PROPAGATION, GRAFTING AND TRANSPLANT PRODUCTION IN CLOSED SYSTEMS WITH ARTIFICIAL LIGHTING FOR COMMERCIALIZATION IN JAPAN

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Abstract

A ‘closed plant production system’ or simply a ‘closed system’ is defined in this paper as a warehouse-like structure covered with thermally insulated opaque walls, in which ventilation is kept at a minimum, and artificial light is used as the sole light source for plant growth. CO₂ is enriched at a level of 1,000 μmol mol⁻¹ and evaporated water is collected at a cooling panel of air conditioner to recycle it for irrigation. No waste water containing chemical fertilizer is released to the outside. Advantages of a closed system over a greenhouse for production of plants shorter than 30-40 cm in height include: 1) rapid and uniform growth of high quality plants, 2) over 10-fold productivity per floor area per year, rapid growth, high planting density and high yield rate, 3) high utilization efficiencies of water and CO₂, 4) high light utilization efficiency of plants due to optimized temperature, light intensity and period, CO₂ concentration and water content of the substrate, and 5) virtually no heating cost is required in winter even in northern countries. Initial and operation costs per plant production capacity in closed systems are comparable to or lower than those in greenhouses. In 2007, the closed systems are used at 45 different locations in Japan for commercial production of transplants, herbal/medicinal plants and leafy vegetables, and at 15 different locations for research purposes.

Key words: air conditioner, CO₂ enrichment, environmental control, lamp, light, transplant

INTRODUCTION

Recently, we developed a closed plant production system with lamps (called ‘closed system’ for short hereafter) aiming at commercial production of high quality plants, using minimum electricity, water, CO₂ and labor in a reduced floor area. Its details are described in Kozai et al. (2004, 2005a, 2005b and 2006).

In the closed system, plant environment can be controlled precisely as desired, regardless of the weather, and irrigated water can be recycled by collecting evaporated water from plants and substrate at the cooling panels of an air conditioner. Then, high quality plants without insect pests can be produced using no agrochemicals and minimal amounts of other resources. Electricity cost is roughly 1.0 US cent per transplant, which accounts for 1-5% of the sales prices of tomato, eggplant, pansy, and virus-free sweet potato transplants. This remarkable reduction in electricity cost per transplant was achieved by using thermally insulated walls, multi-shelves, advanced lighting and air conditioning systems, etc. Annual production capacity of transplants per floor area is about 10 times or higher in the closed system than that in the greenhouse, mainly due to the use of multi-shelves, rapid growth, high planting density and high percentage of salable transplants. The closed system needs 30% less amount of fertilizer because of no release of water containing fertilizer to the outside, 90% less of water because of recycling use of evaporated water for irrigation, and virtually no pesticide. There are many other advantages of the closed system over the greenhouse, as described later. The closed system can also be applied for production of herbal/medicinal plants, ornamental plants and leafy vegetables, if their height is lower than about 30-40 cm.

In this paper, we describe briefly the definition, concept, theoretical backgrounds, methods, materials, applications, and advantages of the closed system using lamps over a greenhouse using sunlight from biological, engineering and economic points of view. This paper is a summary of the recent ‘closed system research’ at our laboratory. For detailed technical data, refer to the literature cited.
CLOSED PLANT PRODUCTION SYSTEM

Definition and main components

A 'closed plant production system' or simply called 'closed system' in this paper is defined as a warehouse-like structure (Fig. 1), 1) covered with thermally insulated roof/walls, 2) in which ventilation is kept at minimum, and 3) which uses lamps (e.g., fluorescent tubes) as the sole light source for plant growth.

Main components of the closed system are: 1) a warehouse-like structure covered with opaque thermal insulators, 2) multi-shelves having lamps and their fixtures, installed in the warehouse-like structure (Figs. 2, 3 and 4), 3) air conditioners, which are mostly used for cooling and dehumidification, and sometimes for heating, 4) fans for internal circulation of air (Fig. 5), 5) a CO₂ supply unit for promoting plant photosynthesis, 6) a nutrient solution supply unit, and 7) an environmental control unit. Fluorescent lamps are usually used as a light source, although LED (light emitting diode), etc. can also be used as light source. Plug trays with cells are often used and placed on the shelf for production of plug transplants.

Fig. 1. Schematic diagram showing four main components of the closed plant production system.

Fig. 2. External view of a closed system unit.

Fig. 3. This room (69 m²) can hold 284 plug trays each with 288 cells or 110,000 tomato transplants, with an annual production capacity of 2.6 million transplants.

Fig. 4. External view of the closed system consisting of 21 units.

Fig. 5. Microenvironment in each shelf is almost the same as that in other shelves. The air current speed and direction are almost the same over the plug trays.
**Characteristics of main components of closed systems**

All the main components of the closed system are mass-produced for home use or for industrial use. Therefore, in most countries, regarding the main components: 1) a considerable discount is common for bulk purchases due to the significant reduction in costs for packaging, labor, shipping, transportation, etc., 2) significant technical advancement and price reduction have been achieved year by year, which are forced by strong competition among manufacturers, and 3) recycling and/or reuse systems for fluorescent tubes, air conditioners and thermal insulators have been established by laws for environmental conservation and resource saving.

These main components of the closed system are used without any modification for constructing the closed system, and each component has a rich variety of types, sizes, capacities, prices, etc. Therefore, we are able to construct various types of closed systems as desired, just like to construct a computer system with the most suitable types of parts or units, for instance, a central processing unit (CPU), a mother board, a hard disk, memories, printers, etc. These characteristics significantly reduce the investments for research and development of the closed system, and increase the flexibility of the closed system.

**Components unnecessary in the closed system, but necessary in the greenhouse**

Components which are unnecessary in the closed system, but are often necessary in the greenhouse are: 1) thermal and shading screens installed under the roof, 3) roof/sidewall ventilators or fan ventilators, 4) heaters, 5) benches, beds or bags containing substrate, 6) glass sheets or plastic films as covering material. In some cases, the following components are also necessary in the greenhouse: 7) an evaporative cooling system and/or a supplemental lighting system. Most of these greenhouse components have been developed and used only in the greenhouse industry. Thus, investment for research and development of the greenhouse components is costly. Components often common to both closed system and greenhouse for transplant production are plug trays with cells, an irrigation unit and an environmental control unit. However, control algorithms of these units for the closed system are much simpler than those for the greenhouse, because the environment in the closed system is little affected by weather. A CO₂ supply unit is indispensable for the closed system with minimum ventilation, but is dispensable for the greenhouse with ventilation.

**Advantages**

Advantages of the closed system over a greenhouse include: 1) rapid and uniform growth of high quality plants (Fig. 6), 2) over 10-fold productivity per floor

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**Fig. 6.** A sweet potato transplant grown for 14 days in the closed system, starting with a single node cutting with a leaf.

**Fig. 7.** Spinach seedlings 12 days after sowing grown on 228-cell trays in the closed system and those grown of 144-cell trays in the greenhouse.

**Fig. 8.** Tomato seedlings 14 days after sowing grown on, respectively, 128-, 200- and 288-cell trays in the closed system.
area per year mainly due to the use of multi-shelves, rapid growth (Fig. 6), high planting density (Figs. 7, and 8), easy grafting (Figs. 9 and 10) and high yield rate (Figs. 11 and 12). 3) high utilization efficiencies (Fig. 13 and 14) of water and CO₂ due to the minimized ventilation and recycling uses of water and CO₂.
Resource saving and high performance characteristics of the closed system

The following is a summary of resource-saving and high performance characteristics of the closed system in comparison with those of the greenhouse (Details of those characteristics and their reasons are explained in Kozai et al., 2005a, 2005b) and Kozai (2006): 1) Initial investment cost per unit transplant production capacity is comparable to or lower than that of the greenhouse, 2) Operation costs are low due to a reduced floor area to about 1/10, and thus is reduced labor cost, 3) Uniformity and precise control of microenvironment over the trays are achieved by using micro-fans installed at each shelf for air circulation, 4) Growth and development of plants and their uniformity are enhanced due to optimized environment control, 5) Yearly production capacity per floor area is about 10 times that of the greenhouse as stated above, 6) Heating cost is a several percent of that of the greenhouse even during winter in northern countries, 7) Cooling load does not change significantly throughout the year, because it is determined by the rate of heat generation from lamps, no: the rate of heat transmission through walls, 8) Electricity cost for cooling accounts for about 20% of that for lighting, cooling, etc., by using an air conditioner having a value of COP (coefficient of performance) greater than 5 under standard weather conditions, 9) Electricity consumption per transplant in the closed system is often a few times that for supplemental lighting in the greenhouse during winter in northern USA, The Netherlands, England, etc., 10) Electricity cost is only 2-5% of sales price of plants, 11) Relative humidity during photoperiod is always kept at about 70% due to a moisture balance between rate of dehumidification by air conditioners and rate of evaporranspiration from plants and substrate in the closed system, 12) PAR (photosynthetically active radiation) utilization efficiency is about 10% due to the optimized environment, which is about 2 times that in the greenhouse, 13) No ventilation cost is required because no ventilation system is installed, 14) CO₂ enrichment cost is considerably small because the closed system is nearly airtight, so that about 85% of CO₂ gas supplied to the closed system is fixed by photosynthesis of plants, 15) The amount of water required for irrigation is a few percents of that in the greenhouse due to the recycling use of evaporated water, 16) Disinfection of the closed system is relatively easy because it is nearly airtight. 17) An environmental control unit is much simpler than that for the greenhouse as stated previously, 18) Production management is easier than in a greenhouse because the environment inside the closed system and thus plant growth are not affected by weather, 19) Release of pollutants from the closed system is considerably restricted because the use of pesticide is minimal and there is no residual irrigated water containing fertilizer.

CONCLUSIONS

It can be concluded that quality and growth rate of plants or transplants are considerably higher when produced in the closed system than in the greenhouse. The closed system is energy and material efficient especially with respect to the amounts of water required for irrigation and energy required for heating in winter. In addition, the closed system is an environmentally friendly system for plant production in the sense that it does not release polluted water that contains fertilizers to the outside and that it seldom requires pesticide and fungicide. Electricity consumption and its cost for lighting and cooling of the closed system is minimum and accounts for only a few percents of sales price of plants. Initial and operation costs of the closed system per annual plant/ transplant production are lower than or comparable to those of the greenhouse, and it has been used in 2005 at about 30 different locations in Japan for commercial production of transplants, leafy vegetables, herb and medicinal plants.

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REFERENCES


