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REVIEW

Semiautomatic Planting Machine Based on Physical Properties of the Rush Seedling

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Abstract

The purpose of this study is to develop a planting machine for rush seedlings. In rush seedling production systems, the use of plug seedlings has been widely popularized in Japan. However, the planting operation requires a great deal of labor and takes a long time because a large quantity of seedlings that have a few main stems and a bud are individually picked from the mother plants, and are planted in a tray by manual operations. Therefore, it is desirable to introduce machinery into the planting operation. In this paper, a semiautomatic planting machine was manufactured based on the physical properties of the rush seedling and planting experiments were carried out. The machine mainly consisted of planting unit, tray shifter, controller and air compressor. From the results of planting experiments, the success rate for planting was approximately 90%.

Discipline: Agricultural machinery
Additional key words: seedling production, mechanization

Introduction

The object of this study was to develop a planting machine for rush (*Juncus decipiens* Nakai) seedlings. As a first step of the study, the physical properties of the rush seedling were measured in order to decide the specifications of a machine. Secondly, a planting machine was manufactured based on the measured physical properties of the seedling. Finally, planting experiments were carried out to confirm the effectiveness of the planting machine.

High quality rushes have been produced in some regions in Japan, such as Kumamoto Prefecture, although the production scale has decreased mainly due to the influence of labor shortages and low-priced imports. Rushes have deeply affected the life-style in Japan, they are used as the *tatami* facing, and therefore production systems that can provide high-quality and low-priced rush are desired.

The conventional procedure for producing rush using plug seedlings is as follows: (1) pick seedlings, that have two or three stems and one or two buds individually, from the mother plants; (2) cut each stem to a length of approximately 15 cm and each root to a length of 2 cm or less, respectively; (3) bundle the seedlings and soak their roots in water until an appropriate amount of the seedlings are prepared; (4) plant them in a tray which is filled with soil; (5) transplant the seedlings in the field approximately 50 days after planting. The tray used in this study has 320 cells (10 × 32) and rectangular holes on both sides as shown in Fig. 1. The depth, upper diameter and bottom diameter of a cell are 25, 16 and 13 mm, respectively.

In this process, some workers prepare seedlings and others plant them in the tray when an appropriate amount of seedlings are provided. This means that several workers are required to perform the planting operation. In this study, we have investigated a newly designed rush planting machine. With this machine, as a worker prepares seedlings, he may also carry out planting operation at the same time.

Physical properties of seedlings[1]

1. Shapes

The shapes of seedlings were measured to obtain fundamental data for designing a planting machine.

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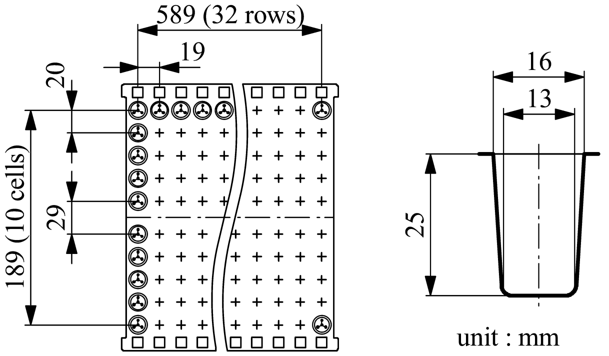

Fig. 1. Dimensions of tray

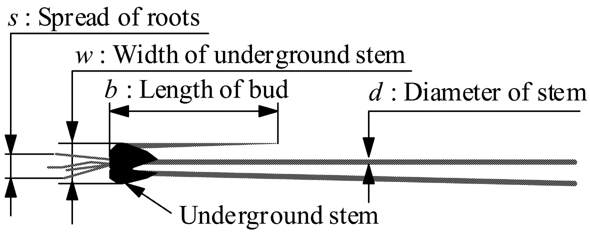

Fig. 2. Measured dimensions of seedling

Table 1. Dimensions of seedlings prepared by the conventional method

Dimension of seedling	Minimum	Maximum	Average
		[mm]	
d	1	2.4	1.7
s	9	35	23.6
w	6	15	9.3
b	5	110	23.5

d : diameter of stem. *s* : spread of roots.
w : width of underground stem. *b* : length of bud.

Fig. 2 shows the measured dimensions of a seedling prepared by the conventional method. Table 1 shows the results of measurements. From the results, the average and maximum values of the spread of roots were 23.6 and 35 mm, respectively. The maximum width of the underground stem was 15 mm, while the diameter of a cell was 16 mm. It was considered that extended roots should be narrowed to less than 15 mm so that seedlings were planted securely. A positioning mechanism was also required so that each seedling was planted into the appointed cell. The maximum length of the bud was 110 mm while the average value was 23.5 mm. A bud should not be grasped directly by mechanical fingers because the growth of a seedling could be prevented if the bud is injured. Therefore, the upper part of a seedling should be grasped at planting time.

2. Dynamic properties

Seedlings should be securely planted in the bottom of a cell without buckling. The 4 items including compressive strength, buckling strength, friction coefficients and penetration resistance were measured to obtain basic data to design a planting machine.

A compression test was carried out in order to investigate the force required to grasp a seedling as shown in Fig. 3-(a). Each stem was compressed by 2 plates 10 mm wide at a speed of 10 mm/min in order to investigate the bioyield point of a rush seedling. This bioyield point is an indication of initial cell rupture in the cellular structure of the material[2]; therefore, a seedling should not be grasped at a force beyond the bioyield point. From the experiment, it was observed that the proper compressive strength for a stem was approximately 2 N. Therefore, the maximum grasping force for an ordinary seedling which had 2 or 3 stems was approximately 4 N when the stems were grasped in parallel to fingers of a mechanical hand. In a preparatory experiment, it was observed that almost all the stems were grasped in parallel to fingers.

In the buckling test, each stem cut into a length of 150 mm was compressed in the axial direction as shown in Fig. 3-(b). From the results, the average buckling force was 1.9 N. In the actual planting operation, the buckling resistance of a seedling can be approximately 4 N because a seedling usually has 2 or 3 stems connected with an underground stem.

In the measurement of the friction coefficients, each

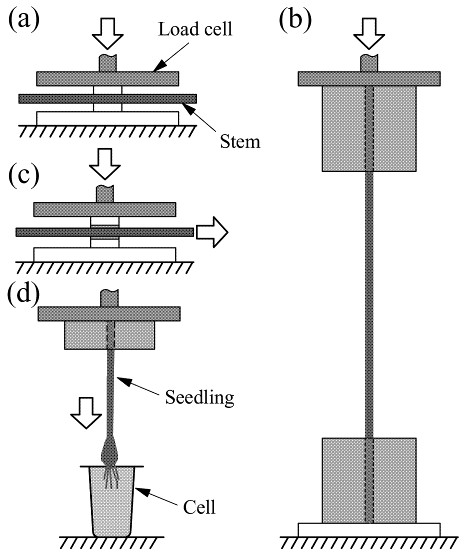

Fig. 3. Measuring methods for mechanical properties of seedling
(a): compression test. (b): buckling test.
(c): measurement of the friction coefficients.
(d): penetration test.

stem was radially compressed at 2 N between 2 plates and was pulled in the axial direction as shown in Fig. 3-(c). Three materials including aluminum, sponge, and rubber were pasted on the plates. From the results, the friction coefficients between stems and aluminum, sponge, or rubber were 0.48, 1.26, and 1.59, respectively.

The resistance when a seedling penetrated into the soil of a cell was measured in order to investigate the force required to plant a seedling in the bottom of a cell whose depth was 25 mm, as shown in Fig. 3-(d). Seedlings that had 2 stems and 10 mm length roots were employed in this test. From the results, the average penetration resistance was 4.3 N.

Mechanical planting method

In this chapter, a planting mechanism is described. From the compression test, the appropriate grasping force for a stem is approximately 2 N; therefore, a grasping force of approximately 4 N can be applied to a seedling with two stems. From the buckling test and the measurement of penetration resistance, the force necessary to plant a seedling with two stems in a cell without injury and buckling is approximately 4 N. It is desirable to grasp stems with as small a force as possible so that stems are not injured. In other words, it is desirable to employ a material that has a high friction coefficient for gripping a seedling. From the results of the measurement of the friction coefficients, the friction coefficient between stems and rubber was 1.59. When rubber is pasted on fingers, the necessary grasping force for a seedling is approximately 2.5 N in order to plant the seedling in a cell. A seedling slips from the rubber when an axial force more than 4 N is applied. This means that a seedling can be planted in a cell without buckling.

Next, a planting machine is desired to have a mechanism to plant a seedling in the target cell accurately. It is difficult to plant a bent seedling of 15 cm long in a cell whose diameter is 16 mm by mechanical fingers that move down toward the cell. Therefore, a positioning device to guide the center of a seedling to the center of a cell is required.

In this study, the planting mechanism shown in Fig. 4 was employed. The mechanism mainly consisted of 2 fingers and 2 pipes of different diameter. The outer pipe, with a hole of 15 mm diameter at its tip, freely slid along the inner pipe. A pair of fingers that grasped a seedling moved downward. The mechanism prevented the seedling from buckling by slipping the stems from the fingers when the force over the set value was applied to the seedling.

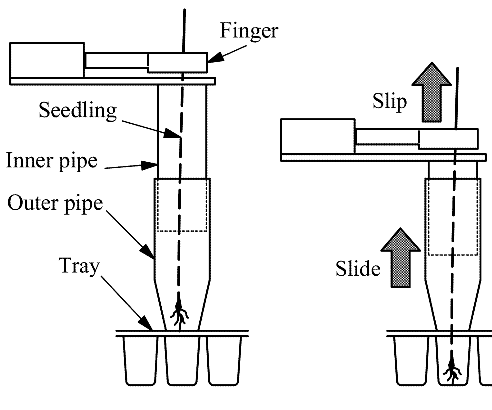

Fig. 4. Planting mechanism

Planting machine[3]

Fig. 5 and 6 show the planting machine manufactured based on the physical properties of the rush seed-

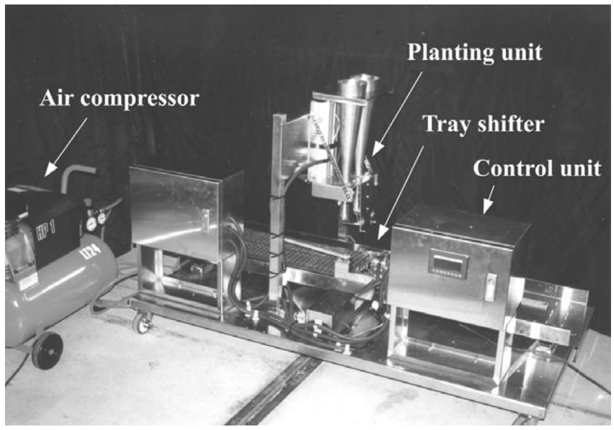

Fig. 5. Planting machine

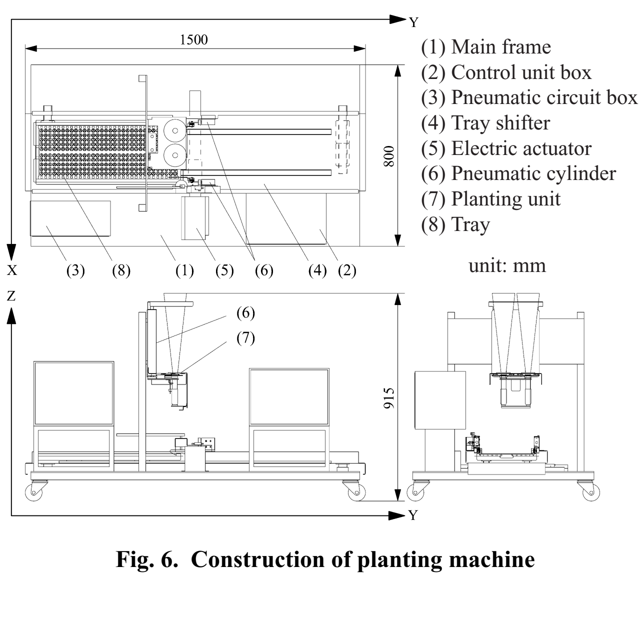

Fig. 6. Construction of planting machine

ling. The machine mainly consisted of planting unit, tray shifter, control unit and air compressor. The dimensions of the machine was 1,500 mm long, 800 mm wide, and 915 mm high, excluding the air compressor.

The planting unit shown in Fig. 7 mainly consisted of pneumatic cylinder, hoppers, pneumatic hands, photo sensors, planting pipes and shutter. Two pairs of pneumatic hands and planting pipes were mounted on the end plate which was attached to the piston rod of the cylinder, therefore 2 seedlings were planted at a time.

A seedling placed into the hopper was stopped at the shutter after passing through the planting pipe. The shutter started to open as the piston rod descended, though the hole on the pipe tip was covered with the shutter when the piston rod ascended to the top of the stroke because the shutter was pulled by a chain connected to the end plate. The photo sensors were mounted on the upper side of each pipe in order to detect the seedling. The width of the sensor element was 30 mm and the minimum width of the detecting object was 0.3 mm. Fig. 8 shows the pneumatic hand used to grasp a seedling. U-shaped plates were attached to the fingers. The center of a seedling corresponded to the center of a cell when the fingers closed. This mechanism prevented a seedling from tilting at planting time. Rubber sheets were attached to the fingers and the grasping force was adjusted to 2.5 N, based on the results of the dynamic properties of the seedling. The fingers grasped at the position 100 mm above the bottom of the seedling, therefore the buds were not injured by the mechanical contact.

Fig. 9 shows the planting procedure used by the machine. (1) Two pairs of pneumatic hands attached to the end plate grasped seedlings and moved down as soon as both the photo sensors detected individual seedlings in the planting pipes. (2) The shutter started to open as the piston rod descended. (3) The planting pipes slid as soon as their tips came in contact with the tray, and the seedlings were planted in the target cells. The seedling slipped from the fingers when the force over the set value was applied to the seedling. The mechanism was capable

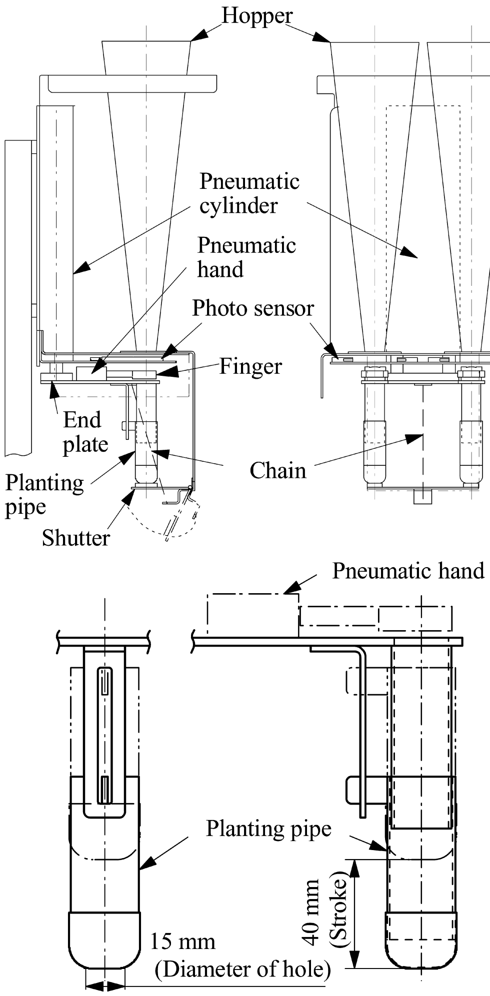

Fig. 7. Planting unit

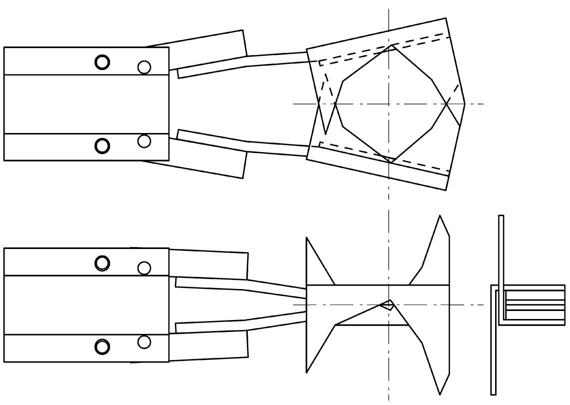

Fig. 8. Pneumatic hand

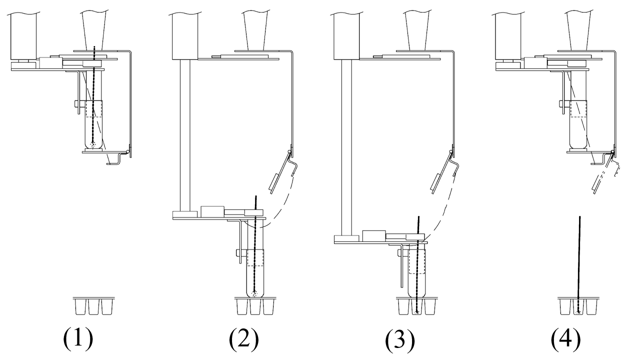

Fig. 9. Planting procedure

(1) Pneumatic hands grasp seedlings and move down; (2) shutter starts to open; (3) seedlings are planted in the target cells; (4) shutter closes and the tray is shifted the next position.

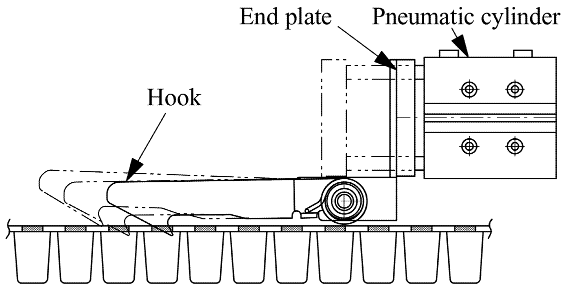

Fig. 10. Shift of tray

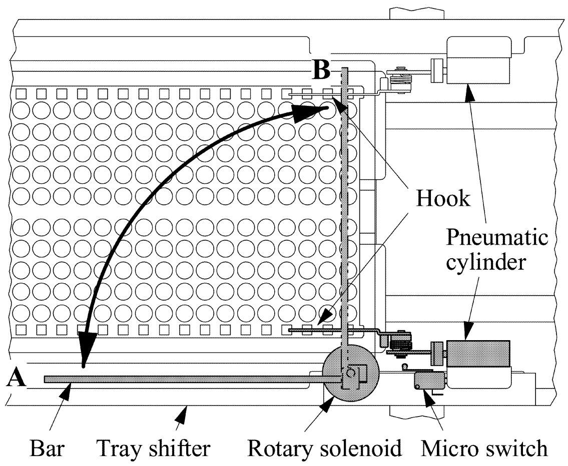

Fig. 11. Mechanism to arrange posture of seedlings

of planting the seedlings into the tray at a fixed depth. The fingers opened to release the seedlings when the piston rod moved to the bottom of the stroke. (4) The shutter started to close as the piston rod ascended and then the tray was shifted to the neighboring cell position. The tray was shifted to the next row after 10 seedlings were planted. The time required to finish the procedures from (1) to (4) was approximately 1 s. Therefore, an improvement in work performance by using the machine can be expected because it takes approximately 3 s to plant a seedling by a human worker.

An electric actuator shifted the tray in the X-axis direction (Fig. 6) at intervals of 20 mm. The shift in the Y-axis direction (Fig. 6) was carried out by 2 pairs of pneumatic cylinders installed on both sides of the tray shifter (Figs. 10 & 11). Two pairs of hooks attached to the piston rod tips shifted the tray by hitching to holes on both sides of the tray when the piston rods moved back and forth.

It was difficult to plant a seedling successfully when seedlings in the neighboring cells expanded and tilted. Therefore, a device to arrange the posture of already planted seedlings was mounted on the tray shifter as shown in Fig. 11. The device consisted of rotary solenoid, bar and micro switch. The bar was located at the position A until 10 seedlings were planted. The piston rod moved forward to shift the tray after 10 seedlings were planted. The bar rotated from the position A to the position B when a lever of the micro switch was pushed by the end plate because the electric power was supplied to the rotary solenoid through the micro switch. The posture of seedlings that were planted over the neighboring row was arranged by this action. The bar returned to the initial position as the piston rod went back. This process was repeated whenever 10 seedlings were planted.

A programmable controller with a display was employed to control the machine. An air compressor was used for the primary drive to activate the pneumatic cylinders and hands. The maximum pressure, the rate of flow and the capacity of the air tank were 0.8 MPa, 130 L/min and 24 L, respectively.

Planting experiments

1. Experiment 1

A planting experiment was carried out to evaluate the performance of the planting machine. Two hundred and thirty seedlings were employed in the experiment since the tray had the same number of cells. Each stem was cut to a length of 15 cm and its roots were cut to less than 2 cm, respectively. The tray which was filled with soil was soaked in water for 15 min. The soil used in this study was a mixture of clay and forest soil. The experiment was started 25 min after the tray was removed from the water.

Table 2 shows the results of the planting experiment. From the results, 89.1% of seedlings were planted successfully. Twenty-two seedlings, which were planted obliquely or had extended stems, were pulled up or were brought down when a neighboring seedling was planted. Two seedlings were not planted in the cells because adjacent seedlings, which were planted obliquely or whose stems spread out, obstructed planting. This means that the posture of already planted seedlings are influencing the success of planting considerably. The bar rotated by the solenoid was able to arrange the posture of a set of 10

Table 2. Results of experiment 1

State of seedling after planting	No. of seedling
Planted	285 (89.1%)
Pulled up	22 (6.8%)
Obstructed before arriving at pipe	6 (1.9%)
Obstructed by other seedlings	2 (0.6%)
Others	5 (1.6%)
Total	320 (100%)

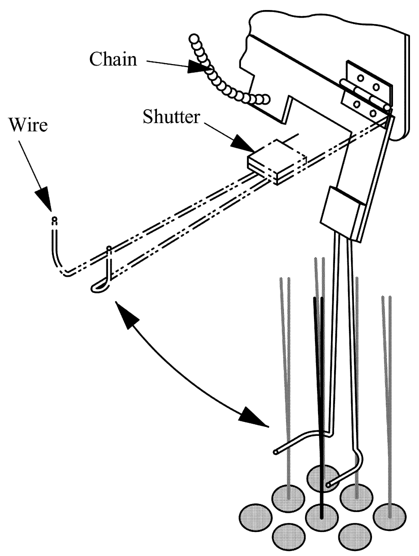

Fig. 12. Mechanism to secure the seedling path

seedlings, however, the posture of each seedling in the same row was not arranged. Therefore, it was considered that a mechanism to secure the space where the planting pipe passed would be required. Six seedlings did not pass through the planting pipe because of their wide roots and extended stems. In order to further raise the success rate of the mechanical operation, the seedling shape and size should be standardized.

2. Experiment 2

To solve the problem that the success rate was influenced by the seedling posture, a device shown in Fig. 12 was added to the planting machine and tested. The device was attached to the shutter which opened and closed synchronizing with the vertical motion of the planting pipe. The crooked wires descended over the target cell before the planting pipe came down in order to secure the path of a seedling to be planted. The wires ascended to the initial position as the planting pipe went up.

Table 3 shows the results of the second planting experiment. From the results, 92.8% of seedlings were planted successfully. The number of seedlings, that were pulled up when a neighboring seedling was planted, decreased to 2 by using the mechanism to secure the path of the seedling pipe, although there were 22 seedlings pulled up in planting experiment 1. However, 9 seedlings were flicked away when the crooked wires ascended to the initial position because their expanded stems could not pass through the space between 2 wires. To solve this problem, it was considered that planting 10 seedlings at a time could be effective because interference between neighboring seedlings in the same row might be eliminated[4].

Table 3. Results of experiment 2

State of seedling after planting	No. of seedling
Planted	297 (92.8%)
Pulled up	12 (3.7%)
Obstructed before arriving at pipe	5 (1.6%)
Obstructed by other seedlings	1 (0.3%)
Others	5 (1.6%)
Total	320 (100%)

Conclusion

The planting machine for rush seedlings was manufactured based on the physical properties of the seedling and planting experiments were carried out. From the results, the success rate was approximately 90%. It was considered that the planting mechanism of using fingers and sliding pipes was effective for planting the seedling without buckling, and that the success rate was influenced by the posture of the seedling. In order to further raise the success rate of the mechanical operation, the method of seedling preparation, including the bend and spread of stems, and the spread and length of roots, should be standardized.

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