural solution had 10 operational units recorded by the end of 2023 and is currently available in 20 countries worldwide.

Both of the AGXEED robots incorporate comprehensive safety features to ensure operational integrity. These include a Geofence system, visual indicator lights, audible warning alarm, and strategically placed emergency stop buttons surrounding the machine. Moreover, their robust Obstacle detection system comprises a LIDAR sensor positioned atop the machine, ultrasonic sensors seamlessly integrated into the safety bumper, radar sensors also integrated into the safety bumper, and a

contact sensitive bumper integrated into the safety bumper, collectively enhancing operational safety and risk mitigation (Figure 2).

Figure 2 **AGXEED's AgBot 2.055W4 multipurposed agricultural robot** (https://www.agxeed.com/)

The multipurpose ROBOTTI LR, engineered by AGROINTELLI (https://agrointelli.com/robotti/lr/), showcases a robust array of specifications tailored for soil preparation (with optional PTO at 540 RPM with 14 kW/18 hp). Its design features include a Kubota diesel engine with 4 cylinders, providing 54/72 kW/PS and adhering to EPA/CARB Tier 4 + EU Stage V emissions standards. Enhanced with Bosch Rexroth Load-Sensing-Hydraulics and equipped with three double-acting outlets (max. 50 l/min) featuring free return, the ROBOTTI LR offers versatility in agricultural operations. Boasting a diesel tank capacity of 300 L and a dry weight of 2850 kg, this model ensures extended operational periods while minimizing power consumption, being capable of up to 60 hours of continuous operation before requiring refueling, with an output of 2.5 ha/h. Notable attributes include high on-wheel torque, improved hydraulics, and a lifting capacity of 1.2 tons. Operating autonomously, the ROBOTTI LR executes field tasks continuously, day and night, facilitated by its dual RTK-GPS positioning system, ensuring precision within +/- 2 cm. Implements suitable for the ROBOTI LR can be sourced from PÖTTINGER and MONOSEM, providing a range of options for various agricultural tasks, including soil preparation. Stubble cultivators from PÖTTINGER could range in price from €10,000 to €30,000 or more, while disc harrows could range in price from €15,000 to €40,000 or more, depending on the specific model, size, features, and any additional customization options. Moreover, short combination cultivators as a fuel-saving seedbed preparation option could range in price from €20,000 to €50,000 or more. Additionally, implements from MONOSEM such as the Multicrop and Supercrop cultivators could range in price from €20,000 to €50,000 or more. Priced at €179,858, ROBOTTI LR has the option for rental bases, with annual rental costs starting from €32,000. By the end of 2023, 16 operational units were recorded, with dealers accessible in 22 countries worldwide (Figure 3).

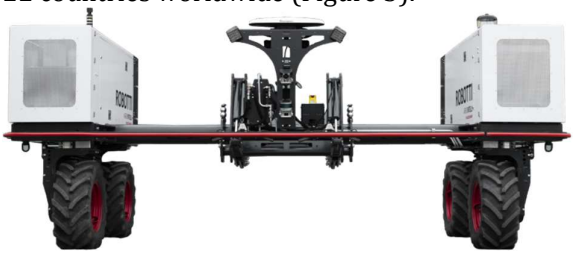

Figure 3 **AGROINTELLI's ROBOTTI LR multipurposed agricultural robot** (https://agrointelli.com/)

Orio, developed by Naïo Technologies (https://www.naio-technologies.com/en/orio-is-the-most-versatile-tool-carrier/), represents a significant advancement in agricultural robotics, with a particular focus on soil preparation. Its design emphasizes the accessibility of the toolholder, facilitating easy adjustment of tool settings crucial for soil cultivation. Notably, Orio's compact turning pattern is designed to minimize soil compaction, demonstrating a keen commitment to soil health preservation. Enhanced by powerful motors and a pivot point in the rear axle, Orio ensures reliable performance even in challenging terrain, making it highly adaptable for various soil preparation tasks. Operating solely on battery power and driven by electric motors, Orio prioritizes environmental sustainability in its operations. The robot boasts a carrying capacity of 600 kg for tools in the centered toolholder, enabling it to accommodate a variety of implements necessary for soil preparation tasks. Implements suitable for the Orio can be sourced from companies like K.U.L.T. One such option is the K.U.L.T.iVision PV cultivator or the K.U.L.T.iSelect, which offer advanced features tailored for precision agriculture. The price range for the K.U.L.T.iVision PV cultivator or the K.U.L.T.iSelect can range between €15,000 to €30,000, or more. With its impressive capabilities, Orio can achieve speeds of up to 5 km/h for durations of up to 10 hours on a single charge, covering an area of up to 6 hectares per charge. Featuring four independent motors, each with 3000 watts of power, Orio delivers robust performance, ensuring efficient and effective soil preparation operations. Its dimensions, measuring 4.00 m in length, 2.25 m in width, and 2.00 m in height, allow for maneuverability in various field environments. For applications requiring narrower tracks, Orio offers a track width option ranging from 1.5 m to 1.75 m,

enhancing its versatility across different field configurations. Additionally, the robot features a zero-turn radius, further facilitating precise navigation and maneuvering in tight spaces. Priced at €200,000 and backed by a robust 5-year warranty, Orio has garnered significant attention in the agricultural robotics market. It emerges as a promising solution for soil preparation tasks, thanks to its innovative design, environmental sustainability, and impressive performance capabilities. With 50 operational units sold by the end of 2023, Orio is readily available for purchase worldwide, solidifying its reputation as a reliable and effective choice (Figure 4).

Figure 4 **Naïo's Oriomultipurposed agricultural robot** (https://www.naio-technologies.com/en/home/)

Similarly, the Naïo Oz, an innovative creation from Naïo Technologies (https:// www.naio-technologies.com/en/oz/), revolutio -nizes soil preparation in agricultural robotics. This compact robot, powered by a LiFePo4 lithium battery and electric drive system, excels as a versatile farm assistant. Featuring a rear-mounted tool carrier with a lifting capacity of up to 60 kg, complemented by an optional front weight kit, the Oz ensures efficient handling of soil preparation implements. Implement options compatible with the Naïo Oz are available from companies such as Ebra, providing a diverse range of solutions for agricultural tasks, including soil preparation. Prices for Ebra implements typically range from €1500 to €2500 or higher, depending on the specific model and features. Powered by a 100 Ah battery pack, the Oz boasts an impressive operational endurance of up to 8 hours on a single charge, covering an area of up to 1 hectare per charge. With a robust 4-wheel drive driveline, the Oz delivers reliable performance across various terrains, enhancing its suitability for soil preparation applications. Equipped with a front-mounted pressure-sensitive sensor for obstacle detection, the Oz navigates through fields with ease, minimizing disruptions to soil preparation tasks. Its compact dimensions, measuring 1.30 m in length, 0.47 m in width, and 0.83 m in height, contribute to its agility and maneuverability, ensuring optimal performance in diverse field conditions. Priced competitively at €40,000 and boasting a reassuring 5-year warranty, the Oz underscores its significance and widespread adoption in the agricultural robotics market. With 220 operational units sold by the end of 2023, it's readily available for purchase worldwide, highlighting its effectiveness and reliability (Figure 5).

Figure 5 **Naïo's Ozmultipurposed agricultural robot** (https://www.naio-technologies.com/en/home/)

Robots for Seeding

Expanding upon their multifunctionality, the AgBot 5.115T2 from AGXEED and the AgBot 2.055W4, also from AGXEED, as well as the multipurpose ROBOTTI LR by AGROINTELLI, offer versatile solutions for seeding operations. Similarly, Naïo's Orio and Oz, known for their focus on soil preparation but also designed as multipurpose robots, can also be adapted for seeding operations, demonstrating their multifunctionality in agricultural robotics.

The AgBot 5.115T2, previously discussed, can be equipped with a 3 m front tender packer and 3 m rotary harrow with a sunflower precision drill for seeding tasks, with prices ranging from €50,000 to €100,000 or more. With a speed range of up to 8-12 km/h, it ensures efficient and precise seeding operations (Figure 1).

Similarly, the AgBot 2.055W4, as highlighted earlier, offers flexibility in seeding methods. It can utilize a 3 m rotary harrow with a 3 m mechanical drill, with prices ranging from €60,000 to €120,000 or more, operating at speeds of up to 5 km/h and consuming approximately 6 l/h of fuel. Alternatively, it can employ a 4-row 75 cm precision drill with a fertilizer front hopper, with prices ranging from€80,000 to €150,000 or more, achieving a

speed of 6 km/h while consuming 12 l/h of fuel. This configuration enables precise seeding with a seed distance of 16 cm, a seed quantity of 86,000/ha, and fertilizer application of 500 kg (Figure 2).

The ROBOTTI LR by AGROINTELLI is capable of performing the seeding process for sunflowers efficiently and effectively. It utilizes its multipurpose design to adapt to various agricultural tasks, including seeding. The seeding process for sunflowers with the ROBOTTI LR typically involves the attachment of a specialized seeding implement, such as a precision drill tailored for sunflower seeds. The ROBOTTI LR's precise control and maneuverability, facilitated by its advanced technology and autonomous operation, enable it to navigate through fields with accuracy. It can adjust the seeding depth and spacing according to specific requirements for sunflower cultivation. Additionally, the robot's robust construction and high lifting capacity allow it to carry the necessary seed and fertilizer loads for large-scale seeding operations. With its integrated RTK-GPS positioning system ensuring precise accuracy within +/- 2 cm, the ROBOTTI LR can maintain consistent seed placement and spacing, optimizing the potential yield of sunflower crops. Implements suitable for the ROBOTI LR can be sourced from PÖTTINGER and MONOSEM, providing a range of options for various agricultural tasks, including seeding operations. PÖTTINGER's seed drill machines could range in price from €20,000 to €100,000 or more, depending on the specific model, size, features, and any additional customization options. Additionally, implements from MONOSEM such as the VALOTERRA, MONOSHOX NG PLUS M/ME, MONOSHOX NX M/ME, NG PLUS 4/4E and NC PLANTER, all have sunflower seeding capabilities, with prices ranging from €50,000 to €150,000 or more, depending on the specific model, size, features, and any additional customization options (Figure 3).

Naïo's Orio and Oz, known for their multifunctionality in agricultural robotics, can also be adapted for seeding operations, including the seeding process for sunflowers. These robots leverage their compact yet robust designs to perform a range of tasks, including seeding, with precision and efficiency. For the seeding process of sunflowers, Naïo's Orio (Figure 4) and Oz (Figure 5) can be equipped with specialized seeding implements suitable for sunflower cultivation. These implements may include precision drills or mechanical seeders designed specifically for sunflower seeds. Implements suitable for the Orio can be sourced from companies like K.U.L.T., with prices ranging from from €10,000 to €30,000 or more. Implement options compatible with the Naïo Oz are available from companies such as Ebra, providing a diverse range of solutions for agricultural tasks, including seeding operations. Prices for Ebra implements typically range from €2000 to €3500 or higher. Both Orio and Oz utilize their battery-powered electric drive systems to maneuver through fields, ensuring precise seed placement and spacing. Their compact dimensions and agile maneuverability allow them to navigate between rows and around obstacles with ease, optimizing seed distribution across the field. Equipped with advanced navigation systems, such as GNSS and RTK corrections, Orio and Oz can follow predefined paths with accuracy, ensuring consistent seed placement throughout the seeding process. Additionally, obstacle detection sensors integrated into these robots enable them to navigate around obstacles autonomously, minimizing disruptions to the seeding operation.

Robots for Phytosanitary Treatments and Fertilizer Application

Expanding its application beyond orchard management, the AgBot 2.055W3 & CF2000-AB from H.S.S. (https://holsprayingsystems.com/producten/hss-fruit-agbot-autonomous-machine/) represents a groundbreaking innovation in agricultural robotics, tailored for sunflower cultivation. This autonomous machine offers multifunctional capabilities, including crop protection, weed control and precise liquid nutrition application. For crop protection, the AgBot features a module with a 2000-liter tank, an electrically driven fan, and 16 nozzles for uniform distribution. Weed control and liquid feed application are achieved with a three-point-supported frame, equipped with adjustable spray hoods and a dosing pump for agent injection. In the fertilizing process for sunflower cultivation, the AgBot 2.055W3 + CF2000-AB plays a pivotal role, ensuring precision and efficiency. Equipped with versatile features such as a standard hitch, power take-off (PTO), auxiliary valves, load sensing, and a high-voltage connector, the robot adapts seamlessly to various agricultural operations, including fertilization. The AgBot boasts advanced technical specifications, featuring a 55 kW Deutz 2.9 TCD diesel engine and a 170-liter fuel tank,

coupled with electric drive for the rear wheels, providing stepless speed control. Navigation is seamlessly managed through a remote control and receiver with ECU, complemented by a GNSS receiver for driving and safety systems. Utilizing a diesel-electric drive train, the AgBot harnesses its 55 kW engine to drive a generator, powering electric drives for propulsion, PTO operations, and implements. This configuration yields approximately 45 kW of PTO power and enables a lifting capacity of 3 tons. Navigation during fertilization tasks is enhanced by LiDAR, ultrasonic, and tactile sensors, ensuring precise maneuvering and collision avoidance. Powered by a diesel engine driving a generator, the AgBot offers up to 24 hours of operational endurance, ensuring continuous productivity throughout sunflower cultivation. Priced at €261,291, the H.S.S AgBot 2.055W3 + CF2000-AB boasts 10 operational unit sales recorded by the end of 2023, with availability in the Netherlands, Canada, France, Italy, and New Zealand (Figure 6).

Figure 6 **H.S.S AgBot 2.055W3 + CF2000-AB sprayer** (https://holsprayingsystems.com/)

The Arbus 4000 JAV from Jacto (https://jacto.com/asia/products/autonomous-sprayer/arbus-4000-jav), emerges as a cutting-edge solution tailored specifically for precision fertilizer spraying in sunflower cultivation, embodying advanced technology to optimize performance and efficiency in this agricultural sector. This autonomous machine features a multifan system equipped with intelligent section control, ensuring precise spraying solely where needed within sunflower fields, thereby minimizing wastage and environmental impact. Enhanced by a laser scanning system, the Arbus analyzes the environment to adjust application rates based on the size of the sunflower plants, further enhancing accuracy and effectiveness. Additionally, the electric motor-driven fan system reduces fuel consumption while maintaining high performance during fertilizer spraying operations. Interactive control of the Powered by a diesel engine, the Arbus 4000 JAV boasts characteristics optimized for sunflower cultivation, including a generous 4,000-liter tank capacity and a maneuverable steering system, enabling operation in challenging field conditions. Once in operation, the Arbus utilizes onboard sensors and software to adapt to uncertainties such as obstacles or moving objects within the field. With dimensions optimized for field work and adjustable height, the Arbus offers versatility and agility in sunflower cultivation. Powered by an intelligent hydrostatic transmission system integrated with a 132 hp diesel engine, it boasts a range of up to 20 hours of continuous work on a full tank of 230 liters. The Arbus 4000 JAV aims for operational efficiency, targeting a capacity of 4 to 6 hectares per hour for fertilizer spraying in sunflower fields. Jacto's Arbus 4000 JAV fertilizer is available for rental at a competitive rate of €5.69, with 2 operational units rented as recorded by the end of 2023. However, availability for rental is currently undisclosed (Figure 7).

Figure 7 **Jacto's Arbus 4000 JAV fertilizer** (https://jacto.com/europe)

In our evaluation of cutting-edge agricultural technologies, we have also considered future projects such as Ecorobotix's Avo spraying robot (https://ecorobotix.com/en/avo/). Ecorobotix, a Swiss manufacturer, introduced the Avo autonomous spraying robot in 2014, marking a significant advancement in precision agriculture technology. Designed for targeted application of fertilizers, the solar-battery powered Avo utilizes camera recognition in row crops, meadows, and intercropping cultures. Equipped with RTK GPS, AI, and vision capabilities, the Avo detects and selectively sprays weeds with remarkable precision,

reducing herbicide usage by up to 95 %. Its spot spraying technology offers a spray resolution of up to 24 cm^2 on the ground, ensuring efficient and environmentally friendly weed control. Priced at €90,000, the Avo has gained traction in the market, with five units currently active in France, Italy, Germany, and Switzerland. However, it is important to note that it is currently still in the testing phase and not available for sale as of the end of 2023 (Figure 8).

Figure 8 **Ecorobotix's Avo spraying robot** (https://ecorobotix.com/en/)

Robots for Weed Elimination

Robot One from Pixelfarming (https://pixelfarmingrobotics.com/robot-one/) is engineered to autonomously combat weeds, eliminating the need for manual labor or chemical herbicides, thus aligning perfectly with the principles of sustainable and organic sunflower farming. Its sophisticated vision-based technology enables precise weed detection and control, offering a viable alternative to traditional weed management practices. With robust processing capabilities and seamless cloud connectivity, Robot One is ideally suited for large-scale sunflower fields, fostering biodiverse environments conducive to optimal crop growth. Robot One is equipped with 10 arms and three specialized tools – including a hoe, mill, and streamer – to facilitate efficient weed management. Moreover, the purchase package encompasses an Onboarding program, ensuring seamless integration and operational understanding for users venturing into sunflower cultivation. Powered by an all-electric drive train featuring 4-wheel drive and 4-wheel steering with a 12 kW system, Robot One operates at speeds ranging from 2.5 cm/s to 1.2 m/s. Each of its ten arms boasts a lifting capacity of 80 KG, totaling 800 kg, ensuring efficient weed management across vast sunflower fields. The Robot One incorporates an array of advanced sensors and processing power to optimize its performance in agricultural tasks. Featuring 6 stereographic cameras for obstacle detection and an additional 6 cameras for image recognition, the Robot One enhances its perception and awareness of its surroundings. Supported by an NVIDIA Ampere GPU and a 12-core Arm Cortex CPU, boasting an impressive AI Performance of 275 TOPS (INT8), the Robot One's processing power enables seamless navigation and weed control. Integrated with a dual RTK-GPS and camera sensing system, this technology ensures accurate positioning and precise operation in the field, further enhancing the Robot One's efficiency and effectiveness in agricultural operations. Measuring 2300 mm in length, 3750 mm in width, and 2230 mm in height, Robot One offers variable track width settings to adapt to the specific requirements of sunflower cultivation. With the ability to turn on its axis, it delivers unparalleled maneuverability, essential for navigating through sunflower rows. Weighing 2140 kg, the robot is powered by all-electric drivelines, complemented by 1110 Wp solar panels and a 13.5 kWh battery pack, ensuring uninterrupted operation even in remote sunflower fields. The Robot One boasts an impressive output capacity, capable of covering 1 hectare per hour for mechanical weed control, ensuring high productivity during operation. On a bright day, the Robot One can operate continuously and return to the field with fully charged batteries.

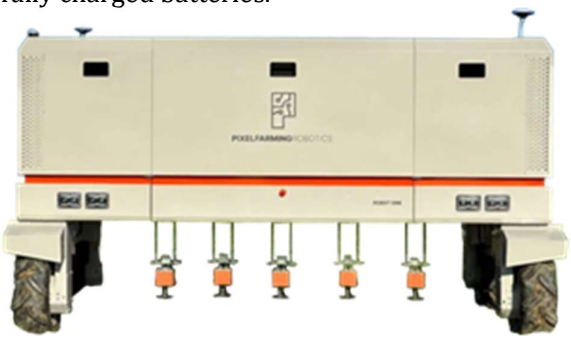

Figure 9 **Pixelfarming's Robot One chemical-free weeding robot** (https://pixelfarmingrobotics.com/)

However, the range may vary depending on the specific tools used in conjunction with the Robot One. Priced at €249,000, Robot One is an advanced and reliable solution tailored for chemical-free weed control in sunflower cultivation. The sales price includes Robot One equipped with 10 arms and 3 different tools: a hoe, mill, and streamer, along with the Onboarding program. Through this program, the buyer is guided on how to successfully integrate Robot One into their business operations. Additionally, the CO_2 laser option is available upon request. As of the end of 2023, Pixelfarming intended to have 15 operational units in total.

Robot One is currently available for sale in

Europe (Figure 9).

The WEAI robot from Ekobot(https://www.ekobot.se/products/ekobot-weai/), emerges as a groundbreaking solution tailored for the meticulous weed management essential in sunflower cultivation. Designed specifically for row-seeded vegetables, WEAI stands out as an invaluable asset in the battle against weeds, particularly crucial in the context of sunflower fields. Equipped with mechanical arms for inter-row weeding and a specialized hoeing system for intra-row weed removal, WEAI significantly reduces the reliance on herbicides. By minimizing chemical intervention, farmers can effectively cut costs while promoting environmentally friendly agricultural practices, thus fostering sustainable sunflower cultivation. Notably, trials conducted in Sweden have showcased the transformative impact of WEAI, demonstrating increased yields compared to conventional pesticide-based weed control methods. The Generation-3 model of WEAI weighs 600 kg and features four-wheel drive and four-wheel steering, ensuring seamless navigation through sunflower fields. The robot boasts dimensions of 2.0 meters in length, 2.8 meters in width, and 1.8 meters in height, with track widths available in both 2.0 meters and 2.25 meters. Its autonomous operation, powered by an electric system with a battery swap mechanism, enables continuous weed management, vital for maintaining the integrity of sunflower crops. Utilizing advanced RTK GPS technology for precise positioning, coupled with sensor fusion for obstacle detection, WEAI navigates sunflower fields with unparalleled accuracy and efficiency. With dimensions optimized for agricultural applications, WEAI guarantees agile maneuverability within sunflower rows, contributing to streamlined weed management operations. Powered by two 48 V batteries producing 7.4 kWh, WEAI ensures uninterrupted productivity throughout the sunflower cultivation process with a runtime of up to 9 to 10 hours per charge. Leveraging the mechanical tool arms, the Robot One efficiently covers 10 hectares in 4.5 days. When combined with the hoeing system, this capacity can be further optimized to cover the same area, offering enhanced efficiency and productivity in agricultural operations. Priced at €95,000, alongside a service fee, this innovative system operates with exceptional precision, meticulously targeting weeds within and between rows, thereby optimizing sunflower yield potential. With availability in Denmark, Netherlands, Sweden, and potentially Belgium as well, and with 5 operational units by the end of 2023, the WEAI robot offers efficient and effective weed control solutions across multiple countries, enhancing agricultural productivity and sustainability (Figure 10).

Figure 10 **Ekobot's WEAI weeding robot** (https://www.ekobot.se/)

Robots and Drones for Crop Monitoring

Tom v4, developed by Small Robot Co (https://smallrobotco.com/#tom), alongside with DJI Mavic 3M (https://ag.dji.com/mavic-3-m), transforms sunflower farming through precise per-plant crop counting, weed detection, and data visualization. This innovative solution autonomously maps fields, providing crucial insights into crop health and weed density. Tom utilizes AI to generate treatment maps for targeted herbicide application and variable-rate nutrient use, optimizing resource efficiency and reducing environmental impact in sunflower fields. Equipped with an electric drivetrain and Swift nav GPS system, Tom ensures accurate positioning, essential for effective monitoring. Its 6m camera coverage and 4 TB data storage capacity facilitate comprehensive data collection and analysis, empowering farmers with informed decision-making tools. Tom is powered by four rechargeable batteries (1.56 kWh each) and is equipped with a Swiftnav GPS system featuring two GNSS receivers. Additional features include eight 6-megapixel cameras, a ground sample distance (GSD) of 0.28 cm per pixel, and a static ground pressure of less than 31 kPa. Weighing 350.6 kg, Tom's dimensions comprise a track width of 1.04 meters, a wheelbase of 0.95 meters, a robot length of 1.55 meters, a robot width of 1.54 meters, a robot height of 1.3 meters, a boom deployed width of 5.56 meters, and a turning radius of 0.74 meters. Tom's energy source is electricity/batteries, providing a range of four hours on a single battery charge, with the flexibility for farmers to swap batteries to continue operation. It boasts an impressive output capacity of 2.2 hectares per hour and utilizes two GNSS receivers to provide RTK position with a 1 cm accuracy. Pricing for Tom v4's services is £150 per hectare, which

includes three surveys. These surveys provide valuable tools for sunflower cultivation, including green-on-brown maps for targeted herbicide application, variable-rate nitrogen application maps based on plant counts and biomass assessments, and broadleaf weed maps for precise herbicide application during autumn and spring seasons. Availability is currently limited to the UK, with the total number of operational units by the end of 2023 undisclosed (Figure 11).

Figure 11 **Small Robot Co's Tom v4 monitoring robot** (https://smallrobotco.com/)

Potential Robot for Harvesting

In the realm of sunflower harvesting, several companies have introduced innovative solutions aimed at enhancing efficiency and productivity. FieldRobotics, Monarch, Sitia's TREKTOR, and Amos have all developed autonomous tractor solutions that offer promising advancements in sunflower cultivation. However, among these, NEXAT's (https://www.nexat.de/en/products/carrier-vehicle/) all-in-one solution stands out for its comprehensive approach. Even though it is not fully autonomous, NEXAT is engineered to oversee all aspects of sunflower cultivation, including solutions that integrate cutting-edge technology to streamline the harvesting process. NEXAT's sunflower-specific harvesting system, developed entirely in-house, integrates the NEXCO harvesting module, setting new standards in sunflower harvesting technology. With a cutter bar width of 15 m, the NEXCO module ensures an efficient flow of material, boasting an enormous throughput of 120-200 t/h tailored for sunflower crops. This innovative system minimizes losses and the share of broken grains while featuring a 32 m^3 grain tank and evenly distributing straw over the entire working width, crucial for sunflower cultivation. Swath deposit is also possible, with an impressive unloading rate of 650 l/sec and unloading completed in less than 1 minute, enhancing operational efficiency during sunflower harvesting. The system employs a revolutionary Dual Tangential Axial Flow threshing concept, specifically optimized for sunflower crops, dividing the crop into two even flows transverse to the driving direction for optimal throughput. With headers from leading manufacturers like Geringhoff, GTS, Franco Fabril, and MacDon, offering specialized options for sunflower crops, NEXAT's solution ensures high efficiency, reliability, and economic viability in sunflower harvesting operations. Nexat is currently in the process of becoming fully autonomous, with ongoing efforts to achieve this goal and to transition it to electric power fueled by a hydrogen fuel cell generator. The standalone Nexat unit is priced at approximately $1.3 million. However, when considering all available applications, the total cost escalates to around $2.75 million (Figure 12).

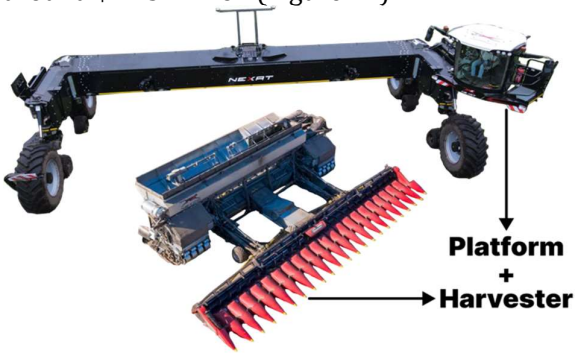

Figure 12 **NEXAT's all-in-one system** (https://www.nexat.de/en/)

CONCLUSIONS

In conclusion, the integration of advanced agricultural robotics and sustainable energy practices in sunflower cultivation represents a pivotal step towards achieving both environmental stewardship and operational efficiency. The implementation of a biogas generator, fueled by onsite organic waste, not only enables self-sufficiency in energy but also significantly reduces carbon emissions associated with traditional farming practices. Moreover, the utilization of photovoltaic panel systems further enhances sustainability efforts,

providing renewable energy sources to power farm operations. These initiatives underscore the commitment of the agricultural sector to reducing its environmental footprint while embracing innovative technologies.

By harnessing the power of renewable energy and leveraging cutting-edge agricultural robotics, sunflower cultivation can not only enhance productivity and efficiency but also contribute to global efforts aimed at mitigating climate change and promoting sustainable development.

In summary, the combination of agricultural robotics, AI and sustainable energy practices presents a promising pathway towards a more environmentally friendly and economically viable future for sunflower cultivation. As the agricultural industry continues to evolve, it is imperative to prioritize sustainability and adopt practices that safeguard the environment for future generations. The sustainability of agriculture reflects the approach aimed at incorporating the values of Industry 5.0 (a human-centred approach to digital technologies, upskilling and reskilling European workers, especially digital skills, modern, resource-efficient and sustainable industries and the transition to a circular one). economy, a globally competitive and world-leading industry accelerating investment in research and innovation) in what we call Agriculture 5.0 (European Commission, 2022).

The robotization of agriculture would greatly help the Romanian farmer and Romanian agriculture, the development of agriculture in the Western Plain of Romania and its alignment with EU standards.

Just as farmers have gotten used to using drones, and those who haven't are thinking of buying or renting one, in the coming years robots will become a normal reality and can already be bought in Romania. By choosing an appropriate robot system, we will be able to respect sustainable sunflower cultivation technologies, protecting the environment and resulting a superior quality products.

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