State-of-The-Art
Factory-Style Plant Production Systems

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Abstract

Factory-style plant production systems of various kinds are the final goal of greenhouse production systems. These systems facilitate planning for constant productivity per unit area and labor under various outside weather conditions, although energy consumption is intensive. Physical environmental control in combination with biological control can replace the use of agricultural chemicals such as insecticides, herbicides and hormones to regulate plants. In this way, closed systems which do not use such agricultural chemicals are ideal for environmental conservation for the future.

Nutrient components in plants can be regulafied by physical environtal control including nutrient solution control in hydroponics. Therefore, specific contents of nutrients for particular plants can be listed on the container and be used as the basis of customer choice in the future.

Plant production systems can be classified into three types based on the typeof lighting: natural lighting,supplemental ligting and completely artificial ligtitng (Plant Factory). The amount of energy consumption increases in this order,although the degree of weather effects is in the reverse order.

In the addition to lighting, factory-style plant production systems consist of mechanized and automated systems for transplating, environmental control, hydroponics, transporting within the facility, and harvesting.

Space farming and developement of pharmaceutical in bio-reactors are other applications of these types of plant production systems.

INTRODUCTION

Various kinds of state-of-art factory-style plant production systems are discussed in the present paper. These systems are, in general, rather sophisticated and mechaized, and energy consumption is intensive.

Factory-style plant production is the final goal of greenhouse production systems and the possibilities for the future are infinte but not clear.

STRUCTURAL COMPONENTS OF FACTORY-STYLE PRODUCTION

Lighting systems

Natural lighting systems

Productiviy per unit land is much higher in enclosed plant production systems than that in outside fields where the effect of weater variation is large. In enclosed production systems, it is rather difficult to differentiate between conventional type greenhouse production and factory-style systems under natural light. The main differences are the higher degree of mechanization and automation in factory-style production systems, and hydroponics which is an essential component of factory-style systems.

An example of a factory-style system with natural lighting is the production of Japanese radish sprouts(Takakura,1985). One system consists of 6 span greenhouses where the total area is 7,260m^2 and annual production is 200,000 packages. Seeds are dipped in water for 3 hours and then put in a geminator for one day. A machine is used to plant seeds into styrofoam trays, which have 30 hollows/tray. Each tray produces radish sprouts for 30 packages. These trays are carried automatically on a chain-conveyer to the next stage when the trays are stored vertically in stacks of 10, in the greenhouse for 3 for 4 days. In thise stage, light is not necessarily required, but temperatuer above 20°C is recommended. Next, the sprouts are moved into the conventional and exposed to natural light. They stay two days in the greenhouse before harvesting. Watering is done automatically by different methods in these two stages. In the first stage, where the trays are in stacks, spray nozzles move automatically to the spray locations after the trays are spaced apart vertically by a synchronized arm operation. In the second stage, where the trays have been spread out horizontally, spray nozzles mounted on a gantry are moved over the trays. Basically, pure water without any nutrient is supplied for the whole period.

Supplemental lighting systems

In Sweden, a factory-style system with supplemental lighting produces over 10,00 lettuce/day under 4,800m^2 glass. Lettuce seeds are planted in peat moss cubes and set in a hydropic tray 10m long with a distance of 15cm between plants in a tray. The spacing between trays is controlled by an automatic spacing machine witch move to various locations in the greenhouse according to the growth stages of the plants. A large robotic arm can hold both edges of the 10m long tray and shift the trays to spacific positions. In the first stages, the trays are set as close together as possible, and in the final stage they are set 25cm apart. The trays move from one side of the greenhouse to the other, make a U-turn, and then come back. The travel distance is 60m for each side, and during this 120m trip, the lettuce completes its growth. Therefore, transplanting seedlings to trays, harvesting and packing are done at the same side of the greenhouse, and efficiency is improved.

Continuous lighting of 5,000lx is applied over the lettuce by metal halide lamps. Air temperature is set at 15 to 22℃ during the daytime and several degrees lower in the night. Environmental and hydroponic control are done by computer. The largest part of the energy cost is electricity consumption, which is 2million kWh/year. Continuous lighting helps in heating the facility during the winter period and supplemental heating by hot water is provided for extremely cold conditions. The energy cost is less than 5% of the total production cost, partly because the total production cost, partly because the unit price of electricity is low in Sweden.

Completely artificial lighting systems(Takakura,1986; Takakura, 1987; Takacura and Sekiyama, 1994)

In Japan, a plant factory in Shizuoka prefecture produces two kinds of leaf lettuce at the rate of almost 500 heads of lettuce/day throughout the year. The factory consists of a nursery room of 70㎡ and a growing room of 240㎡. These two rooms are fully insulated and air-conditioned. Air temperature in the growing room is kept at 24℃ in the daytime and 20℃ at night throughout the year. High-pressure sodium lamps are installed in the growing room and the nursery room to produce 20,000lx at the plant level and 12hour day length. CO_2 enrichment is at the level of 1,000ppm. Lettuce is seeded on small urethane cubes and set on the surface panels of the DFT hydroponic system. Thirty days are needed from seeding to the harvest of 150g lettuce.

The percentage of the electricity cost in the total production cost is apparently very high at 33% and depreciation cost of the construction is 24%. This means the operational cost is just above the break-even point. Another system, TS system,is a compact modular system with a sloped A-frame bed. Artificial lighting by high pressure sodium lamps is used.

Table 1 shows the estimated standard cost of the TS-1250 type system. Economy of the system is drastically improved over the plant factory in Shizuoka. However, energy cost is still high. For xample, electricity cost is over 25% of the total operational cost for leaf lettuce production.

Table 1. Estimated standard cost of the TS-1250 type system (Takakura and Sekiyama, 1994).

Item	Leaf lettuce	Celery
Production(plants/year)	470,000	2,352,000
Operational cost (yen/plant)		
Fertilizer, Seeds, CO_2	3.18	2.40
Panels, Urethane cubes	3.39	1.41
Lamps, Mechamical parts	3.25	0.65
Electricity cost	12.02	2.37
Water	0.40	0.08
Labor	16.67	4.04
Packing	9.50	3.17
Sub-total	47.41	14.12
Construction cost (yen/plant)		
Depreciation	22.68	4.53
Interest	5.67	1.09
Property Tax	1.59	0.32
Sub-total	29.94	5.94
Total	77.35	20.06

Since the system is energy intensive, plants which need less light intensity are the main crops produced in this type of system; that is, leaf vegetables such as leaf lettuce, celery, spinach and leek. Some herbs such as basil and coriander can also be produced in the system. Additionally, flowers such as mini-roses, viola and dianthus can be grown.

In a plant factory, an artificial lighting system is an essential component since it is the only source of light available for photosynthesis. High-pressure sodium lamps are the most popular for not only the main lighting system but also supplemental usage since energy efficiency is higher than with other types of lamps. For the lamp spectrum, deficiencies in the blue region should be supplemented by either metal halide or fluorescent lamps which have sufficient energy in the blue region. Fluorescent lamps illumination has advantages and disadvantages. With fluorescent lamps, it is relatively easier to obtain uniform light distribution over plant surfaces and the lights can be set up closer to the plants. However, more space is required over the ceiling for lamp set up. Uniform light distribution is important and should be paid more attention in a system of point light sources such as high pressure sodium lamps. In most cases, it is assumed that uniform illumination can be achieved by uniform distribution if light sources. It should be noted that not only lamp arrangement but also the optical properties of wall and ceiling surfaces play a large role in light distribution at the plant level. Lamp life-time and aging problems should also be considered.

In supplemental lighting systems where natural sunlight is the main light source, shading effects from the lamp arrangement should be minimized.

Transplanting systems

Automated transplanting systems have been installed in some large-scale nurseries for plug seedlings in Europe. For example, Hamer Co. in the Netherlands, similar to Walz Co. in Germany, produces 250 million plug seedlings per year for over 6,000 customers. Production is fully automated with seeding machines by Visser Co., The main parts of these systems are the transplanting machines. The same size tray can be used for 104 to 594 plugs. Each tray has a specific number of hollows, but the trays are checked by machine vision to find seedlings which need from the bottom drain holes in the trays and then filled with normal seedlings from another tray by a robot arm.

Environmental control systems

It is very common to use computers for environmental control of conventional type greenhouses (Takakura, 1992a; Takakura, 1993;Takakura, 1994). Color monitors with windows-type software are becoming popular, and in some systems, network software and hardware canbe installed. Over 5,000 computers are operated in greenhouses in the Netherlands,and over 1,000 in Japan. Since computer control has many advantages over conventional analog controllers, the expansion of computers can not be stopped from neither economical nor functional viewpoints.

Now the remaining problem is sensor development, especially humidity and individual ion sensors. Reliable humidity sensors which can operate in high humidity close to or over 100% are needed. In hydroponic systems, pH and EC are monitored and adjustment of nutrient solutions is done automatically. However, further adjustment or replcement of nutroent solutions is base on full chemical analysis of the solution in a batch treatment.

Transporting systems

Computer-controlled transporting systems are now installed in some conventional type greenhouses for pot-plant and seedling operations in Europe. The robots used on the systems are often called agri-robots. Efficient use of greenhouse floor area is arranged by a computer. The computer controls a machine which carries trays and pots, according to the customer's order and controls environmental conditions specific to each plant variety and growth stage. Movements in two directions in the horizontal plane are required in the greenhouse. One type of robot rotates four wheels at 90 degrees to change direction. Another type has two modes of movement: wheels for movement in one direction, and a hanging arm which latches onto an overhead frame for movement in the other direction. Robots which can move in two directions are usually battery operated.

Spacing is important in plant factories, since efficient space utilization in the system is required. Control of two directional spacing would be ideal but usually spacing in only one direction is controlled. It is easy to change the spacing between trays, but more difficult to change plant spacing within a tray. In small modular systems, two dimensional spacing is possible. At present, human labor is used when transplanting is still required between panels with different plant densities.

Harvesting systems

Harvesting requires sophisticated management processes, and it is rather difficult to automate whole processes. Even in manual harvesting, intensive human labor can be reduced if laborers are not required to move around in the system. For example, in Swegro Co. in Sweden, harvesting an packing can be done at the same time in one side of a cultivation area, so human labor is minimized.

Hydroponic systems

Hydroponic systems are also essential components of factory-style plant production system. The most important factor is that the nutrient solution should be in a completely closed system. Phyiological disorders caused by an imbalance of nutrient absorption have been identified for many crops. Discharge of organic acids and accumulation of unused ions require the complete replacement of the nutrient solution at certain intervals, and the replacement frequency is accelerated by cultivation intensiveness. The situation is more severe in plant factories than in conventional greenhouse cultivation.

BENEFITS OF CLOSED SYSTEMS

An ideal factory-style production system would be completely closed environmentally. This means the system should have artificial lighting in an air-tight house, and hydroponic solution should be recirculated. The system should be fully air-conditioned, with no air exchange with unfiltered outside air. In this type of system, high energy consumption is the main problem.

Biological control is now becoming more popular in conventional type greenhouse cultivation. However, in closed systems, inside air is regularly circulated between the cultivation area and air-conditioning units at rather high speed, so it is not practical to involve insects are rarely imported from outside, biological control is usually not necessary for closed system.

FUTURE ASPECTS

Space farming (Takakura,1992b:Takakura et al.,1996)

CELSS(Controlled Ecological Life support Systems) is a current topic for space research. Fresh vegetable production is type of CELSS study and will be important for living on the moon or in satellite stations. In this sense, completely colsed systems are essential. Additional environmental factors such as gravity and hypobaric pressure should also be taken into account.

Metabolic fermentation

Syntheses of ginseng roots and indigo components in bio-reactor type systems are popular research topics in metabolic fermentation. Liquid jar fermentation systems are usedfor this type of tissue culture. Cultivation density can be drastically increased compared to conventional cultivation methods and a 10 ℓ volume jar can exceed the production of several hectares of greenhouses.

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