DEVELOPMENT OF TRANSPLANT PRODUCTION IN CLOSED SYSTEM (PART II)
- Irrigation Scheduling based on Evapotranspiration Rate-

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ABSTRACT

A new transplant production system that produces high quality plug seedlings of specific crop has been studied. It is a plant factory designed to produce massive amount of virus free seedlings. The design concept for building this plant factory is to realize maximum energy efficiency and minimum initial investment and running cost. The basic production strategy is the sitespecific management. In this case, the management of the growth of individual plantlet is considered. This requires highly automated and information intensive production system in a closed aseptic environment the sterilized specific crops. One of the key components of this sophisticated system is the irrigation system. The conditions that this irrigation system has to satisfy are: 1. to perform the site specific crop management in irrigation and 2. to meet the no waste standard. The objective of this study is to develop an irrigation scheduling that can implement the no waste standard.

Key word : Irrigation system, Sweet potato, Evapotranspiration

1.Introduction

The open field agricultural system is a typical example of a large-scale complex system that has attracted the attention of researchers and scientists in various scientific and engineering fields. Now PA promises to handle such complex systems, and has received significant support from both agricultural and industrial sectors. Although a plant factory is also a large-scale complex system, it is much less complex than an open field system. There are quite a few plant factories operating commercially in Japan. PA is nothing but integrated technology, designed to optimize the cultivation process. The fully controlled environment of a plant factory can be considered an ideal cultivation system in terms of alternative agriculture. Most of the environmental factors in a fully controlled plant factory are observable and controllable; a plant factory can be optimized more easily than an open field. This paper proposes using microprecision agriculture in a fully controlled plant factory. Microprecision agriculture can be attained by using plant factories to realize profitable alternative agriculture. This article reviews the scientific and technological achievements of plant factories as alternative agriculture, and introduces a hardware system developed to implement microprecision agriculture in a plug seedling production factory.

1. Development of Plant Factories

In 1970, a plant growth system consisting of systematically integrated growth chambers was used to demonstrate that plant growth can be significantly improved by applying optimum growth conditions in terms of environmental factors such as temperature, humidity, light intensity, and CO_2 gas concentration. Those scientific achievements motivated the early development of a closed plant growing system with a controlled artificial environment. The research and development was extended to the development of plant factories that involve technologies such as process control for the plant growth environment, mechanization for material handling, system control for production, and computer applications. The advantages of a plant factory include production stabilization, higher production efficiency, and better quality management of products through a shortened growing period, better conditions, lower labor requirements, and easier application of industrial concepts.

A precise definition of a plant factory has yet to be established. In a broad sense, a plant factory is defined as "a production system in which plants are under continuous production control throughout the growth period until harvest". A narrow definition is "a year-round plant cultivation system in a completely artificial environment. There are many commercially operating greenhouse-type plant factories, which are heavily equipped with sophisticated environment control systems, machines, instrumentation, and computers. Some use only natural light, but others occasionally use artificial light as a supplement during the seasons with low solar radiation. Ultimately, a greenhouse-type plant factory is not an ideal system because of unavoidable, unpredictable, and uncontrollable external disturbances. However, growers have more readily accepted greenhouse type plant factories, mainly because of current energy costs and the high initial investment required for a fully artificial plant factory.

2.A new transplant production system

A new transplant production system that produces high-quality plug seedlings of a specific crop was studied in a plant factory designed to produce massive amounts of virus-free seedlings. The plant factory was designed to realize maximum energy efficiency with minimum initial investment and operating costs. The basic production strategy is site-specific management. This paper considers management of the growth of individual seedlings. This requires a highly automated and information-intensive production system in a closed aseptic environment for specific crops. One of the essential components of this sophisticated system is the irrigation system, which must 1) perform site-specific crop management in irrigation and 2) produce no waste. The objective of this study was to develop an irrigation schedule to implement the no-waste standard.

3. Microprecision Irrigation System

This section introduces an example of microprecision technology that has actually been implemented in a plug seedling production factory. A microprecision irrigation system was developed for a plug production system. It is a kind of variable rate technology for precision agriculture. The traditional irrigation method for plug production is overhead watering, which provides growing plug seedlings with excess nutrient solution. In the traditional system, some of the irrigated nutrient solution is absorbed by the substrate (soil) and then taken up by the plant, some stays on the leaf surface, and the rest falls to the ground and wasted. This has been a major drawback of using the traditional irrigation method in plug production, both economically and environmentally.

3.1. Irrigation concept

The seedling should be irrigated with only the proper amount of water (nutrient solution) for the particular plant, delivered to the developing roots. This concept assures the minimization of waste□ irrigation water and does not leave a residual solution on the leaf surface. No recycling of the nutrient solution is considered, since there is no excess nutrient solution. Therefore, the water (nutrient solution) must be supplied from the bottom of the cell.

3.2. Design concept

The nutrient solution should be injected directly into the substrate (soil) where the roots develop, so that the leaves are not moistened by the irrigating solution. The nozzle for water injection should be inserted from the bottom of a plug cell, therefore the cells must have an appropriate-sized hole in the bottom. The injection process should be completed as quickly as possible, since a very large number of seedlings has to be irrigated. Leakage of solution from the cell should be avoided or at least minimized during and immediately after injection.

3.3. Irrigation device

A microprecision irrigation device was developed. The device was designed to fit a 300 x 600 mm cell tray containing 72 cells. The solution is discharged from 72 nozzles fixed on an aluminum plate, which can be moved up and down. It is actuated by a ball screw hooked to a servomotor, which controls the vertical position of the injection nozzle tip relative to the interior of a plug cell filled with a substrate (soil mass) and roots. The amount of solution discharged from each nozzle is regulated by the time that a solenoid valve connected to the nozzle remains open. Seventy-two solenoid valves are controlled individually, so that the amount of solution discharged from each nozzle can be varied as required. This can be considered as a variable rate technology such as those highlighted in PA. Figure 1 shows the irrigation device with a schematic diagram of its mechanism.

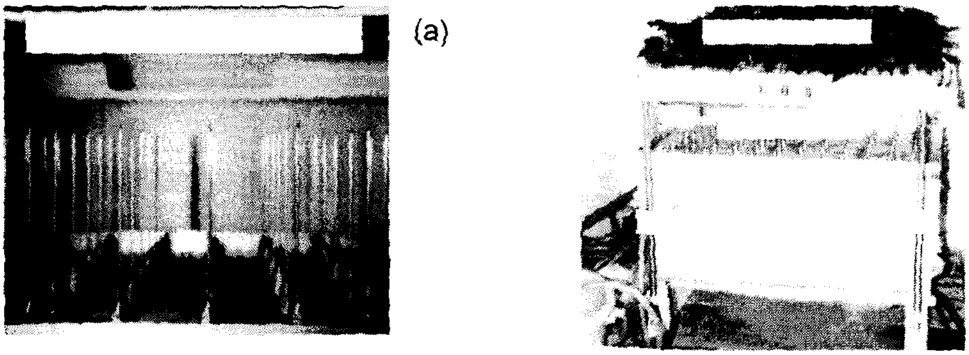

Fig. 1. Pictures (a),(b) of irrigation device.

4.Irrigation system

Figure 2 illustrates the irrigation system schematically. The irrigation device is mounted on a multi-functional shifter that can both position a cell tray on the irrigation device and weigh each cell tray before and after irrigation, to monitor the amount of water used or evaporated from the cell tray. Many cell trays are stored vertically in a two-dimensional array. The irrigation unit can move the irrigation device to the location of each cell tray requiring irrigation. Irrigation scheduling and operation should be controlled by computer. The irrigation unit is mounted on the transport equipment which can position the irrigation device precisely under the plug tray which is to be irrigated .

5.Prediction of Evapotranspiration

The best way to achieve no-waste irrigation is to balance the amount of irrigation water with the amount of water lost by evapotranspiration. The injection-type watering device developed for this irrigation system is capable of supplying a predetermined amount of water to each plant growing in a plug tray. Each plug seedling is irrigated by water injected directly into the root zone. This irrigation system identifies the right amount of water to maintain healthy growth. The evapotranspiration rate is affected by the growth stage, temperature, humidity, photosynthetic rate, and culture medium. Since the environmental conditions in this production system can be regulated, practical prediction of the evapotranspiration rate is possible.

6.Estimation of Evapotranspiration Rate

The evapotranspiration rate of plug seedlings was measured under a controlled environment using sweet potato. The whole weight change of the plug tray containing growing seedlings was measured at 24-hour intervals to determine the average evapotranspiration rate (cc/day).

7.Experimental Method

Sweet potato seedlings and a two-layer culture medium were used for this experiment. The upper layer consisted of a material made from paper pulp and the lower layer was standard culture soil. After cuttings were planted, the evapotranspiration rate was monitored for 14 days. The seedlings were grown under fixed conditions: temperature of 30°C, 80% humidity, light intensity of 250 $molm^{-2}s^{-1}$, and a 12-hour lighting interval. The nutrient solution (water) was equivalent to the amount of water lost by evapotranspiration. When the quantity of water supplied was from 1 to 7 cc, the water was ejected at location A in the root zone. When it exceeded 7 cc, it was ejected at location B, as shown in Fig. 1.

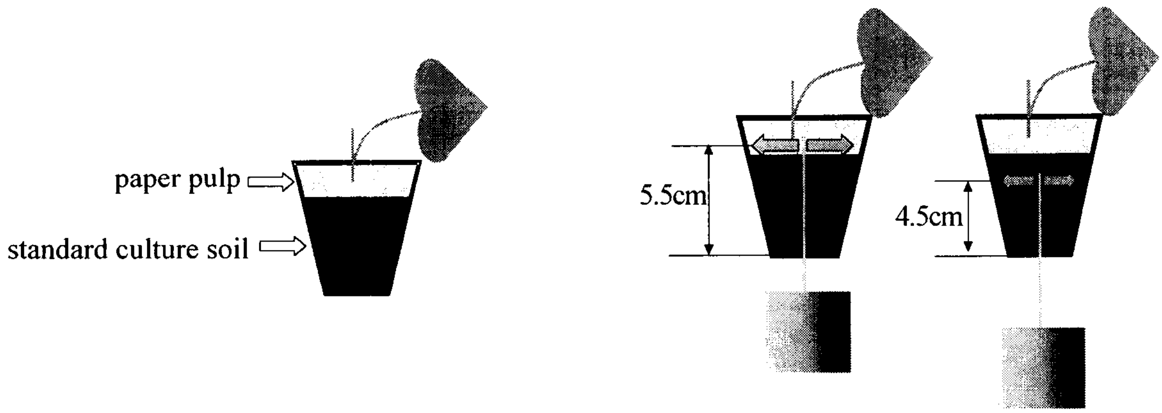

Fig. 1 Location A Location B

8.Results and Discussion

Table 1 shows the variation in the evapotranspiration rate over 14 days. Table 2 indicates the quantity of water used to irrigate the plug seedlings based on the measured evapotranspiration rate. Seedling growth and the leakage of irrigated water, which is considered waste, were carefully observed for 14 days.

Table 1

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Evapotranspiration (cc)	2.75	2.88	3.04	2.74	4.58	5.35	5.3	6.76	7.13	7.3	8.75	8.56	8.54	8.94

Predicted amount of irrigation

Table 2

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Irrigation (cc)	3	3	3	3	5	5	5	7	7	7	9	9	9	9

The irrigation schedule used in this experiment was satisfactory in terms of seedling growth and met the no-waste standard (no leakage of irrigated water). However, future studies will be required to determine more general irrigation scheduling for various growth conditions, different varieties of plants, and so forth.

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