Commercialized Closed Systems with Artificial Light for Plant Production

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Acknowledgement

• Eiji Goto
• Masahiro Inayoshi
• Maroya Nobugai
• Katsumi Okabe
• Katsumi Ohyama
• Wu De
The closed system consists of a warehouse-like structure covered with thermally insulated walls, in which ventilation is kept at minimum, along with an Air conditioner for home use, Multi-shelves with Fluorescent tubes, and CO₂/water supply unit.

This room (69 m²) can hold 384 plug trays each with 288 cells or 110,000 tomato transplants, with an annual production capacity of 2.6 million transplants. Tokushima Prefecture, Japan
Fluorescent lamps and air distribution fans are installed on each shelf. The 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.

In the closed system, air is moved horizontally at 50 cm/s using fans in each shelf to promote photosynthesis and transpiration.

- The 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.
Nutrient solution supply unit

Nutrient solution tanks & controller  Intermittent sub-irrigation

CO₂ supply unit

Liquid CO₂ container  Infra-red type CO₂ controller
Almost all the components of the closed system are:

1) mass-produced at low costs,
2) their recycling systems have already been established, and
3) cost performance of each component has been improved significantly every year.

The closed system has been sold to more than 40 different customers in Japan.
Economic analysis of a closed system currently used for commercial production of tomato transplants in Shizuoka Prefecture, Japan

External view of the closed system commercially used for tomato transplant production in Japan

CO₂ supply system

Shizuoka Prefecture, Japan
Common conditions for comparison of initial investment cost for tomato transplant production between the closed system and the greenhouse.

<table>
<thead>
<tr>
<th>Item</th>
<th>Closed System (CS)</th>
<th>Greenhouse (GH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS (Floor area: 92 m²)</td>
<td>29,400</td>
<td>-</td>
</tr>
<tr>
<td>Work room for CS (663 m²)</td>
<td>13,650</td>
<td>-</td>
</tr>
<tr>
<td>GH (Floor area: 1,994 m²)</td>
<td>-</td>
<td>35,700</td>
</tr>
<tr>
<td>Env. Cont. Units for GH</td>
<td>-</td>
<td>20,475</td>
</tr>
<tr>
<td>Potting/Mixing Units</td>
<td>3,045</td>
<td>3,045</td>
</tr>
<tr>
<td>Construction</td>
<td>6,566</td>
<td>4,998</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>52,661</strong></td>
<td><strong>64,208</strong></td>
</tr>
</tbody>
</table>
Comparison of Operational costs per transplant between closed system and greenhouse (Unit: JPY)

<table>
<thead>
<tr>
<th>Item</th>
<th>Closed system</th>
<th>Greenhouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seeds, Substrate, Plug Trays, Pots</td>
<td>31.3</td>
<td>30.9</td>
</tr>
<tr>
<td>Electricity</td>
<td>8.2</td>
<td>2.4</td>
</tr>
<tr>
<td>Agro-chemicals</td>
<td>-</td>
<td>0.7</td>
</tr>
<tr>
<td>Land</td>
<td>0.2</td>
<td>0.7</td>
</tr>
<tr>
<td>Depreciation</td>
<td>12.4</td>
<td>13.4</td>
</tr>
<tr>
<td>Labor</td>
<td>5.8</td>
<td>8.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>57.9</strong></td>
<td><strong>56.1</strong></td>
</tr>
</tbody>
</table>

Comparison of labor time per transplant between closed system and greenhouse (Unit: Second)

<table>
<thead>
<tr>
<th>Item</th>
<th>Closed System</th>
<th>Greenhouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seeding</td>
<td>5.36</td>
<td>4.31</td>
</tr>
<tr>
<td>Transportation</td>
<td>0.86</td>
<td>6.05</td>
</tr>
<tr>
<td>Environ. management</td>
<td>-</td>
<td>2.37</td>
</tr>
<tr>
<td>Potting</td>
<td>20.20</td>
<td>23.43</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>26.42</strong></td>
<td><strong>36.16</strong></td>
</tr>
</tbody>
</table>
Electricity cost for lighting/cooling of the closed system is 1.1 Euro (or 1.3 US$)/tray/week when PPF is 250 μmol m\(^{-2}\) s\(^{-1}\) and photoperiod of 16 h/d. The cost decreases with increase in number of cells per plug tray and decreases in period of transplant production and air temp. outside.

- The electricity cost per transplant are 0.046 Euro and 0.011 Euro, respectively, for plug trays with 72 and 288 cells, when transplant production period is 3 weeks.

Electricity consumption for lighting is low, because

1) PPF (light intensity) is 200-300 μmol m\(^{-2}\)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.
Cost performance of the closed system can be improved further by adopting our research results showing that:

- Planting density can be doubled without stem elongation and growth retardation.
- Transplant production period can be shortened by 30-50%.
- Uniform and vigorous growth can be achieved.
- High quality scions & root stocks for grafting can be obtained.
- Flower bud development and bolting can be enhanced or controlled.
- Growth after transplanting in the greenhouse can enhanced.
- Insect- and insecticide-free transplants can be produced.

1) Planting density can be doubled without stem elongation and growth retardation
Tomato seedlings in a plug tray with different numbers of cells, 14 DAS

128 cells/tray  200 cells/tray  288 cells/tray
Cv. House Momotaro, 14 DAS

Cabbage transplants 13 DAS at different transplanting density

128 Cells/Tray  200  288
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
Greenhouse 144 cells/tray 17 DAS
Greenhouse 144 cells/tray 13 DAS
Closed system 288 cells/tray 12 DAS
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⁻² s⁻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

Light 22°C / Dark

Light 28°C / Dark 19°C

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
5) Flower bud development can be enhanced or controlled.
苗質の安定
トマト接ぎ木苗「桃太郎ファイト×Bバリア」の果房着生葉位（％）

<table>
<thead>
<tr>
<th>1段花房</th>
<th>2段花房</th>
<th>3段花房</th>
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<tbody>
<tr>
<td>9節</td>
<td>5.9</td>
<td>12節</td>
</tr>
<tr>
<td>13節</td>
<td>2.5</td>
<td>15節</td>
</tr>
<tr>
<td>16節</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>10節</td>
<td>90.0</td>
<td>12節</td>
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<tr>
<td>13節</td>
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<td>14節</td>
<td>2.5</td>
<td>16節</td>
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<tr>
<td>17節</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>11節</td>
<td>4.1</td>
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<tr>
<td>17節</td>
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</tr>
<tr>
<td>14節</td>
<td>2.5</td>
<td>17節</td>
</tr>
</tbody>
</table>

※6月22日　120株調査
※播種日（台木4月10日，穂木4月11日）
※鉢上日（5月4日），定植日（5月21日）

Pansy Transplants at Shipping
64 DAS

Closed System Greenhouse
6) Growth after transplanting in the greenhouse is enhanced.

Hydroponic spinach grown in the greenhouse

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 evapotranspired 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.
Production of leafy vegetables in closed systems

Anthocyanin production in leaf salads under lamps
St. John’s wort

Glycyrrhiza uralensis plants on Day 90
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
- Resource Saving Farming in Cultivation Fields
- Closed Transplant Production System
- 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

\[ \frac{\text{Fixed}}{\text{Supplied}} = \frac{192}{221} = 0.87 \]

CO₂ utilized: 192
CO₂ supplied: 221

Number of air changes

\[ = 0.01 \text{ h}^{-1} \]

Water utilization efficiency

\[ \frac{\text{Dehumidified} + P + S}{\text{Irrigated}} = 0.985 \]

Dehumidified for Re-use: 2014

Irrigated: 1667

P: Increase in plants
S: Increase in substrate

P: 42
S: -414

Ventilated: 39
(Unit: kg)
Water utilization efficiency

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

Dehumidified for Re-use: 2014

Irrigated: 1667

P: Increase in plants
S: Increase in substrate

Ventilated: 39 (Unit: kg)

P: 42
S: -414
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</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>