

Development of Fully Automatic Vegetable Transplanter

Konosuke TSUGA

Institute of Agricultural Machinery, Bio-oriented Technology Research Advancement Institution
(1-40-2, Nisshin, Ohmiya, Saitama, 331-8537 Japan)

Abstract

We developed 3 models of riding-type, fully automatic vegetable transplanters. These prototypes are suitable for cell mold seedlings and pulp mold cell pot seedlings, mainly of leaf vegetables such as cabbage, Chinese cabbage, and lettuce. The prototypes enabled continuous transplanting work on 2 rows simultaneously, a planting speed of 60 cells/row/min, with vegetable seedlings fed automatically. The transplanting accuracy, in terms of the rate of misplanted hills, was 3% or less, and the working capacity per worker was approximately 10 a/h. We estimated that the annual coverage area of this machine for cultivating cabbage is 53 ha/year, and the minimum economically suitable area for use is 8.2 ha. Based on these prototypes, transplanters have been put on the market by several companies and are now being used in various areas. In this study, we presented a draft of the standards for seedling trays, such as cell mold seedling trays and pulp mold cell pots (paper pots), for possible use of a fully automatic vegetable transplanter. At present, 4 million or more trays are supplied to the market.

Discipline: Agricultural machinery

Additional key words: transplanting, machine, seedlings, cabbage, lettuce

Introduction

Vegetable cultivation in Japan lags behind in terms of mechanization of transplanting and harvesting operations. Seeding and transplanting operations, in particular, are mainly performed manually, accounting for approximately 40% of total working hours. Recently, however, the mechanization of soil filling, seeding, germination, and the raising of seedlings has advanced, and mass raising of seedlings is performed now in production areas. Transplanters are presently used for leaf vegetables such as cabbage, Chinese cabbage, and lettuce.

Current vegetable transplanters are divided into 2 categories: fully automatic transplanters and semi-automatic transplanters. The semi-automatic transplanter has a limited operating speed due to the need for manual feeding of one seedling cell after another and is not suitable for continuous operation over a long period of time. The fully automatic transplanter allows for high-speed operation and labor-saving, because seedlings fed automatically by the machine itself can be planted. However, the fully automatic transplanters that have been developed so far can use only limited types of seedling trays and the working capacity is low because they are of the walking-type. There was a demand for fully automatic transplanters capable of higher speed and small labor load. Therefore, the Bio-oriented Research Technology

Advancement Institution proposed standards for seedling trays of vegetables suitable for use with fully automatic transplanters in the "Urgent Development of Agricultural Machinery" implemented during the period from 1993 to 1995. The Institution also developed jointly with Iseki Noki Co., Ltd., Kubota Co., Ltd., and Yanmar Noki Co., Ltd. riding-type, fully automatic transplanters for vegetables.

In this paper, we will describe the transplanters, the kinds of seedlings, and the standards for trays (standardization), mainly for leaf vegetables, as well as introduce the outline of the riding-type, fully automatic transplanter that achieved the highest performance in Japan.

Prototypes suitable for seedlings³⁾

Transplanters can be broadly divided into those to which seedlings are fed manually (semi-automatic transplanters) and those to which seedlings are fed automatically (fully automatic transplanters), as shown in Table 1. These are further divided into the walking-type and the riding-type. In addition, the type of transplanter may vary depending on the seedlings to which it can adapt. Seedlings used for transplanting by a machine can be broadly divided into seedlings with soil and seedlings without soil (bare seedlings). Seedlings with soil can be further divided into cell mold seedlings, paper pot seedlings, kneaded nursery seedlings, and soil block seed-

Table 1. Classification of vegetable transplanters and seedling types

| Transplanter | | Seedlings | |
|-----------------|--------------|---|--|
| | | Seedlings without soil (bare seedlings) | |
| Semi-automatic | Walking-type | Seedlings with soil | Soil block seedlings |
| | Riding-type | | Cell mold seedlings Paper pot seedlings |
| Fully automatic | Walking-type | Seedlings with soil | Cell mold seedlings |
| | Riding-type | | Pulp (paper) pot seedlings Linked paper pot seedlings |

lings. Recently, since the mechanization of seeding and that of transplantation are progressing in parallel, the use of seedlings with soil, adjustment of the properties of seedlings, and reduction in size of the seedlings are also making progress. In this study, we developed riding-type, fully automatic transplanters that are suitable for cell mold seedlings and pulp mold cell pot seedlings (a kind of paper pot seedlings).

Standardization of seedling trays

To transplant cell pot seedlings and paper pot seedlings, the fully automatic transplanter requires the use of seedling trays in which the arrangement of the seedlings is suitable for the seedling feeding device applied. Therefore, seedlings must be grown in trays that are suitable for the particular transplanter to be used, and the seedling form will differ from one kind of tray to another. If the same types of trays are used, the machine has to be adjusted to the number of cells per tray. Therefore, attempts were made to develop trays that were interchangeable among the seedlings from various seedling centers and among transplanters from different manufac-

turers. In this study, we prepared a draft of the standards for seedling trays, such as cell mold seedling trays and pulp mold cell pots, for possible use of a fully automatic vegetable transplanter (Fig. 1). As a result, the form and dimensions of these trays have been standardized, as shown in Table 2.

The cell mold seedling tray is made of flexible plastic, and there are 3 types of trays, containing 128, 200, or 288 cells, in which the arrangement of cells is 8×16, 10×20, and 12×24. The shape of the trays is that of an inverted pyramid.

The pulp mold cell pot is a kind of paper pot, in which the pulp mold is made of used paper, etc. Pot dimensions are 30 mm² (128 pots) and 25 mm² (200 pots), and the seedlings are arranged in the form of a pyramid. The arrangement of cells is 8×8 and 10×10, and each pair of pots is arranged on an under-tray.

Both types of standard trays can use a rice seedling box as the under-tray. Four million or more of these standards trays had been supplied to the market as of 1998.

Development of riding-type, fully automatic transplanters^{1,5)}

1) Outline of fully automatic transplanter

We developed 3 models of riding-type, fully automatic transplanters that allow continuous transplanting work on 2 rows simultaneously at a planting speed of 60 cells/row/min, with vegetable seedlings fed automatically. The prototypes manufactured in 1995 consist of 2 models for cell mold seedlings (Type A in Fig. 2, Type B in Fig. 3) and a model for pulp mold cell pot seedlings (Fig. 4). The outline of each model is described below.

(1) These machines handle mainly leaf vegetables such as cabbage, Chinese cabbage, and lettuce (Fig. 5), with cell mold seedlings and pulp mold cell pot seedlings. As the under-tray, a rice seedling box is used. Since the numbers of cells (pots) per tray are 128 and 200, standard trays can be used.

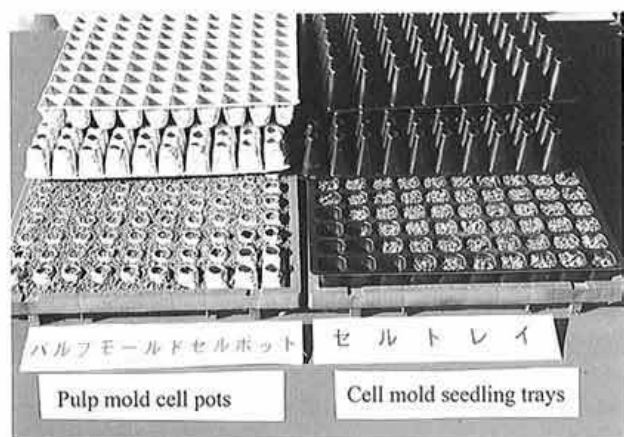
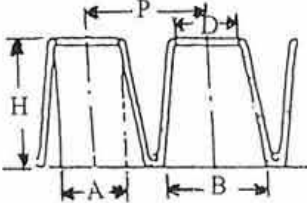
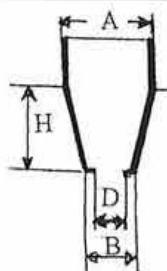


Fig. 1. Cell mold seedling trays and pulp mold cell pots (paper pots)

Table 2. Standards of vegetable seedlings trays in Japan⁴⁾

| Classification | | Pulp mold pot | | Classification | | Cell tray | | |
|--|--|----------------|-----------|----------------------------|--|---------------------|-----------|-----------|
| | | 128 | 200 | | | 128 | 200 | 288 |
| Outer frame | Size | 288×2 | 288×2 | Outer frame | Size | 590 | 590 | 586 |
| | | 278 | 278 | | | | 300 | 300 |
| | R on Corner | 8 | 8 | | R on Corner | 10 | 10 | 10 |
| Arrangement of cell number | | 8×8 | 10×10 | Arrangement of cell number | | 8×16 | 10×20 | 12×24 |
| Pitch | Longitudinal (P) | 35.9 | 28.7 | Pitch | Longitudinal | 36.6 | 29.2 | 24.3 |
| | Lateral | 34.5 | 27.7 | | | Lateral | 36 | 28.7 |
| | Height(H) | 40 | 32.5 | | Height (H) | 44 | 44 | 38.5 |
| Cell size | Upper part Length(A) | 19.2 | 16 | Cell size | Upper part (A) | 31 | 26 | 21.5 |
| | Side | 17.8 | 16 | | | | 10 | 7 |
| | Lower part Length(B) | 29.9 | 24.7 | | Lower part (B) | 18 | 12 | 9 |
| | Side | 28.5 | 23.7 | | | | 7 | 5 |
| | Diameter of seeding hole(D) | 18 | 15 | | Diameter of hole (D) | 12 | 9 | 7 |
| Volume of cell (cc) | | about 23 | about 12 | Volume of cell (cc) | | about 25 | about 14 | about 9 |
| Soil capacity per tray(L) including cover soil | | about 5.7 | about 4.0 | Soil capacity per tray(L) | | about 3.2 | about 2.8 | about 2.6 |
| | | | | Cover soil capacity(L) | | 0.5 | 0.5 | 0.5 |
| Weight of tray (g) | | about 71 | about 76 | Weight of tray (g) | | about 150 | | |
| Thickness of cell (mm) | | about 2 | | Thickness of cell (mm) | | 0.6(side · base0.1) | | |
| Material | | Used newspaper | | Material | | Polystyrene(PS) | | |
| Remarks |  | | | Remarks |  | | | |

(2) The basic configuration of these machines is that of a small, riding-type machine consisting of a 2-row planting device mounted on the back of a vehicle. The planting device is composed of the seedling feeding and transplanting sections. The vehicle has a 4 wheel-drive system and is well adapted to slopes. The standard adjustment range of the tread (distance between the right and left wheels) is 90 to 120 cm. Although usually riding-type machines are very long and require a considerable area at the end of the field for turning, the current machine is a compact 4-wheel-drive vehicle, adapted to such use, and requiring only 3 to 4 m of headland for turning. This riding-type is suitable for relatively small fields.

(3) The models for cell mold seedlings (Types A and B) pull out seedlings one at a time from the tray using a seedling take-out claw of the holding type and discharge seedlings into the bill-type opener. The opener, which is interlocked with the claw, transplants the seedlings to the tamped surface of the ridge, and the tamping ring at the rear presses soil from the left and right to cover the seedlings. The automatic-planting-depth control unit and the ridge-following control unit allow stable transplanting

with the use of hydraulic devices. Since the seedlings are independent cells, growth control is easy, growth rates are similar, and they display an outstanding initial rooting capacity after transplanting. The vehicle consists of a 4-wheel-drive system with either a diesel engine (Type A) or a gasoline engine (Type B).

(4) The model for pulp mold cell pot seedlings holds seedlings that are each wrapped by a paper pot (pulp mold) and transplants them continuously by separating them into individual hills. It allows the transplanting of seedlings with a wide range of sizes over a long period of time and is suitable for transplanting regardless of the degree of growth of the individual seedlings.

The model for pulp mold cell pot seedlings scratches off seedlings with the paper attached (pulp mold), after separating them into each hill with a transplanting claw, and transplants them in the hole opened by the arm. After transplanting, the soil is tamped. This transplanting claw consists of 2 blade-like claws and an extrusion arm. The blade-like claws scrape each seedling pot to separate it from the others and hold it, and the arm extrudes the seedling pot into the soil to plant it. Soil is pressed then from both sides of the planted seedling by the tamping

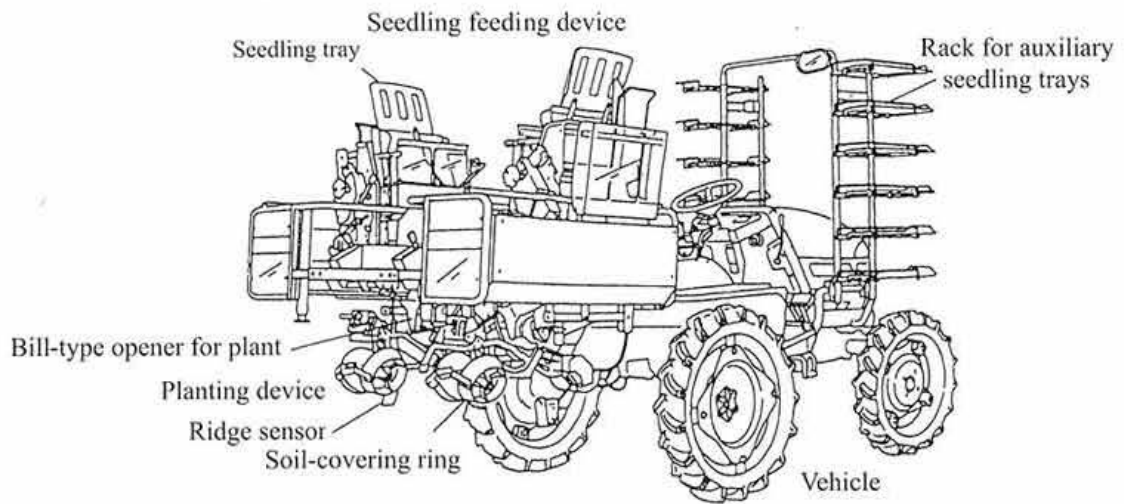


Fig. 2. Fully automatic transplanter model PR2 for cell mold seedlings

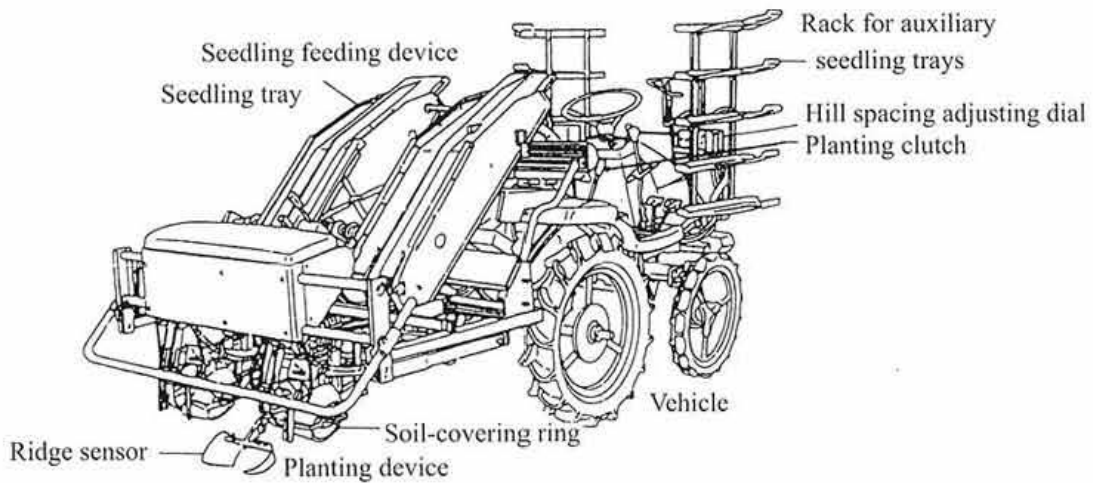


Fig. 3. Fully automatic transplanter model SKP20 for cell mold seedlings

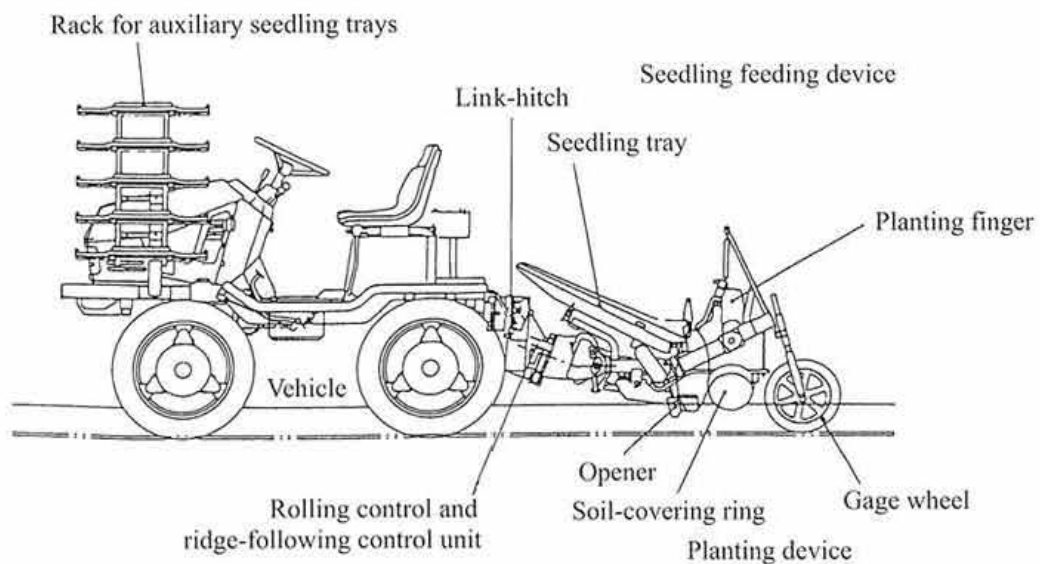


Fig. 4. Fully automatic transplanter model PVP200 for pulp mold cell seedlings

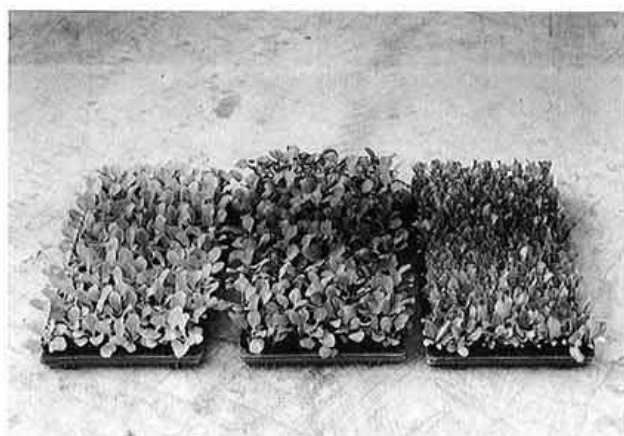


Fig. 5. Chinese cabbage and lettuce seedlings

ring to complete transplanting. The automatic-planting-depth control unit and ridge-following control unit allow stable transplanting with the use of hydraulic devices. The vehicle has a 4-wheel-drive system that allows

maneuvering of both front and rear wheels.

(5) Planting conditions common to all the 3 models include an adaptable ridge height of 0 to 25 cm, a hill space of 25 to 50 cm, and a ridge space of 45 to 60 cm, in which the model for cell mold seedlings (Type A) allows zigzag planting on 2 rows.

2) Performance of the prototypes

(1) Working accuracy²⁾

Based on operation tests on the prototypes using seedlings of cabbage, Chinese cabbage, and lettuce, we confirmed that hill spacing, planting depth, and soil cover can be adjusted easily, a planting speed of 60 to 70 hills/row/min is possible, and the ratio of misplanted hills is 3% or less (excluding non-seeded hills in the tray). Lateral displacement of planting positions (rows), changes in hill spacing, and the ratio of slanted hills were also small. In the case of planting on slopes (maximum of 10°), number of misplanted hills and changes in hill spacing were

Table 3. Test results on working accuracy (Aichi Prefecture Agricultural Experimental Station, as of 1994)

| Model under test | Planting speed (m/s) | Number of misplanted hills | | Number of continuous misplanting positions | Changes in hill spacing | |
|----------------------------------|----------------------|----------------------------|-------|--|-------------------------|-------------|
| | | Left | Right | | Left | Right (CV%) |
| For pulp mold cell pot seedlings | 0.22 | 2 | 1 | 0 | 3.7 | 3.0 |
| | 0.30 | 0 | 4 | 0 | 2.6 | 1.9 |
| | 0.38 | 2 | 4 | 0 | 3.0 | 2.5 |
| Type A for cell mold seedlings | 0.22 | 2 | 0 | 0 | 3.2 | 3.0 |
| | 0.30 | 0 | 0 | 0 | 4.0 | 4.3 |
| | 0.37 | 0 | 1 | 0 | 4.2 | 4.7 |
| Type B for cell mold seedlings | 0.27 | 0 | 3 | 0 | 7.0 | 3.0 |
| | 0.31 | 1 | 0 | 0 | 3.9 | 3.7 |
| | 0.33 | 1 | 0 | 0 | 5.7 | 3.9 |

Sample seedling/hill spacing : Cabbage/30 cm. Number of hills measured : 200.

Table 4. Test results on working capacity (Aichi Prefecture Agricultural Experimental Station, as of 1994)

| Model under test | Seedlings used | Working speed (m/s) | Total working time (min) | Time ratio of operation (%) | | | | | |
|----------------------------------|----------------|---------------------|--------------------------|-----------------------------|---------|-------------------|--------------|------------|--------|
| | | | | Planting | Turning | Tray replenishing | Tray feeding | Adjustment | Others |
| For pulp mold cell pot seedlings | 200 cells | 0.35 | 52 | 70.4 | 10.6 | 10.4 | 8.1 | 0 | 0.5 |
| | | | | | | (4 times) | (12 times) | | |
| Type A for cell mold seedlings | 200 cells | 0.39 | 54 | 61.2 | 12.7 | 9.6 | 12.6 | 2.0 | 1.9 |
| | | | | | | (4 times) | (12 times) | | |
| Type B for cell mold seedlings | 200 cells | 0.33 | 54 | 73.9 | 8.7 | 7.0 | 10.4 | 0 | 0 |
| | | | | | | (3 times) | (12 times) | | |

Test conditions

Test field: 9.36 a (65m×12 strokes). Operator: 1.

Seedling: Cabbage. Planting: Row spacing, 60 cm; Hill spacing, 30 cm.

Table 5. Sample calculation of the maximum working area of the machine

| Item | | Calculated value | |
|-----------------------|--------------------------------------|------------------|------|
| | Working capacity | 0.103 | ha/h |
| | | 9.71 | h/ha |
| Per day | Working hours | 4.0 | h |
| | Actual working rate | 70 | % |
| | Time available for work | 2.8 | h |
| | Working area | 0.29 | ha |
| Fixed planting period | | April ~ November | |
| Per year | Number of working days | 244 | d |
| | Ratio of days available for working | 75 | % |
| | Number of days available for working | 183 | d |
| | Maximum working area | 53.1 | ha |

small. Table 3 shows the results of the planting accuracy test performed in Aichi Prefecture in 1994.

(2) Working capacity⁴⁾

We found that when 12 to 14 trays were mounted on the seedling tray and the auxiliary seedling tray, it was possible to transplant 2,400 or more hills without requiring the operator to get off the vehicle. Working time per 10 a per operator, including the planting time, seedling feeding time, turning time, etc., was approximately one hour. Table 4 shows the results of the working capacity test performed in Aichi Prefecture in 1994, indicating that when one operator planted cabbage (at a hill spacing of 30 cm and row spacing of 60 cm), the working speed was 0.33 to 0.39 m/s, and all the 3 models showed a working capacity value of approximately 10 a/h. A similar value of working capacity of approximately 10 a/h was reported in a test on commercial machines.

3) Economic efficiency of the prototypes⁴⁾

(1) Maximum working area

We calculated the maximum transplanting working area per year achieved by these prototypes in the case of cabbage cultivation (Table 5). The time available for transplanting work was 2.8 h per day. This value was calculated on the assumption that half a day (4 h) can be used for transplanting work, to avoid other conflicting tasks and poor rooting conditions, as well as high temperatures in summer and low temperatures in early spring. Assuming that the actual working rate is 70%, the maximum working area per day was 0.29 ha/day, based on the time available for transplanting work and the working capacity of the machine. Next, the number of days available for working was 183, on the assumption that the ratio of days available for work is 75% because transplanting work is performed over a period of 8 months from April to November, including the days when rain prevents outdoor work. The maximum transplanting

working area per year (cumulative working area per year) was 53.1 ha, based on the calculation of the maximum working area per day and the number of days available for working per year.

(2) Cost and economic efficiency

We calculated the cost of using these machines in the case of cabbage cultivation. The costs included fixed costs (expenses required for owning the machine) and variable costs (operating costs, including fuel, lubricating oil, and labor). Fig. 6 shows the relationship between the area covered and the cost of the machine. To evaluate the economic efficiency, we calculated the minimum economical area for using this machine based on the work contract wage for manual transplanting. Based on that wage, the result was 8.21 ha. Since the maximum transplanting working area per year is 53.1 ha, and since this machine can cover an area 6.5 times as large, we consider

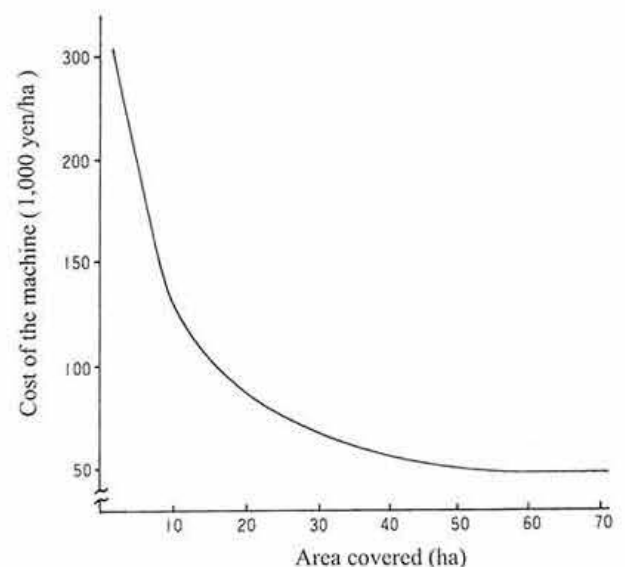


Fig. 6. Relationship between the area covered and the cost of the machine



Fig. 7. Fully automatic transplanter Model PR2 for cell mold seedlings (Yanmer Noki, Co., Ltd, for cabbage in Ogoori, Fukuoka)



Fig. 8. Fully automatic transplanter model SKP20 for cell mold seedlings (Kubota, Co., Ltd., used in Takeda, Kumamoto)



Fig. 9. Fully automatic transplanter model PVR200 for pulp mold cell pot seedlings (Iseki Noki, Co., Ltd., used in JA Kazuno, Akita)

that this machine is economically efficient.

Conclusion

We developed 3 models of small-sized, high speed, riding-type, and fully automatic vegetable transplanting machines for the first time in Japan. These machines feed vegetable seedlings automatically and enable continuous transplanting work on 2 ridges simultaneously at a planting speed of 60 hills/row/min. The machines can be used for cell mold seedlings and pulp mold cell pot seedlings. In Ogoori City, Fukuoka Prefecture, where the machine was put on the market and used, cabbage is cultivated over the year on a 15-ha field, using a transplanter model for cell mold seedlings (manufacturer, Yanmar Noki Co., Ltd.), as shown in Fig. 7. This was part of a thorough mechanization system, including general-purpose use of this vehicle and the introduction of harvesters. Fig. 8 shows another model for cell mold seedlings (manufacturer, Kubota Co., Ltd.), which is used for transplanting cabbage, etc., in a farm where cabbage, Chinese cabbage, and lettuce are cultivated (25 ha) in Takeda City, Kumamoto Prefecture. Six riding-type transplanters of the model for pulp mold cell pot seedlings (manufacturer, Iseki Noki Co., Ltd., Fig. 9) were used for a thorough mechanization system, including general-purpose use of this vehicle, in Kazuno City, Akita Prefecture, where a cabbage production center of 100 ha is being constructed. As a result, dozens of such riding-

type, fully automatic transplanters have been introduced already in various areas and we anticipate that their use will be disseminated throughout the country.

We thank the Agricultural Experimental Stations of Iwate Prefecture and Aichi Prefecture for their cooperation during the field tests of the automatic transplanter.

References

- 1) Bio-oriented Technology Research Advancement Institution (ed.) (1997): Full automatic vegetable transplanting machine. Outline of agricultural machines developed by the project of urgent development of agricultural machinery, 2.
- 2) Foundation Agricultural of Industry Development Assistance (Nousangyou-Shinkou-Shoureikai) (ed.) (1995): Technical report of field test on the project of urgent development of agricultural machinery, 25-64 [In Japanese].
- 3) Japanese Society of Agricultural Machinery (ed.) (1995): Vegetable machinery. Introduction to Japanese Agricultural Machinery (III), 31-37.
- 4) New Agricultural Mechanization Enhancement Co., Ltd. (Shinnouki) (ed.) (1996): Fully automatic vegetable transplanter. Mechanical cultivation manual, 1-18 [In Japanese].
- 5) Tsuga, K. (1997): Full automatic vegetable transplanter. *J. Jpn. Soc. Agric. Mach.*, 59 (2), 109-110 [In Japanese].

(Received for publication, February 25, 1999)