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Abstract.

The objective of this review is to present the current status of precision agriculture and smart agriculture in Japan. As of 2023, there are approximately 150 precision agriculture-related venture companies in Japan, and the number is increasing every year. Research related to precision agriculture is mainly conducted by the IT and Mechatronics Subcommittee of the Japanese Society for Agricultural and Biological Engineering, which consists of about 1,000 researchers from universities and national research institutes. As for the Extension of Precision Agriculture, the Ministry of Agriculture, Forestry and Fisheries (MAFF) has been conducting a national on-farm experiment to introduce domestic and foreign precision agriculture technologies to farmers starting in 2020, and this is still ongoing. In addition, private companies such as Kubota, Yanmar, Iseki and Topcon are building smart agriculture pilot farms for rice cultivation and orchards and introducing them to farmers as showcases. Japan is characterized by the development and diffusion of agricultural robots, such as harvesting robots and unmanned vehicles for transporting heavy loads, especially for horticultural facilities, by start-up companies. There is also an attempt to promote agricultural robots from the perspective of consumer electronics to the rest of the world. In addition, companies that develop applications for the carbon dioxide emission rights business in rice paddies and actuators for water management have recently begun to develop new businesses that connect farmers and businesses that purchase emission rights, increasing the importance of data standardization. Thus, extension of precision agriculture is beginning to move beyond its traditional focus on automation and efficient use of fertilizers in the direction of developing and disseminating elemental technologies to create new business opportunities. ISPA is correct in its reconsideration of the concept of precision agriculture. Based on the above, this report introduces the status of the introduction of precision agriculture technology to farmers and the development trend of the industry in Japan, and discusses the challenges and future prospects of precision agriculture.

Keywords.
List both specific and general terms that will aid in searches.

Introduction

Japanese agriculture faces numerous challenges, including a declining birthrate, an aging population, a decrease in agricultural workers, and urban population concentration. As of 2022, the population of agricultural workers in Japan is approximately 1.76 million, with the average age being about 67 years. This situation is exacerbated by the fact that over 60% of these workers are aged 65 or older, highlighting the critical issue of an aging workforce (MAFF, 2022). In comparison, the United States and Europe, although facing similar aging trends, have younger agricultural workforces. In the United States, the average age of farmers is around 57 years, while in Europe, it is approximately 51 years (USDA, 2021; Eurostat, 2024). This discrepancy underscores the unique severity of Japan's agricultural demographic issues. One promising solution to these issues is precision agriculture has become a term almost everyone knows as smart agriculture in Japan. The smart agriculture leverages cutting-edge technologies such as IoT, big data, and AI to enhance agricultural production efficiency and quality. However, the implementation and widespread adoption of smart agriculture encounter various problems and challenges. Japan and various Asian countries are grappling with significant challenges in the adoption and implementation of smart agriculture technologies. 60% of the farming enterprises that utilize data are farming with 50 ha or more, indicating that data utilization is an indispensable tool for promoting large-scale and labor-saving farming. Although the level of data utilization may vary depending on the individual farmers and the target crops, we believe that it is necessary to formulate a future vision and take concrete measures to achieve the policy goal set by the Ministry of Agriculture, Forestry, and Fisheries: "By 2025, almost all farmers will be practicing data-intensive agriculture”. In considering the direction of precision agriculture in the unique environment of island nations like Japan. The objectives of this review are to describe (1)Statistical analysis of Japanese agriculture, (2) Trends of private companies and start-ups towards data-driven agriculture, (3) Challenges of precision agriculture based on the current situation.

Background analysis of Japanese agriculture using statistical data

Trend of Fertilizer Price

Japan's chemical fertilizer market is heavily dependent on international supply sources, and since the import sources are concentrated in specific countries, it is highly susceptible to various external factors such as geopolitical risks and changes in trade policies. In particular, Japanese reliance on supplies from Malaysia, China, and Canada is high. Any changes in the production conditions or export policies in these countries are likely to have a direct impact on the prices of

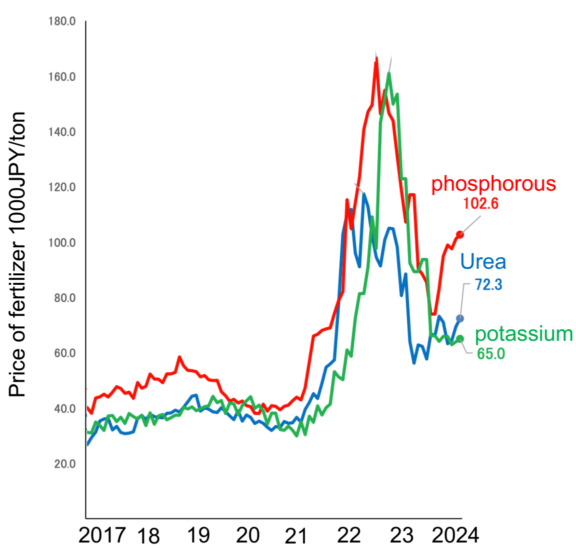

Fig. 1 Price changes in imported fertilizers

fertilizers in Japan. As shown in Figure 1, the price of fertilizer in Japan has increased by 3.5 times in terms of nitrogen content compared to 2017 due to reflect the influence of such external factors. In 2024, the retail price for farmers purchasing fertilizer is 966 USD per ton, which is three times the global average price in 2023. This indicates that fertilizer management has a direct impact on business operations. It is evident that effective fertilizer management is crucial for business management.

Trends in Production Volume of rice

The production volume of rice in Japan peaked during the post-war economic boom and the bubble economy era. However, since the 1990s, production has been on a downward trend. Specifically, rice production was approximately 11.81 million tons in 1990, but decreased to about 7.48 million tons in 2020. This represents a 36.6% decrease over roughly 30 years. The main reason for this decline is the decrease in domestic demand for rice. As Japanese dietary habits have diversified, rice consumption has been declining. For example, the annual per capita rice consumption dropped from 118.3 kg in 1962 to 52.9 kg in 2020. This decrease in consumption has been accompanied by a reduction in rice production. Similar trends can be seen in the cultivated area. The cultivated area was about 2,300,000 ha in 1990, but decreased to about 1,530,000 ha in 2020 (Ministry of Agriculture, Forestry and Fisheries, 2020). This represents a 33.5% decrease. This decline is mainly due to the aging of farmers and the lack of successors, leading to the abandonment of farmland. Additionally, urbanization and changes in industrial structure have resulted in the conversion of farmland to residential and industrial land.

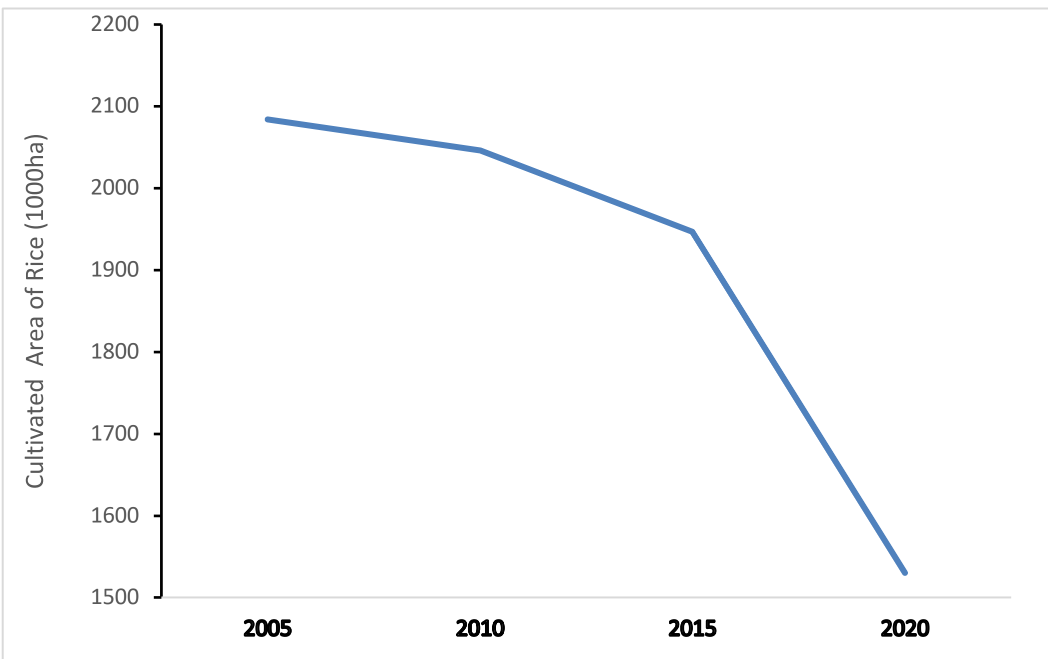

Fig. 2 Yearly changes of rice planted area

Challenges in Implementing Smart Agriculture Technologies in Japan

One of the most significant challenges facing the adoption of smart agriculture technologies in Japan is the aging farming population. The average age of farmers in Japan is over 66 years old, and many are nearing retirement. Older farmers may be less inclined to adopt new technologies due to unfamiliarity with digital tools and a preference for traditional farming methods. This reluctance can slow down the integration of smart agricultural practices. There is a considerable knowledge gap between the older generation and the younger, tech-savvy individuals who are more comfortable with modern technologies. Bridging this gap requires significant educational efforts and support. Many farms in Japan are small and fragmented, which makes the implementation of large-scale smart agriculture technologies more difficult and less economically viable. The small size of individual plots limits the scalability of high-tech equipment designed for larger farms. The initial investment required for smart agriculture technologies, such as drones, automated machinery, and advanced sensors, can be prohibitive for small-scale farmers. **The return on investment may not be immediately apparent, making it harder to justify the expenditure.** To address this challenge, initiatives such as targeted training programs and demonstrations of the practical benefits of smart farming technologies can help increase adoption rates among older farmers. In addition, incentives and support for startups in the field of agricultural technology should be provided through the introduction of subsidies. Subsidies should also be provided to producers who adopt the technology to facilitate a smoother. Trends in farmers' incomes are as shown in Figure 3, which shows that there are financial hurdles to adopting the system on a self-help basis. Government subsidies and financial incentives can also play a crucial role in making these technologies more accessible and affordable for small-scale farmers. Total government budget for smart agriculture-related research and extension in 2024 is about 10 billion yen.

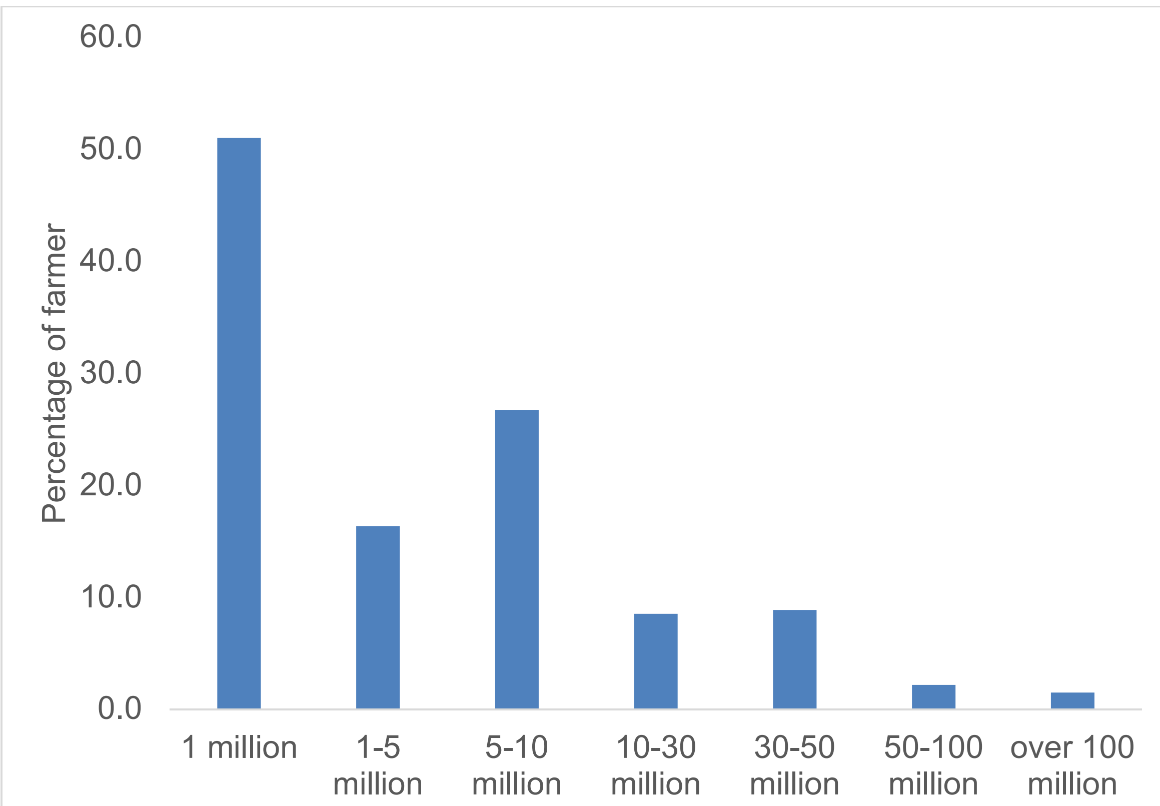

Fig. 3 Sales of agricultural products in 2023

Reducing Environmental Impact through Precision Agriculture by government

Since the formulation of the "Green Food System Strategy" (GFSS) by the Japanese government in 2021, the development and dissemination of new technologies along with the pursuit of sustainability in agriculture have become the focus. For example, in addition to the labor reduction effects, the "Smart Agriculture Acceleration Demonstration Project," which was open for applications in June 2021, considered contributions to the GFSS during the evaluation process. Furthermore, the "Strategic Development and Improvement of Smart Agricultural Technologies," which was open for applications in mid-July 2022, awarded additional points for technological developments that promote the same strategy. The approach of pursuing sustainability through smart agriculture is not new in Europe and the United States. The environmental impact reduction effects of smart agriculture were already demonstrated in the 1990s when GNSS began to be used in agriculture (Bongiovanni, 2004). Specifically, with the spread of smart agriculture since the 2000s, by 2020, auto-guidance systems were being used on approximately 60% of the corn acreage in the United States. As a result, in addition to increased yields, the use of herbicides was reduced by 9%, fossil fuels by 6%, and water by 4%.

Management and Production control using data

In smart agriculture, fields and management/production control systems are connected through ICT, enabling precise management using agricultural data. However, at this stage, only a limited number of farms are actually utilizing agricultural data. Let's look at the 2020 Census of Agriculture and Forestry. Only 17% of farms reported recording or using information such as financial data, market conditions, production history, growth status, weather conditions, and cultivation management for efficient and effective farm management (fig. 4).

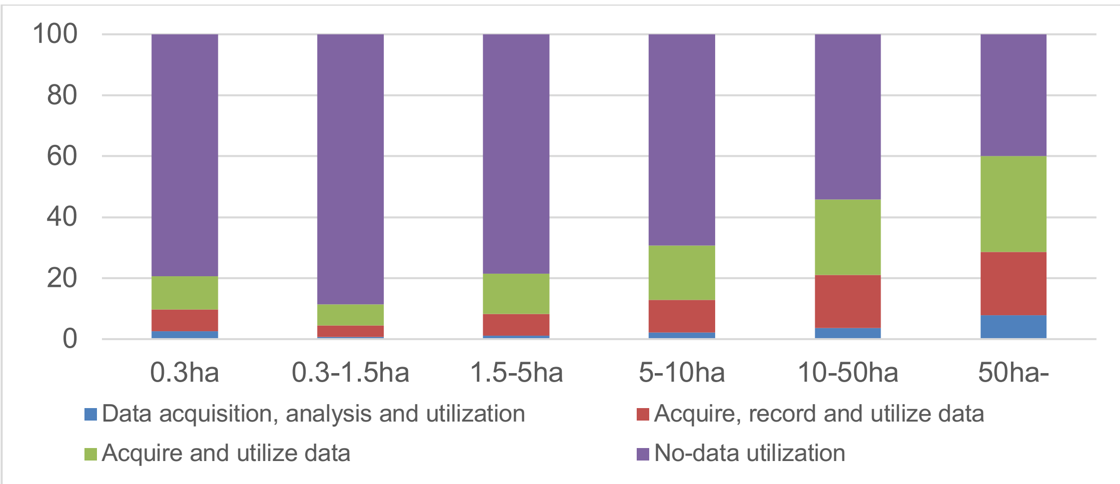

Fig 4. Data utilization in agricultural management in Japan

There are differences based on sales scale and age groups. For example, only 10.1% of all farms reported using external data such as weather and maps. Farms that have introduced weather data, production history, and sensing technology account for 11% of all farms, with higher adoption rates among those with sales between 50 million to 100 million yen, those with sales over 100 million yen, and those under 30 years old. While the utilization of agricultural data is advancing among young and large-scale farmers in Japan, it appears to be even more widespread in the United States. Firstly, the highest proportion of responses was for "maps (yield, electrical conductivity, etc.)." This is similar to "external data such as weather and maps". While in Japan, just under 20% of producers use such data, in the US, 80% of dealers responded positively. Notably, the practice of "not aggregating farm data and only processing data from individual farms" has decreased since 2019, while "aggregating farm data (limited to within business partners)" rose to 34% in 2021 (Erickson. et.al., 2022). While there is variation among respondents each year, indicating the need for caution, it could be inferred that dealers are increasingly taking on the function of aggregating agricultural data. On the assumption that Japan will follow the same trend, it is necessary to discuss more about data standardization and how data should be handled.

Trends of private companies and start-ups towards data-driven agriculture

Kubota

Around 2011, Kubota became the first farm machinery manufacturer in Japan to begin studying precision farming. This proactive initiative bore fruit in May 2014, when Kubota announced the development of the Kubota Smart Agri System (KSAS), which supports farmers to achieve more efficient production. As indicated by the system's name, Kubota had already set its sights on "smart farming," which includes precision farming. While precision farming can be defined as a farming management technique that utilizes data by way of ICT and IoT to increase operational efficiency, smart farming supports farm management by combining such data utilization with the automation of farm machinery. It is said that the percentage of farmland managed by certified farmers among the total farming area increased 80% by 2023. As farmland concentration accelerates and the labor force decreases, farmers are faced with a diverse array of challenges, including appropriate management of multiple fields, improvement of yield and quality of crops, reduction of production costs, and the need to add extra value to their produce. KSAS represents a novel support system for farm management and services, developed. It enables farmers to adopt a profitable Plan-Do-Check-Act (PDCA) management approach by leveraging agricultural machinery and ICT to collect and utilize information regarding work activities and crop data (including yield and taste). Illustrated in Figure 1, the overarching structure of this system encompasses KSAS agricultural machinery equipped with wireless LAN hardware and direct communication units, KSAS Mobile equipment facilitating work recording and information relay by workers, and a KSAS cloud server system dedicated to storing and analyzing information. Complementary farming support and machinery service systems operate atop these components, aiming to provide value through the following means:

Farming Support System

(a) Cultivating flavorful rice with high yields

(b) Ensuring safe and traceable crop production

(c) Enhancing farm efficiency and facilitating knowledge transfer among farmers

(d) Establishing robust foundations for farm management, including cost analysis and reduction

Machinery Service System

Minimizing downtime during peak seasons by promptly providing location-based, operation-specific, and error-driven services informed by agricultural machinery data

PDCA Agriculture Based on Data

The central piece of the current KSAS system is the combine harvester, equipped with load cells and near-infrared spectroscopic analysis sensors for real-time measurements. These sensors not only gauge the weight of rice in the grain tank but also assess its protein and moisture content, key indicators affecting rice taste. Post-harvest, the measurement data is transmitted to a cloud server alongside the combine harvester's operational data. Initially, this transmission occurred via a KSAS mobile device; however, since 2019, it has been facilitated through direct communication channels. Through this system, farmers can access cloud-stored data, including work records and yield/flavor distribution in each lot, via a PC in their office (as depicted on the left side of Figure 5). By integrating this information with soil analysis results, tailored soil improvement measures and fertilizer plans for subsequent years can be devised. Planned fertilizer application data can then be communicated to KSAS rice transplanters and tractors through operators' mobile devices. Upon receipt, KSAS agricultural machinery autonomously regulates fertilizer dosage, simplifying fertilization across numerous rice fields, even for inexperienced operators. This iterative process of data collection, work planning, cultivation/harvesting, and further data gathering facilitates continuous enhancements in crop yield and taste. This approach embodies a PDCA methodology in agriculture grounded in data utilization, a novel application in Japanese agriculture. During a three-year trial across Niigata prefecture and other regions in Japan, this approach yielded a 15% increase in yields and ensured a better and more consistent final product taste. Moreover, farmers were able to market premium-quality rice at higher prices, owing to its superior taste, and streamline product quality and sorting based on moisture content to reduce drying costs. Users of the KSAS system have attested to heightened field management efficiency and improved rice quality and yield. Over the approximately five-year period since its launch in June 2014, roughly 1,860 farming systems have been deployed across over 8,000 subscribers (including service systems). These systems span a total registered area of 78,000 hectares (with an average of 42 hectares) and encompass 357,000 lots (averaging 190 lots).

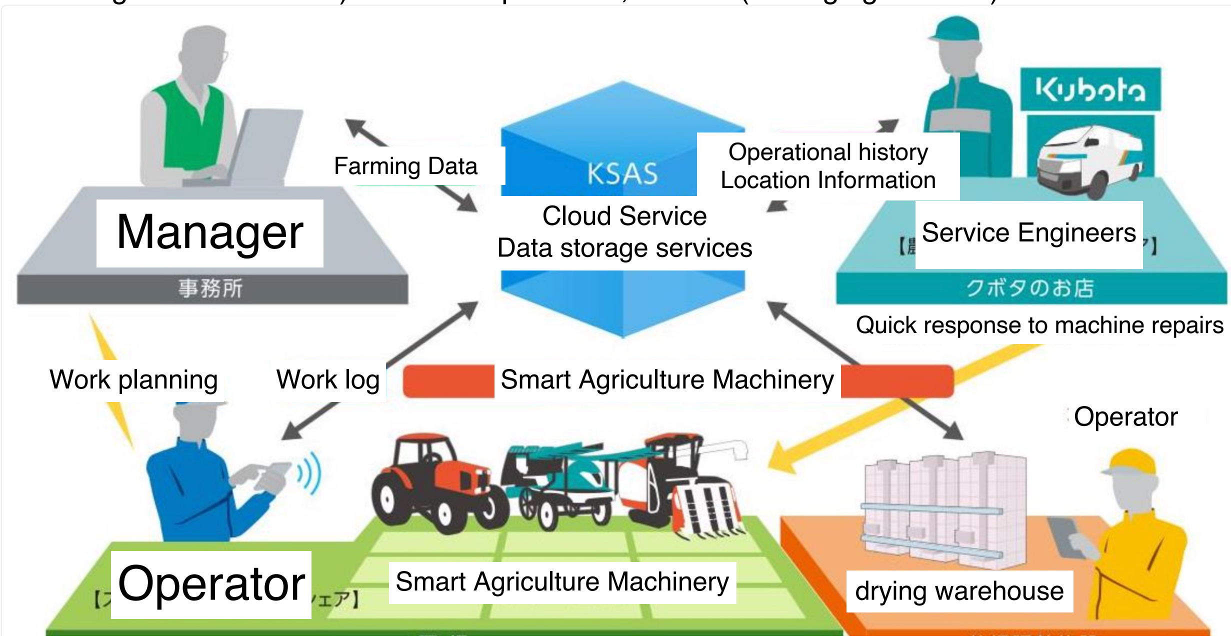

Fig. 5 Concept of Kubota Smart Agriculture System

Topcon

Designed for farmers, dealers, agronomists, and input suppliers who need to gather and consolidate key operational information, the Topcon Agriculture Platform (TAP) brings connectivity to every phase of the farming cycle, automating the data workflow, so users can focus on action. TAP is an easy-to-use tool to organize, visualize and make better farm management decisions based on data from across the entire farming operation.Constant connectivity, any data format, clear visualization, and secure sharing. With TAP, Topcon now offers a comprehensive and clear path into digital farm management.

Topcon Agriculture X35 Console and TAP (Topcon agriculture platform):

The X35 Console is a cutting-edge agricultural display system designed to provide farmers with precise control over their farming operations. It offers advanced guidance and steering capabilities, allowing for accurate navigation of farm machinery. Additionally, it integrates with various agricultural implements and sensors to enable data-driven decision-making, optimizing inputs and maximizing yields. Designed for farmers, dealers, agronomists, and input suppliers who need to gather and consolidate key operational information, the Topcon Agriculture Platform (TAP) brings connectivity to every phase of the farming cycle. TAP is a simple tool to organize, visualize, and automate information, helping farmers make better decisions based on data from across the entire operation. With TAP, we now offer a comprehensive and clear path into digital farm management was shown in Fig. 6.

Fig. 6. Topcon products for data-driven agriculture

CropSpec Sensors: CropSpec sensors are advanced optical sensors designed to assess crop health and nutrient levels in real-time. These sensors utilize multispectral technology to measure various indicators of plant health, such as chlorophyll content and nitrogen levels. By providing accurate and timely data on crop conditions, CropSpec sensors enable farmers to implement precise nutrient management strategies, ensuring optimal crop growth and yield potential while minimizing environmental impact. These products exemplify Topcon Precision Agriculture's commitment to delivering innovative solutions that empower farmers to optimize their operations and maximize productivity sustainably.

Agrist

Agrist was founded in 2019 by a team of passionate innovators and agricultural experts in Miyazaki Prefecture, a region renowned for its agricultural productivity. In the face of an aging population and labor shortages, Japanese agriculture is encountering a critical challenge: the negative spiral where the lack of harvesters leads to missed opportunities for farm expansion, resulting in decreased income and further reduction in the workforce. Agrist, a startup based in Miyazaki Prefecture, proposes a solution to this problem through the implementation of robotics to mitigate labor shortages. Agrist was founded in response to the pressing need for efficient, cost-effective agricultural solutions. Historically, while agricultural robots have existed, their high cost and multifunctionality prevented widespread adoption. Agrist focused on creating a specialized, affordable solution tailored to the specific needs of farmers. The development of Agrist's flagship product, the "L" robot, began with thorough field research was shown in Fig. 7. Located adjacent to a greenhouse cultivating bell peppers in Shintomi Town, Agrist's development team engaged extensively with local farmers. These discussions revealed a clear demand for a robot with minimal but essential functions at an affordable price. Based on this feedback, Agrist

Fig. 7 Sweet pepper harvesting robot "L"

designed the "L" robot, which autonomously identifies and harvests bell peppers using image recognition technology. The "L" robot is priced comparably to a light truck at 1.5 million yen and operates on a rental model, charging a 10% commission on harvest sales. This setup makes the technology accessible to farmers and is expected to increase harvest volumes by 20-30%, thereby enhancing farm revenue and scalability. The name "L" was inspired by farmers' requests to harvest only the large "L-sized" sweet peppers. By removing these larger peppers, the yield of the higher-priced "M-sized" peppers increases. The robot's design, including a suspension system to navigate muddy and leaf-littered grounds, and its straightforward functionality, stems directly from farmers' input. This is an example of farmer centric agriculture, the central concept of precision agriculture. Agrist continually improves the "L" robot, incorporating advanced features such as high-performance image recognition AI for nighttime operations, remote control capabilities, and enhanced robotic arms. These updates aim to maximize efficiency and ease of use.

Future Goals

Microsoft Japan has selected this start-up that solves agricultural issues through technology, for Microsoft for Startups in 2022. Microsoft Japan supports AGRIST in realizing its goal of "sustainable agriculture that will last for 100 years" by utilizing data obtained through automated harvesting robots and collaborating with Microsoft Japan's worldwide network. Agrist is developing an operating system (OS) to maximize harvest rates and support global scalability. The goal is to create an adaptable platform that allows integration with third-party technologies, catering to diverse agricultural environments worldwide. This initiative aims to improve food security globally, enabling engineers in various countries to customize and control agricultural robots and greenhouses according to local needs.

Conclusion and future perspective

Smart agriculture in Japan has seen rapid development in recent years. Particularly, various technologies have been developed and implemented by startups and existing agricultural machinery manufacturers. However, due to the characteristics and scale of Japanese agriculture, it is not easy to establish a business by focusing solely on the domestic market. Therefore, when considering future prospects, it is necessary to have a broader perspective. One perspective is to focus on rice cultivation. Japan is one of the major producers of rice, and the potential value of applying smart agriculture technologies to rice production is considerable. However, there are limitations in the acreage of rice cultivation and the number of farmers in Japan. Therefore, it is important to expand into regions where rice is a major crop, such as Asia and Oceania. This could allow Japanese smart agriculture technologies to be utilized in a wider market, potentially creating new business opportunities. Similarly, there are similar prospects for field crops. Therefore, it is important for Japanese smart agriculture technologies to have a global perspective in field crop production as well. Through such global expansion, Japanese agricultural technologies can contribute to improving agricultural productivity worldwide, thereby revitalizing agricultural economies both domestically and internationally. Furthermore, integrating with precision agriculture technologies already in use in Europe and North America is also important. Advanced agricultural technologies are actively adopted in these regions, and efficient agricultural production utilizing data is being conducted. By integrating Japanese smart agriculture technologies with precision agriculture technologies from Europe and North America, a more advanced agricultural production system can be established. This ***mutual complementation of technologies is expected to result in more effective improvement in agricultural productivity***. In conclusion, Japanese precision agriculture technologies have the potential to further grow by expanding globally. By actively entering markets worldwide, focusing on rice and field crop production, and integrating with existing precision agriculture technologies, more efficient and sustainable agricultural production can be realized. This will lead to further development of Japanese agriculture, contributing to the revitalization of regional economies and improvement of food security.

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