STRATEGIES OF PRECISION AGRICULTURE: COMPARISON OF COUNTRIES WITH/WITHOUT LAND RESOURCE

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Abstract

This paper compares the present situation of precision agriculture (PA) practices in US and Japanese rice production and presents desirable strategies for implementation. First, the accessibility of PA technology in the farm equipment market by farmers is investigated through interview surveys among Global Positioning System (GPS) dealers and salespersons of leading companies. Second, the actual uses of PA equipment are assessed by interview surveys among rice farmers in California and Japan. Third, the break-even cost reduction rate (BECR) of PA investment on farms is calculated to find out how much a farmer should reduce cost (or improve profit) to cover the overhead of PA equipment. The technology seems to be disseminating among relatively large farmers there in spite of the limited accessibility of PA and the small scattered rice fields in Japan. The BECR of the farms in both countries is quite similar—around 1%. It probably reflects the risk and benefit of introducing PA to each farm. Since Japanese rice farmers obtain higher prices for the rice they produce not only because of the tariff barrier but also the quality standard, they can achieve a low BECR despite the smaller farm size.

Keywords: Precision agriculture, Rice production, Global Positioning System (GPS), Break-even point

Subtheme: Farm management (or Innovation and leadership)

1. Introduction

Precision agriculture (PA) is defined as "a management strategy that uses information technology to bring data from multiple sources to bear on decisions associated with crop production" (Committee on Assessing Crop Yield: Site-Specific Farming, Information Systems, and Research Opportunities, National Research Council, 1997), which consists of field mapping, decision support systems, and variable rate applicators. Generally, PA is considered a series of technologies combining the Global Positioning System (GPS), Geographical Information Systems (GIS), electric sensors, and other spatial information technologies. The ultimate fully equipped PA has not been widely observed. However, spatial information technologies such as GPS and GIS have been gradually adopted by farmers and will change farm management procedures eventually.

Bullock et al.(2002) and Daberkow et al. (2006) showed the adoption rate of the PA technology in the US. For example, yield monitors were adopted by 36.5% of corn farmers and 28.7% of soybean farmers in the early 2000s. Variable rate applicators (VRA) were adopted by 5% to 10% of these farmers in the same period. Questionnaire surveys by Banerjee et al. (2008) revealed that 19% of cotton farms introduced GPS guidance. The recent dissemination of PA in the US has been stimulated by the development of the Navigation Satellite System (NSS), commonly called GPS. The accuracy of GPS for civilian uses was improved in 2000, and the Satellite-Based Augmentation System (SBAS), (e.g., WAAS) was introduced after 2003. Real-Time Kinematic (RTK) GPS enables users to recognize a location with an accuracy of 2 to 3 cm.

Previous research studies (Banerjee et al., 2008; Daberkow and McBride, 2003) revealed that younger farm managers who were familiar with personal computers tend to implement PA equipment. The farm size, crop yield, and reliance on agricultural income also had a positive impact on the adoption rate. Countries, such as Japan, with scarce land resource and young farm managers may lag behind in the use of PA or may find original strategies to make use of the technology. In 2009, leading GPS companies such as TR and TC introduced GPS guidance equipment in the Japanese language. However, few studies have investigated the potential of PA technologies in countries with scarce land resources on the basis of the accessibility of PA by farmers, actual usage by farmers, and comparisons with countries with large-scale farming operations. Hence, this paper compares the present situation of PA practices between US and Japanese rice production and presents desirable strategies for the implementation of state-of-art technologies.

2. Methodology

First, the accessibilities of PA technologies by farmers in the farm equipment market were investigated through interview surveys among GPS dealers and salespersons in the leading companies. The surveys were conducted in March, April, and August 2010 among the persons in charge of sales for TR and TC companies in both California and Japan. The prices and functions of PA equipment were figured out through the survey.

Second, the actual uses of PA equipment were assessed by interview surveys among rice farmers in California and Japan, conducted in March and August 2010. Farm practices and post-harvest handling were compared to understand the differences.

Third, the break-even point of PA investment for a farm was calculated to find out how much a farmer should reduce cost (or improve profit) to cover the overhead of PA equipments. The break-even cost reduction rate (BECR) is defined as

$$BECR = V/TTC,$$

where V is the annual overhead of PA equipment and TTC is the annual summation of the targeted total cost, which should be reduced by increasing investment.

3. Result

3.1 PA technologies available in the US and Japan

Table 1 compares the PA markets in the US and Japan. US cropland area is 174 million ha which is forty times as large as Japan. The average planted area of a rice farm in the US is 165 ha, whereas it is only 0.99 ha in Japan (2005). Among 2.92 million ha of cropland (excluding orchard and grassland) in Japan, farms holding 20 ha and more account for 469, 000 ha (16.0%) and those of 100 ha and more make up 39, 000 ha (1.3%) of cultivated farmland. Japanese agriculture is so highly capital intensive that tractors number 1.91 million, one-fourth of those in the US. According to a private company source, the agricultural GPS market is expanding in both countries. The US market is 300 times as large as that of Japan.

In contrast to the US PA market, the available equipments in Japan are limited to GPS guidance system and auto-steering devices. In the US, most GPS equipments are accessible through agricultural machinery companies such as tractor and harvester dealers. Most Japanese agricultural machinery companies have just started dealing with GPS—in 2009 or 2010. Applicators have just been started to be supported since 2010.

Table 2 is a summary of the functions and price level of GPS equipment available to farmers. Each model includes a display monitor of corresponding screen size. The following functions are available.

i) Wheel control

GPS guidance system is a basic function that costs \$1,500 to \$3,000, including a monitor. The guidance system displays the locus and range of application or tillage on the screen. It helps operators to avoid overlap or skip of operation. Auto steering allows operators to drive tractors without handling steering wheels, and costs about \$4,000 to \$4,500 without monitors. About half of the newly sold tractors over 160 hp are equipped with auto-steering devices, and there are about 600 to 700 auto-steering tractors in California's rice farms, according to the dealer interviewed.

ii) Variable rate applicator

Variable rate applicators control quantities and ranges of application of fertilizer and chemicals in accordance with the GPS locus. Section control can deal with the range of application, and rate control can change both the range and quantity. Prices differ depending on the number of inputs the system can handle at a time. A nitrogen sensor enables recognition of crop development and required fertilizer quantity.

iii) Yield monitor

Some models implement yield monitors displaying crop yield on the screen with the use of information sent from yield sensors of harvesters. Yield sensors are quite popular in the US and are set up with most harvesters shipped from factories, while few models are available in Japan.

iv) Real-Time Kinematic (RTK)

Real-Time Kinematic (RTK) improves the GPS accuracy up to about 2 to 3 cm. Static RTK costs about \$25,000, including a base station (\$12,000–13,000), rover station (in the GPS component), and upgrading software. VRS-RTK with mobile phones does not require base stations. VRS-RTK is not popular in California, and static RTK implemented by individual farmers and dealers covers almost all rice fields there, although farmers need to have a GPS system to receive the signal. An RTK network has already been built in Japan, and VRS-RTK is available through private providers for about 300 100 JPY per month. The radio-wave of the base station for static RTK can reach out to a radius of about 20 km if accuracy is not required. However, the Japanese Radio Act restricts its range within 1 km.

Table 1 Summary of the PA Equipment Market

		USA	Japan
Market overview	Farmland area (1,000ha)	174,448(2005) (rice: US 1,099, CA 216(2007))	4,306(2007) (rice: 1,673(2007))
	Number of tractor and horse power	4.76 mil. (increasing) Ave. 54.1hp	1.91 mil. (decreasing) Ave.27.0hp
	Market size of GPS for agriculture[1)]	20～30 billion yen (increasing)	0.08 billion yen (increasing)
Availabilities of PA equipments	Available functions	Guidance, auto steering variable rate applicator, yield monitor	Guidance, auto steering
	Alliance with machinery companies	JD deals with own brand. AC, CI, and HD sell as OEM. GPS equipments are sold with tractors.	YN, IS, MB and NH have started dealing with GPS equipments in 2009 and 2010. Applicators are supported from 2010.

Source) Market size of GPS for agriculture is based on Investors Relations Report of TC (2009).

Table 2 Functions and Price Level of GPS Equipment

Model	TR			TC		
Functions	A	B	C	A	B	C
Display size(inch)	4.3	7.0	12.1	5.0		8.4
Wheal control						
Guidance	V	V		V	—	V
Auto steering	△[2)]	△[2)]		—	V	△
Price (US$)		+4,000				+4,500
Variable Rate Applicator						
Section Control	—	△[3)]		△[3)]	△	V
Rate Control	—	△[3)]		—	—	△
Price (US$)		+2,000～10,000				+2,000～
Nitrogen Sensor	—	—	△	—	—	△
Yield monitor	—	—	V[4)]	—	—	—
2cm Accuracy (Static RTK)[5)] Price (US$)	—	△ +18,000		—	△ +17,000	
Total price (US$)	1,500～	3,000～	6,000～	about3,000	8,000～	5,000～
Availability in Japan Price(100JPY)	V 3,600	V 6,900	—	V 4,000	—	—

Source) Interview survey and brochures in March-April 2010.

1) V : Standard equipment, △ : Compatible equipment. WAAS 30cm accuracy is standard equipment for every model.

2) Hydrogenatic Auto Steering is available for B and C models.

3) Not available in Japan at that point.

4) Available for JD harvesters.

5) Static RTK requires Base and Rover station.

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3.2 PA adoption in Japanese rice farms

In March and April 2010, we conducted interview surveys in Japan among five rice farms recently equipped with GPS guidance (Table 3). These farms are consideratelY large in size compared to the average rice farm there. Most rice farms adopt transplanting of seedlings since they prefer to improve the yield of the Koshihikari variety in the limited-size farmland rather than improve labour efficiency by direct drill seeding or aerial planting. Few operations are carried out by aerial application except for spraying on rice. GPS guidance is used for soil paddling in which operators on rice fields can easily lose track of where they are and what they have done because of the muddy water. Farm managers do not use the equipment for transplanting and harvesting since these operations need higher accuracy, and operators can recognize the progress in the field. GPS guidance is used about one to four times in an annual sequence for rice cropping and one to three times for wheat, barley, and soybean. For example, Farm IC, YJ, and YM use seven to nine times (80 ha–100 ha), ten times (210 ha), and once (40 ha) in a year, respectively. This is equal to two to ten US dollars of annual depreciation cost of GPS guidance per ha. Although Farm YJ tries to integrate the existing GIS systems it has been using for several years with GPS guidance, there have still been problems of incompatibilities. Most software problems are not likely to be dealt with easily since the software was written in the US and intended for large-scale operation on farms of large size.

Table 3 Application of PA Equipment in Each Farm and Practice

Farm (location)	Crop		Application of PA equipment								
			Tilling	Base Fertilizer	Seeding	Soil Paddling	Trans-planting	Top-dressing	Weeding	Spraying	Harvest
MM (hk)	Rice	2.5ha	—	—	N/A	GD	—	—	N/A	N/A(air)	—
	Wh	12ha	—	—	—	N/A	N/A	N/A	N/A	GD	—
IC (mj)	Rice	10ha	GD	GD	N/A	GD	—	—	N/A	N/A(air)	—
	Wh/Bl	13ha	GD	GD	—	N/A	N/A	N/A	N/A	△GD	—
	Sybn	13ha	GD	GD	—	N/A	N/A	N/A	—	△GD	—
YJ (mj)	Rice	11ha	GD	GD	N/A	GD× 2	—	—	N/A	—	—
	Wh/Bl	30ha	GD	GD	—	N/A	N/A	N/A	N/A	GD	—
	Sybn	25ha	GD	GD	—	N/A	N/A	N/A	—	GD	—
	Soba	20ha				N/A	N/A	N/A	N/A		—
YM (mj)	Rice	40ha	—	—	N/A	GD	-	-	N/A	N/A(air)	—

Source: Interview survey by authors (March-April 2010)
Legend: -Crop: Wh: Wheat, Bl: barley, Sybn: Soybean
-Location-: hk: Hokkaido, mj: Mainland Japan
-Application of PA equipment- GD: Guidance

3.3 PA adoption in California rice farms

Table 4 shows an overview of farming operations in the rice farms of California, surveyed by the authors in August 2010. These farms are relatively large in size compared to the state average of 165 ha (2007). Operations are carried out about five to eight times, and tractors with GPS can be utilized for land preparation before aerial seeding. According to a cost study published by University of California, Davis, Cooperative Extension (2007), operation procedure before seeding needs generally about seven times of paths containing two times of chiseling, two times of discing, and each time of levelling by a triplane, applying aqua ammonia and applying starter fertilizer. A few ground operations are scheduled after seeding until harvesting by combine harvesters. Farmers owning RTK levelling equipment tend to merge small plots and consolidate them into large square fields of 8 to 12 ha. Harvesting moisture can be recognized during the operation by yield monitors. Farm RS communicates real-time information between two harvesters and mixes the green paddy in order to achieve adequate moisture level. Too low harvesting moisture causes cracks and broken rice kernels. However, the practical harvesting moisture is fairly low in spite of the dry weather. This is partly because the USDA grain standard (USDA, 2005) regards kernels with one-fourth removed or with cracks as whole kernels.

Table 5 summarizes the situation of PA equipment implementation in the surveyed farms. The phases of diffusion can be observed from the year of adoption of PA equipment. Yield monitors and GPS guidance were introduced in some farms about five to ten years ago. Then, auto steering was gradually disseminated, and RTK has been adopted recently, mainly for levelling operations. The initial investment cost for PA in each surveyed farm is estimated at 32,000 to 63,000 US dollars.

3.4 Break-even rate of cost reduction to cover PA investments

Figure 1 indicates the calculation result of BECR: the percentage of cost reduction in order to cover the investment cost of PA on rice farms in Japan and California. TTC here includes variable inputs (seed, fertilizer, chemicals, fuel, lube, and electricity, and interest on operating capital) and labour (unpaid and hired) since these two items are the most common targets to reduce costs by PA implementation. Calculation is based on 5 years of depreciable life, and 4 % of interest on fixed capital. The BECR of an average-size rice farm in Japan (0.99 ha) and California (165 ha) are 166% and 1.3% for RTK and 22% and 0.2% for guidance, respectively. This difference is considered to be the main reason for the dissemination gap between the two countries.

Table 6 shows the BECR of surveyed farms. Interestingly, BECR results for the PA equipment adopted are almost similar, ranging around 1%. This range is likely to suggest the subjective optimum level of investment, considering the risk of the new technology. Although we did not experimentally measure actual cost reduction, we can assume farm managers weigh the benefit of adopting PA against the investment and probably achieve the BECR. This assumption is rational when farmers have equipped and updated the technology for more than years. The relatively low BECR of the surveyed Japanese rice farms, despite their farm size, is due to the high cost structure because of the high price of agricultural commodities. Although the high cost structure due to high tariff rate on rice is still controversial, surveyed farmers able to make use of the new technology and produce high-quality and high-value crops in the current situation.

Table 4 Overview of the Rice Farming Operation in Interviewed Farms (California)

Farm	Rice planted area	Farm labour	Each plot size	Operation					Distribution
				Levelling	Operation before seeding	Operation after seeding	Harvesting paddy moisture	Drying	
PF	1,420ha 8 brands (Drill seed 80ha)	198 workers (incl. processing and sales)	7～8ha	Possessed	5 times	(partly sprayed by air)	19-23%	Possessed	Owing mills and accepting rice paddy (Organic)
RS	1,050ha 2 brands	Family 6 Hired 8-10	4～8ha	Possessed Every 3-7years	7times	Spraying by ground (top-dressing by air)	20-24%	Cooperating	Cooperating with other farms
GT	280ha 1 brand	Manager 1 Full time hired 1	8ha	rarely by custom	7～8times	(custom spraying by ground, top-dressing by air)	20-22%	Professional dryer	FRC
CM	200ha 1 brand	Manager 1 Full time hired 1		Possessed Every year	5times	(spraying and top-dressing by air)	20-22%	Professional dryer	FRC
Note	CA average 165ha[1)]		About 8ha	Every 7years[2)]	7 times[2)]	Air application[2)]	22%[2)]	Professional dryer[2)]	FRC has largest share.

Source) Interview surveys by authors from August 2nd to 5th, 2010.

1) USDA Census of Agriculture (2007).

2) University of California, Davis, Cooperative Extension (2007).

Table 5 Implementation of PA Equipments in Interviewed Farms (California)

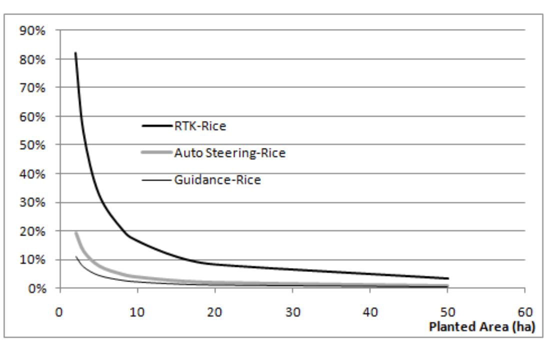
Farm	Ag. Machinery	PA equipment and initial cost	Operation	Year of adoption		
				1995-2000	2001-05	2006-10
PF	— 1)	AS ×2	Levelling			RTK(10)
		RTK, LV	Land preparation		AS(05)	RTK(10)
		$46,000	Plant management		AS(05)	RTK(10)
			Harvest			
RS	Tractor4～8 harvester×2(21feet)	AS ×3 RC	Levelling			RTK(10)
		RTK, LV YM	Land preparation		GD(02)AS(04)	RC(08)RTK(10)
		$63,000	Plant management		GD(02)AS(04)	RTK(10)
			Harvest		YM(02)	
GT	Tractor ×4 Harvester×2 (6m)	AS ×2	Levelling	(by custom operator)		
		RTK	Land preparation		GD(04)AS( )	RTK(10)
		YM **$39,000**	Plant management		GD(04)AS( )	RTK(10)
			Harvest	YM(00)		
CM	Tractor 1) Harvester ×2 (25feet)	RTK, LV	Levelling			RTK(10)
		YM	Land preparation			
		$32,000	Plant management			
			Harvest	YM(97)		

Source) Interview surveys by authors from August 2nd to 5th, 2010.

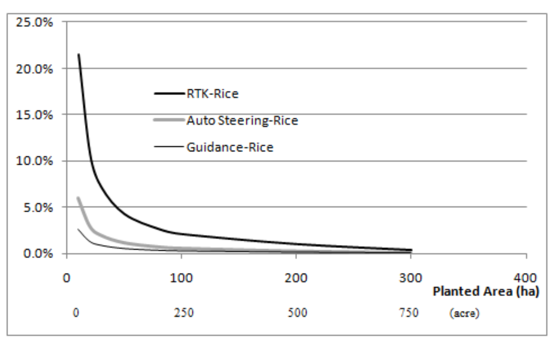
Legend) GD: Guidance, AS: Auto steering, LV: GPS levelling software, YM: Yield monitor, RC: Variable rate applicator.

PA initial costs are estimated as RTK $25,000, LV $7,000, AS $7,000 and RC 10,000. The cost of YM was not available.

Note 1) Information was not collected for these numbers.



Japan



California

Table 6 Break-even Cost Reduction Rate of Interviewed Farms

		BECR (How much cost should be reduced)			
Japan（2008）	Variable input and labour cost (10,000yen)	Adopted equipment	Guidance:40 (10,000yen)	Auto Steering:70 (10,000yen)	RTK：300 (10,000yen)
IC（rice, soybean, wheat and barley）	1,081	0.8%	0.8%	1.4%	6.1%
YJ（*ditto*）	1,871	0.5%	0.5%	0.8%	3.5%
YM（rice）	1,622	0.5%	0.5%	0.9%	4.1%
USA（2008）	（100$）—	Adopted equipment	—:30 （100$）	—:70 （100$）	—：250 (100$)
PF	36,323	0.3%	0.02%	0.04%	0.2%
RS	26,983	0.5%	0.02%	0.06%	0.2%
GT	7,265	1.2%	0.1%	0.2%	0.8%
CM	5,189 4)	1.4% 4)	0.1%	0.3%	1.1%
cf. (IL, corn and soybean）	6,173	-	0.1%	0.2%	0.9%

1） Estimation based on planted crop of each farm.

2） Source of cost figures are MAFF, Statistical Survey on Farm Management and Economy,2008, (Statistics on Production Cost of Soybean, Individual Management; Statistics on Production Cost of Wheat and Barley, Individual Management; and Individual Management; Statistics on Production Cost of Rice), and ERS/USDA, Commodity Costs and Returns.

3) Variable input includes seed and seedling, fertilizer, chemicals, fuel, lube and electricity and interest on operating capital. Calculation is based on 5 years of depreciable life, and 4 % of interest on fixed capital.

4) Figures of Farm CM does not include their custom levelling work which should increase input cost and decrease BE rate.

4. Conclusion

This paper has compared the present PA adoption situation in US and Japanese rice production (Table 7). Since the fairly accurate GPS signal became available for civilian use in 2000, PA has been applied to farming operations in the US—in the form of yield monitors and guidance systems, for example. Early adopters have begun to employ RTK recently. In Japan, the software was translated into the own language in 2009 and introduced to the market. It seems to be disseminating among relatively large farmers there in spite of its limited accessibility and the small scattered rice fields. BECR results, at around 1%, are quite similar between farms in both countries. This probably reflects the risk and benefit of introducing PA to each farm. Since Japanese rice farmers obtain higher prices for the rice they produce not only because of the tariff barrier but also the quality standard, they can achieve a low BECR despite the smaller farm size. Many large rice farms, for example, own drying facilities and take care of paddy moisture rather than paying for professional dryers' services. Grain grade is quite high in spite of the strict standard on whole kernel. If either of the farm size, the rice price, or most importantly PA cost is adjusted at least to a level where the BECR would be around 1%, RTK and the integrated PA technology will be disseminated rapidly.

Table 7 Summary of the comparison

		USA	Japan
PA equipment	PA dissemination	After 2000, when GPS accuracy for civilian use was improved.	After 2009, when translated version of PA equipments were introduced.
	PA availability	Widely available through machinery dealers	Limited availability
	RTK	Market penetrating	Not adopted
	BECR	About 1%	About 1%
Farming	Seasonal operation frequency	About 7 times for land preparation. Direct seeding by airplane.	About 6 times. Trans planting requires high accuracy.
	Plot size	4-8ha, in several fields	0.3-1.0ha, scattered around
Postharvest handling and marketing	Dryer	Professional dryers	Dried by farmers
	Grading	About 90% of rice is 1st grade Whole kernel includes kernels with one forth removed or with cracks	85.2% of rice is 1st grade

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