FROM FARM MACHINERY TO FIELD ROBOTS
The History of Farm Machinery in Japan

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Abstract: *In Japan the development of farm machinery started in earnest in the 1960s. The mechanization of Japanese agriculture improve the labor and land productivity, and also labor load was reduced from heavy labor to light labor. Japanese agriculture faces low food self-sufficiency rate and high production cost. However Japan is mountainous and hilly island. Farming using large machines are not applicable. Farming using the advanced technologies which combines robotization with precision farming is necessary. These technologies made possible to establish large scale farm. In this paper the history of the development of farm machinery and robot, also future problem for practical use are introduced.*

Key Words: *Farm Machinery, Robotization, Postioning, Satellite Navigation*

CHARACTERISTIC OF ASIAN MONSOON REGION AND RICE

The land surface in Asian monsoon region is only 14 % of that of the earth. However 4 billion people live in the region. It is 54% of world population of 7.3 billion. There also are arable land of 1.4 billion ha on the earth, but paddy filed is only 0.1 billion ha. Almost paddy are in Asian monsoon region. Namely rice per arable land can support such many people in comparison with wheat, maize and other crops. Farm machinery for rice cultivation is completely different from the machinery for other crop on upland field. In this paper, upland field means the field except paddy filed.

THE DEVELOPMENT OF FARM MACHINERY IN JAPAN

Farm machinery had been developed in USA in the beginning of 20th century as the countermeasure of labor shortage and the machinery spread to European countries. High economic growth of Japan started in 1960s. Labor force of rural area moved to secondary industry. This induced increasing income and labor shortage in rural area. The mechanization of Japanese Agriculture was stimulated. However there was not farm machinery for rice cultivation at that time. A paddy field enclosed with levees. A section of Japanese paddy field is about 0.3 ha. The small tractors of 15-25 PS were required. Also the transpalnting and harvesting work of Japonica rice using machine had been considered very difficult, but the development of transplanting by using young or plug seedling and that of combine equipped with Japanese traditional head-feeding thresher realized the mechanization of these tasks.

Tilling machine

In Japan the Japanese hoe (Fig. 1) for primary tilling had been used instead of a heavy plow for 300 years until 100 years ago. At the period of animal farming, Japanese plow with short sole (Fig. 2) were originally developed in 1920s and used until 1960s all over Japan. Kerosene and Diesel engine were available and rotary tiller has been developed. If tractor equipped with rotary tiller (Fig. 3) is used, it can simultaneously invert, pulverize and level soil as shown in Fig. 4. The tiller with Japanese original shape blade has been developed and spread as primary tilling machine for rice cultivation. In Europa the rotary tiller with L-shaped blade (Fig. 5) has been mainly used as a cultivator that is secondary tilling after plowing. The function of the rotary tiller is the difference between rice and other upland crops production. The rice is the staple food in Asian monsoon countries for instance Thailand, Indonesia and Vietnam. In these countries a rotary tiller has been used as primary tilling machine, too. However the climate and soil condition of these countries are different from Japanese one. Thus different shaped blade and the alignment of blades shown in Fig. 6 are used.

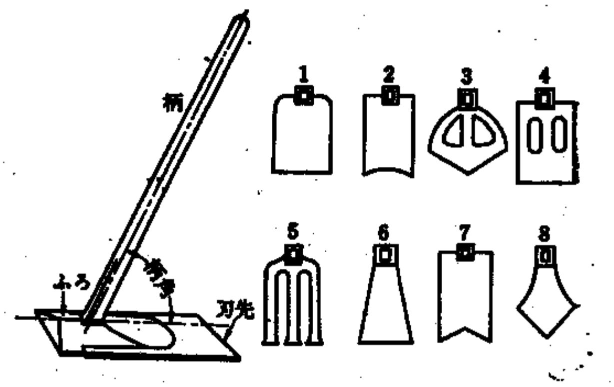


Fig. 1 Japanese Hoe (Primary tilling tool)

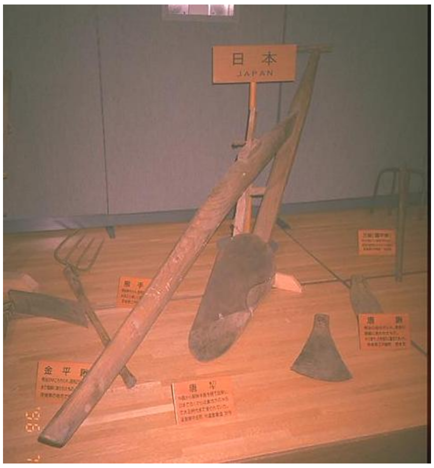


Fig.2 Japanese Plow with short Sole

Fig. 3 Tractor with Rotary Tiller

Fig. 4 Soil Condition after Rotary Tilling

Fig 5 L-Shaped Blade for Upland Crop
(Secondary Tilling)

Fig 6 Blade for Thai rice cultivation

Tractor

Rotational speed of a power take off (PTO) shaft of Western type tractor is only 540 rpm or 1000rpm. However the rotary tiller for rice cultivation requires various rotational speeds. Japanese tractor (Fig. 3) provides 4 range speeds of PTO shaft. Also the rotary tiller pushes a tractor during tilling operation. Thus tractor needs little traction force in comparison with Western type tractor. On the other hand, the tractor should often cross the levees. The front and rear wheel weight balance suites 45 % and 55 %, respectively. Furthermore the tractor needs to puddle the soil on an irrigated field as shown in Fig 7. The tractor is required high water resistant.

Fig 7 Puddling on irrigated paddy field

Fig 8 Rice-Transplanter

Rice Transplanter

There are a plenty of water and heat in Asian monsoon region. This condition gives the advantage for all plants even weed. In other words rice cultivation is the fight against weed. Seedling transplanted gets an advantage over weed. Manual transplanting using root-washed-mature-seedling had been done from 2000 years ago. Farmers want to continue transplanting even though the period of the farm mechanization. To respond farmers' request, rice transplanters using young an plug seedling have been developed as shown in Fig. 8. It has four bar link mechanism or cutting edge non-circular planetary gear mechanism.

Combine

There are two rice types. One is indica type and other is japonica type. Indica type is widely produced in Southeast Asia. In East Asia like Japan, Korea and China, japonica rice is produced. The thresherbility of japonica is difficult. Thus the Japanese original

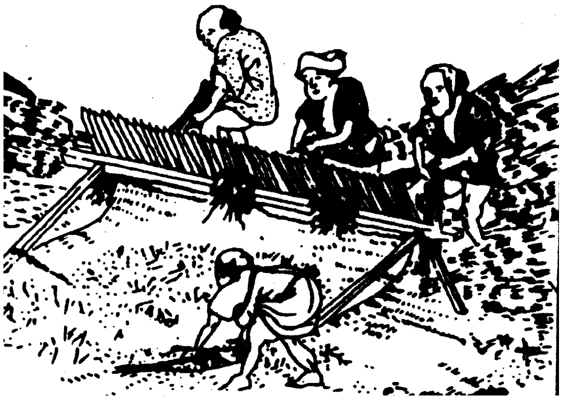
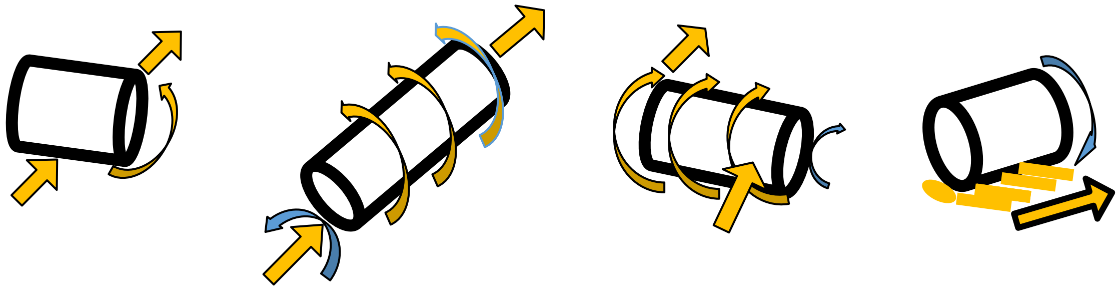


Fig 9 Japanese Old Thresher in 1700s

Fig 10 First Head-Feeding Combine in 1966

thresher called Senba that means thousand teeth was used since 300 years ago as shown in Fig.9. A pedaling and power rotational thresher were used from 100 years ago until 50 years ago. In 1966 the first head feeding combine as shown in Fig 10 was putted on the market. The head-feeding combine has been widely used all over Japan from 1970 to the present.

There are four type threshers (Fig. 11). Tangential follow is the most popular for upland crops. A combine equipped with tangential flow thresher calls a conventional combine. In 1967 an axial flow thresher was developed in USA. On the other hand, a tangential feed



Tangential Flow | Axial Flow | Tangential Feed and Axial Flow | Head-feeding

Fig. 11 Different feeding crops for various thresher

and axial flow thresher shown in Fig 12 has been widely used in Southeast Asia. In 1990s a combine equipped with this type thresher has been developed. Both threshers for indica and japonica rice are originally designed for rice threshing.

Fig. 12 Tangential Feed and Axial Flow Thresher in Indonesia

Labor Loads

The mechanization of Japanese Agriculture contributed to improve labor and land productivities. The average working hours of rice cultivation per 10a decreased from about 170 hours in 1960 before the farm mechanization, to 60 hours in 1980, 33 hours in 2000 and 28 hours in 2006. The working hours of 10-20ha farm decreased 16 hours per 10a in 2006. During these years, the yield of rice increased by about 1.3 times. Manual labor load of rice cultivation also were RMR 7.0 in tilling with Japanese hoe, RMR 3.8 in tilling with a bull, RMR 3.6 in rice-transplanting, RMR 4.5 in rice reaping with a sickle, RMR 5.7 in threshing with pedaling thresher. However the usage of riding farm machines reduced all farming loads like tilling, transplanting and harvesting to RMR 0.6. RMR stands for Relative Metabolic Rate. It means the strength of labor load and calculates following equation.

$$RMR = \frac{\text{Energy consumption at working} - \text{Basic energy consumption}}{\text{Basic energy consumption}}$$

Basic energy consumption is energy consumption at rest (about 2000 kcal/day person).

RMR 1-2, 2-4, 4-7, and more than 7 are defined as Light labor, Middle labor, Heavy labor and Extreme heavy labor, respectively.

Agricultural Robot in 1980s

Farming needs to adapt for the variability of crops, field and climate condition. For this purpose, the application of automatic control for farm machinery has been studied from the last of 1960s. In 1980s microcomputer was available and image processing technique to recognize fruit and so on made possible. By around 1980s the mechanization of crop production was almost established. However fruit harvesting was not mechanized yet, because the harvesting required human recognition and judgment for the position and manure of fruits. The computer technology might realize that the tasks were automated and became unmanned operations. First the development of agricultural robots started from fruit harvesting.

Prof. T. Fujiura and et al at laboratory of Agricultural Machinery of Kyoto University developed the tomato and citrus harvesting robot. Meanwhile orange and apple harvesting robot were developed in USA and France. In Australia also wool cutting robot was developed. However the performance and price of the robot hardly reach on a suitable level for practical use.

Field robotics initiative

In 1990s the positioning of farm machinery on a filed by using GPS made possible. The farm machines on the fields call robot-tractor, -transplanter or -combine had been developed instead of the fruit harvesting robot. The positioning technique made possible yield monitor and variable rate fertilizer application. Namely IT and GPS technologies realized a precision agriculture and a farm robotization.

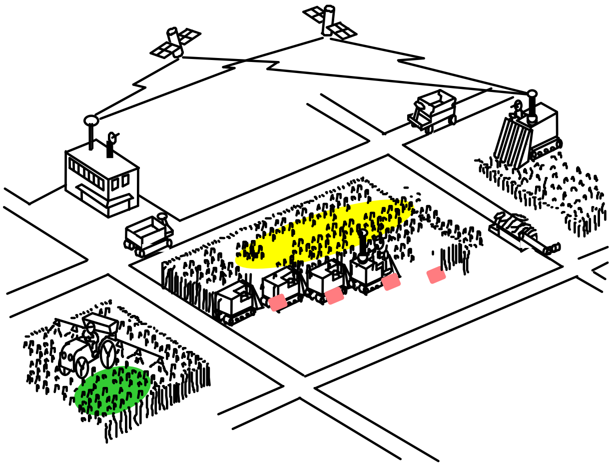


Fig. 13 Field Robotics Initiative in 1997

Fig. 14 Autonomous Transporter by Dr. M. Suguri

Fig. 15 Group Control of Combines by Prof. M. Iida

Fig. 16 Watermelon Harvesting Robot by Prof. M. Umeda

However Japan’s calorie supply and grain self-sufficiency rate are 39% and 29% in 2014, respectively. Then the average labor force participation rate of the developed countries is 2% in primary industry, 25% in secondary one and 73% in tertiary one. Japan’s primary industry rate is 4% in 2014, but considering food self-sufficiency, Japan’s its rate is equivalent to 10%. In such a situation, Japan includes raising food self-sufficiency rate from 39% to 45% in calorie base, which makes it necessary to increase land and labor productivity. However Japan is mountainous and hilly island without much plain. Farming using large machines which are observed in many Western countries are not applicable. Farming using the advanced technologies which combines robotization with precision farming is necessary. These technologies made possible to establish large scale farm. They remarkably improve land and labor productivity, and increase food sufficiency rate of Japan.

Prof. M. Umeda and his staffs at Laboratory of Field Robotics of Kyoto University imaged how to manage 100ha field by husband and wife, which is extra large-scale-farming for Japanese rice cultivation. The Image shown in Fig. 13 was named Field Robotics Initiative. To realize this concept, group control technique of small combines to manage the vehicles group by one operator was developed by Prof. M. Iida (Fig. 14), an autonomous transporter by Dr. M. Suguri (Fig. 15), and a watermelon harvesting robot by Prof. M. Umeda (Fig. 16) in the late of 1990s. The concept of group control and this photo was often introduced in Europe in particular Germany.

Field robots for Japanese agriculture between 1990s and 2000s

Various robots for Japanese agriculture have been developed through 1990s and 2000s by National Institutes and universities in Japan. An autonomous tractor equipped with GDS (Geomagnetic Direction Sensor) was developed by Dr. O. Yukumoto and Dr. Y. Matsuo of BRAIN (Bio-oriented Technology Research Advancement) since 1993. A tractor equipped with GPS also was developed by Prof. N. Noguchi of Hokkaido University. An autonomous rice-transplanter equipped with RTK-GPS was developed by Dr. Y. Nagasaka of NARO (National Agriculture Research Organization). It used long mat type seedlings without any new seedling mat supply. An autonomous head feeding rice combine equipped with RTK-GPS was developed by Prof. M. Iida of Kyoto University. Also, an automatic straight running tractor equipped with an angular velocity sensor was developed by late Dr. Y. Nishiike of Kyoto University. In addition fruit harvesting robots were developed by Prof. T. Fujiura of Osaka Prefecture University and Prof. M. Monta and N. Kondo of Okayama University.

In addition to GPS, GLONOS from Russia and GALILEO from EU are available. At the present Satellite Navigation System calls GNSS (Global Navigation Satellite System).

The latest field robots

The performance of vehicle robots is greatly dependent on the navigation system that detects the vehicle position and its heading in the field. In 2010s the rapid progress of positioning techniques by GNSS, automatic control device, IT (Information Technology) have been drastically improved the performance of robot-tractor, -rice-transplanter and -head feeding combine. During these years, researchers’ achievement contributes these progress. Moreover JAXA (Japanese Aerospace Exploration Agency) launched QZS (Quasi Zenith Satellite) in 2010. QZS is anticipated to improve the accuracy of positioning within Japan. Meanwhile agricultural machinery companies that suspended to develop farm robot, restarted autonomous tractor and have developed the Information System for farming and the maintenance of machines.

In 2014 the Cabinet Office of the Japanese Government set up Cross-Ministerial Strategic Innovation Promotion (SIP) Program with the amount of research fund of JPY 51.8 billion. The program requests practical application and implementation to combine the new researches with the results of the past vast researches. “Advanced Project improving

Agricultural Production System utilizing IT and Robots technology" has been selected as one of SIP Program. The amount of research fund is JPY 2.72billion for 5 years. All famous researchers and companies' engineers join the project in other words the research team is all Japan. SIP program stimulates to realize robotization which made possible the management of large-scale-farm and to improve the land and labor productivity, and increase food self-sufficiency rate of Japan.

CONCLUSION

The robotization will come on the basis of the robot technology and farm mechanization technology. The recent rapid progress of positioning techniques by GNSS and IT is participated to reach the practical use level. Japan succeeded in the agricultural mechanization, but Japanese agriculture faces some problems, including low food self-sufficiency rate and high production cost. The robotization is one of solution. The shift from mechanization to robotization is inevitable. We will see robots of diverse design and having many function s in rural areas across Japan in near future.

All of the robots described above will reach, from technical viewpoint, practical use in near future. To ensure safety for the operation on the field and the transportation on the road, laws and regulations should be prepared just in time. Also the price of robot system is important for practical use. In addition to the robot of rice cultivation, the development of robot for horticulture like strawberry and others harvesting must be required.

Moreover the Southeast Asian countries face the period of taking-off the agricultural mechanization. Japanese Engineers also should challenge the development of orthodox farm machinery for Southeast Asian countries.

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