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Irrigation System for a Roller-Type Onion Pot Seeding Machine

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Abstract: An irrigation system for roller-type onion pot-seeding machines was developed. It is a drip-type and can be installed easily to the existing roller-type onion pot-seeding machines by its modular design. The components were selected to satisfy the required irrigation conditions for onion seeding. The operating condition was determined from a factorial experiment. A verification test was conducted and the result showed that the irrigation system developed made a significant positive contribution to the growth of onion seedlings.

Keywords: agricultural machine; irrigation system; onion pot-seeding machine; roller type

1. Introduction

As the consumption of onions has been increasing worldwide, the onion cultivation area has increased by about 4 times, from 2,403,700 ha to 9,464,473 ha, from 1994 to 2014. In addition, onion production has more than doubled, from 38,902,195 tons to 88,694,456 tons for the same period [1]. As the demand for onion is expected to grow continuously in the future, cultivation methods that can improve the efficiency and productivity need to be researched.

In China, the global leader in onion production, onions are seeded and cultivated in pot trays and then transplanted to the field [1,2]. The production per unit cultivation area as of 2014 is 22.19 t/ha. In India, the second-largest producer of onions next to China, onion seeds are directly sown and cultivated in the field by manpower [3]. The production per unit cultivation area as of 2014 is 16.12 t/ha. In order to increase the production efficiency, a preferable method is to cultivate high-quality seedlings in pot trays and transplant them to the field.

The mechanical pot-seeding machines are suitable for sowing onion seeds in pot trays efficiently, because they consume less manpower and demonstrate a high work capacity [4]. They are classified into the roller type and the vacuum nozzle type, depending on the operating method. The roller type is more suitable for general use in various countries including developing countries, because it is less expensive and more durable than the vacuum nozzle type [5,6]. However, it has a disadvantage that the watering should be performed after sowing by manpower because it does not comprise an irrigation system. Watering by manpower cannot produce uniform irrigation, and the germination period may be long, if sufficient water is not supplied earlier after sowing [7,8]. Therefore, it is necessary to develop an irrigation system capable of uniform watering in order to eliminate manpower and improve the germination conditions.

In agricultural applications, the irrigation systems are typically categorized into three types: sprinkler, drip, and spray type. The sprinkler type is used to supply a large quantity of water in a short time. Therefore, this type is mainly used in the greenhouses to control the temperature and humidity. The spray type can irrigate a specific area uniformly. The water is sprayed through the nozzle installed to the high-pressure spraying device, and mobile watering is possible by the rail and

traction device. The drip type supplies water by dropping an appropriate amount of water. Among all the types, it uses the smallest amount of water, and location-specific watering is possible even at a low pressure. This can prevent the loss of soil and fertilizer caused by high watering pressure. The spray and drip types have been used in the irrigation system of pot-seeding machines of various vegetables (except for onion). The spray type is especially used for nursery plants in a large facility, due to its characteristics of uniform irrigation on a relatively large area [9]. The drip type is mainly used for small-size mechanical pot-seeding machines because of the low water usage [10].

In this study, we developed a highly effective drip-type irrigation system for the roller-type onion pot-seeding machine. The system has a sufficient and uniform watering when seed positions do not change and bed soil loss does not occur. Also, it is small and modular, so that it can be easily attached to and detached from the existing roller-type onion pot-seeding machines, for usability.

2. Materials and Methods

2.1. Structure of Existing Roller-Type Onion Pot-Seeding Machine

The roller-type onion pot-seeding machine consists of an auto-feeding device, hoppers, rollers, a seeding device, and a power source [6]. The shapes and main specifications are shown in Figure 1 and Table 1, respectively. The operational procedure is as follows: when the pot trays are supplied in succession from an auto-feeding device, the bed soil is fed to them by the hoppers (Hopper-1 and Hopper-2). Then, the bed soil is compressed by the rollers (Roller-1, Roller-2, and Roller-3), seeds are sown by the seeding device, and covering is performed by the covering hopper (Hopper-3). The operation of the roller-type onion pot-seeding machine is completed with two bed soil inputs, one seeding, and one covering. It has no inbuilt irrigation system.

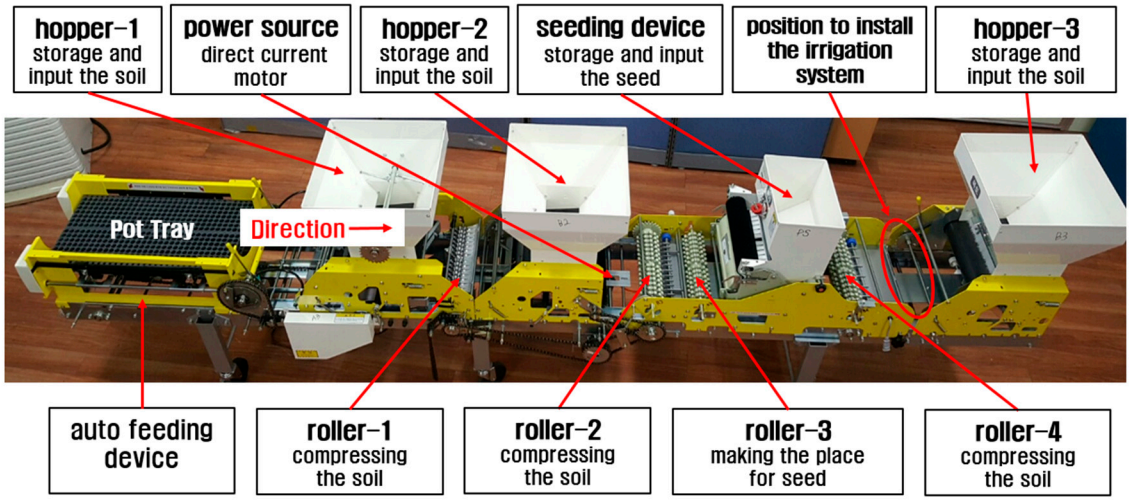


Figure 1. Picture of the roller-type onion pot-seeding machine.

Table 1. Specifications of the roller-type onion pot-seeding machine.

Classification	Contents
Length × Width × Height	3477 × 510 × 975 mm
Total weight	165 kg
Operation capacity	360 pot trays/hour
Number of cells in pot trays	448

2.2. Requirements for the Irrigation System

In view of the purpose of the irrigation system, the components should be selected with the following considerations.

A. Watering by each pot tray cell should be possible to uniformly irrigate the seeds and bed soil of each cell.

B. A proper covering volume is important to maintain the water content of the bed soil [11]. Therefore, the irrigation system should be placed between the seeding device and covering hopper, and not after the covering hopper, to prevent covering soil loss in the watering process. This is advantageous for maintaining the proper covering volume and, moreover, sufficient water can be transferred to the bottom of the bed soil by direct supply of water to the seeds and bed soil.

C. The roller-type onion pot-seeding machine can be used for sowing small seeds with a diameter of about 4 mm, as well as onion seeds. Therefore, it should be constructed so that the watering quantity can be controlled according to the target crop.

2.3. Specifications of the Irrigation System Developed

The irrigation system developed here is a drip-type, and the schematic is shown in Figure 2. The main components are the water tank, water pump, pressure gauge, irrigation pipe, irrigation height regulator, and hand valve. Their characteristics and functions are as follows:

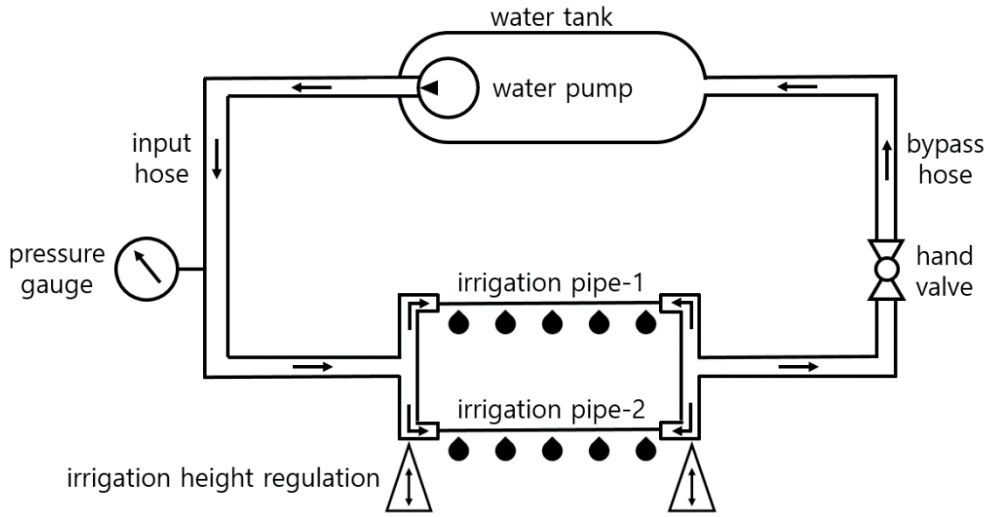


Figure 2. Schematic of the developed irrigation system.

A. Water tank: this stores the water to be used for irrigation. Water can be filled continuously through a water supply hose, using a float valve system, or it can be used as a storage tank without the water supply hose (Figure 3). The storage capacity is 50 liters. A transparent container was utilized to check the level of remaining water in the tank.

B. Water pump: the water stored in the water tank is circulated by the water pump to transport it to the irrigation pipe. A filter at the inlet of the water pump prevents foreign substances from entering the irrigation pipe. The capacity of the water pump was determined by preliminary experiment, to ensure a sufficient flow rate. The specifications of the water pump are provided in Table 2.

Table 2. Specifications of the water pump.

Classification	Contents
Model/Manufacturer/Nation	UP300/Hyubshin Water Design/Korea
Rated voltage	30 W
Maximum discharge	18 L/min
Displacement	1080 L/h
Gross pump head	2600 mm
Length × Width × Height	89 × 112 × 98 mm

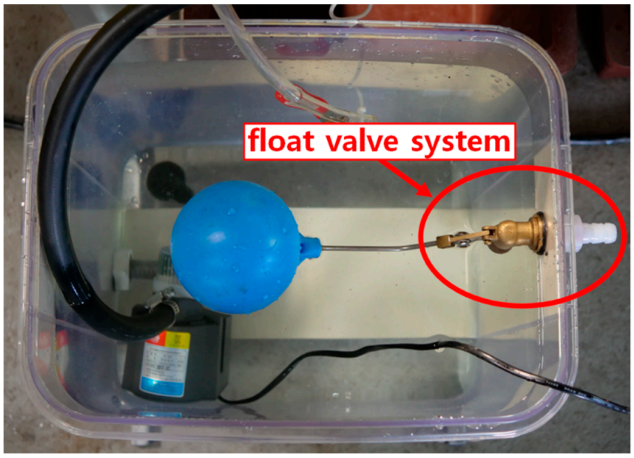


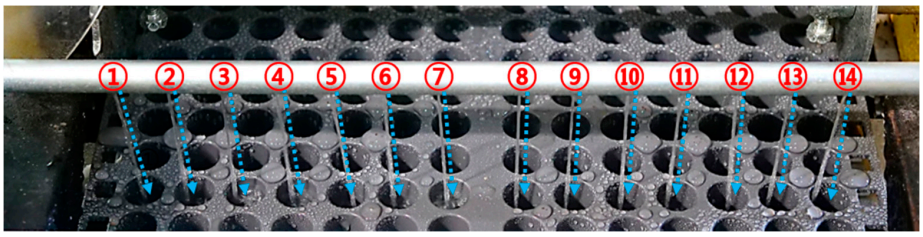
Figure 3. Picture of the water tank.

C. Pressure gauge: this is installed between the water pump and irrigation pipe inlet to measure the pressure of water entering the irrigation pipe. Its measurement range was selected by preliminary experiment to cover the actual pressure range. The specifications of the pressure gauge are listed in Table 3.

Table 3. Specifications of the pressure gauge.

Classification	Contents
Model/Manufacturer/Nation	SS-3011/Konics/Korea
Accuracy	±1.5%
Measurement range	0–1 bar
Applicable temperature	20–40 °C

D. Irrigation pipe: this is the part that performs watering on the crops. Two identical irrigation pipes with an inner diameter of 12 mm are aligned for two times watering. Each irrigation pipe has 14 irrigation holes in a row, and the location of each irrigation hole coincides with the position of each pot tray cell, allowing watering by individual cells. The positions of irrigation holes and a picture of the irrigation pipes are shown in Figure 4.



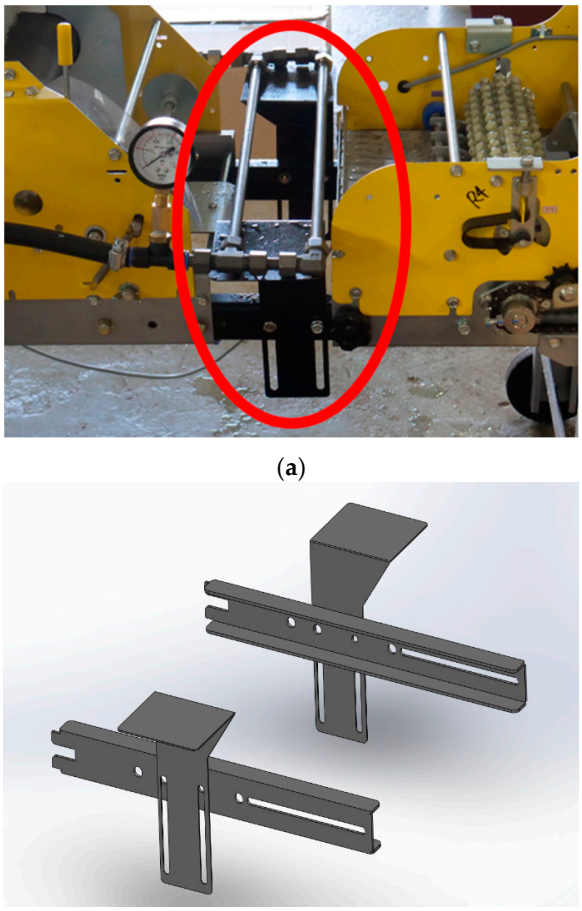
(**a**)



(**b**)

Figure 4. A view of the irrigation pipe: (**a**) position of the irrigation holes; (**b**) picture of the irrigation pipe.

E. Irrigation height regulator: this is used to regulate the height of the irrigation pipe. The irrigation pipe is mounted on the upper end of the height regulator. The height regulator is attached to the side frame of the roller-type onion pot-seeding machine, and the height can be adjusted through the sliding hole and bolted connection. Its height is controllable up to 150 mm from the top of the pot tray, and its schematic is shown in Figure 5.



(**a**)

(**b**)

Figure 5. Shape of the irrigation height regulator: (**a**) height regulator attached to the pot-seeding machine; (**b**) 3D modeling of height regulator.

F. Hand valve: this component is used to control the flow rate of water by varying the water pressure of the irrigation pipe. It is installed between the irrigation pipe outlet and bypass pipe. The water pressure and flow rate increase when the hand valve is opened, and decrease when the valve is closed. The shape and specifications are shown in Figure 6 and Table 4, respectively.



Figure 6. Picture of the hand valve.

Table 4. Specifications of the hand valve.

Classification	Contents
Model/Manufacturer/Nation	GHVFF/Sang-A Newmatic/Korea
Forms	T-Valve
Internal diameter	12 mm
Material	Plastic

The operation procedure of the irrigation system is as follows: the water stored in the water tank moves to the irrigation pipe using the water pump, and is supplied to each cell of the pot tray by dropping through the irrigation holes. The residual water after irrigation returns to the water tank through the bypass pipe. The water pressure and flow rate are regulated by the hand valve. The developed irrigation system attached to the roller-type onion pot-seeding machine is shown in Figure 7.

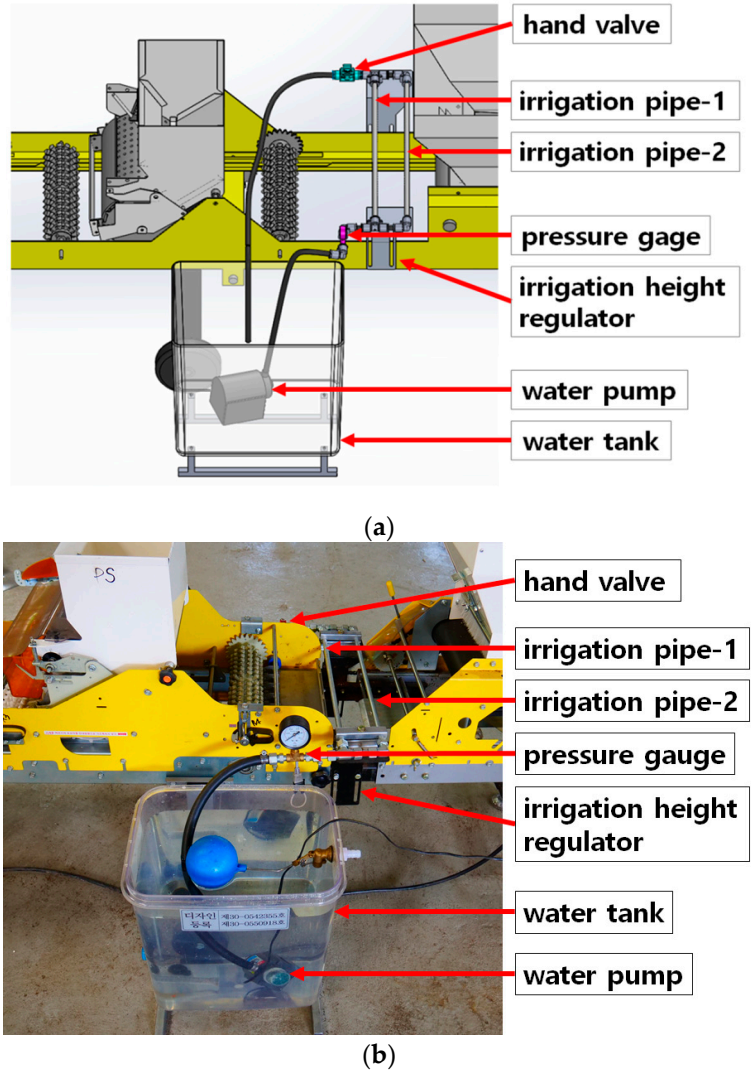


Figure 7. Irrigation system mounted on a roller-type onion pot-seeding machine: (**a**) 3D modeling; (**b**) picture of real system.

The developed irrigation system is a modular system that can be easily installed to the roller-type onion pot-seeding machines. It is located between the seeding device and covering hopper. All the requirements discussed in the previous chapter are satisfied.

2.4. Factorial Experiment to Determine the Proper Operating Condition

2.4.1. Experimental Conditions

A factorial experiment was conducted to determine the proper conditions, to supply the sufficient amount of water to each pot tray cell and prevent the loss of bed soil and change of seed position during the irrigation process. The diameters of the irrigation holes and hand valve opening/closing were selected as experimental factors. The irrigation hole diameters were set at two levels (1.0 mm and 1.5 mm) considering the inner diameter of the irrigation pipe and capacity of the water pump. Summarized experimental conditions are listed in Table 5.

Table 5. Experimental conditions.

ID	Conditions	
	Hand Valve	**Irrigation Hole Diameter (mm)**
Case 1	Open	1.0
Case 2	Close	1.0
Case 3	Open	1.5
Case 4	Close	1.5

2.4.2. Experimental Indexes

Water flow rate, loss of bed soil, and the change of seed position after irrigation were investigated for each experimental condition. In the flow rate test, among the two irrigation pipes, the pipe that waters the pot tray first was set as Irrigation Pipe 1 and the pipe that waters second was set as Irrigation Pipe 2 (Figure 8). The height of the irrigation pipes was fixed at 50 mm from the top of the pot tray by the preliminary experiment. The experiments were carried out indoors because seeding work using pot-seeding machines is usually performed indoors to prevent disturbances such as wind. Also, the bed soil and seeds which are commonly used in Korea were used in this experiment.

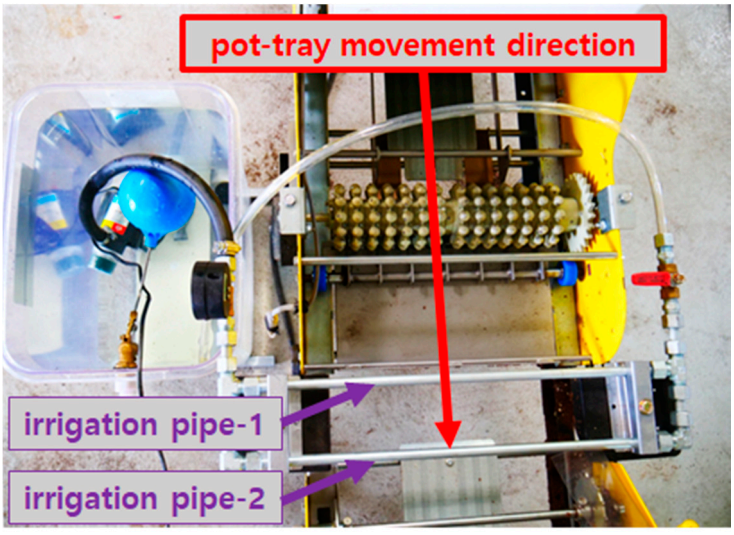


Figure 8. Numbering of irrigation pipes.

(1) Flow Rate Test

The flow rate was measured for each irrigation pipe to verify if the two irrigation pipes maintain the same flow rate. The flow rate was calculated using the mass of water dropping through all 14 irrigation holes of the pipes for 30 seconds (Figure 9). The density of water was assumed to be

1.0 g/ml. The measurement was performed three times under the same conditions, and the average value was used as a representative value.

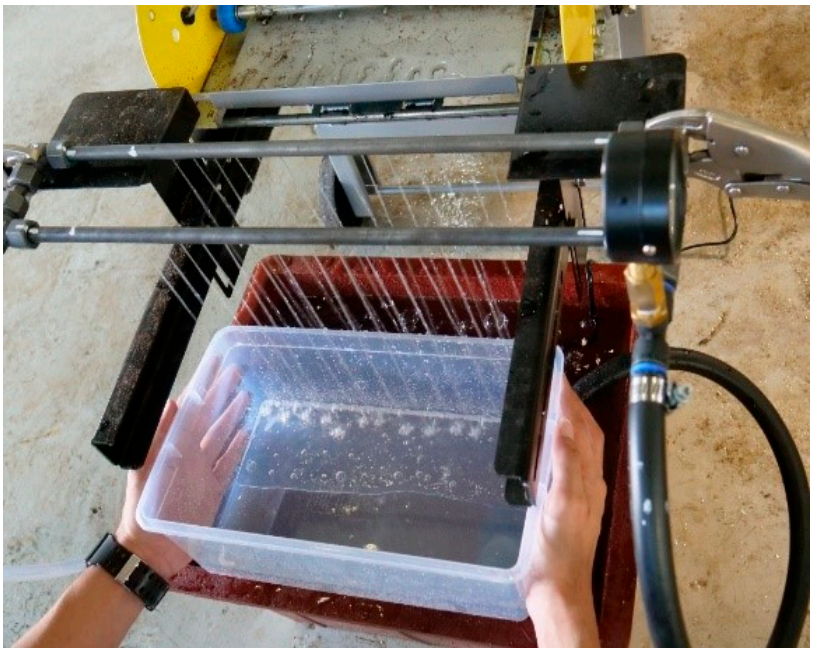


Figure 9. Measurement of flow rate of each irrigation pipe.

To verify the uniformity of flow rate according to irrigation hole positions, the flow rates of four irrigation holes (No. 1, 6, 9, and 13) were measured for the two irrigation pipes (Figure 10). The flow rate was calculated for 30 seconds, using the volume of water dropping through each irrigation hole. The volume of water was measured using a measuring cylinder (Figure 11). Three tests were performed under the same conditions, and the average value was used as a representative value.



Figure 10. Target irrigation holes.

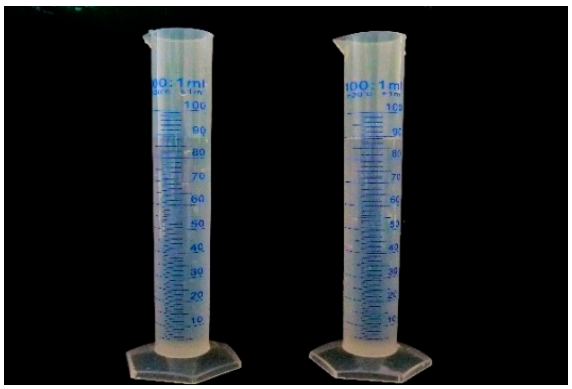


Figure 11. Measuring cylinder used.

(2) Investigation of Seed and Bed Soil Condition

To determine proper operating condition, the loss of bed soil and change of seed position in the irrigation process were investigated for each experimental condition. The developed irrigation system was attached to the pot-seeding machine, and the seed and bed soil condition of each pot tray was investigated, when it passed through the irrigation system.

3. Results and Discussion

3.1. Results of Flow Rate Test

The test results of flow rate are summarized in Table 6. For the same experimental conditions, the difference in flow rate between Irrigation Pipe 1 and Irrigation Pipe 2 was less than 5%. Thus, these two irrigation pipes had almost the same flow rate. For the same irrigation hole diameters (Cases 1 and 2, Cases 3 and 4), for the two irrigation pipes, when the hand valve was closed, the flow rate was higher by about 1.63 to 1.71 times, than when the hand valve was open. Also, under the same hand valve conditions (Cases 1 and 3, Cases 2 and 4), for the two irrigation pipes, the flow rate was about 1.38–1.47 times higher for the irrigation hole diameter of 1.5 mm than that for the irrigation hole diameter of 1.0 mm. Thus, the highest flow rate was obtained when the irrigation hole diameter was 1.5 mm, with the hand valve closed (Case 4). The second highest flow rate was obtained when the irrigation hole diameter was 1.0 mm, with the hand valve closed (Case 2).

Table 6. Flow rate of each irrigation pipe.

ID	Irrigation Pipe 1 (ml/s)	Irrigation Pipe 2 (ml/s)	Error (%)
Case 1	26.67	25.4	4.76
Case 2	43.51	41.88	3.75
Case 3	36.73	35.87	2.34
Case 4	60.61	61.42	1.34

Assuming the same flow rate distribution for all irrigation holes, the theoretical water flow rate of each irrigation hole can be derived by dividing the flow rate of irrigation pipe by the irrigation hole number (14), as shown in Table 7.

Table 7. Theoretical flow rate of each irrigation hole.

ID	Irrigation Pipe 1 (ml/s)	Irrigation Pipe 2 (ml/s)	Error (%)
Case 1	1.91	1.81	3.72
Case 2	3.11	2.99	6.10
Case 3	2.62	2.56	5.18
Case 4	4.33	4.39	8.72

The water pressures measured by pressure gauge are shown in Table 8. The water pressure was higher when the hand valve was closed than when it was open. Depending on the irrigation hole diameter, the water pressure was higher for smaller diameter. Thus, the highest water pressure was obtained when the irrigation hole diameter was 1.0 mm and the hand valve was closed (Case 2). The lowest water pressure was obtained when the irrigation hole diameter was 1.5 mm and the hand valve was open (Case 3).

The test results are outlined in Table 9, and the flow rate error of each irrigation hole was derived by comparing the actual flow rate from Table 9 with the theoretical flow rate from Table 7 (Table 10). The error was the largest in the 13th irrigation hole of Irrigation pipe 2, with an average error of 9.43%. Depending on the experimental conditions, the average error was the largest in Case 1, because the absolute value of the flow rate is small, which causes a large error with a small change of flow rate.

In all the conditions, the average errors were below 10 %. Therefore, it can be considered that a uniform irrigation is obtained regardless of the irrigation hole position.

Table 8. Water pressures according to experimental conditions.

ID	Water pressure (Bar)
Case 1	0.02
Case 2	0.03
Case 3	0.01
Case 4	0.02

Table 9. Actual flow rate of each irrigation hole.

ID	Irrigation Pipe 1 (ml/s)				Irrigation Pipe 2 (ml/s)			
	Hole Number				Hole Number			
	1	6	9	13	1	6	9	13
Case 1	1.87	2.10	1.98	1.99	1.62	1.78	1.66	2.00
Case 2	2.93	3.01	3.13	2.93	2.77	2.91	3.09	3.35
Case 3	2.67	2.41	2.50	2.65	2.56	2.65	2.30	2.75
Case 4	4.27	4.28	4.07	4.47	4.69	4.75	4.05	4.73

Table 10. Flow rate error of each irrigation hole.

ID	Irrigation Pipe 1 (ml/s)				Irrigation Pipe 2 (ml/s)			
	Hole Number				Hole Number			
	1	6	9	13	1	6	9	13
Case 1	2.09	9.95	3.66	4.19	10.50	1.66	8.29	10.50
Case 2	5.79	3.22	0.64	5.79	7.36	2.68	3.34	12.04
Case 3	1.91	8.02	4.58	1.15	0	3.52	10.16	7.42
Case 4	1.39	1.15	6.00	3.23	6.83	8.20	7.74	7.74
Average	2.79	5.58	3.72	3.59	6.17	4.01	7.38	9.43

3.2. Irrigation Amount of Pot Tray

The irrigation amount of each pot tray cell can be determined using the flow rate of each irrigation hole, translational speed of pot tray, and irrigation length of the pot tray cell (Equation (1)) [12]. The shape of the pot tray cell is a truncated cone with its top diameter being larger than the bottom diameter [6]. Therefore, the top diameter of the pot tray cell is considered for the irrigation length. The sum of theoretical flow rates of irrigation pipes 1 and 2 (Table 7) was taken as the flow rate per irrigation hole. In the roller-type pot-seeding machine used in this study, the translational speed of the pot tray is 74.93 mm/s and the top diameter of the pot tray cell is 16 mm [6]. The calculated irrigation amounts per pot tray cell are given in Table 11. The irrigation amount per pot tray cell is in the range of 0.79–1.86 ml. The largest irrigation amount is obtained when the irrigation hole diameter is 1.5 mm and the hand valve is closed (Case 4). The smallest irrigation amount is obtained when the irrigation hole diameter is 1.0 mm and the hand valve is open (Case 1).

$$Q_{cell} = \frac{q \times d_{cell}}{v_{pot}} \quad (1)$$

where

Q_{cell} = irrigation amount per pot tray cell, ml
q = flow rate per irrigation hole, ml/s
v_{pot} = translational speed of the pot tray, mm/s

d_{cell} = top diameter of the pot tray cell, mm

Table 11. Irrigation amount of each pot tray cell.

ID	Irrigation amount (ml)
Case 1	0.79
Case 2	1.30
Case 3	1.11
Case 4	1.86

Furthermore, the total amount on the entire pot tray, when it passes through the ambit of water sprayed from the irrigation pipes can be determined by Equation (2) using the total length of pot tray. The total length of pot tray used in the roller-type pot-seeding machine is 619 mm [6]. The calculation results are listed in Table 12. The total irrigation amount of the pot tray is in the range of 30.73–72.04 ml. The largest irrigation amount is obtained when the irrigation hole diameter is 1.5 mm and the hand valve is closed (Case 4). The second irrigation largest amount is obtained when the irrigation hole diameter is 1.0 mm and the hand valve is closed (Case 2).

$$Q_{pot} = \frac{q \times l_{pot}}{v_{pot}} \quad (2)$$

where

Q_{pot} = irrigation amount of the entire pot tray, ml
l_{pot} = total length of pot tray, mm

Table 12. Irrigation amount of the entire pot tray.

ID	Irrigation Amount (ml)
Case 1	30.73
Case 2	50.39
Case 3	42.79
Case 4	72.04

3.3. Seed and Bed Soil Condition

The test results for seed and bed soil condition indicated that the seed position change and bed soil loss were small for the conditions of Cases 1–3. However, the condition of Case 4 showed a large variation in seed location and a significant loss of bed soil (Figure 12).

If the seeds are located closer to the center of the pot tray cell, rooting is better when they germinate [13]. Well-rooted seedlings yield many advantages such as improved crop productivity and reduced labor force required for supplementary transplanting work due to poor growth [14]. Also, a sufficient quantity of water should be supplied to shorten seed germination time. The quantity of water sprayed on the pot tray cell was in the order of Case 4, Case 2, Case 3, and Case 1. In Case 4, the quantity of water supplied was the highest, however, the seed location change and bed soil loss were large. Therefore, Case 2 (irrigation hole diameter 1.0 mm and valve closed), which has the second-largest quantity of supplied water and almost no change of seed position and no loss of bed soil, is the most appropriate irrigation condition.

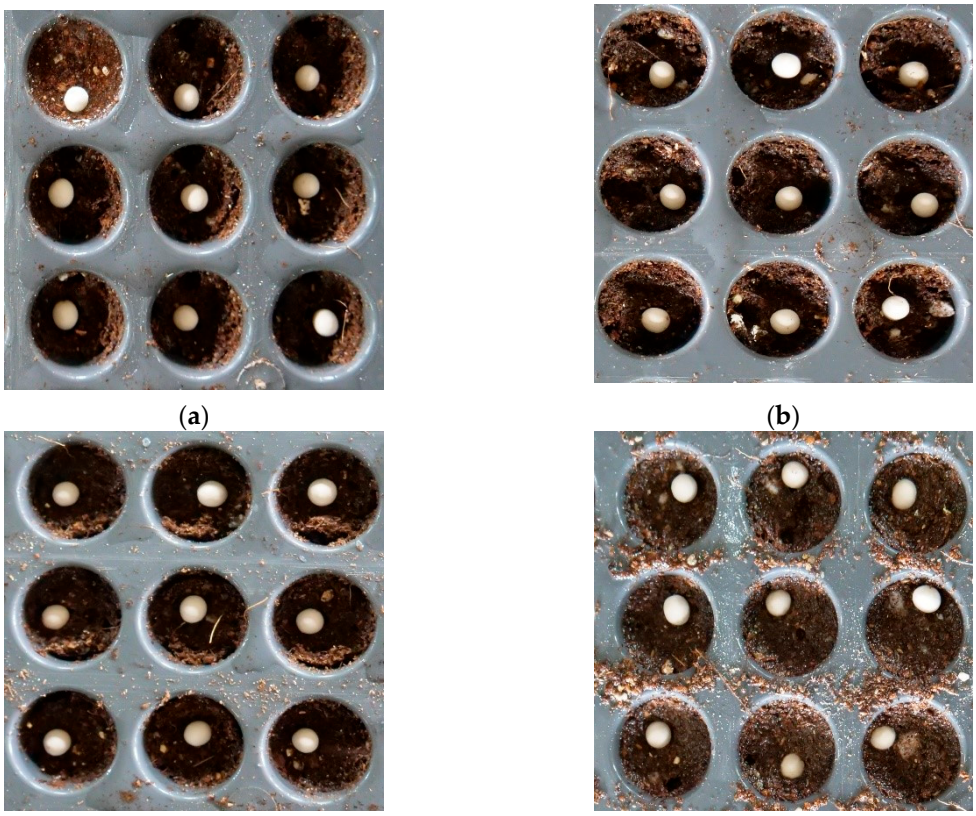


Figure 12. Seed and bed soil conditions after irrigation: (**a**) Case 1; (**b**) Case 2; (**c**) Case 3; (**d**) Case 4.

3.4. Verification of the Developed Irrigation System

The verification test was conducted to investigate the effectiveness of the developed irrigation system. The seeding was conducted by using both the original pot-seeding machine (Group 1) and the pot-seeding machine with the developed irrigation system (Group 2), and the growth conditions of onion seedlings were compared for each group after 8 weeks of growth. The best operating condition which was determined from a factorial experiment (irrigation hole diameter 1.0 mm and valve closed) was applied for the irrigation system. The seeding was carried out simultaneously for both groups at 5 pm in a local nursery, and manual irrigation was performed daily at 10:00 and 17.00, from the following day of seeding for the both groups. The growth level was observed at intervals of one week (Figure 13).

In the test, for the both groups, the same bed soil and seeds were used in the same growth environments (temperature, humidity, etc.) so that only the irrigation conditions became influential factors. Also, the results were analyzed using sufficient number of samples to ensure high reliability.

The growth status of 1344 onion seedlings was analyzed for both Group 1 and Group 2. Germination rate, number of leaves, diameter and length of stem, and length of root were used as representative factors to determine the growth status [15]. Germination rate is defined as the ratio of the number of holes with the onion seedlings to the total number of holes on the pot-tray. Definition of other factors is shown in Figure 14. The average values of the factors are listed in Table 13. The germination rate, leaf number, stem diameter, stem length, and root length were higher in Group 2 than in Group 1 by 7.37%, 0.02 pieces, 0.21 mm, 25.7 mm, and 7.6 mm, respectively.

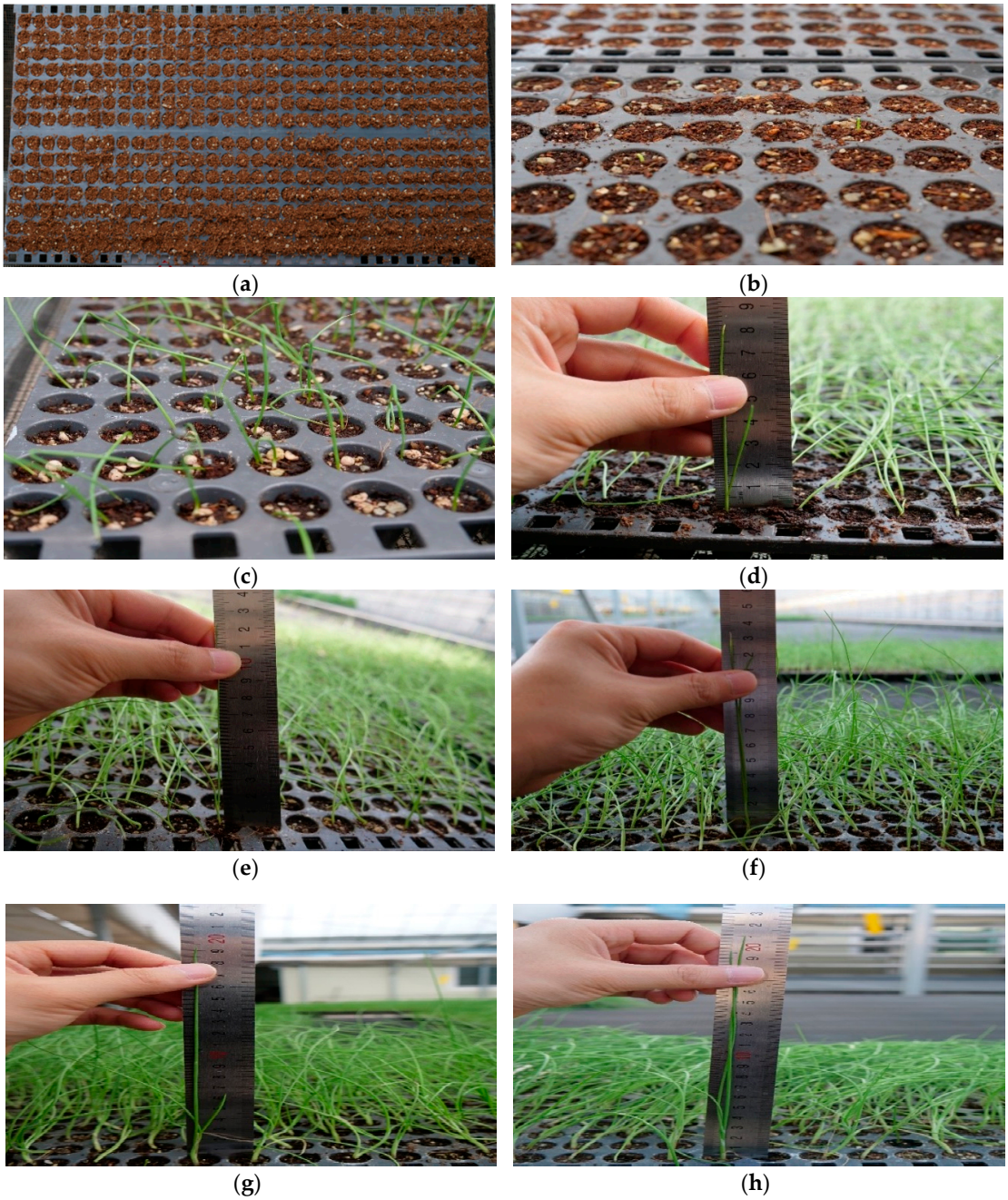


Figure 13. Growth status of onion seedlings: (**a**) Week 1; (**b**) Week 2; (**c**) Week 3; (**d**) Week 4; (**e**) Week 5; (**f**) Week 6; (**g**) Week 7; (**h**) Week 8.

Table 13. The onion seedling growth states for both groups.

Factors	Group 1	Group 2
Germination rate (%)	78.79	86.16
Number of leaves (pieces)	3.03	3.01
Diameter of stem (mm)	2.41	2.62
Length of stem (mm)	244.4	270.1
Length of root (mm)	28.8	36.4

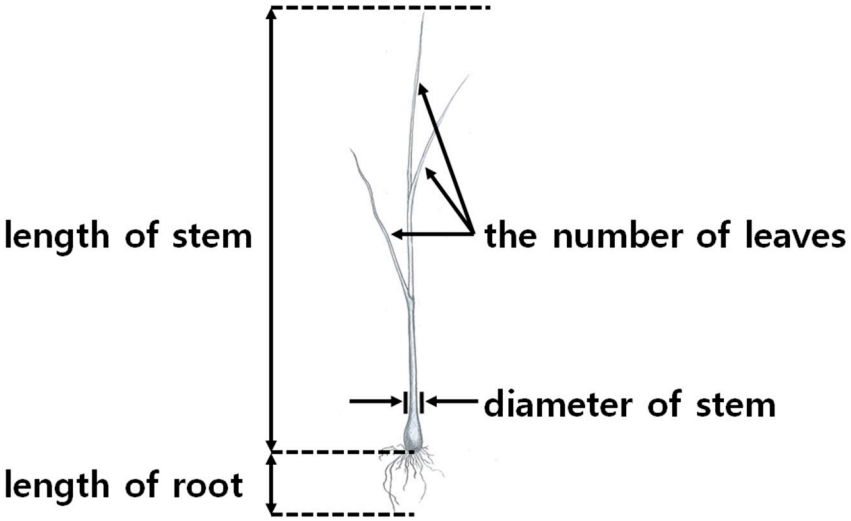


Figure 14. Factors for growth status.

Statistical analysis was performed on the difference of growth status for both groups through analysis of variance (ANOVA). Except for the germination rate, which shows a significant difference, leaf number, stem diameter, stem length, and root length were set as the analysis factors. The results of each factor are listed in Tables 14–17. At a 5% significance level, except for leaf number, the stem diameter, stem length, and root length demonstrated significant differences between Group 1 and Group 2. Therefore, it is clear that using the developed irrigation system in the onion pot-seeding machine can increase the production efficiency of healthy seedlings.

Table 14. Analysis of variance (ANOVA) table for leaf number.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.126	0.126	0.39	0.535
Error	737	242.568	0.329	-	-
Corrected Total	738	242.695	-	-	-

Table 15. ANOVA table for stem diameter.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	7.854	7.854	44.67	< .0001
Error	737	129.581	0.175	-	-
Corrected Total	738	137.436	-	-	-

Table 16. ANOVA table for stem length.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1212.012	1212.012	93.21	< .0001
Error	737	9583.126	13.002	-	-
Corrected Total	738	10795.138	-	-	-

Table 17. ANOVA table for root length.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	143.594	143.594	236.98	< .0001
Error	737	446.573	0.605	-	
Corrected Total	738	590.168	-	-	-

4. Conclusions

In this study, a drip-type irrigation system applicable to the roller-type onion pot-seeding machine was developed. The main components are water tank, water pump, irrigation pipe, irrigation height regulator, and hand valve. A factorial experiment was conducted with the hole diameter of the irrigation pipe and the hand valve opening and closing set as the experimental factors. The condition with the high irrigation amount and almost no bed soil loss and seed position change was selected as the proper operating condition, i.e., 1.0 mm of irrigation hole diameter and closed valve condition.

The effectiveness of the irrigation system developed was verified through seedling test. Growth statuses of two groups of seedlings, one sowed using the existing method without irrigation system and the other sowed using the developed irrigation system, were analyzed with the factors of germination rate, leaf number, stem diameter, stem length, and root length. The results showed that the application of the irrigation system developed here can improve the growth of seedlings by early and sufficient watering.

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