MICROPRECISION AGRICULTURE

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ABSTRACT

Micropreсision agriculture for a fully controlled plant factory is proposed in this paper. Microprecision agriculture can be attained by using plant factories to realize profitable alternative agriculture. A closed, fully controlled, plant-growing factory is far better in terms of minimizing all sorts of waste. The limit and optimum design concept has to be applied to establish an economically feasible, fully controlled, plant-growing factory. To achieve this objective, microprecision technologies have to be developed. Microprecision technologies should be involved in sensing, modeling, controlling, and collecting information for the mechatronics for plant production. Basic technologies for microprecision are already available; they are SPA (speaking plant approach to environmental control), AI (artificial intelligence: expert systems, neural networks, genetic algorithms, photosynthetic algorithms etc.), bioinstrumentation, non-invasive measurement, biomechatronics, and biorobotics. A microprecision irrigation system for plug production is an example of a microprecision technology that has actually been implemented in a plug seedling production factory.

Key Word :Plant Factory, Variable Rate Technology, Plug Seedlings

INTRODUCTION

Reducing the use of the off-farm inputs with the greatest potential to harm the environment or the health of farmers and consumers has become a very important environmental issue. While LISA (low-input sustainable agriculture) has been losing appreciable support from the agricultural sector (National Research Council, 1991), since it decreases profits, implementation of precision agriculture (PA) has been embraced. The development of precision technologies to reduce the use of off-farm inputs supported by the extensive application of information technology, including GPS and GIS, and mechatronic technology, including sensor fusion and intelligent control, has become a major issue in precision agriculture.

The open field agricultural system is a typical example of a large-scale complex system that has attracted a lot of attention from researchers and scientists in various scientific and engineering fields. With significant support from both the agricultural and industrial sectors, PA is now promising to be able to handle such a complex system. PA is simply integrated technology, designed to optimize the cultivation process. Although the plant factory is also a large-scale complex system, it is much less complex than the open field system. There are many commercial plant factories in Japan. The fully controlled environment of a plant factory is 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 for a fully controlled plant factory. Microprecision agriculture can be attained by using plant factories to realize profitable alternative agriculture.

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. Hashimoto et al. (1984a, 1984b, 1985) have been very successful in conducting research works on plant physiology and its growth under artificial environment by engineering approach. 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. Takatsuji (1986, 1987, 1994) wrote many books on plant factories based on his work devoted for the development of plant factories .

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.

MICROPRECISION TECHNOLOGIES

A closed fully controlled plant-growing factory is much more advantageous in terms of minimizing waste. Limits and the optimum design concept have to be applied in order to establish an economically feasible, fully controlled, plant-growing factory. To achieve this objective, microprecision technologies must be developed. Microprecision does not mean a higher order of engineering precision. Microprecision in agriculture is the technological means to first identify what is needed and how much is needed as precisely as possible, and then to perform the job required to fulfill the identified quantitative and qualitative needs as precisely as possible. Microprecision technologies involve sensing, modeling, control, information, and mechatronics for plant production. Basic microprecision technologies are already available; they are SPA (Speaking Plant Approach to environmental control), AI (Artificial Intelligence: expert systems, neural networks, genetic and photosynthetic algorithms, etc.), bioinstrumentation, non-invasive measurement, biomechatronics, and biorobotics (Hashimoto and Nonami 1992).

MICROPRECISION IRRIGATION SYSTEM

This section introduces an example of microprecision technology implemented in a plug seedling production factory, as an example of variable rate technology used in precision agriculture. A microprecision irrigation system was developed for a plug production system. The traditional irrigation method used for plug production is overhead watering, which provides excess nutrient solution to growing plug seedlings. 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 is wasted. This is a major drawback of the traditional irrigation method in plug production, both economically and environmentally.

Irrigation Concept

Only a seedling that requires water (nutrient solution) should be irrigated, with the proper amount of solution needed for a particular plant dispensed in the proper location where the roots of that particular plant have developed. This minimizes waste of irrigation water, and there is no residual solution on the leaf surface. No recycling of nutrient solution is considered, since there is no overflow of the nutrient solution. The water (nutrient solution) must be supplied from the bottom of the cell.

Design Concept

The nutrient solution should be injected directly into the substrate (soil) where the roots have developed, so that the leaves remain dry. The nozzle for water injection should be inserted from the bottom of the plug cell. The cells must have a hole of appropriate size at the bottom. The injection process should be completed as quickly as possible, since a very large number of seedlings must be irrigated. Leakage of solution from the cell should be minimized or avoided, both during and immediately after injection.

Irrigation Device

A microprecision irrigation device was developed (Fig. 1). The device was designed to fit a 300 × 600 mm cell tray with 72 cells. The solution is discharged from 72 nozzles fixed on an aluminum plate. This plate is moved vertically by a ball screw linked to a servo motor that controls the vertical position of the injection nozzle tip relative to the interior of a plug cell filled with substrate (soil mass) and roots. Controlling the opening of a solenoid valve connected to the nozzle meters the amount of solution discharged from each nozzle. 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 an example of the variable rate technologies highlighted in precision agriculture.

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.

RESULTS AND DISCUSSION

Three microprecision irrigation devices were installed in a pilot plug seedling factory located at Chiba University. One unit was used to check the performance of the entire production system. Sweetpotato was used in this experiment. Currently, the daily weight change of each cell tray is used to schedule irrigation, but this only provides the average water requirement of the cells. When seedlings are missing from a cell tray due to poor initial growth, there is a severe solution leak from the cell with the missing plant. Since the new irrigation device is designed to irrigate cells independently, it is possible to avoid irrigating those cells, provided that the locations of empty cells are known. In the future, the microprecision concept should be applied to monitoring the growth of each seedling, so that the variable rate function of the irrigation device can be fully realized. Initially, leakage of a small amount of water from cells during irrigation was a minor problem, but this was solved by placing a thin synthetic sponge under the cell tray. Overall, the irrigation device is acceptable.

CONCLUSIONS

A practical example of microprecision technology in biomechatronics was introduced. A fully controlled plant factory is an ideal system, in which microprecision farming can be used to nearly eliminate energy and material waste and environmental impact. This approach should make agriculture profitable, while dealing with environmental concerns and feeding the world's growing population. Microprecision agriculture using plant factories is becoming economically feasible, but requires more research and development.

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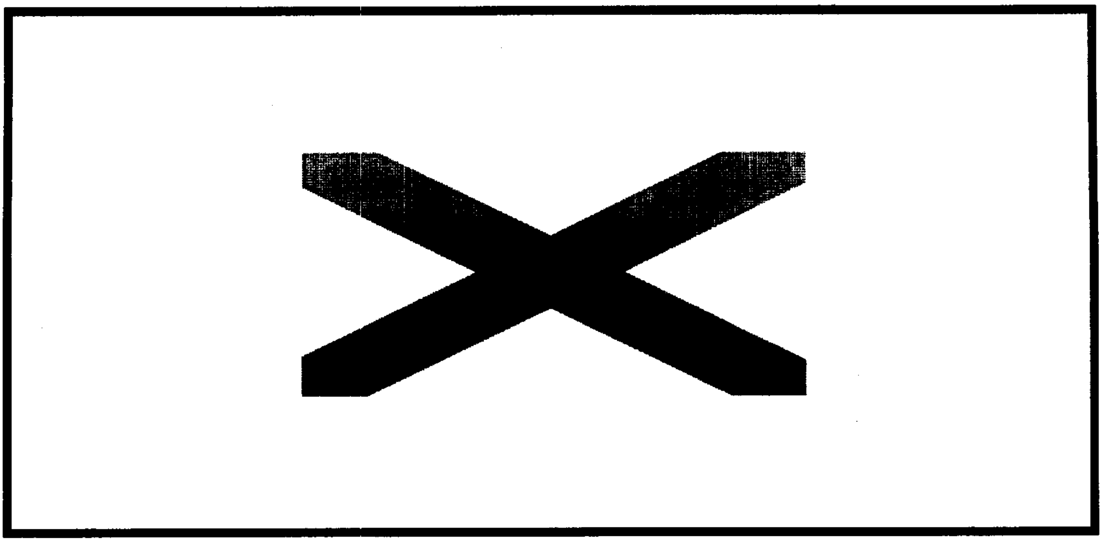

Fig. 1. Pictures (a,b) of irrigation device and a schematic representation of the device mechanism (c).

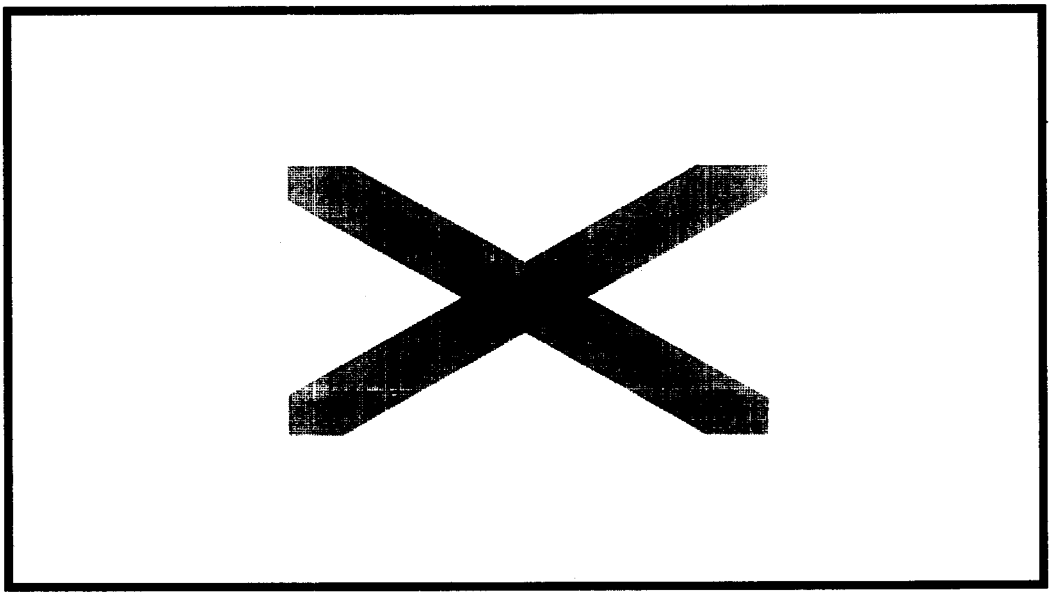

Fig. 2. Microprecision irrigation system. The irrigation unit is mounted on the transport equipment which can position the irrigation device precisely under the plug tray which is to be irrigated