Commercialized Closed Systems with Artificial Lighting for High Quality Transplant Production at Low Costs and Minimum Resources

Toyoki Kozai
Chiba University, Japan
October 12, 2004, Beijing, China at CIGR 2004

Shortages of Natural Resources
Shortages of Food & Feed
Shortages of Seedlings & Plantlets
Environmental Pollution
An increasing number of high quality transplants is also needed in residential and industrial areas for improving our quality of life. In order to produce a large number of high quality transplants at low costs using minimum resources without environmental pollution, we developed a closed transplant production system for its commercialization.
The closed transplant production system consists of:

- A warehouse-like structure covered with opaque thermal insulators, in which ventilation is kept at minimum.
- Air conditioner for home use
- Multi-shelves with fluorescent tubes
- CO2/water supply unit

A prototype of the closed transplant production system
The closed transplant production system commercially used in Japan

Internal View of the closed system

Tomato seedlings

Plug Tray 30 cm x 60 cm
This room can hold 384 plug trays each with 288 cells, producing 110,000 per batch, 220,000 monthly, and 2.6 million transplants, annually.

Fluorescent lamps and air distribution fans on each shelf
**CO₂ supply unit**

- Liquid CO₂ container
- Infra-red type CO₂ controller

**Nutrient solution supply unit**

- Nutrient solution tanks & controller
- Intermittent sub-irrigation
Our recent research revealed that, in the well designed closed systems,:
1) Electricity cost is low.
2) Transplant quality is high.
3) Initial cost is low
4) The closed system can be commercialized.

All the components of the closed system are:
1) mass-produced at low costs,
2) their recycling systems are established, and
3) cost performance of each component has been improved significantly every year.
In the closed system, air is moved horizontally at 50 cm/s to promote photosynthesis and transpiration.

Electricity consumption for lighting is low, because

1) PPF (light intensity) is 200-300 \( \mu \text{mol m}^{-2}\text{s}^{-1} \),
2) Production period is 2-3 weeks,
3) Planting density is high (1000\(>\) plants m\(^{-2}\)),
4) Transplants are placed 20-30 cm below fluorescent lamps.
Electricity consumption and its cost per transplant are, respectively,

- 67 Wh (or 242 kJ) and 0.5 US cent, respectively, in a plug tray with 200 cells.
- 34 Wh (or 120 kJ) and 0.25 US cent, respectively, in a plug tray with 400 cells.

In Japan, this electricity cost accounts only for a few % of the production cost.

This electricity consumption of 67 Wh (or 242 kJ) is well over-compensated by reductions in consumptions of labor, pesticide, water, fertilizer, space, and construction materials, and by environmentally friendlyness and higher commercial value of transplants.
1) Planting density can be doubled without stem elongation and growth retardation.
Cabbage transplants 13 DAS at different transplanting density

128 200 288 Cells/Tray

cv. Kinkei 201

Crisp head lettuce transplants 16 DAS

Closed system

cv. Cisco

200 cells/tray 288 cells/tray

Greenhouse 200 cells/tray 288 cells/tray
Spinach transplants

<table>
<thead>
<tr>
<th>Greenhouse</th>
<th>Greenhouse</th>
<th>Closed system</th>
</tr>
</thead>
<tbody>
<tr>
<td>144 cells/tray</td>
<td>144 cells/tray</td>
<td>288 cells/tray</td>
</tr>
<tr>
<td>17 DAS</td>
<td>13 DAS</td>
<td>12 DAS</td>
</tr>
</tbody>
</table>

2) Transplant production period is shortened by 30-50%.
Standard environments to shorten the production period by 30-40%.

- CO2 of 1000 μmol mol⁻¹ (ppm)
- PPF (light intensity) of 200-300 μmol m⁻²s⁻¹
- Photoperiod of 16 h d⁻¹
- Air current speed of 50 cm s⁻¹ using fans

Sweetpotato Single Node Cutting (Day 0) and Transplants on Day 14
Cabbage transplants 14 DAS

**cv.: Kinkei 201**

Closed system: 16 h/d photoperiod

Greenhouse: Sown on Oct. 18

---

Cabbage transplants 13 DAS

as affected by daily light period

**cv.: Kinkei 201**

Daily light period

12 h/d 16 h/d 20 h/d

Light 22°C/Dark 19°C
3) Growth is uniform and vigorous

Pansy seedlings ready for potting 29 DAS (August 10, 2000)

Closed system    Greenhouse

cv. Iona Yellow
Pansy Transplants 29 DAS

Closed system Greenhouse

Tomato seedlings 20 DAS

cv.: House Momotaro, (June 27, 2003)
4) Scions and root stocks suitable for grafting

Cucumber seedlings for scions
7 DAS

cv.: encore 10
Grafted cucumber transplants

19 DAS

Scion: encore 10, stock: Hikari Power G

Grafted tomato transplants

20 DAS

Scion: House Momotaro, Stock: encore
5) Flower bud initiation and growth can be enhanced or controlled.
6) Growth after transplanting in the greenhouse is enhanced.

Greenhouse-grown transplants were used.

Closed system-grown transplants were used.

Jan. 4, 2001 (38 DAT), cv.: Mistral
Since the closed system is thermally well insulated and the environment is well controlled,

- Electricity consumption for cooling is minimum and for heating is null.
- Percentages of electricity consumption is 80% for lighting, 15% for cooling and 5% for fans/pump operations,
- Transplant productivity of the system per floor area is 10 times compared with that of the greenhouse.

10-fold productivity per floor area of the closed system compared with that of greenhouses results from:

- 2-fold planting density
- 4 layered shelves
- 30% reduction in production period
- 10% increase in yield rate
- 20% increase in market price

\[2 \times 3 \times 1.3 \times 1.1 \times 1.2 = 10.2\]
Reduction in costs

- 50% reduction in labor due to the reduced floor area by 90%.
- 95% reduction in an amount of water for irrigation by water recycling
- 30% reduction in fertilizer due to the no release of waste water.

Since the ventilation is minimized in the closed system,

- Amount of water used for irrigation is saved by 95%, since 95% of evaporated water is condensed at the cooling panel (or evaporator) of air conditioners and is reused for irrigation.
- No water and fertilizer are released to the outside so that water and fertilizer consumptions are saved by 30% or more and the system is environmentally friendly.
- 85% of supplied CO₂ is fixed by plants.
Since the floor area of the closed system is only 10% of the greenhouse for the same productivity, the construction cost of the closed system per production can be comparable to or lower than that of the greenhouse.

High yield and quality in the fields with resource saving by use of quality transplants

- High Yield & Quality, No Environmental Pollution
- Closed Transplant Production System
- Resource Saving Farming in Cultivation Fields
- High Quality Transplants Tolerable to Stressful Environments and Pests
Production of transplants using the closed system is a new area of bio-industry, positioned between agriculture and current industries, so that qualified engineers are needed for its optimum operation.

The closed system can be used also for production of high value plants with short height, such as leafy vegetables, some kinds of medicinal plants and bedding plants.
An increasing number of high quality transplants is also needed in residential and industrial areas for improving our quality of life.
Thank you for your attention.
**CO₂ utilization efficiency**

\[
\begin{align*}
\text{Fixed} & = \frac{192}{221} = 0.87 \\
\text{Supplied} & = 221 \\
\text{Number of air changes} & = 0.01 \, \text{h}^{-1}
\end{align*}
\]

**Water utilization efficiency**

\[
\begin{align*}
\text{Dehumidified + P + S} & = \frac{0.985}{\text{Irrigated}} \\
\text{Irrigated} & = 1667 \\
\text{P: Increase in plants} & = 42 \\
\text{S: Increase in substrate} & = -414 \\
\text{Ventilated: 39} & \text{ (Unit: kg)}
\end{align*}
\]
Water utilization efficiency

\[
P \frac{42}{Irrigated 1667} = 0.025
\]

Dehumidified for Re-use: 2014

Irrigated 1667

P: Increase in plants
S: Increase in substrate

Ventilated: 39

P: 42
S: -414

(Unit: kg)
Research Unit on Closed Plant Production Systems established in 1999 at Chiba Univ

Production of tomato seedlings in the closed transplant production system
Fluorescent lamps

7-layered shelves with environment control units

A computerized transportation/irrigation system
Production of virus-free transplants of sweetpotato

Examples of value-added transplants

1) Pathogen and pest free sweetpotato,
2) Tomato and eggplant with enhanced flower bud development,
3) Spinach with delayed bolting,
4) Vigorous Chinese cabbage
Electricity consumption, E
7 MJ (2.2 kWh) per plug tray per week

<table>
<thead>
<tr>
<th>No. of cells/tray</th>
<th>E/plant/2 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>70 kJ</td>
</tr>
<tr>
<td>100</td>
<td>140</td>
</tr>
<tr>
<td>50</td>
<td>300</td>
</tr>
</tbody>
</table>

Price of Electricity per KWh in US cents

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>15-20</td>
</tr>
<tr>
<td>USA</td>
<td>5-10</td>
</tr>
<tr>
<td>Canada</td>
<td>3-6</td>
</tr>
</tbody>
</table>