Actual State and Practical Use of the Factory-style Plant Production System in Japan

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1. INTRODUCTION

The importance of plant factory which blend agriculture and manufacture has been discussed widely. This company has researched hydroponics technique for cultivation which has been mainly developed in the sites of Okinawa and Hyougo Prefecture. In 1987, we stopped the previous research there, and started a new one for plant factory at the Agricultural Research Center of Chiba Prefecture. In 1989, we built four experimental plant factories ($120m^2$) at Chiba Oil Factory Refinery in Ichihara-city, developing techniques of cultivation, equipment production and environmental control for cultivation system of tomato, strawberry and leaf vegetables. We considered that it was difficult to popularize the plant factory for leaf vegetables, although it was still possible to become an economic system based on labor saving and efficiency on large scale. Therefore, in October 1992, in order to prove these results in a lager scale, we built another plant factory ($1500m^2$) using sunlight and artificial light in Sanbu-cho, Sanbu-gun, Chiba. Test were started in the following year and, in March 1995, we finished the basic design for improvement of this system under commercial base.

2. SYSTEM OBJECTIVES

a. To make good environment for agriculture and farming, improving conditions for family work.
b. To rise earnings to 10,000,000yen, decrease working hours to 2,000hour/year/person, employ about 5 labors and clean working environment.

3. CHARACTERISTICS OF PLANT FACTORY SYSTEM IN THIS COMPANY

In Japan, diffusion of the present plant factory system is slow, because the high cost of production in vegetables, and the wholesale prices being about 2 times than the ordinary cultivation. A system with an increased consuming price of daily vegetables and a higher production cost than the imported ones are against a profit for consumption of vegetables and

for the purchase of such plant factory system. In a plant factory system which is $1000m^2$, we made set-points of cost for equipment, cost for fluctuations and production output based on average wholesale price for vegetables in all 68 Japanese markets. After we calculated the cost using these set-points, the plant factory system was built and tested. Therefore, we could obtain an economic prospect of the plant factory.

We have a perspective to apply a moving cultivation bed using a sprayer, making a total production system using robots. It was indispensable to increase production by reducing the span of production, increasing planting density for effective practical use of planting area, increasing plant weight, decreasing yield and cost of cooling system, as well as personnel expenses, in order to decrease the production cost. The characteristics, equipment and business at the plant factory tested in Sanbu is commented below.

3-1. Characteristics

We had developed a system to make a total automation supported by management and production for the new agricultural style. The environmental control and mechanization during production equipment were also under consideration.

1) Plant factory used both sunlight and artificial light for cultivation.

2) Cultivation technique was developed based on a moving cultivation bed using a sprayer. This was effective for:

(1) decreasing diseases,

(2) cultivating all year-round,

(3) making a spacing machine using two shafts in x-y axis,

(4) decreasing cost for cooling of solutions.

3) We had power of technological development and knowledge for cultivation and control.

(1) Development and use of an original computer for environmental control in plant factory. We work together with Shikoku Research Institute Inc. and create such a computer.

(2) Automation for efficiency of operations and labor saving.
It was possible to cultivate leaf vegetable by five labors.

(3) Cultivation technique for increase in harvest and improvement quality.

a. Increase the density of cultivating plants
The spacing machine using two shafts in x-y axis was controlled three or four stage based on plant growing.

b. Decrease rotation span of cultivation using large sampling
The seedling term became longer using large size of urethane substrate.

(4) Decrease of the equipment cost and running cost.
It was based on improvement of cooling system , lighting system and cultivation system of hydroponics.

4) We made the system which had competitive economic power. Based on combined

techniques of cultivation, production, environmental control and automation (robotics); this system was able to keep enough gain which was the same gain in field culture, and production cost was half of the system made by other companies.

5) We could supervise production management in different places using a computer support system for following and controlling the production. Such an information was supplied for maintenance of a low cost factory management by classification of important equipment, low running cost analyzing the operation of machines and information of market, weather and local production for management strategy.

3-2. Components of equipment

1) Greenhouse type: Dutch light type in Netherlands (height: 3.8m),
2) Cooling system: pat and fan,
3) Heating system: warm-air heating,
4) Shield type: double curtain,
5) Seedling type: seedling under water weight (patented),
6) Hydroponics type: moving cultivation bed using a sprayer,
7) Lane numbers: 20,
8) Automation systems (Number of patents): planting machine (1), spacing machine (2), panel server (2), leaf shifter (3), harvesting regulator (1), packing machine (1)

3-3. Results of productive days

<objects of production> all leaf vegetables (we already got technique and knowledge for more ten kind of vegetables)

<quantity of production> spinach: 75 t/year, leaf lettuce: 80t/year

Table 1. Example of productive days for spinach and leaf lettuce.

	Seedling under water	rising	Cultivation				Number of repetition
			1st Stage	2nd Stage	1st Stage	2nd Stage	
Spinach	4	10	3	7	4	-	26
Leaf lettuce	4	21	4	4	4	4	23

3-4. Cultivation results of plant factory experiments carried out in Sanbu-cho.

The plant factory experiments carried out in Sanbu-cho was a prototype test for commercial scale. We had some troubles and a great deal of hardships, however one year later, troubles decreased in our plant factory. The results obtained during this period are as follows:

1) Designed production power was 90t/year, but real production power was 75t/year. It was caused by the tact time of robot movement which was designed for four minutes, actually being necessary five and half minutes. That is because the robot control method did not use

parallel control, but series control instead. Afterwards, we improved this robot control method.

2) The primary production yield was 50%. In the present time, it is increased to 90%, thus, we achieved the desired purpose in production yield.

3) Production weight which was 35g/cube also achieved the desired values. However, it was varying in the panel (98 cube/panel).

4) Production quality is shown in table 2 and 3. These tables show that nutrients content was good, and the nitrogen in nitric acid and the oxalic acid content was in low level. In this way, spinach is edible uncooked, and can be used for baby food. So we could get a good estimation for this product and its wholesale to maintain the same price all year-round, which is two times than the field cultivated one.

Table 2. Example of the analyzed spinach nutrients.

	Vitamin		Nitrogen in nitric acid (mg/100g)	Oxalic acid (%)
	Carotene	A		
Plant factory	3060	170	286	0.58
Field culture	3100	1700	1000	1

Table 3. Analysis of bacteria population in spinach.

	Amount of bacteria (/g)	Colon bacillus	Yellow staphylococcus
Plant factory	$5.9 * 10^3$	none	none
Field culture	$1 * 10^5$	present	none

5) Working time is shown in table 4. Initially, we planned the work for three labors, as it became hard, we restarted employing five labors .

4. ABOUT AN IMPROVEMENT OF PLANT FACTORY SYSTEM

We confirmed to establish roughly the techniques of cultivation, equipment production and environmental control. We had some problems during improvement of the techniques, such as to reduce the robot tact time, keep stability in movement, keep sensors and drive in the automation system. This plant factory system was idealized based on the combination of both computer man-machine interface and living plants. For the completion of this system, we sent two FA (Factory Automation) technicians to Sanbu-cho for a day, in order to find out, analyze troubles, and prepare reports for further improvement. In March 1994, we designed a basic plan of plant factory system using automation, and later, we projected an expansion of this system.

Table 4. Working time in a day (holidays on Sunday and Saturday).

Work	Time (minute)
Seedling	45
Raising	120
Planting	360
Harvesting and leaf cutting	390
Packing	360
Making cardboard box	90
Transportation to market	15
Moving machinery parts	30
Cleaning machinery parts	60
Total	1800

6 hours/day, 5 labors/day.

4-1. Characteristics of the expanded new system (Table 5).

It was based on the robot operation for safety, stability and decreasing work time to 8hours/day. The characteristics of this system are as follows:

1) To keep machine stability, hole pattern in the panels was changed from 98 alternated to 100 parallel holes.

2) In the previous method, spacing machine was moved along the panels, but in the new method, spacing machine was fixed and panels were moved.

3) We separated the movements of moving panels and spacing plants machines, which were connected before, and the tact time could be decreased.

4) In the previous method, when trouble appeared, all system was stopped. In the new method, only ineffective parts were stopped.

5) To decrease tact time, robots were controlled in parallel.

6) We decided that in plant factories less than $1000m^2$, moving panels should be used but not planting machines, because human hand could be more effective to avoid injury. However, we also idealize an expanded plan which included planting machines.

Table 5. Automatic machines in previous and new plant factories.

	Previous system	New system
Planting machine	1 (vertical type)	0 (only moving panels)
Spacing machine	1 (moving type)	1 (fixed type)
Panel server	2 (moving type)	none
Lane shifter	3	none
Panel transport	none	3
Harvesting machine	1 (over the panel)	1 (on the panel)
Packing machine	1	1

4-2. Production

We are proud of designing an agricultural robots system, and believe to have achieved our goal. Production plan is shown in table 6.

Table 6. Production plan.

	Production condition	
	Previous plan	New plan
Area	32m * 36.6m=1153.92m^2	32m * 36.6m=1153.92m^2
Cultivation stage	3	3
Lanes	1st stage 29m 3lane (3days) 2nd stage 29m 10lane (7days) 3rd stage 29m 7lane (3days)	1st stage 30.7m 4lane (3days) 2nd stage 31.4m 12lane (7days) 3rd stage 31.4m 4lane (4days) 29.1m 3lane
Panels	1st stage 177 2nd stage 420 3rd stage 189 total 786	1st stage 204 2nd stage 444 3rd stage 190 total 838
Cube/panel	98	100
Yield	90%	90%
Cultivation days	365	365
Trading days	250	250
	Production quantity	
*Quantity/day (package)	768/13x98x0.9/4=1333.2	838/14x100x0.9/4=1345.8
Quantity/year (package)	1333.2x356=486,610	1346.8x365=491,577

* panel / planting days x cube x yield / numbers of package

Table 7. Equipment cost.

	Cost (million yen)
Greenhouse	34
Cultivation unit	17
Nutrient supplying unit	14
Environmental control unit	22
Automation equipment	45
Other equipment	2
System design	20
Total	154

4-3. A trial calculation in economics

Equipment cost is shown in table 7, production cost in table 8, and balance in table 9. Total equipment cost was about 150million yen. Production cost was about 50 yen, the same as the

market average. In this way, it is possible to achieve a production which will allow gains of 15 or 20 million yen to rationalize the transportation cost.

Table 8. Production cost (in Chiba).

		Cost (thousand yen)	Cost/package (yen)	note
Fixed cost	Depreciation	9,000	12.00	15 years
	Keeping cost	1,298	1.73	
	Insurance cost	276	0.37	
	Basic interest	3,000	4.00	Super L Fund (2%)
	Land rent	100	0.13	2,000m^2
	Personnel expenses	3,675	4.90	payment for part-timer (250days x 3persons x 7hours x 700yen
Moving cost	Seed cost	2,385	3.18	seed
	Urethane cost	2,862	3.82	
	Fertilize cost	596	0.79	including CO^2
	Expenses for light and fuel	4,330	5.77	
	Fuel expenses	772	1.30	crude petroleum type A
Sales cost	Packing cost	3,990	5.32	cardboard box, films for fresh
	Carriage cost	695	0.93	
	Market charge	3,506	4.67	
	Management charge	975	1.03	
	Tax	525	0.70	
	Total	37,985	50.60	

Table 9. Management revenue and expenditure by users

	Substitution of field vegetables	Standard	Edible uncooked	Standard without cardboard box
Sales price	4,125	4,875	6,000	4,875
Sales expenses	905	969	1,064	300
Moving cost	1,094	1,094	1,094	1,094
Fixed cost	1,735	1,735	1,735	1,735
Profit	391	1,077	2,107	1,746
Unit price (yen/100g)	55	65	80	-

4-4. Company management

Company's balance means the same of the system for agricultural balance. We had to design a system which connects plant factory to revolution in process production, in order to bring profit to the maker, producer, dealer and consumer. Makers invested a large amount of money to develop the system.

We need a plant factory system which is able to be supplied and maintained continuously by the maker. In such a system, profit must be kept in order to increase sales and stimulate other companies to start developing plant factories. Nowadays, it seems difficult to popularize the piant factory system. We expect that in near future, it will be a more widely applied system, yet it can last until the end of this century.

5. STORAGE SYSTEM FOR ENVIRONMENTAL CONTROL DATA

For plant factory, we used a computer work unit developed by Shikoku Research Institute Inc.. We have adapted this computer unit to be used for a commercial base system, after testing it in Sanbu-cho and at Kizu high-school in Kyoto. It was an integrated computer connected to network, this computer could control conditions for shoot and root growth making estimation based on measured data. This computer has good algorithm for controlling, can avoid troubles and is easy to maintain the system. When serious problems appear, the computer is able to show troubles and reply questions when requested.

We can observe the plant factory function, check production result and get measurement data from distance. We use a workstation to analyze this data, and get knowledge for decreasing energy and improving environmental conditions. Set-points can be rapidly changed for control.

6. CONCLUSION

Results obtained from a questionnaire, which propose substitution of field cultivated spinach by our pesticide and bacteria-free spinach, inform us that the new product is welcome if its price does not exceed more than 1.2 times of the traditionally cultivated spinach. As consumers need to be satisfied by the appearance of the product, transportation and packages (cardboard box, packing paper, etc.) expenses may fluctuate. In order to decrease cost, vegetables cutting companies propose to stop using cardboard box and packing paper but use only plastic box instead. To demonstrate the advantages of plant factory system, it is important to decrease the product cost and so, it can be popularized for sales in the market.

We are proud of the plant factory system made by our company which leads to a standard for a near future. Our experiments demonstrated that we cannot escape from automation (computer

and robotics) when the total system is considered (production and transportation). Our company has already concluded the systems for both hydroponics and plant factory cultivation, and more than 10 kind of vegetables were cultivated. At this moment, we are not developing the system but renting the license to use for another company.