The FUTURE VISION OF ADVANCED FARMING

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Contents

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EXECUTIVE SUMMARY

Precision agriculture (PA), which leverages cutting-edge IT, sensing, and machinery systems, is expected to bring about a transformation in agriculture. The world's population is continuously growing, and the demand for crops remains high, but there is a limited supply of new farmland. Increasing yields and improving profitability are common challenges faced by farmers around the world. Technologies that can reduce costs without lowering yields have long been in demand.

The U.S. and EU have long supported the development of PA, placing high expectations on its potential. PA could manage crop growth by analyzing heterogeneous sensing data streams from satellite, in-field, and agricultural machinery and predict both yields and crop quality. PA gained remarkable attention from large producers in the U.S. and Europe in the early 1990s, and after a quarter of a century, certain components of PA technology have been implemented and are contributing to improved labor efficiency. The once-envisioned future of technology-led agriculture is slowly but steadily taking shape in the real world.

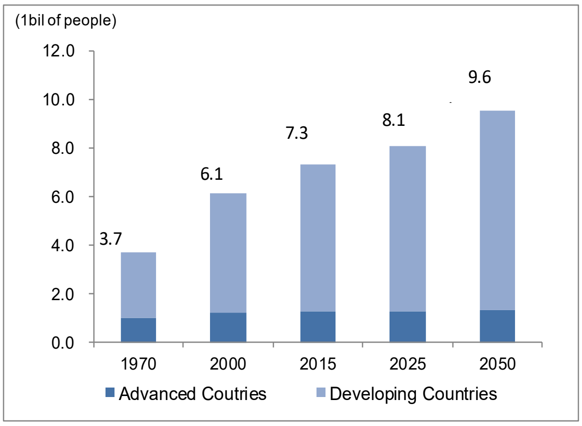
CHAPTER 1　The Current Landscape of Agriculture

Increasing Crop Yields and Fertilizer Use

Demand for grain has increased for decades, reflecting the world's growing population and changes in dietary habits (Figure 1). Accordingly, the use of fertilizer has increased steadily to boost crop production (Figure 2). Farmers have made a substantial contribution to increased crop production through the extensive use of synthetic fertilizers and pesticides to control pests and crop diseases. Today, many farmers are concerned that crop yields may decline without the use of fertilizers. Global consumption of fertilizer comprised about 188 million tons in 2011, in which China was the largest user, accounting for 30% of total fertilizer consumption, followed by 15% in India and 10% in the U.S.

Figure 1

WORLD POPULATION PROSPECTS

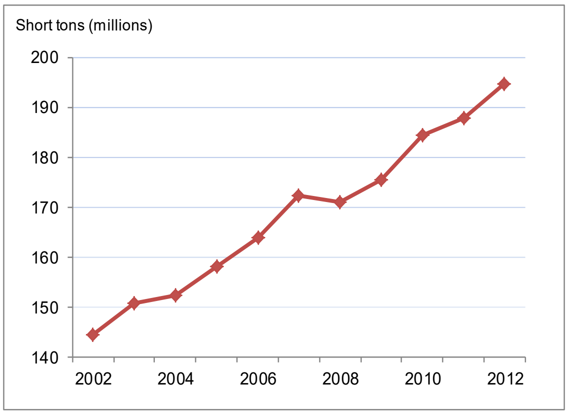


Source: "World Population Prospects: The 2015 Revisions" by United Nations

Note: Estimates are from 2015 onward

Figure 2

WORLD FERTLIZER CONSUMPTION



Source:　FAOSTAT

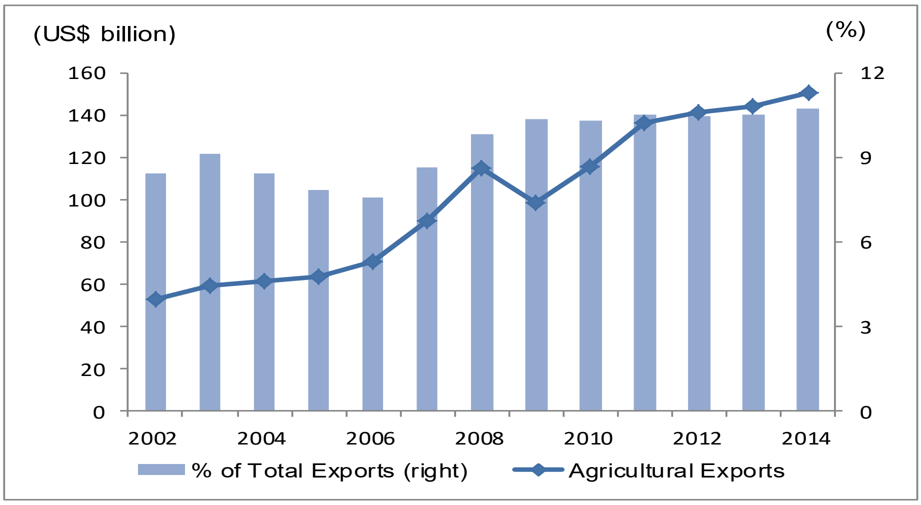
Note: Total of nitrogen, phosphate, and potash fertilizers

U.S. Agricultural Production Costs

For large-scale U.S. farmers, the key to adopting PA lies in whether it can reliably increase yields and improve profitability.　U.S. agricultural exports have been increasing since 2002, with the exception of 2009, accounting for 10% of the country's total exports (Figure 3). In 2012, fertilizers and chemicals (including pesticides and herbicides) each accounted for less than 10% of total farm production costs, but both have increased significantly over the past ten years (Figure 4). A spike in fertilizer costs is particularly noticeable (Figure 5).

Figure 3

U.S. AGRICULTURAL EXPORTS



Source: USDA

Figure 4

U.S. FARM PRODUCTION COSTS (2012)

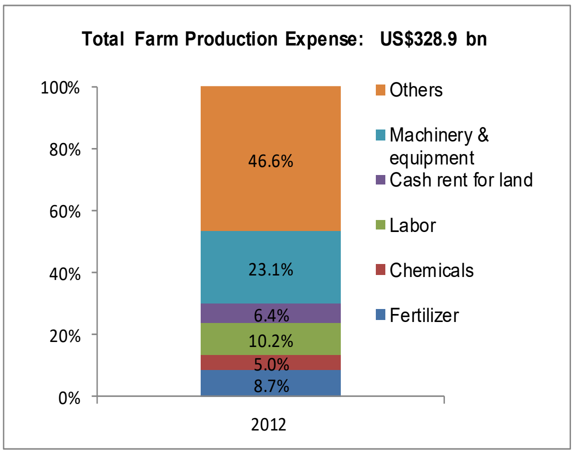
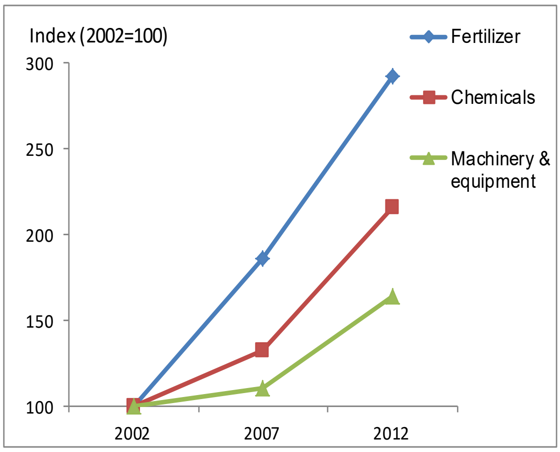


Figure 5

TREND OF FARM COSTS



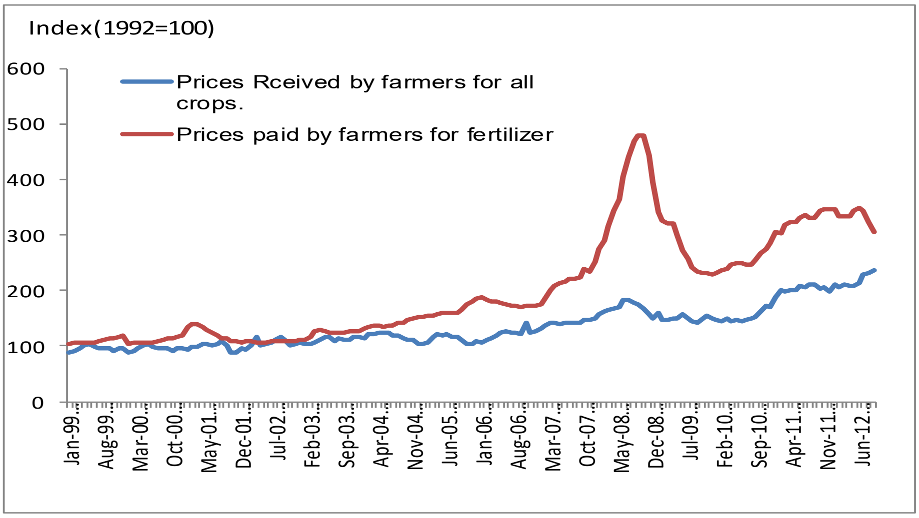
Source: "*The 2012 Census of Agriculture – United States Data*" by USDA, National Agricultural Statistics Service

Note1: Farms include agriculture, livestock, and poultry.

Note2: Machinery and equipment include gasoline, repairs and maintenance, interest and depreciation expenses, and rent and lease expense for machinery.

Figure 6

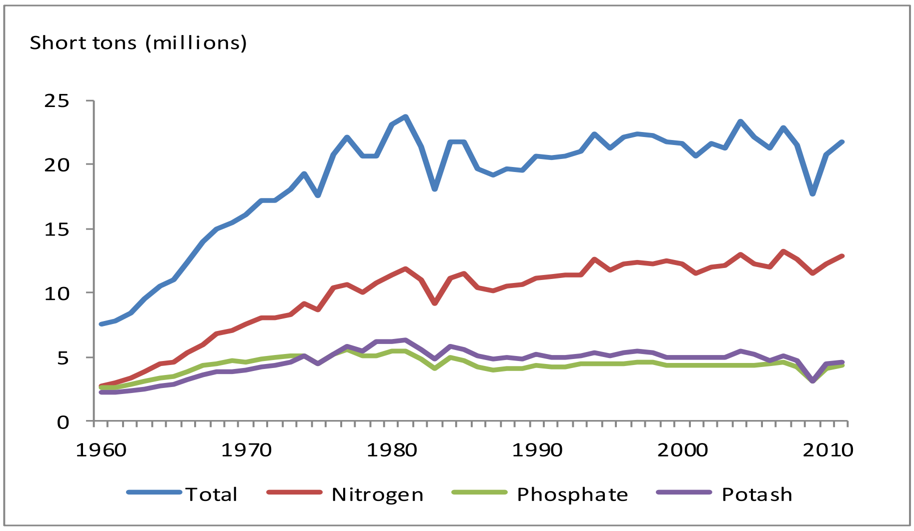
MONTHLY PRICES PAID BY FARMAERS FOR FERTILIZER AND PRICES RECEIVED FOR ALL CROPS



Source: USDA Economic Research Service using data from USDA-NASS, and Bureau of Labor Statistics

Figure 7

FERTILIZER USE IN U.S. AGRICULTURE



Source: USDA, Economic Research Service, using data from Association of American Plant Food Control Officials and The Fertilizer Institute

A rise in fertilizer costs cuts down farmers' profits. Annual fertilizer prices paid by farmers have increased rapidly from 2003, outpacing the increase in crop prices received by farmers (Figure 6)[1]. Fertilizer price increases through 2008 were largely driven by high energy prices—in particular, natural gas, which is one of the main raw materials of fertilizer.

Use of nitrogen fertilizer is extremely high in the U.S. (Figure 7). The main component of nitrogen fertilizers is ammonia, and natural gas is the primary feedstock used to produce it. As WTI crude futures reached a record high of US$145.29 per barrel in July 2008, natural gas prices—which move in tandem with crude oil prices—surged sharply.

According to the U.S. Department of Agriculture, in response to record fertilizer prices in 2008, farmers reduced fertilizer use to 18 million tons, which resulted in a significant decline in fertilizer prices through 2010. As the U.S. become a major shale gas producer in 2009, the raw material cost of fertilizer declined significantly. In 2010, fertilizer prices hit the bottom and moved up once again. Grain prices rose in the commodity market, leading to increased demand for fertilizers as producers sought to boost yields on existing farmland, which in turn pushed prices higher.

Nitrogen fertilizer use has increased faster than phosphate and potash, driven by seed varieties that show stronger yield responses to nitrogen. Corn, which needs intensive fertilizer application, accounts for around 40% of U.S. fertilizer consumption.

Agricultural Reforms in Japan

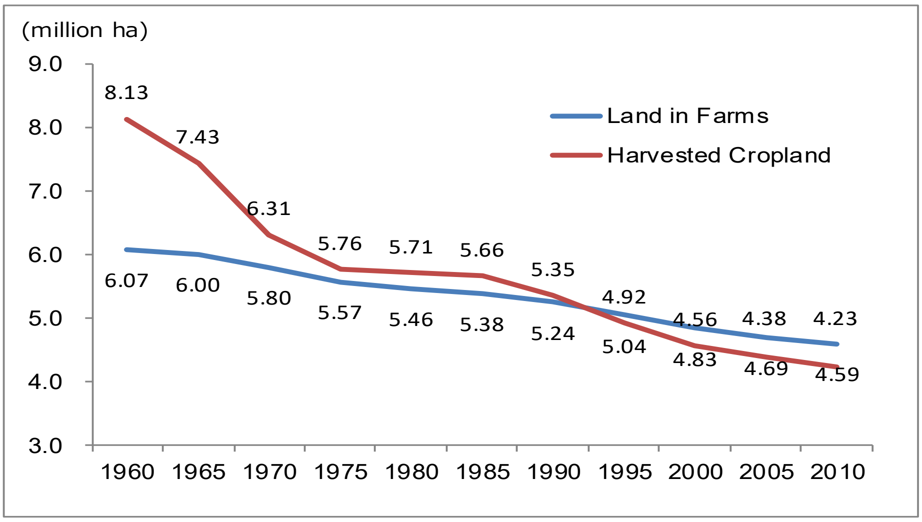
The Japanese government has announced a policy to consolidate small plots into larger-scale farms while encouraging corporate participation to foster new agricultural producers. The aging of Japan's farming population and the shortage of successors are pressing challenges. In addition, areas of arable land continue to shrink over time (Figure 8). If current trends persist, Japan's agriculture will weaken, leading to concerns about reduced production and higher agricultural product prices. The amendments to the Agricultural Land Act, which took effect in 2009, significantly eased restrictions on corporate participation in agriculture. In response to the amendments, 1,071 new corporations entered the agricultural sector between 2009 and 2012. The government

[1] USDA, "Chemical Inputs", http://www.ers.usda.gov/topics/farm-practices-management/chemical-inputs/fertilizer-use-markets.aspx

set a goal of 50,000 corporations to make this move by 2025. However, the number of corporate farms has remained almost unchanged from 2012, totaling only 14,600 companies in 2013 (Figure 9).

Figure 8

LAND IN FARMS AND HARVESTED CROPLAND ACROSS JAPAN



Source: The Ministry of Agriculture, Forestry, and Fisheries (MAFF)

Figure 9

CORPORATE FARMS AND AS A % OF TOTAL FARMLAND

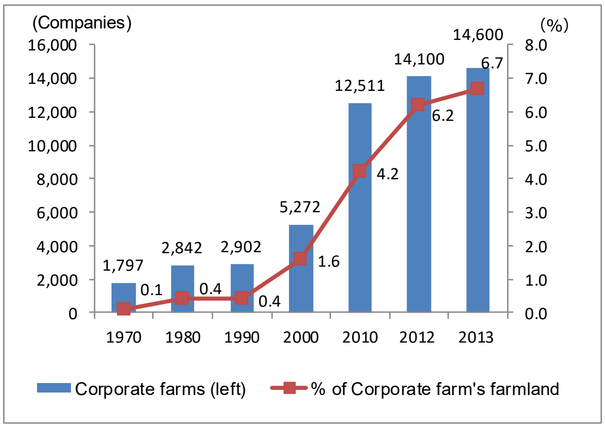
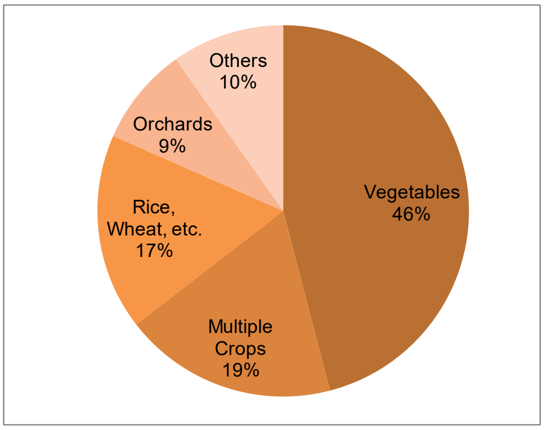


Figure 10

CROPS PRODUCED BY NEW CORPORATE FARMS



Source: MAFF

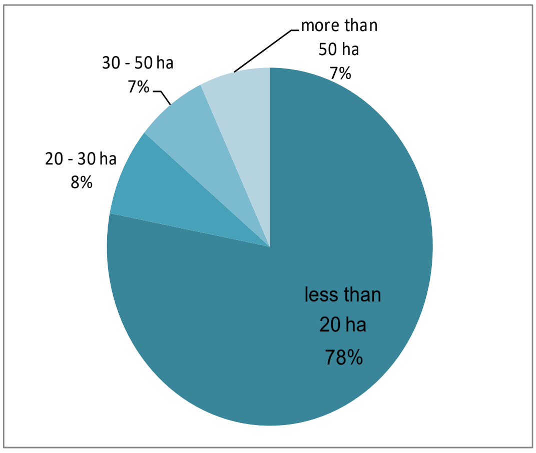
Note1: "Rice, Wheat, etc." includes buckwheat, soybeans, azuki beans, etc.

Note2: "Multiple crops" indicate that more than two kinds of crops are grown.

By industry, newly entered corporations are predominantly in food manufacturing and food wholesale, followed by construction. Food manufacturers and wholesalers enter the agricultural sector to secure a stable supply of agricultural products and distinguish and add value to their products. In the case of construction companies, their aim is to diversify business and protect jobs for employees. The majority of new corporate farms grow vegetables (Figure 10). Corporate farms with less than 20 hectare (ha) of farmland accounted for about 80% of total corporate farms (Figure 11). Nevertheless, for rice and wheat, the percentage of corporations that own more than 20 ha of farmland is increasing, reaching 32% in 2010 (Figure 12). The consolidation of fields into larger farmland has been slow due to the enactment of legislation, budget allocations, and ongoing discussions regarding farmland ownership.

Figure 11

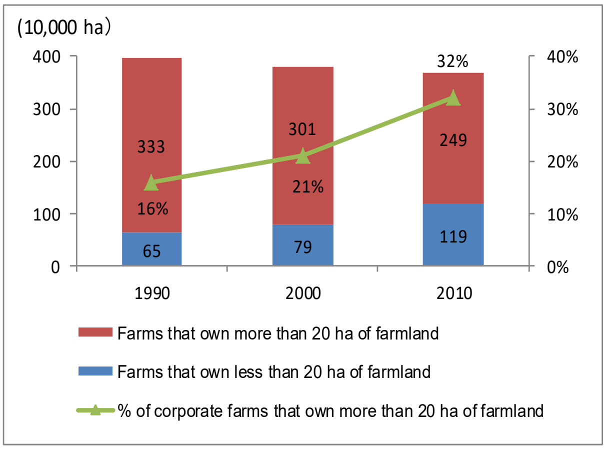
SIZE OF FARMLAND BY CORPORATE FARMS (2010)



Source: MAFF

Figure 12

OVER 20 HA FARMLAND OWNED BY CORPORATE FARM



Note: only rice and wheat

Agricultural Production Costs in Japan

The volatility of resource prices, such as those for gas and minerals, impacts farmers' profitability. For rice production in Japan, fertilizers and chemicals as a percentage of total costs accounted for 7.9% and 5.6%, respectively (Figure 13). The price of fertilizer soared significantly in 2009, reflecting a sharp surge in the price of mineral resources and natural gas, which are the raw materials of fertilizers (Figure 14). Japan heavily relies on resource imports such as gas, chloride of potash, ammonium phosphate, and phosphate rock from overseas. For example, Japan imports phosphate rock and potash primarily from the major natural resource-producing countries shown below (Figures 15 and 16). Japan imports more than 70% of its ammonium phosphate from the U.S.

Figure 13

RICE PRODUCTION EXPENSE PER 10A (2014)

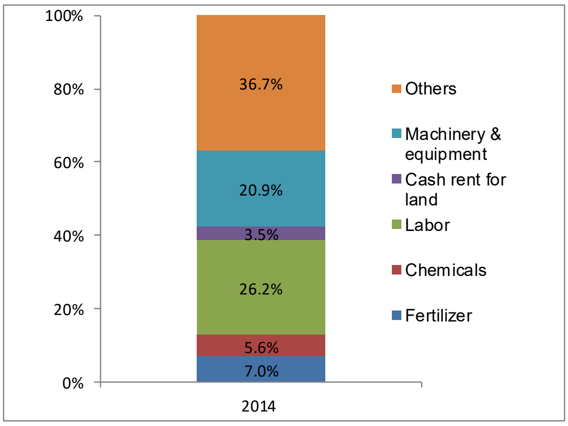
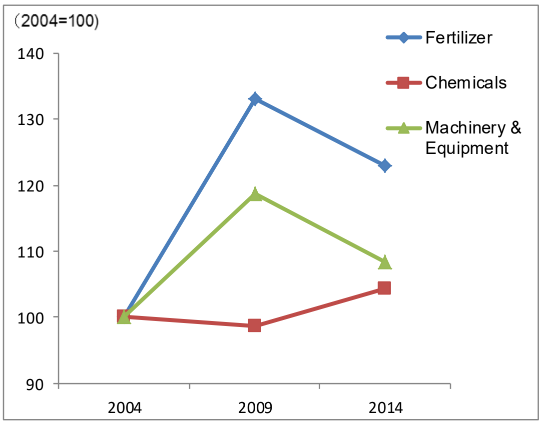


Figure 14

TREND OF FARM EXPENSE



Source: MAFF

Figure 15

PHOSPHATE ROCK OUTPUT (2008)

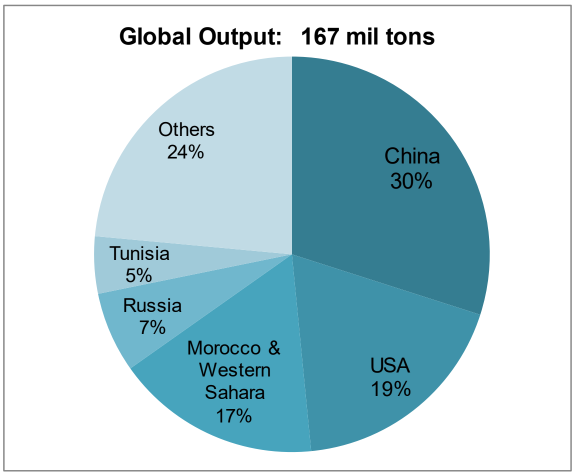
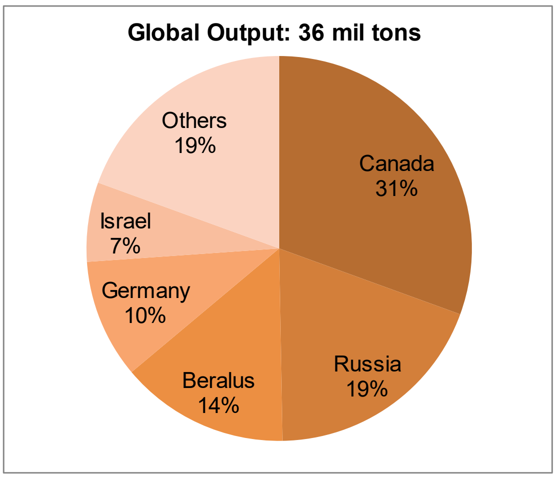


Figure 16

POTASH ORE (CHLORIDE) OUTPUT (2008)

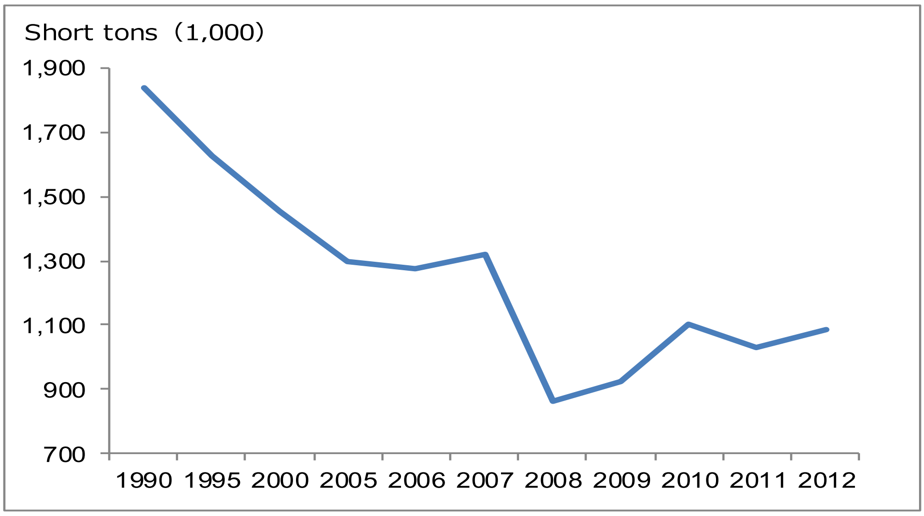


Source: USGS Mineral Commodity Summaries (2008)

The top producers of natural resources for fertilizers are just a few nations, who monopolize the supply and have pricing power (Figures 15 and 16). In fact, commodity prices of phosphate rock and urea have continued to rise since the end of 2007. In particular, China imposed export restrictions on phosphate rocks, which resulted in tight supplies and a record commodity price. After the 2008–09 global financial crisis, commodity prices have stabilized in the global market; however, concerns remain.

Figure 17

FERTILIZER CONSUMPTION IN JAPAN



Source: MAFF

In response to record fertilizer prices, Japanese farmers also reduced the use of phosphate and nitrogen fertilizers between 2008 and 2009 (Figure 17). However, fertilizer consumption has been increasing since 2010 despite a decrease in harvested cropland. This suggests that Japanese farmers are using fertilizers and chemicals more intensively than ever before. (Figures 8, 14, and 17).

Compared to fruits and vegetables, labor costs account for a large proportion of rice production costs, making up 26.2% (compared to 10.2% in the U.S.) (Figures 4 and 13). In the US, capital investment in agricultural machinery has helped contain labor costs, whereas in Japan, farmers' investments in equipment may not necessarily lead to productivity improvements.

CHAPTER 2 Precision Agriculture (PA)

What Is Precision Agriculture?

Precision agriculture (PA) integrates sensing, IT, and machine systems to manage crop growth. GPS-based systems are used for accurate positioning of agricultural machinery, guiding the operator to drive along repeatable tracks with accuracy by adjusting the position of the machinery.

Satellites' on-board hyperspectral sensors can measure soil moisture and chlorophyll in plants to determine the level of plant activity—including the protein contained in plants, which indicates crop maturity—and quantify spatially variable field conditions. Furthermore, micro-climate data on solar radiation, soil temperature, and moisture can be obtained from in-field sensors. Sensors mounted on agricultural machinery collect data on soil variables, crop yield, and moisture content in the field while crops are being harvested. Images taken via crop-scouting drones or a farmer's smartphone and/or tablet are uploaded to servers and stored in a database.

Massive data are analyzed to generate models for each crop. The models alongside weather forecasts can predict the future condition of crops and help producers make proactive decisions to optimize seeding, application of input, irrigation, and harvesting in the right place at the right time. In addition, simulation models can also be used to estimate crop growth, yields, and quality. PA is expected to mitigate crop damage from climate change.

Core Technologies

Precision Agriculture (PA) aims to improve crop yields, product quality, and productivity based on sensing technologies and historical data. The key component technologies of PA are outlined below (Figure 19).

Figure 19

COMPONENT TECHNOLOGIES

Components	Details	Price (US$)
Auto Steer	> If the tractor goes off its path, the auto steering system gives a signal to the operator to adjust the vehicle back to the right track. Hence, the operator can reduce human errors.	10,000–60,000
GPS Guidance System	> GPS systems give the current location of the tractor displayed on a tablet by accurately measuring its position, assisting operators in driving the pre-set traffic paths in the fields. The system improves the efficiency of operations before daylight and during busy seasons. > The system provides auto steering and mapping of the areas where the work is done and manages work records, opting for add-on functions. > Some systems can record sites and dates when fertilizers and chemicals were applied.	2,000–40,000
Yield Monitor	> The yield monitor displays yield mapping in each area of a field. > Sensors installed in agricultural machinery collect georeferenced data on crop yields, soils, and grain moisture, which are different in each section of the farm field, while the crop is being harvested.	4,000–7,000
Variable Rate Technology (VRT)	> Based on in-field and/or remotely sensed data in addition to historic yield and crop quality data, VRT is used to optimize the application rate of inputs at precise times and locations to adjust for in-field yield variability. > VRT is used to fertilize, seed commodity crops, and/or apply pesticides and herbicides.	NA

The core technologies of PA are auto steering, GPS guidance systems, yield monitors, and variable rate technology (VRT). Custom operators in the U.S. have made greater use of GPS guidance systems: 56% used a GPS guidance system with auto steering for at least some of their work in 2009, up from 28% in 2008. Yield monitors are available as standard equipment on some tractors and combines.[2]

Farmers can expect to lower labor costs thanks to the introduction of auto steering and GPS guidance systems. Both systems can be used during planting, tillage, and chemical application. It is difficult to secure experienced operators of agricultural machinery at large farms. However, these two systems enable machines to drive along repeatable tracks with accuracy, decreasing errors made by operators with less experience driving a tractor, reducing fatigue, and permitting more timeliness of operations. Moreover, the two systems help reduce areas of soil compaction and crops crushed by heavy machinery.

Hurdles

Yield improvements are the main driver of PA adoption by farmers. Large-scale producers of high-volume, specific commercial grains benefit the most from PA. However, PA acceptance by the agricultural community has been slow due to substantial initial costs, uncertain economic returns, and the complexity of the technology.

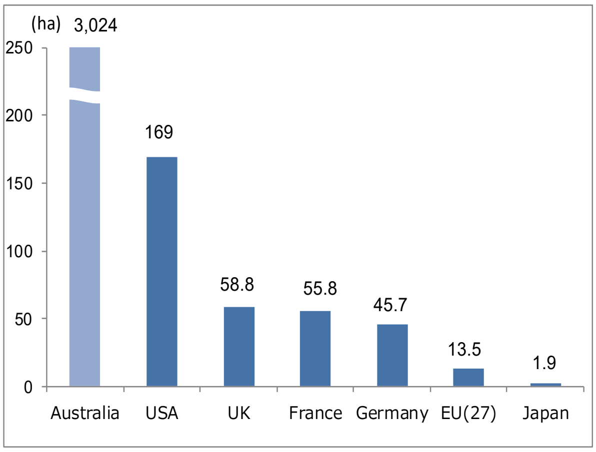
Even large-scale farms face significant challenges in bearing the cost of initial investment. For example, the price range of an auto-steering system varies from less than US$10,000 to more than $60,000. A GPS guidance system is more or less the same, having a wide price range from US$2,000 to $40,000. Accuracy and capabilities are reflected in the systems' prices. A study in Germany found that farms with 100 to 300 ha of arable land were able to recover their investment in auto-steering and GPS guidance systems.

As we see 100 ha (about 246 acres) fields per farm by country, the most promising markets for PA are narrowed to only the U.S. and Australia. Farms with more than 100 ha, for example, account for 30% of total farms in the U.S. as of 2012 (Figure 20). The 2012 Census of Agriculture showed that the average farm size rose to 434 acres (175 ha) in 2012 from 418 acres (169 ha) in 2007. In the U.S., where farmland is increasingly consolidated, there is underlying demand for the adoption of PA, provided that it offers clear economic advantages. If a wider range of price points becomes available, the conditions are in place to accelerate the adoption of such services and products.

[2] USDA, "On the Doorstep of the Information Age", August 2011

Figure 20

AVERAGE FARM SIZE BY COUNTRY

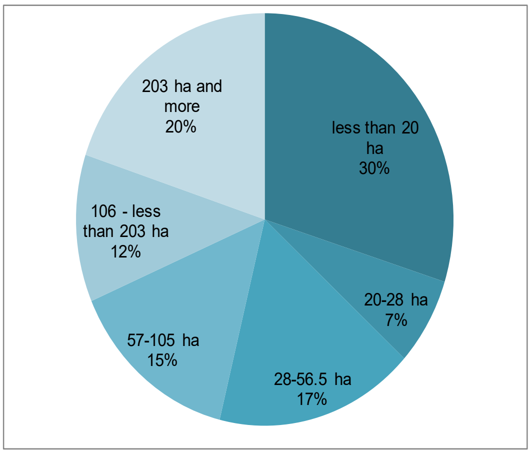


Source: MAFF

Note: Each country's data is based on 2007 except Japan, which is 2009.

Figure 21

DETAILS OF FARM SIZE IN THE US (2012)



Source: "*The 2012 Census of Agriculture*"

Note: Analysis of farm size is based on harvested cropland.

Development of cost-effective sensors for agriculture is critically needed. The current market size for agricultural sensors is so small that commercialized sensors are costly. Technological improvements and the availability of low-cost sensors will help drive the widespread adoption of PA.

Variable Rate Technology (VRT)

Variable rate technology (VRT) is expected to reduce the use and costs of input (labor, fertilizer, chemicals, seeds, water, energy, etc.). For example, based on satellite imagery, crops' growth conditions can be observed and diagnosed with a resolution varying from 50 centimeters to 10 meters per pixel. Crop-scouting drones deliver 2 to 10 centimeters of resolution for observation.

In-field sensors collect micro-climate data on solar radiation, soil temperature, and moisture. Farm machinery-mounted sensors acquire data on soil variables, yields, and moisture content in the field while crops are being harvested. VRT is a technology that enables variable-rate application of fertilizers and pesticides using farm machinery to correct yield and soil variability within a field. VRT is expected not only to reduce the use and cost of synthetic agrochemical inputs, but also to significantly reduce their environmental footprint.

When field sizes are small, farmers have intimate knowledge of every part of their fields and can apply spatially variable treatments tailored to specific locations. As farmland size increases and fields become dispersed across multiple locations, providing optimized treatments and implementing precision farming becomes more challenging. In fact, large producers in the U.S. traditionally apply blanket, averaged treatments for soil, nutrient, moisture, weed, and growth conditions. Necessarily, this has led to over- and under-application of herbicides, pesticides, irrigation, and fertilizers. Excess chemicals from uniform applications run off or leach from fields into groundwater and surface water, negatively impacting ecosystems.

In Europe and the United States, large-scale agricultural producers have conducted pilot trials of VRT, but its cost-effectiveness has yet to be demonstrated. For example, a trial of VRT in Germany reported that, depending on the size of the cultivated area, nitrogen fertilizer use could be reduced by 10–15% while maintaining yields. On the other hand, in Denmark, no cost-effectiveness has been observed for VRT. Similarly, in the United States, VRT has not demonstrated benefits such as yield increases or fertilizer reduction.

One of the greatest challenges lies in developing algorithms that can variably control fertilizer application in a timely, precise, and appropriate manner based on soil conditions and crop growth. Fertilizer application has always been one of the more challenging techniques in agriculture. Moreover, even within a single field, soil properties vary by location, and crops exhibit distinct nutrient uptake characteristics accordingly. There are many types of fertilizers, each with different effectiveness, and their efficacy varies depending on soil conditions and seasons.

The latest VRT technology developed in the US features sensors that automatically adjust nitrogen fertilizer application variably according to conditions at each location within a field, without relying on remote sensing data from satellites or drones. A technology has been commercialized that irradiates crops with lasers, measures their nitrogen content from the reflected light, and controls nitrogen fertilization in real time according to crop growth conditions.

FUTURE OUTLOOK

Precision Agriculture's（PA） initiative is one possible solution to achieving "sustainable agriculture". Several unique factors lie behind the development of PA: the United States is one of the world's leading agricultural powers and a major grain exporter; agriculture is dominated by large-scale producers; and the U.S. Department of Agriculture provides strong institutional support. PA aims to enhance profits by leveraging precision technologies to increase crop yields, enhance productivity through labor- and resource-saving measures, and reduce input costs. The adoption of PA has been increasing, particularly in the Great Plains, and it seems to be showing some promising effects.

There is latent demand for PA among small- and medium-scale agricultural producers as well. To lower the barriers to adoption, one possible approach would be for multiple producers to jointly own the system and share the initial costs. The advantage of joint ownership is that sharing information on how to use PA tools among producers in the group can facilitate earlier benefits from adopting the new technology. Manufacturers and/or universities need to provide training and support to producers on how to use the applications and adopt new technologies.

Efforts to utilize agricultural data can also provide additional benefits by helping agriculture adapt to climate change. Agriculture is highly vulnerable to weather conditions, making climate change a pressing concern for farmers. Extreme weather events such as drought and prolonged rainfall significantly affect crop yields and quality. Adapting to global warming requires changes in agricultural practices, including crop selection, use of equipment, and management approaches. Data collection in agriculture is not the sole responsibility of producers. From a food security perspective, the Ministry of Agriculture, Forestry and Fisheries (MAFF), local governments, agricultural cooperatives, the Japan Meteorological Agency and/or weather data service providers, research institutions such as universities, and manufacturers of fertilizers, pesticides, seeds, and agricultural machinery all play a vital role in cooperating and collaborating on data collection.

There remains significant room for improvement in PA. Specifically, improvements are needed in PA's performance, data-sharing practices, and the quantification of cost-effectiveness. PA tools are continuously being developed and improved, and efforts to pursue greater precision are still ongoing.

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