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Development of Automatic Sugar Beet Transplanter Using Chain Pots

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Abstract

The problem of full automation of sugar beet transplanting was studied in terms of both the paper pot structure and the transplanter itself in order to change the seedling feeding process which is currently manual to an automatic operation, so as to achieve full automation and increase the speed of the transplanters. As a result, continuous paper pot series (chain pots) and a device to separate these paper pots at a high speed into individual seedlings were designed. Furthermore, a new planting device was designed using the drop chute method, which matches the ability of the separating device. The mechanism can be easily operated and is suitable for high-speed planting. Next, a tractor-mounted 2-row transplanter and tractor-trailed 6-row transplanter were designed. Both were equipped with these new devices and experimental planting was successfully conducted, confirming that these devices are not only labor-saving but also highly practical.

Discipline: Agricultural machinery
Additional key words: automation, drop chute, furrow opener, paper pot, seedling

Introduction

Sugar beet is grown around the world over a total area of about 8.7 million ha. In Japan, Hokkaido is the only region where this crop is grown and the cultivated area covers a total of 70,000 ha. The cultivation method widely used in Hokkaido is the paper pot transplanting method, in contrast to other countries where the direct seeding method is used.

The transplanting method has some advantages over the direct seeding method in reducing the time for sowing, thinning and cultivation. On the other hand, the transplanting method requires more time for labor-intensive manual operations such as seed bed preparation at a seeding center, seeding into the paper pots, raising of seedlings and finally, transplanting. To overcome these shortcomings, efforts have been made in the current studies to reduce the amount of labor required. As a result, the transplanting method now requires only as much time as the direct seeding method. In the current studies transplanters were so much improved that working hours were reduced by 50%. The existing transplanters, however, are still semi-automatic, which requires human labor to feed the seedlings to the planting mechanism. Unfortunately, full automation can not be achieved unless there is a radical technical innovation in the seedling mechanism.

Automatic transplanting mechanism with chain pots

1) *Structure of the chain pots and separating mechanism*

Former chain pot automatic transplanters had a fundamental defect, that is, the tendency to misjudge the distance between each pot[1–7]. This defect was taken care of by increasing the speed of the transplanter. An attempt was made to separate the pots without the application of an excessive amount of force and without increasing the speed of the transplanter. It was recognized that this operation could be performed by putting a slit, referred to as a separation-guide-portion between the pots, and connecting the top of the pots in a few areas. The separation force was then concentrated on the first joint while holding the separation-guide-portion, and cutting the joints one after the other. Based on this concept, a separating device was designed to

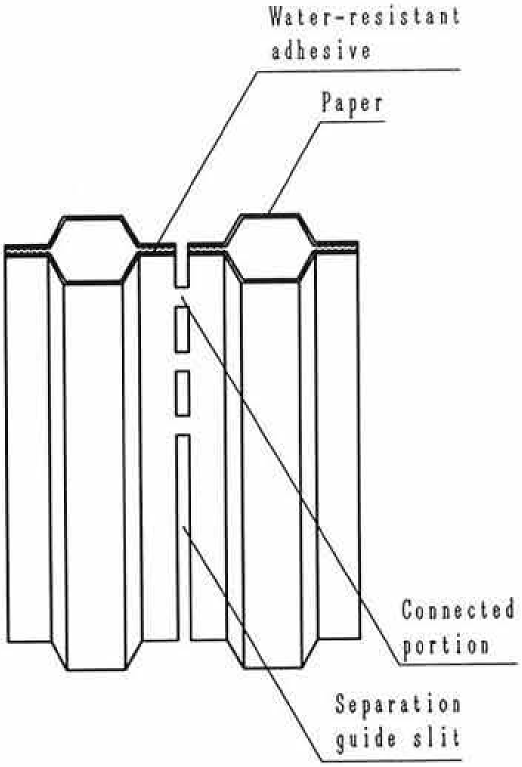

Fig. 1. Structure of chain pots

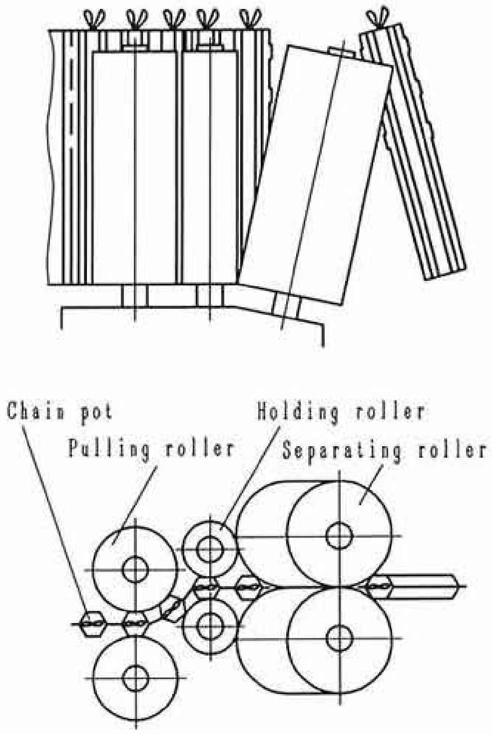

Fig. 2. Structure of separating mechanism

combine the new chain pots and high-speed processing rollers[8]. The structure of the new chain pots is illustrated in Fig. 1 and the separating mechanism is illustrated in Fig. 2.

2) Transplanting mechanism of drop chute type

The speed of planting through the application of the drop chute mechanism which locks underground movable parts increased. It may also be possible to further automatize and increase the speed in conjunction with the separating mechanism.

In the former mechanism, however, the lack of pot inertia, accompanied by the transplanter's movement, resulted in erratic planting. In practice, the use of the transplanter was limited to short and large round potted seedlings, which reduced the traveling speed of the transplanter.

It was assumed that it would be necessary to satisfy the following 2 conditions to increase the speed of the transplanter: (a) the pots should fall at a designated angle into a designated position, and (b) the position of the plant hole, which appears behind the furrow opener, should be uniform. The new planting mechanism was designed based on the assumption that it was possible to meet the 2 conditions by: (a) developing a curved surface on the backboard of the furrow opener based on the falling path of the slower pots, and control the position of the slower pots in this curved surface, (b) setting the length of the furrow opener at its widest zone, and controlling the flow of soil with the lateral wall of the furrow opener. The control mechanism of soil flow is illustrated in Fig. 3 and the transplanting mechanism of the new drop chute type is illustrated in Fig. 4.

Practical application of the chain pots and separating mechanism

A basic experiment was carried out on the separation of the chain pots to acquire fundamental data for designing the chain pots. At the same time, several kinds of chain pots were designed and constructed. An experimental device which allows the separation of the pots at a high speed was also designed and constructed. The practical application of the chain pots and the separating device was investigated[9,10]. The results are summarized as follows.

1) Strength of the joint of the chain pots

The strength of the joint of the chain pots must range between 8 to 14 N, to match the distance over which the chain pots are pulled out from the

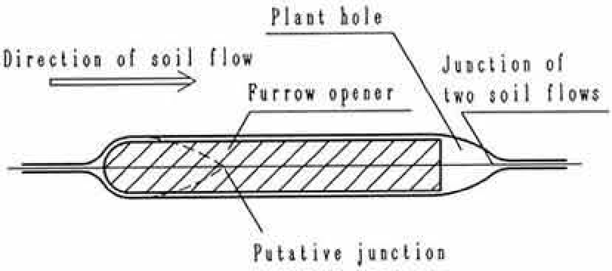

Fig. 3. Control mechanism of soil flow

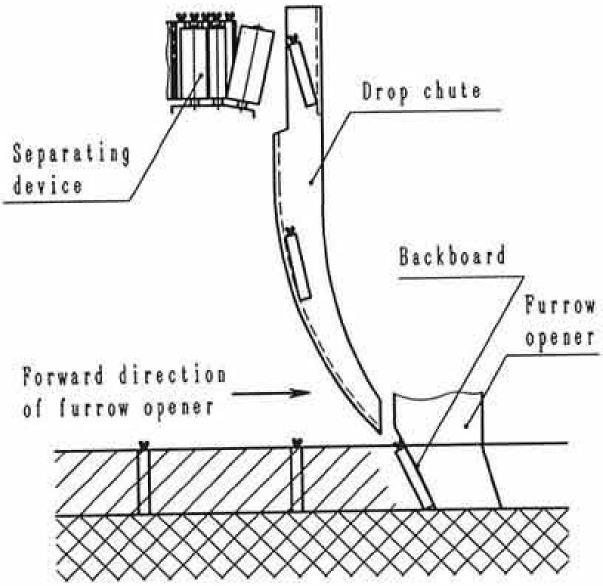

Fig. 4. Transplanting mechanism of the new drop chute type

seedling rows to the separating device. For practical use, the safety factor must be considered in deciding the strength.

2) Length of the separation-guide-portion

Based on an experiment with a single joint it was estimated that the length of the separation-guide-portion should be 30 mm or more. It was also observed that the separation force of the separation-guide-portion could be reduced to 1/3–1/5 of that used for the pots without the separation-guide-portion, as shown in Fig. 5. Also the length of the joint should be less than or equal to 3 mm for normal separation to occur.

In an experiment with multiple joints, similar results were obtained. The separation force can be reduced by 1/5, by tearing apart the joints and separating the pots gradually using the separation-guide-portion. It was found that the separation-guide-portion is a very useful addition.

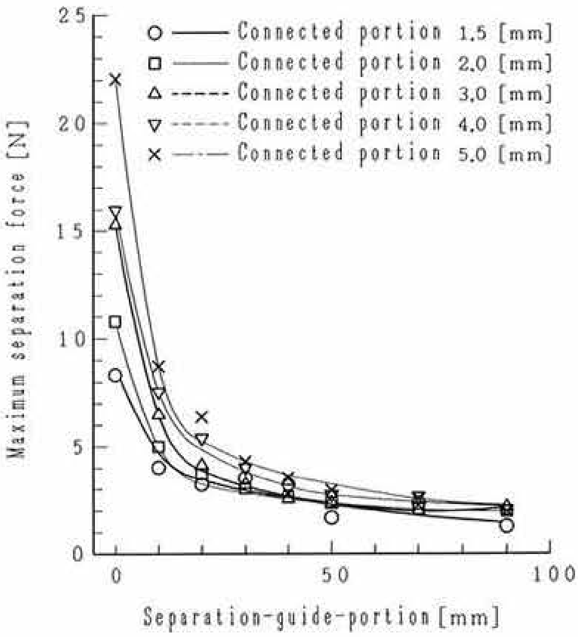

Fig. 5. Relationship between the separation force and the length of the separation-guide-portion

3) Separating velocity ratio and angle of the separating roller

Based on the results of the above experiments, experimental chain pots were manufactured with 3 mm long joints, 4 connected spots and with 3 different lengths of the separation-guide-portions. An experimental device was also manufactured with the ability to separate pots continuously. The separating velocity ratio and angle of the separating roller and its capacity for seedling pots were examined. The highest allowable limit and the most stable separation occurred with a separating roller angle of 12–15° with a separating velocity ratio of 6–7, and separation-guide-portions of 30 mm, as shown in Fig. 6.

Transplanting mechanism of drop chute type

A theoretical investigation of the mechanism for the drop chute type transplanter was carried out. At the same time, fundamental data of the mechanism were collected through experiments for the construction of the prototype. The findings are summarized as follows.

1) Theoretical investigation

Since plant holes behind the furrow opener occur steadily as the furrow opener proceeds, pots will eventually reach the bottom of the furrow if they fall

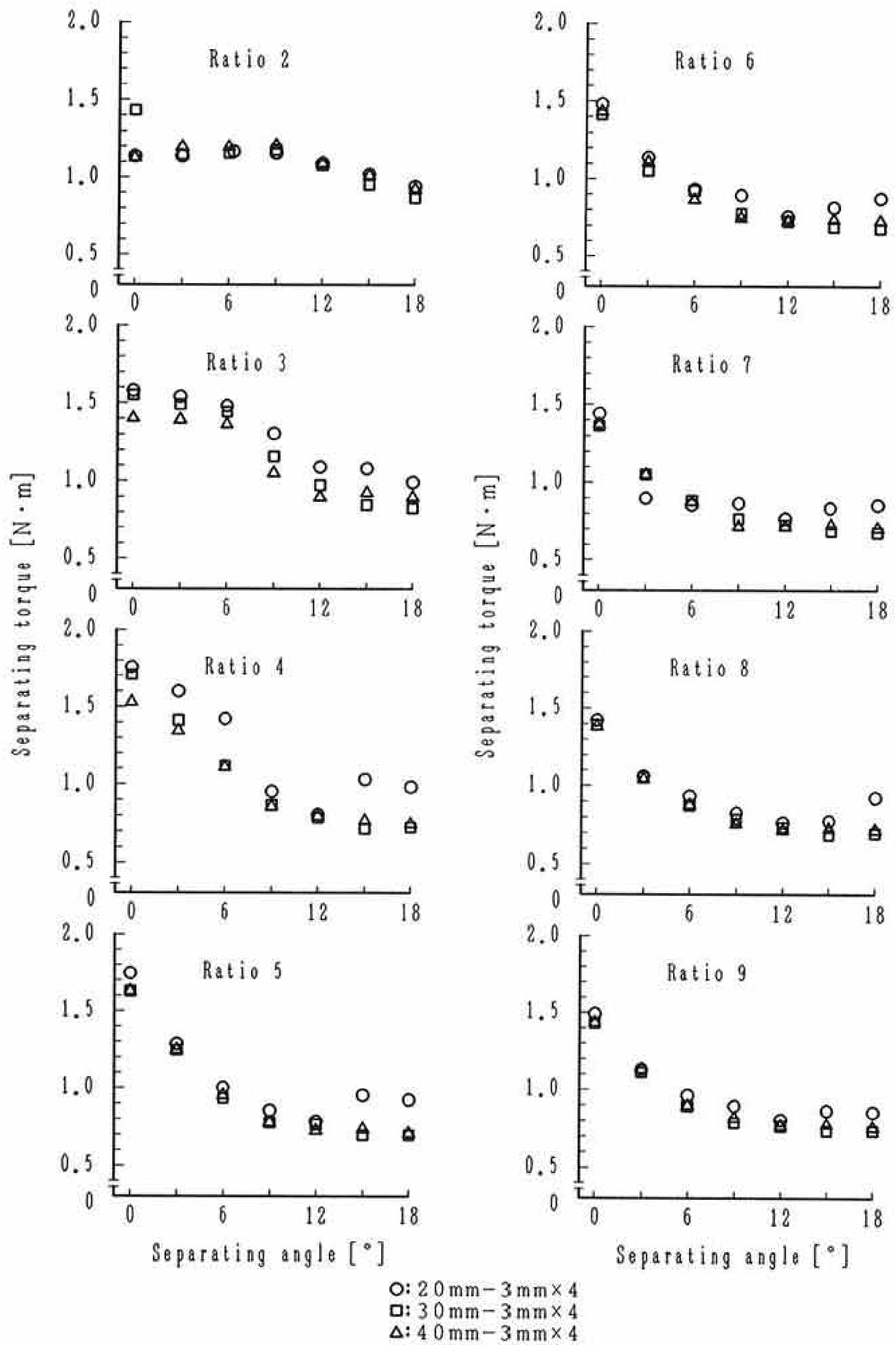

Fig. 6. Relationship between the separating angle and separating torque

along the side of the backboard of the furrow openers. It was observed that the plant holes became refilled as time passed, and the soil, which refilled the plant holes, gradually restrained the pots. The pots were stabilized when their inertia and the soil retention force were equal. The schematic diagram of seedlings held in the soil by the furrow opener is illustrated in Fig. 7.

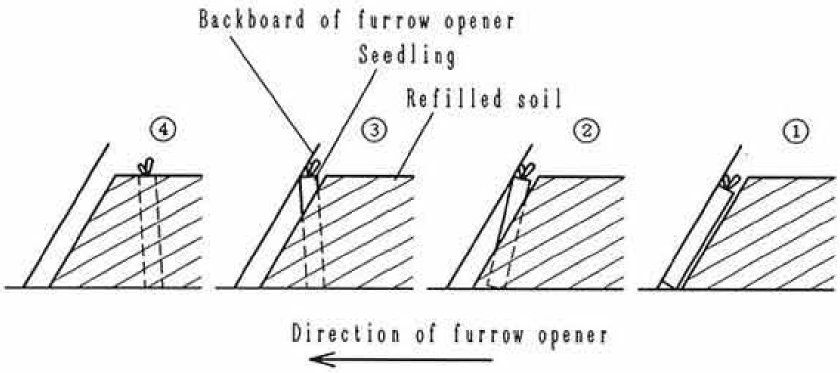

Fig. 7. Schematic representation of seedlings held in soil by the furrow opener

2) Control of the angle and position of the falling seedlings

To drop the pots along the backboard of the furrow opener, the optimum velocity and the angle at which the pots are to be released from the drop chute pipe were selected. To determine the velocity, the height of drop required to achieve the desired velocity had to be estimated by calculating the coefficient of dynamic friction between drop chute pipes. Through the experiments a relational formula was derived to calculate the coefficient of dynamic friction applicable for a practical transplanting mechanism[11]. When released from the drop chute pipe the pots describe a parabola. Therefore formulae were derived to calculate the release angle, the release velocity and landing angle, which are necessary for the pots to fall along the backboard of the furrow opener[12].

3) Control of soil flow by the furrow opener

To convert the experimental transplanting mechanism into a practical one, the shape the furrow formed by the traveling of the furrow opener needed to be regulated. Therefore, an experimental semi-cylindrical furrow opener was constructed and the change (depending on the size of the semi-cylinder, operating speed and the type of soil) in the shape of the furrow behind the furrow opener was observed. The results were as follows:

(1) The length of the furrow varied proportionally to the increase in the traveling speed, and the rate of increase varied with the soil types.

(2) Within the same soil type, the moisture content of soil did not affect appreciably the length of the furrow.

(3) Formulae were derived to calculate the boundary curves of the furrow for volcanic and alluvial soils.

(Volcanic soil)

$$y = \{(0.78\,r + 6.18)(v - 0.14) + 8.28\}x^{0.5} \qquad r_c = 0.98$$

(Alluvial soil)

$$y = \{(0.65\,r + 6.18)(v - 0.4) + 9.83\}x^{0.5} \qquad r_c = 0.99$$

where,

x: x-distance [mm],

y: y-distance [mm],

v: traveling speed of furrow opener [m/s] ($0.4 \leqq v \leqq 1.5$),

r: radius of furrow opener [mm] ($10 \leqq r \leqq 25$).

Using the above findings for the control of the soil flow at the furrow, furrow openers with boundary curves and with a straight shape were manufactured. As expected, satisfactory performance was achieved with both shapes, which enabled to regulate the shape of the furrow[12].

Practical application of the transplanting theory

The findings described in the foregoing paragraph were used during the manufacture of an experimental planting device. The conditions and the accuracy of planting were investigated and data for building working models were collected. The results obtained were as follows:

(1) The value of the planting angle of each furrow opener decreased as the traveling speed increased. The rate at which the value of the angle decreased in relation to the increase of the traveling speed was about 4–5° per 0.1 m/s, as indicated in Fig. 8.

(2) As the value of the backboard angle decreased, that of the planting angle increased. The backboard angle and the planting angle showed an inverse relationship. The rate of increase of the value of the planting angle to the decrease in the value of the

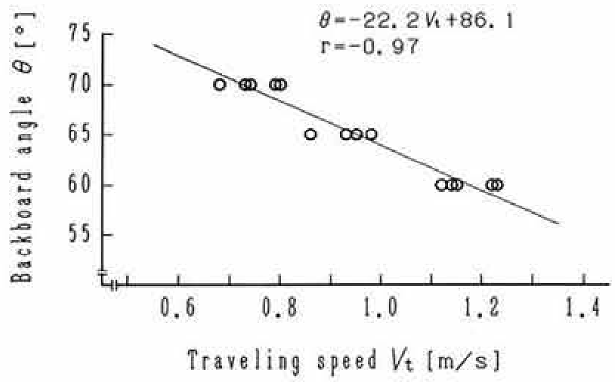

Fig. 8. Relationship between traveling speed and the value of the backboard angle

backboard angle was about 1-2°.

(3) There was no appreciable difference in the values of the planting angles for different soil moisture contents, and there was almost no relationship between them. Also no significant difference in the values of the planting angles for volcanic and alluvial soils was observed.

(4) The standard deviation of the planting angles was within the range of 3-7°. These values are equivalent to that of existing transplanters, confirming that the new transplanter is suitable for practical use. Also, the standard deviation of the planting depth was within the range of 2-6 mm, indicating that the transplanter shows a very high planting accuracy.

(5) Based on the findings outlined in this para graph and the previous one, a traveling speed that enabled the design of the planting device was determined. The following aspects were considered: (a) the angle and the width of furrow openers, (b) flattening of furrow openers and their length, (c) the thickness of furrow openers, (d) the height and angle of drop chute pipes from furrow openers, (e) the release speed of pots and the position of the end of the drop chute pipes in relation to the furrow openers, and (f) the length of drop chute pipes[13].

Performance of the experimental transplanters

1) 2-row transplanter

Tractor-mounted 2-row transplanter was manufactured as reported earlier and its planting accuracy in volcanic loamy and heavy soil fields was tested (Plate 1). The soil type did not affect the planting accuracy. The standard deviation of planting angles was 6.9°, a value slightly higher than that in the experiments reported earlier. The operating speed of the upright planting device was 0.7-0.8 m/s and was different from the design value of 0.95 m/s, presumably due to the difference in the physical properties of the experimental soil, which was subjected to repeated use, and the soil in an actual field. Therefore, it is necessary to decrease the adaptive speed of the furrow opener's backboard by about 0.15-0.20 m/s when designing the working models. The variation of intra-row spacing was equivalent

Plate 1. Tractor-mounted 2-row transplanter

Plate 2. Tractor-trailed 6-row transplanter

to that of the existing models that use rubber discs. The effect on cultivation was acceptable.

Next, experiments were conducted over a period of 5 years in 24 farms covering a total area of 42.1 ha. As a result, it was confirmed that the new models were highly practical, allowing for reduced labor compared with the existing models and showing a high tolerance to various transplanting conditions[14].

2) 6-row transplanter

To accommodate larger fields in European countries and America, a tractor-trailed 6-row transplanter was manufactured (Plate 2). A trailed type was employed, so that the machine may remain in a straight line as it proceeds and maintain a stable planting depth. Also, a semi-mounted mechanism was employed to reduce the turning radius at headlands. The field efficiency was 0.54 ha per hour, and the planting accuracy was as high as that of the 2-row transplanter.

Conclusion

Based on the above data it was concluded that the experimental machines displayed the expected capabilities and that the chain pots, the separating device and planting device were highly useful.

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