JARQ 30, 221-226 (1996)

Development of Seedling Production Robot and Automated Transplanter System

Osamu SAKAUE*

Department of Production Engineering, Tohoku National Agricultural Experiment Station (Morioka, Iwate, 020-01 Japan)

Abstract

This study focuses on vegetable production which plays an important role in Japanese agriculture next to livestock and rice production. For labor-saving and automatic operations of seeding production and transplanting, a robotic farm work system using modern electronics technology was developed. For the automation of seedling operations, development of an effective seedling production operation method was attempted based on the characteristics of the seedlings in relation to crop ecology and physiology, and based on a comparative analysis of various operations involved in conventional seedling production. For the automated seedling production system, a programmable controller-based robot and 8 types of attachment devices were adopted for achieving the automation of the seeding, cultivation and control as well as transportation operations. For the transplanting system, 4 types of transplanting machines were developed to automate feeding and insertion operations of seedlings suitable for transplants in the field which had hitherto been performed manually. Based on the results obtained, it is concluded that automated operations for seedling growth and transplanting using robotics technology could be realized in the near future.

Discipline: Agricultural engineering/Horticulture
Additional key words: Vegetable, seedling characteristics, electronics

Introduction

To alleviate adverse conditions such as high temperature and high humidity in the greenhouse or labor-intensive operations such as seedling transplanting in the field, a robotic system for automating the growth and transplanting operations of vegetable seedlings was developed.

Since conventional automatic cultivation practices in the greenhouse, for example, the use of stationary irrigation devices and sprayers for pest control, are either limited to a particular operation, immovable or require individual control devices, their operational and economic efficiencies are low[1]. Furthermore, since in the open field, current transplanting machines receive the seedlings through manual operations, the efficiency is less than 2,000 plants/h[2].

The objective of the robotic system is to provide a system for automatic growth and transplanting of seedlings to reduce the production cost of seedlings.

Effective methods of seedling production

1) *Materials and methods*

For the automation of seedling production operations, an effective seedling production operation system was developed based on the analysis of the characteristics of the seedlings in terms of crop ecology and physiology and based on a comparative analysis of the various operations involved in conventional seedling production. A multi-porous tray (72 cells) was selected and leaf and stem vegetables such as cabbage, broccoli, lettuce and celery were used as crops in this series of tests. Seedling experiments were carried out in the greenhouse at the Morioka Branch of NIVOT.

Present address:
* Department of Protected Cultivation, National Research Institute of Vegetables, Ornamental Plants and Tea (NIVOT) (Taketoyo, Chita, Aichi, 470-23 Japan)

2) Results and discussion

(1) To facilitate mechanical sorting and automatic transplanting of cabbage and broccoli seedlings, since the emergence of coated seeds tended to be slightly delayed and was not uniform compared with naked seeds, seed processing is required[3].

(2) In order to obtain individual seedlings uniform in weight in a non-destructive way at transplanting time, the plant height for broccoli and the difference in emergence date for cabbage should be determined[3].

(3) To enhance the work efficiency and subsequent plant growth in the case of sowing-thinning of multiple seeds and single seed sowing with seedling compensation, the latter method was decided preferable to the former in terms of work efficiency and convenience of operation when the standing rate of seedlings exceeded 85% as shown in Fig. 1. When a mass-seedling production system will be developed in future, single sowing and seedling compensation methods can be applied with the use of coated seeds[4].

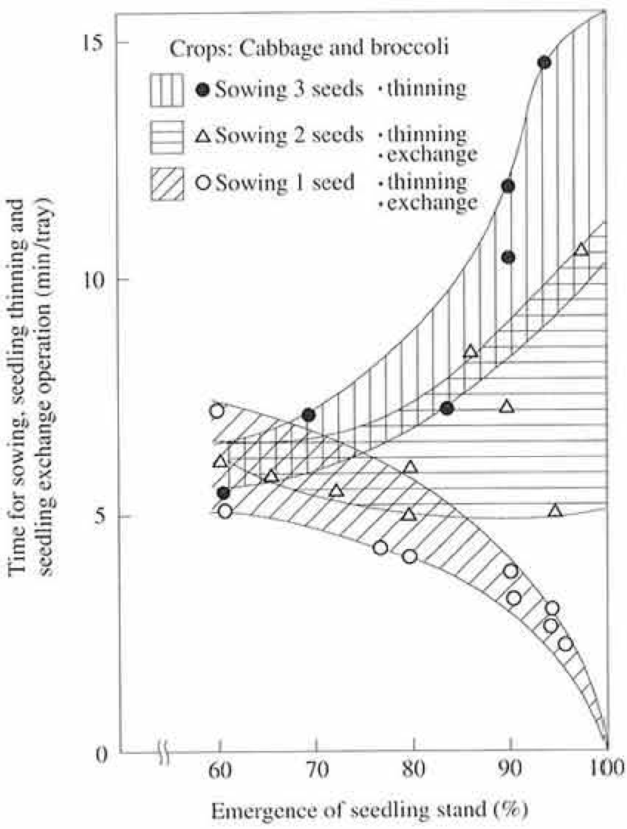


Fig. 1. Relationship between the emergence of seedling stand and time for seed sowing, seedling thinning and seedling exchange operation

(4) The effect of mechanical irritation on seedlings in relation to seedling quality and crop yield was examined in the case of broccoli and cabbage. Due to contact stimulation, in broccoli and cabbage seedlings, plant top height was reduced, plant top weight was lighter, plant stem diameter was larger and showed an increased resistance to pulling of the seedlings[5]. However, crop yield was not adversely affected.

(5) A simple precision planter device for a cell tray was developed and tested. The principle of the planter was to convert the rotating action of an arc cam into a reciprocating motion and shaking under the seed hopper in order to distribute seeds uniformly. The efficiency of the planter device attached to a manual rotation handle was 3-fold higher compared with manual seeding operation.

(6) Water flow-out theory for raising vegetable seedlings by the bath watering method was theoretically analyzed and practically evaluated. Accurate drainage system could be developed by applying the new knowledge to the growth of seedlings by the bath method.

Seedling production robot

The main body of the robot and 8 types of attachment devices were adopted for the automation of seeding, cultivation and control, as well as temporary transplanting operations.

1) Main body of the robot[6]

The main body of the seedling production robot is composed of 2 parts, controlling and driving parts. Table 1 shows the specification of this robot. A programable controller (sequencer) is used as a simple base unit of the robot control to reduce the cost and due to the ease of handling. Many sensors and actuators are connected to the sequencer through

Table 1. Specification of the robot

Size (mm)	L: 610 W: 560 H: 620
Ground clearance, tread (mm)	250, 370
Total weight (kgf)	32
Controller unit	Programable controller
Control method	Stored program method
Number of I/O pins	Input 32, Output 24
Driving power source	25 W AC motor
Final transfer method	V belt
Driving method	2 WD by rubber wheel
Traveling speed	0–4.8 m/min

input and output pins for precision control of operations. A manual controller is fitted with buttons to start the operation, for emergency braking and for the operations related to cultivation while a DIP (dual-in-line package) switch selects the cultivation operation.

The robot has a 25 W AC-motor and moves on rails to monitor the various cultivation devices. One of the main features of the current cultivation robot is that the control unit is able to process in parallel a large number of programs for cultivation operations stored in a memory.

The traverse device transfers the robot and its devices into another lane according to the orders from a robot controller combined with limit switches.

2) Attachments of the robot

Devices for automation of the seedling production operations by the robot that were developed and tested are as follows:

(1) Seeding[7]: A seeding device using a reciprocating cell plate was developed. It is drawn and controlled by the robot and plants coated seeds into a tray where each cell fits to a corresponding aperture. The working rate was 4 times higher than that of manual operation, and seeding errors were extremely few as shown in Table 2.

Table 2. Seeding performance by the robot

Work efficiency		
Time (per tray)	Hand seeding	Robot
Seeding time	1 min 34 s	15 s
Return time	—	6 s
Hand adjusting time	—	5 s
Total	1 min 34 s	26 s
Accuracy of seeding (by robot) 72 cells per tray		
0 grain	1.0[a)]	(1.4%)
1 grain	70.5	(97.5%)
2 grains	0.5	(0.7%)

a): Each of these numerical values indicates the mean value of 5 seedling tryas.

(2) Soil filling or covering[7]: A self-propelled device with a fluted roll was developed which can fill the culture soil automatically into the cell trays by pushing a starting button.

(3) Irrigation, pest control, fertilizer application[9]: The robot-mounted boom nozzle moves slowly along the rails, spraying mist over the seedlings. An electric timer or soil moisture sensor is used to determine the timing of spraying.

(4) Greenhouse temperature control[9]: The curtains on both sides of the greenhouse move up and down in 5 steps, from closed through fully open by a motor according to the signals of 3 thermo-controllers attached to the robot.

(5) Detection of non-emerged cells or smaller plants and removal of these spots[8]: Optical fiber sensor and suction sweeper detect and remove these spots step by step. The positioning of the X-Y direction is regulated by another biaxial robot with stepping motors. It takes about 5 min for the robot to detect and remove small plants in a 72-cell tray.

(6) Carbon dioxide (CO_2) spraying[9]: In response to timer signals in early morning, an electro-magnetic valve is opened by the robot controller and CO_2 gas flows out from the nozzle attached to the robot.

(7) Brushing of plants[8]: Ethylene generated by brushing the plant body leads to the formation of compact, hard and uniform plants. The robot brushes seedlings twice a day for uniform growth. The position of the brush can change automatically in proportion to the plant growth using a photoelectric sensor (through-beam type) and linear head actuator. Table 3 shows the results of the brushing effect by the robot compared with the absence of treatment and manual operation. The robot makes the transplants compact and hard in order to prevent succulent growth of broccoli seedlings.

(8) Topping of transplants[8]: As some crops such as celery should be once-over harvested, uniformity of seedlings is most important. Electric powered reciprocating mower attached to the front of the robot cuts the upper part of celery plants for uniform growth 10 days before transplanting into the field.

Table 3. Brushing effect of broccoli seedlings

Item (per plant)	Treatment			
	Control	Manual	Robot (weak)	Robot (hard)
Plant height (mm)	186	170	172	162
Plant diameter near root (mm)	3.2	3.8	3.7	3.4
Pulling force of plant (kgf)	1.0	1.1	1.4	1.2

(9) Tray transportation[10]: For automation of tray handling operations such as arrangement, movement and loading of trays, the robot arranges the trays on the bed continuously, moves the trays to another area for uniform growth, and loads the trays into pallets for harvesting or shipping seedlings. Two types of linear heads which move vertically and longitudinally were adopted as the main part of this device.

3) Discussion

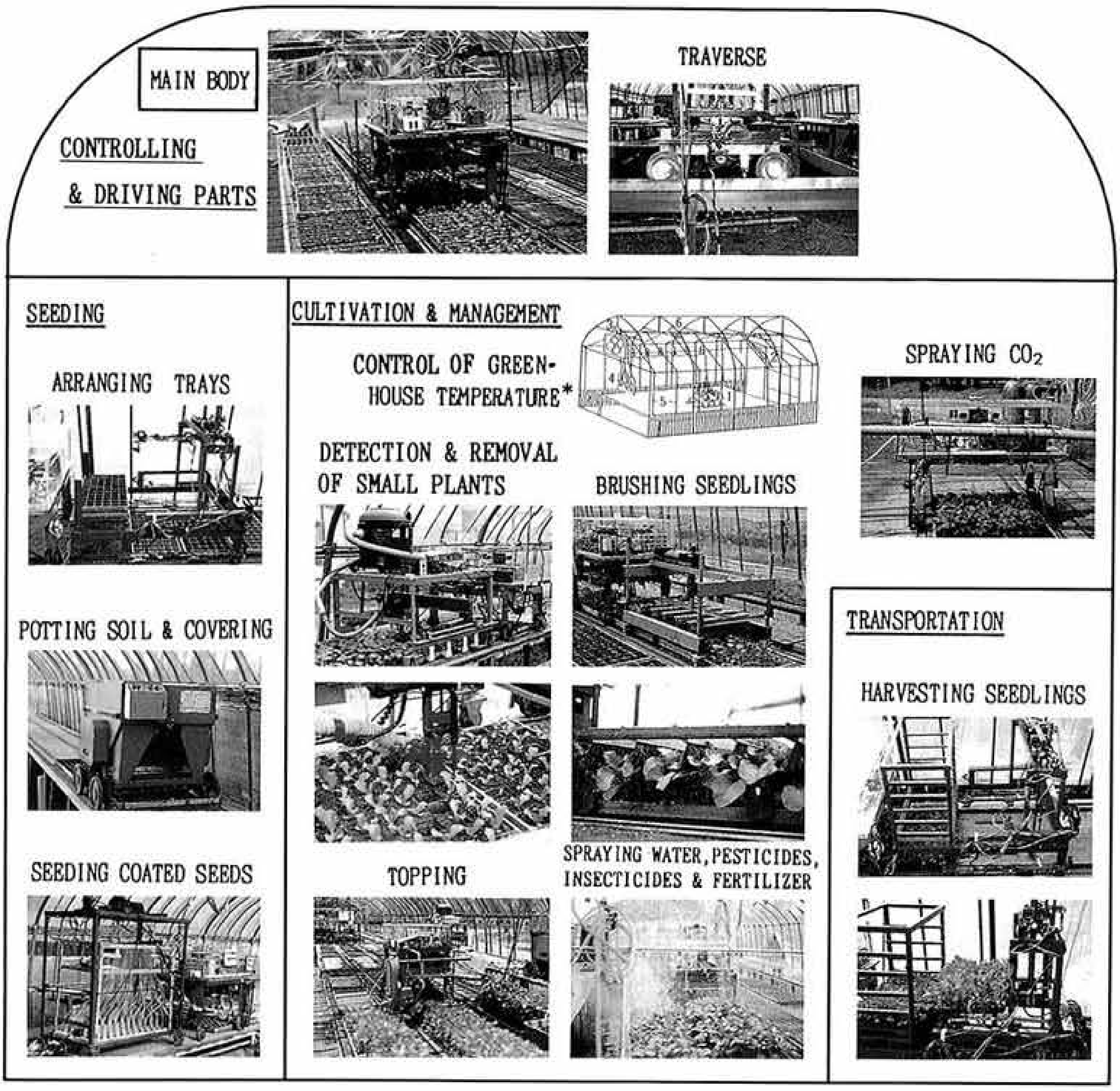
Plate 1 shows the fully developed robotic system for seedling production operations. Almost every seedling production operation in the greenhouse was automated by using this robotic system.

Table 4 indicates the development cost (material cost only) of this robotic system, which suggests that it is comparatively expensive. Therefore, this robotic system may be used by farmers with relatively large scale holdings or farmer groups such as rural agricultural cooperatives which intend to cultivate vegetables.

Transplanting

1) Automatic transplanter development

In Japan, since careful handling of seedlings is required in transplanting operations, it had been



*Control of greenhouse temperature

1. Electric thermostats, 2. Sensors for opening and closing house lateral walls, 3. Motor for opening and closing house lateral walls, 4. Magnetic switches, 5. Wire ropes, 6. Wire winding pipe.

Plate 1. Seedling production robotic system

Table 4. Development cost of the system[a)]

Main body	560,000 yen
Controlling part	510,000
Traveling part	50,000
Attachments	1,400,000
Seeding	60,000
Soil potting	250,000
Brushing	30,000
Irrigation[b)]	50,000
Temperature control	65,000
Detection of small plants	700,000
Transportation	105,000
CO_2 spraying	95,000
Topping	15,000
Traverse	30,000
Additional device	100,000
Total cost	2,060,000

a): Material cost only.
b): Without power pump.

difficult hitherto to develop fully automatic transplanting machines which farmers eagerly expect.

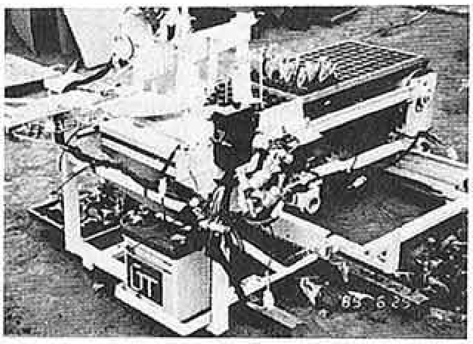
Four prototypes of fully automatic transplanter models were developed and tested at Tohoku National Experimental Station. Plate 2 illustrates these machines.

(1) Automatic seedling feeding device using rotating pickup arm: Work efficiency is 650 plants/h which is quite low for practical application.

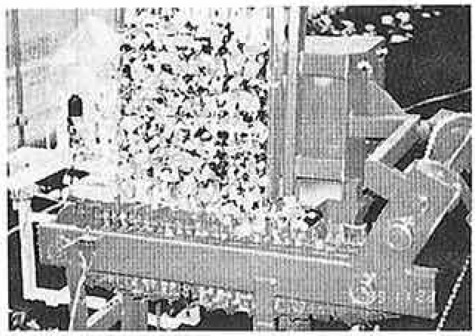
(2) Automatic seedling feeding device using a rank of pistons to push out root blocks from cell tray and a traverse conveyor to transport seedlings toward the rotating part to insert seedlings into soil: work efficiency is 2,250 plants/h which is relatively high. However, the hard tray made of plastic is not compatible with design conditions of compact transplanter size.

(3) Automatic transplanter using pistons, traverse conveyor and rotating insert cup: Table 5 shows the specifications of this machine. Work efficiency of the machine is estimated at more than 2,400 plants/h.

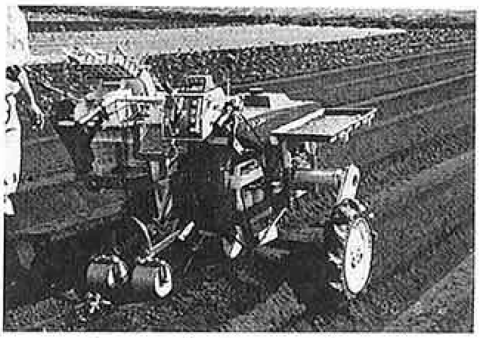
(4) Automatic transplanter using flat belt conveyor, traverse conveyor and rotating insert in cup: Table 6 shows the specifications of this machine. Work efficiency of the machine is more than 2,100 plants/h.



Automatic seedling feeding device
(Prototype No. 1 model)



Automatic seedling feeding device
(Prototype No. 2 model)



Automatic transplanter
(Prototype No. 3 model)

Automatic transplanter
(Prototype No. 4 model)

Plate 2. Development of 4 types of automatic transplanters

Table 5. Specification of the No. 3 transplanter

Item	Characteristics
Size (mm)	L: 1,850 W: 1,150 H: 1,320
Total weight (kg)	230
Power source	Air-cooled 4 cycle 1.6 kW gas engine
Application to crops	Cabbage, lettuce, broccoli, cauliflower
Used tray	98 cells (7 × 14), made of flexible plastics
Plant feeding method	Pushed-out by pistons, traverse conveyor
Transplanting method	Opening and closing cup
Field efficiency	2,400–2,800 plants/h

Table 6. Specification of the No. 4 transplanter

Item	Characteristics
Size (mm)	L: 2,000 W: 1,300 H: 1,200
Total weight (kg)	185
Power source	Air-cooled 4 cycle 1.9 kW gas engine
Application to crops	Cabbage, lettuce, broccoli, cauliflower, celery
Used tray	72 cells (6 × 12), made of fixed plastics
Plant feeding method	Flat belt, traverse conveyor, rotating up
Transplanting method	Opening and closing cup
Field efficiency	2,100–2,200 plants/h

2) Discussion

Though further improvement and experiments are necessary to put these transplanters to practical use, the possibility of fully automatic transplanting operations after the development of a seedling production system using robotics was documented in this study.

Conclusion

Based on the results obtained, it is concluded that automated operations for seedling growth and transplanting using robotics technology could be developed in the near future.

References

1) Sakaue, O. (1988): Automation of vegetable seedling production operations in greenhouse — possibility and problem—. *Agric. & Hortic.*, **63**(4), 65–71 [In Japanese].
2) Sakaue, O. (1991): Automation in vegetable seedling growing and transplanting. *Farming Mechanization*, 2884, 33–38 [In Japanese].
3) Sakaue, O. (1994): Basic study for automation system in seedling production and transplanting operation of vegetable (Part 1). Characterization of vegetable seedlings to facilitate mechanical sorting and transplanting. *J. Jpn. Soc. Agric. Mach.*, **56**(1), 87–93 [In Japanese with English abstract].
4) Sakaue, O. (1994): Basic study for automation system in seedling production and transplanting operation of vegetable (Part 2). Thinning in seedling production. *J. Jpn. Soc. Agric. Mach.*, **56**(2), 109–117 [In Japanese with English abstract].
5) Sakaue, O. (1994): Basic study for automation system in seedling production and transplanting operation of vegetable (Part 3). Effects of mechanical irritation to seedlings. *J. Jpn. Soc. Agric. Mach.*, **56**(3), 101–107 [In Japanese with English abstract].
6) Sakaue, O. (1994): Development of robotic system for automated seedling production (Part 1). Seed planting and soil filling devices. *J. Jpn. Soc. Agric. Mach.*, **56**(5), 81–88 [In Japanese with English abstract].
7) Sakaue, O. (1994): Development of robotic system for automated seedling production (Part 2). Seed planting and soil filling devices. *J. Jpn. Soc. Agric. Mach.*, **56**(6), 87–94 [In Japanese with English abstract].
8) Sakaue, O. (1995): Development of robotic system for automated seedling production (Part 3). High quality seedling production devices. *J. Jpn. Soc. Agric. Mach.*, **57**(1), 59–66 [In Japanese with English abstract].
9) Sakaue, O. (1995): Development of robotic system for automated seedling production (Part 4). Cultivation and management devices. *J. Jpn. Soc. Agric. Mach.*, **57**(2), 77–84 [In Japanese with English abstract].
10) Sakaue, O. (1995): Development of automated seedling production system, Tray handling devices and evaluation of the robotic system. *J. Jpn. Soc. Agric. Mach.*, **57**(3), 111–119 [In Japanese with English abstract].

(Received for publication, November 6, 1995)