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A Planting Machine for Chrysanthemum Cuttings with a Supply Mechanism Using Rotating Cups

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Abstract

The purpose of this study was to mechanize the task of planting chrysanthemum cuttings in plug trays. Seedling production using these trays is common in Japan to produce high-quality chrysanthemums, other flowers, and vegetables. However, chrysanthemum cuttings must be planted manually, which takes considerable time. Two models of planting machines suitable for chrysanthemum cuttings have been developed: a standard model for cuttings with no lower leaves, and a model that automatically removes the lower leaves. Both models are semi-automatic and employ a mechanism using rotating cups to facilitate a supply task of an operator and let two operators work side by side. In our laboratory and field experiments, the standard model had a failure rate of 0.5–3.1% and increased the maximum work efficiency to 2.4 times that of manual planting. The model that removed lower leaves had a failure rate of 0.8–4.5%, but also increased maximum work efficiency to 2.4 times that of manual planting. Although both models are influenced by individual supply variations from the workers, we believe they are ready for commercial use.

Discipline: Agricultural machinery
Additional key words: automation, lower-leaf removal, unsuccessful planting, work efficiency

Introduction

Chrysanthemum is one of the most commercially important flowers. Shipments in Japan in the 2003 fiscal year amounted to 1.94 billion flowers, requiring a production area of 5,953 ha[10]. The total number of working hours to produce a chrysanthemum is 3,770 to 5,240 h/ha, and cutting production accounts for 11.8 to 19.3% of this total[11]. Therefore, mechanization of cutting production has been strongly desired by the chrysanthemum industry.

Vegetatively propagated plants, such as chrysanthemums, geraniums, and carnations, are propagated by means of cuttings from a parent plant. Each cutting is planted in soil or sand after a chemical treatment to promote rooting. These operations are monotonous and require considerable time and labor. Several studies have been conducted on automated cutting production. For example, a robotic system using a machine-vision subsystem was developed to facilitate the cutting operation for geraniums[7,9], and an end-effector was designed to handle a wide range of geranium cuttings, with only slight indications of damage to the cuttings[8]. For chrysanthemums, studies have been conducted in Japan on the development of a planting robot that uses an articulated manipulator[4]. Kondo et al. developed a machine-vision algorithm capable of detecting a suitable point of attachment on chrysanthemums[2,3], and Monta et al. designed a leaf-removing device[5] and a planting device[6]. Although this series of studies demonstrated the feasibility of an automated operation for planting cuttings, the machines performances were not satisfactory. Subsequently, Hayashi et al. designed a mechanism for the removal of lower leaves that uses rotating brushes and V-shaped plates and used this mechanism to develop a prototype planting machine for chrysanthemum cuttings[1]. For the machine to be practical for use by farmers and cutting producers, however, several improvements were required in the supply mechanism and in the scale and weight of the machine.

In the current study, we designed a supply mechanism that uses rotating cups to improve work efficiency,

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and developed two models of planting machine based on this innovation: a standard model and a model designed to automatically remove lower leaves. Both models are semi-automated, and an operator is required to supply cuttings to the rotating cups. The standard model handles cuttings whose lower leaves have already been removed manually by the operator. The second model is similar, but includes a module that removes the lower leaves mechanically. We studied the performance of both models in the laboratory and in the field using several cultivars of chrysanthemum.

Materials and methods

1. Standard planting machine model

The standard model handles chrysanthemum cuttings with no lower leaves. This model comprises a supply unit, a planting unit, a conveyer for the plug tray, and a controller (Figs. 1 & 2); the specifications are provided in Table 1. The machine is compact and lightweight (90 kg), and can be used anywhere that a 100 VAC electrical supply is available.

The standard model is a semi-automatic machine: the operator supplies the cuttings to the machine, with rotating cups employed to facilitate this supply task. The operator simply places a cutting in the next available empty cup. The rotation speed of the cups can be adjusted in four steps to match the speed of the manual supply of cuttings; the resulting planting speed ranges from 2,000 to 5,200 cuttings/h. The current model uses 50 cups, whose shape is illustrated in Fig. 3. The top diameter and height are 46 and 82 mm, respectively, and the bottom of the cup is tapered to a point to guide the cutting's bottom into a vertical position. The supply mechanism for the rotating cups provides enough space for two operators to work, and two alternating cup colors are used so that one operator can place their cuttings in the white cups while the other operator uses the red cups.

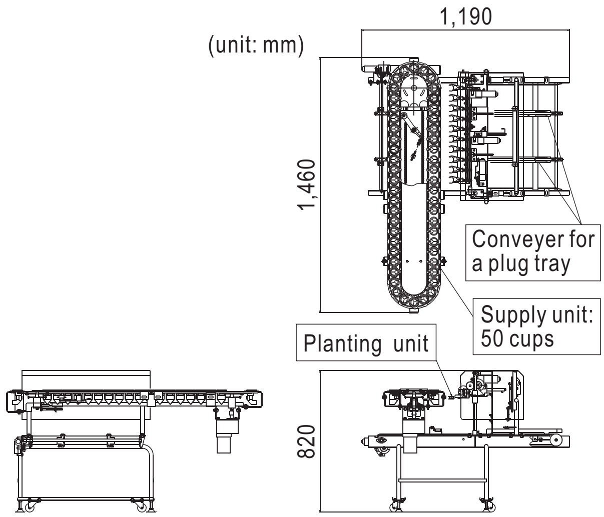

Fig. 1. Schematic diagram of the standard model of the planting machine

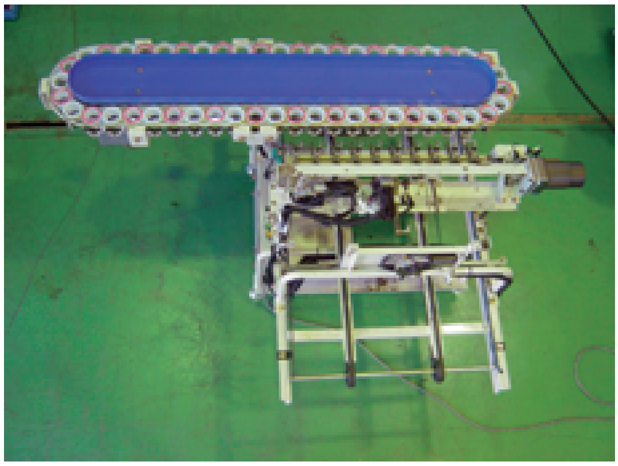

Fig. 2. A photograph of the standard model

Table 1. Specifications for two planting machines

	Standard model	Model with a leaf-removal unit
Dimensions	1,190(L)×1,460(W)×820(H) mm	1,130(L)×2,320(W)×1,225(H) mm
Mass	90 kg	250 kg
Electrical power required	150 W	Main, 400 W; Air compressor, 1,500 W
Supply unit	50 rotating cups	38 rotating cups
Leaf removal unit	–	Brush, V-shaped slit, Hand for grasping stem
Planting unit	10 planting fingers	10 planting fingers
Planting speed	4 steps (2,000 to 5,200 cuttings/h)	Continuously variable speed (0 to 3,000 cuttings/h)
Planting depth	20–30 mm	20–28 mm
Type of plug tray	200-cell plug tray	200-cell plug tray

The tip of the cutting slides to the bottom of the cup as the cup rotates, and 10 planting fingers grasp cuttings and remove them horizontally from the cup as the cups move above the plug tray. The 10 cuttings are then centered over plugs in the tray by the planting fingers and are planted into the plugs simultaneously. The planting motion is represented by the bold arrows in Fig. 4. Two planting motions are thus required to fill a single longitudinal row (20 plugs) in a plug tray (Fig. 5). The machine has two planting modes: a single-action and a double-action mode. In the single-action mode, the planting fingers insert the cuttings into the substrate only once; in the double-action mode, the planting fingers grasp the upper part of the stem a second time and press down again to insert the cutting more deeply and securely into the substrate. Planting depth can be adjusted between 20 and 30 mm to accommodate different sizes of cutting.

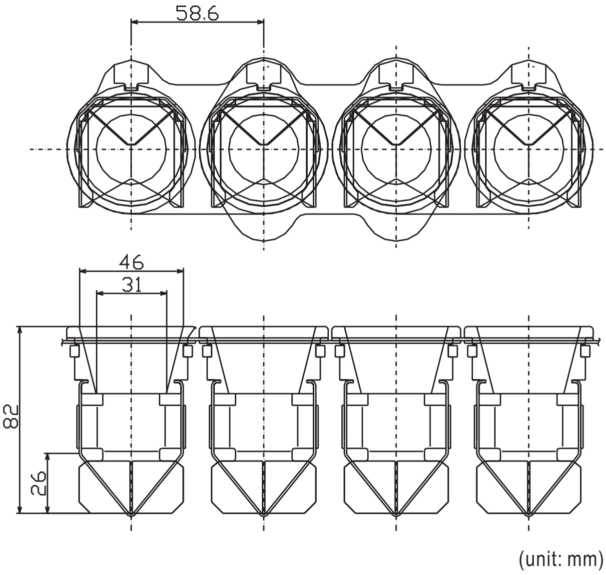

Fig. 3. The rotating cups used in the standard model

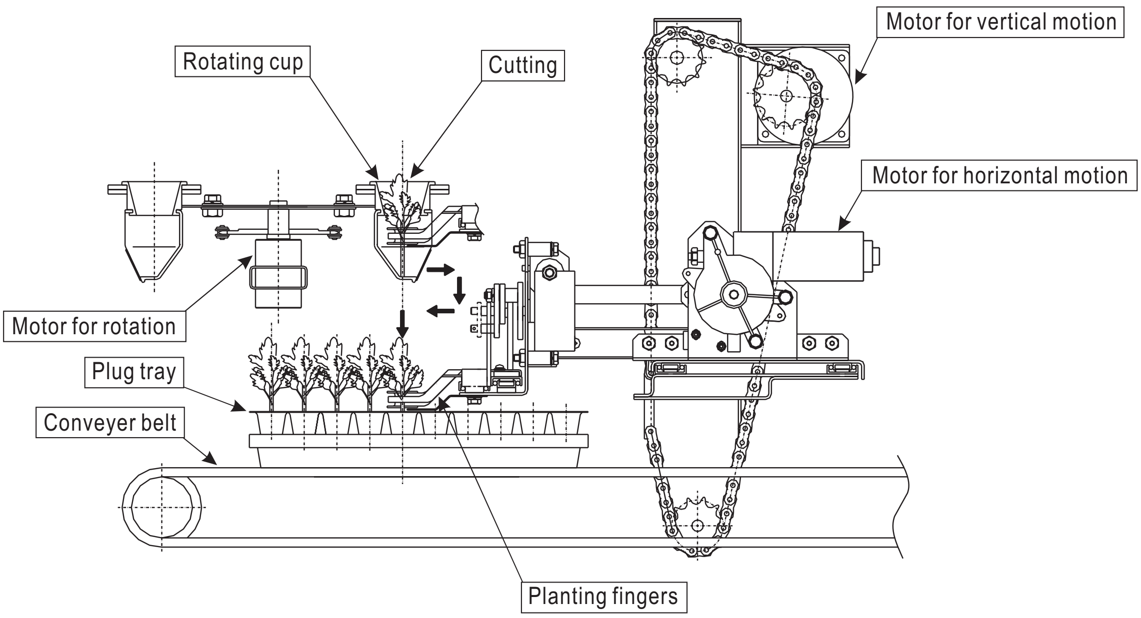

Fig. 4. The planting mechanism used by the standard model

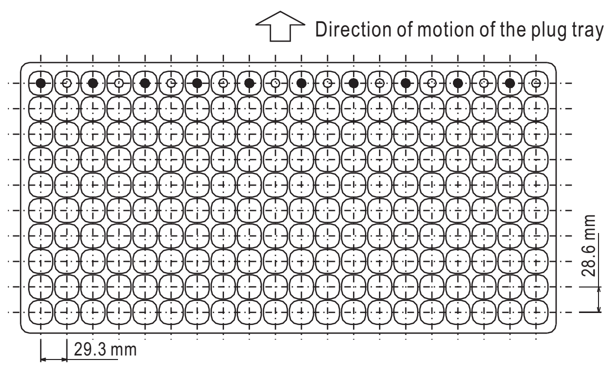

Fig. 5. The order of planting into the plug tray

Cells labeled ● are planted in the first motion.
Cells labeled ○ are planted in the second motion.

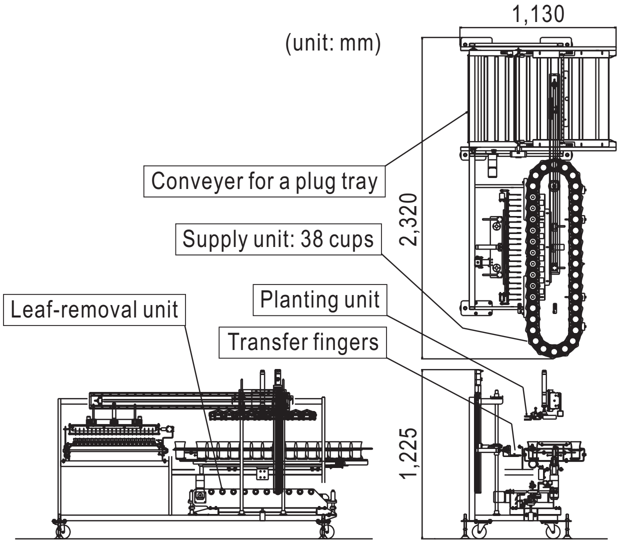

Fig. 6. Schematic diagram of the model of the planting machine with a leaf-removal unit

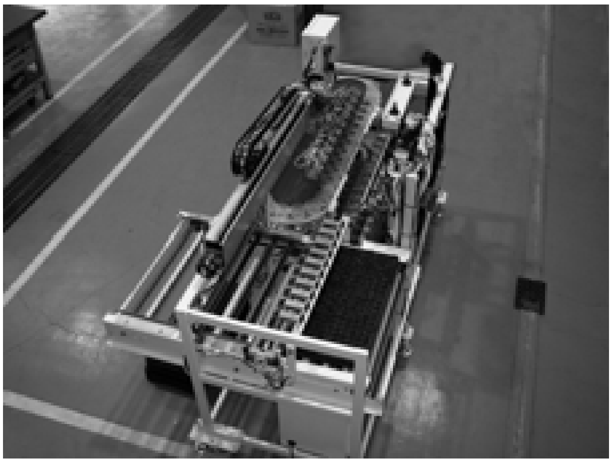

Fig. 7. A photograph of the model with a leaf-removal unit

2. Planting machine that removes lower leaves

The second model also comprises a supply unit, a planting unit, a conveyer for the plug tray, and a controller, but adds a leaf-removal unit (Figs. 6 & 7). Its specifications are provided in Table 1. The most remarkable feature of this version of the planting machine is the mechanism for removing lower leaves, which was developed in a previous study[1]. The use of precision parts were required to perform the complicated motions involved in removing the lower leaves of chrysanthemums, so pneumatic devices were used. As a result, the machine became larger and heavier than the standard model (Table 1) and required the use of an air compressor and 100 VAC power supply.

The same supply mechanism (rotating cups) used in the standard model was used in this second model. However, the rotation speed of the cups can be adjusted by means of a variable-speed motor, and the planting speed can thus be varied continuously from 0 to 3,000 cuttings/h. The maximum planting speed is slower than in the standard model (3,000 vs. 5,200 cuttings/h) because of the time consumed by removal of lower leaves, which requires a multiple-pass process for the mechanical fingers. In addition, the number of the cups was decreased to 38, and the cup shape was changed slightly, as shown in Fig. 8. The top diameter and height of the cups are 77 and 117 mm, respectively. The cups, which are filled by the cutting, rotate above the lower-leaf removal unit. Transfer fingers then grasp the cutting and pass it to the leaf-removal unit. Lower leaves are removed by an up-and-down motion and 180-degree spin, by rotation of the brushes, and by an open-and-close motion of the V-shaped slits that surround the stem (Fig. 9). The cutting then passes from the transfer fingers to planting fingers

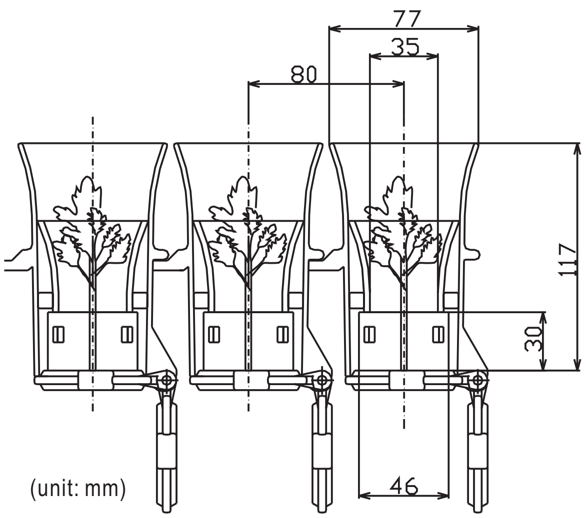

Fig. 8. The rotating cups used in the model with a leaf-removal unit

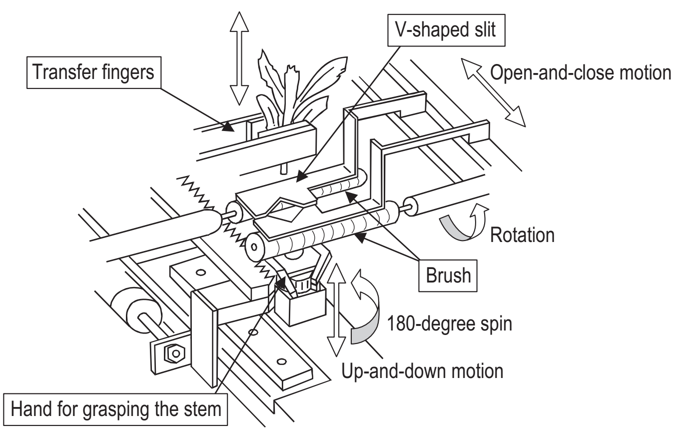

Fig. 9. Schematic diagram of the leaf-removal unit

and is carried horizontally to a position above the plug tray. The cutting is then centered by centering fingers (Fig. 10), then planted in the same manner as in the standard model. The planting motion is represented by the bold arrows in Fig. 10. This model has only a single-action mode, but it can be adjusted to planting depths ranging from 20 to 28 mm.

3. Performance experiments

We conducted a laboratory experiment to test both models in the laboratory using the following chrysanthemum cultivars: ‘Jimba’, ‘Hikaru’, ‘Shiramizu’, ‘Miyabi’, ‘Kinshu’, ‘Prince’, and ‘Shuho’. The goal was to evaluate performance in terms of the failure rate, work efficiency, planting depth, and (for the leaf-removal model) number of leaves removed in one-operator and two-operator work. Each experiment used 600 cuttings, whose properties are shown in Table 2. The length of each cutting was approximately 60 mm, except for ‘Prince’, which was closer to 80 mm long. The ‘Prince’ cultivar can be considered typical of the general size used in conventional manual planting operations. The stem diameter varied among the cultivars; ‘Kinshu’ was thickest (around 4.3 mm), and ‘Shiramizu’ and ‘Shuho’ were thinnest (around 2.7 mm). In the experiment with the standard model, we compared cuttings that retained their lower leaves and cuttings whose lower leaves had been removed in advance, since some producers use both types of cutting.

We also performed a field test of both models using the ‘Jimba’ and ‘Hikaru’ cultivars to evaluate their long-term performance. We measured the same performance factors as in the laboratory experiment. We also examined the overall performance of the standard model when the operator supplied cuttings after manually removing their lower leaves to determine whether this mode of operation was practical. The planting speed was changed during the experiment to match the operator’s supply speed.

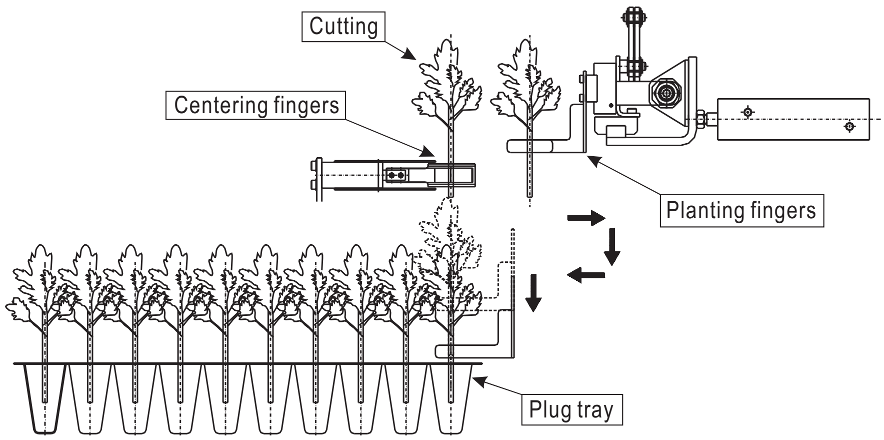

Fig. 10. Schematic diagram of the planting mechanism in the model with a leaf-removal unit

Table 2. The properties of the cuttings used in the experiment

Cultivar	Length (mm)	Width (mm)	Stem diameter (mm)	No. of leaves
‘Jimba’	64.2±3.2	52.6± 7.6	3.48±0.32	5.3±0.5
‘Hikaru’	62.8±3.6	67.3±11.0	3.23±0.27	4.0±0.4
‘Shiramizu’	56.2±3.8	57.3±11.1	2.72±0.23	5.1±0.6
‘Miyabi’	55.2±3.1	53.7± 9.2	2.75±0.31	5.1±0.7
‘Kinshu’	59.5±4.8	68.6± 8.1	4.30±0.69	4.1±0.6
‘Prince’	80.0±5.5	57.3±11.1	3.40±0.45	4.4±0.7
‘Shuho’	54.5±4.9	60.6± 8.4	2.71±0.27	4.3±0.6

Results and discussion

1. Laboratory experiment

The results of the laboratory experiment with both models are shown in Table 3. The failure rate with the standard model ranged from 0.5 to 2.7%. Failure occurred during the planting process and was mainly caused by bending of the cutting's tip. The state of the lower stem (i.e. whether or not the lower leaf had been removed) did not influence the failure rate. In other words, there was little or no difference in penetration resistance between cuttings with and without their lower leaves. The work efficiencies in one-operator and two-operator work were approximately 3,000 and 1,900–2,500 cuttings/h/person, respectively. The maximum work efficiency was thus estimated at about 2.4 times that observed in manual planting without removal of lower leaves, which averaged about 1,250 cuttings/h/person. Planting depth was slightly less than the setting value. The main cause of the shallow planting was bending of the cutting's bottom.

The failure rate on the model that removes lower leaves ranged from 0.8 to 4.5%. This performance was worse than that of the standard model because of additional losses in the leaf-removal unit. The work efficiency in one-operator work and two-operator work was approximately 2,400 and 1,500 cuttings/h/person, respectively. The maximum work efficiency was thus estimated

Table 3. The results of the laboratory experiment

Model	Cultivar	No. of operators	Setting for planting depth (mm)	State of lower leaf	No. of cuttings used	Failure rate (%)	Work efficiency (cuttings/h/person)	Planting depth (mm)*	No. of leaves removed (leaves/cutting)*
Standard model	'Jimba'	1	20	Present	600	1.2	3,030	18.3±1.3	
	'Jimba'	1	20	Removed	600	0.5	3,020	18.8±1.7	
	'Jimba'	2	20	Present	600	0.5	1,900	17.2±2.1	
	'Jimba'	2	30	Present	600	2.0	2,480	28.8±3.4	
	'Jimba'	2	30	Removed	600	1.8	2,480	29.2±3.4	
	'Hikaru'	1	30	Present	600	1.0	2,910	28.4±2.5	
	'Hikaru'	1	30	Removed	600	2.3	2,890	28.9±2.5	
	'Shiramizu'	1	20	Removed	600	2.2	3,030	17.3±1.8	
	'Miyabi'	1	20	Present	600	2.7	2,910	15.8±2.8	
	'Kinshu'	2	30	Removed	600	2.3	2,490	25.8±4.2	
Model with a leaf-removal unit	'Jimba'	1	22	Present	600	1.0	2,350	20.8±1.7	0.7±0.5
	'Prince'	1	22	Present	600	0.8	2,360	21.6±1.5	0.4±0.5
	'Prince'	2	22	Present	600	0.8	1,490	20.5±1.5	0.6±0.5
	'Shiramizu'	1	22	Present	600	4.5	2,370	20.3±2.4	1.2±0.7
	'Miyabi'	1	22	Present	600	4.3	2,360	20.3±1.8	0.3±0.5
	'Shuho'	1	22	Present	600	3.8	2,370	20.6±1.9	1.0±0.3

*: 30 samples, average±standard deviation.

Table 4. The results of the field experiment

Model	Cultivar	No. of operators	Setting for planting depth (mm)	State of lower leaf	No. of cuttings used	Failure rate (%)	Work efficiency (cuttings/h/person)	Planting depth (mm)**	No. of leaves removed (leaves/cutting)**
Standard model	'Jimba'	2	30	Removed	2,200	0.9	1,370	30.8±2.7	
	'Hikaru'	2	28	Removed	2,200	2.0	1,730	–	
	'Hikaru'	2	28	Present*	9,400	3.1	1,300	25.9±3.7	
Model with a leaf-removal unit	'Jimba'	1	28	Present	14,000	1.3	2,260	26.0±2.8	0.5±0.6
	'Jimba'	2	28	Present	2,000	1.5	–	–	–

*: Operator removes lower leaves and supplies cuttings.
**: 30 samples, average±standard deviation.

to be about 2.4 times that observed in manual planting with removal of lower leaves, which averaged about 1,000 cuttings/h/person. The number of leaves removed ranged from 0.3 to 1.2 per cutting, and it was difficult to remove the leaves of the 'Miyabi' and 'Prince' cultivars, whose leaves were wide and erect. Because the same trends were observed in a previous study[1], the leaf-removal mechanism employed in this study seems to be less-well suited to such cultivars. Planting depth was again slightly less than the setting value. The main cause of the shallow planting was also bending of the cutting's bottom.

Throughout the experiments, the operator was easily able to supply cuttings into the cups when the cuttings were placed close at hand near the rotating cups. In two-operator work, cooperative work could be smoothly carried out by using cups with two different colors.

2. Field experiment

The results of the field experiment with both models are shown in Table 4. The failure rate for the standard model was slightly higher than in the laboratory (0.9–3.1%). The work efficiency also decreased compared with the laboratory results, to between 1,300 and 1,730 cuttings/h/person, largely because the inexperienced operator tended to adjust the machine to a slower planting speed or stopped the machine frequently during operation. The work efficiency decreased from 1,730 to 1,300 cuttings/h/person when operators were required to remove lower leaves of 'Hikaru'. The planting depth of 'Hikaru' was also slightly less than the setting value, whereas for 'Jimba' the depth was almost the same as the setting value.

With the model that removed lower leaves, the failure rates were 1.3 and 1.5% for 'Jimba', and these values fell within the range in the laboratory experiment. The work efficiency and number of leaves removed were approximately 2,300 cuttings/h/person and 0.5 per cutting, respectively. The planting depth was slightly less than the setting value, as in the laboratory experiment.

The performance of both models in the field experiment for long-term operation showed almost the same results as in the laboratory experiment. We judged that the performance of both machines would thus satisfy a producer's demands because of the low failure rate and the high work efficiency (roughly 2.4 times that of manual operations). Furthermore, we observed that the following workflow was effective. First, large numbers of cuttings are prepared on a table placed next to the rotating cups after chemical treatment of the cuttings with rooting promoters. Second, the operator supplies the rotating cups with cuttings to fill a plug tray. Third, the operator or another worker removes the filled plug tray and checks for fallen cuttings; these cuttings can be replaced or replanted manually. Finally, the planted trays are placed in a greenhouse.

We observed that 'Hikaru', which is planted by the standard model, rooted more than 25 mm and formed a satisfactory root ball 15 days after planting. The rooting and growth of the cuttings planted by both models were by no means inferior to the cuttings planted manually.

Conclusions

We developed two models of planting machine for chrysanthemum cuttings and conducted laboratory and field experiments to test their performance. The standard model had a failure rate of 0.5–3.1% and a maximum work efficiency of 2.4 times that of manual planting. The model that removed lower leaves had a failure rate of 0.8–4.5% and a maximum work efficiency of 2.4 times that of manual planting; the number of leaves removed ranged between 0.3 and 1.2 per cutting. The supply mechanism that used rotating cups helped operators to facilitate the supply task and resulted in good work efficiency, although the machine's performance tended to be influenced by supply variations among workers. Consequently, we believe that the two models of planting machine developed in this study have now reached a stage at which they are suitable for operational use. This technology would play a role in improving work efficiency and the production of high-quality cuttings in plug trays and establishing a more mechanized work system. Furthermore, it should contribute to strengthening the competitive power of farmers in international markets in the context of increasing globalization of flower culture.

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