Current situation & prophase exploration on vertical farming and urban agriculture in China

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Institute of Environment and Sustainable Development in Agriculture (IEDA), CAAS, Beijing, China
Contents

- Short introduction to CAAS & IEDA
- Why do we need to develop Vertical farming and urban agriculture in China
- Prophase exploration on technologies of vertical farming and plant factory
- Facing Challenges of vertical farming (plant factory)
- Projects on vertical farming and plant factory in China
1. Introduction of CAAS & IEDA
Chinese Academy of Agricultural Sciences (CAAS)

CAAS, located in Beijing, was established in 1957 and is affiliated to the Ministry of Agriculture of China. At present, CAAS has 40 research institutes, and 1 graduate school. About 11,000 technical professionals and over 4000 graduate students (M.S. and Ph.D.) working or studying in the CAAS.
Institute of Environment and Sustainable Development in Agriculture (IEDA), one of the 40 institutes in CAAS, 173 researchers and 250 MSc&PhD students.

Center for Protected Agriculture & Environmental Engineering (CPAEE) in IEDA

Group 1: Greenhouse Engineering

Group 2: Plant factory & Hydroponics

Group 3: Energy-saving Engineering

Group 4: Greenhouse Climate control
2. Why do we need to develop Vertical farming (plant factory) and urban agriculture in China?
Challenges in China

------ Population explosion (now 1.3 billion, to 2030, will be 1.5 billion, food demand rising)

------ Land resources reducing (only 0.08 ha per capita in China, 40% of world average level) & Agricultural pollution, desertification

------ Natural disasters (drought, flood, etc.)

------ Demands increasing for fresh, clean, pesticide-free vegetables

------ Agricultural labors’ aging problem (Young people don’t like to be engaged in agriculture, more than 60% farmers in China are over 60 years old)

......
Population explosion

Increasing trend of population in China
Up to 2025, nearly 70% of Chinese will live in cities with more than 1 million people.
Land resources reducing & Agricultural pollution, desertification (reducing cultivated land 300,000hm² each year)

Natural disasters (drought, flood, etc.)

Cultivated land in China (100 million MU)(1MU=1/15 hm²)
Agricultural labors’ aging problem

The rapid increase of aged people in China
Food demands increasing (470 million tones of vegetables each year (330 million tones of vegetables for the residents in cities) in China)
How to solve the above problems?

Population explosion
Large number of people in cities
More requirements for food (vegetables)

Land resources reducing
Natural disasters
Agricultural labors’ aging problem

Vertical farming (plant factory) could be a possible way to solve the problems
Land use efficiency

- Plant factory with solar light (2-10 times)
- Plant factory with artificial light (>40 times)
- Vertical farming (>1000 times)
3. Prophase exploration on technologies of vertical farming and plant factory
- Having not real vertical farming case in China now (2-3 ongoing projects)
- Plant factory developed very quickly
- Urban agriculture and vertical cultivation developed rapidly
3.1 Development of plant factory in China

◆ Up to 2014, there are about 110 plant factories in China.

◆ PF with artificial light: about 43 plant factories, which are distributed in 13 cities or provinces (Another 10-12 PFs will be constructed recently).

◆ PF with solar light: about 67 plant factories (with hydroponic system for leaf or fruit vegetable production in controlled environmental greenhouses), which are distributed in 15 cities or provinces.
Regional Distribution of Plant Factory in China (2014)

- **Plant factory with artificial light**
- **Plant factory with solar light**

Beijing, total of seven, 6269 m²
Tianjin, total of four, 11300 m²
Erdos, Inner Mongolia, 4000 m²
Qian'an Tangshan, 3000 m²
Yangling, Shanxi, 2000 m²
Xian, Shaanxi, 2000 m²
Zhengzhou, Henan, 2000 m²
Chengdu, Sichuan, 1500 m²
Wuxi, Jiangsu, 10000 m²
Suzhou, Jiangsu, 500 m²
Xiaoshan, Zhejiang, 1500 m²
Shunde, Guangdong, 1000 m²
Shunde, Guangdong, 40000 m²

- **Shanghai**, four PFs, 18000 m²
- **Shanghai**, 10000 m²
- **Changxing, Zhejiang**, 880 m²
- **Zhuhai, Guangdong**, 40 m²
- **Zhuhai, Guangdong**, 4000 m²
- **Shenzhen, Guangdong**, 4000 m²
- **Tianjin**, total of four, 11300 m²
- **Dongguan, Guangdong**, 100 m²
- **Shenzhen, Guangdong**, 100 m²
- **Zhejiang University**, 800 m²
- **Fuzhou, Fujian**, 250 m²
- **Haerbin, Heilongjiang**, 100 m²
- **Changchun, Jilin**, 200 m²
- **Shenyang, Liaoning**, 30000 m²
- **Shenyang, Liaoning**, 3000 m²
- **Langfang, Hebei**, 2000 m²
- **Shenyang, Liaoning**, 3000 m²
- **Shenqiu, Hebei**, 2000 m²
- **Erdos, Inner Mongolia**, 4000 m²
- **Shouguang, Shandong**, 200 m²
- **Tai'an, Shandong**, 15000 m²
- **Gaoqing, Shandong**, 616 m²
- **Nanjing, Jiangsu**, 3000 m²
- **Nanjing, Jiangsu**, 300 m²
- **Shouguang, Shandong**, 200 m²
- **Shouguang, Shandong**, 200 m²
- **Wuxi, Jiangsu**, 10000 m²
- **Shouguang, Shandong**, 200 m²
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3.2 Researches on the key technologies in plant factory

- Digital Measurement and Control
- LED Light Source
- Key technologies In plant Factory
- 3D Soilless Cultivation
- Quality Control
- Internet of Things (IOT)
1. Parameter Optimization of LED Light for Vegetable Cultivation

Field planting

10 days

30 days

20 days
Controllable LED on light Parameters (light quality, light intensity and light period) has been developed in China
### Parameters of Light source for Vegetable Cultivation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LED Wave Length (nm)</th>
<th>number of beads (PCS/cm²)</th>
<th>photosynthetic photon flux density (µmol · m⁻² · s⁻¹)</th>
<th>Power conversion efficiency (%)</th>
<th>Light emitting surface size (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEDA</td>
<td>RED 660</td>
<td>1.82</td>
<td>288</td>
<td>6.7</td>
<td>L54×W28</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>BLUE 450</td>
<td>0.20</td>
<td>29</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEDB</td>
<td>RED 637</td>
<td>0.14</td>
<td>256</td>
<td>28</td>
<td>L54×W28</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>BLUE 460</td>
<td>0.11</td>
<td>42</td>
<td>18</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Light Quality Treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>photosynthetic photon flux density (RED) (µmol · m⁻² · s⁻¹)</th>
<th>photosynthetic photon flux density (Blue) (µmol · m⁻² · s⁻¹)</th>
<th>Total photosynthetic photon flux density (ΣPPFD) (µmol · m⁻² · s⁻¹)</th>
<th>photosynthetic photon flux density ratio (R/B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEDA1</td>
<td>132</td>
<td>22</td>
<td>154</td>
<td>6/1</td>
</tr>
<tr>
<td>LEDA2</td>
<td>136</td>
<td>17</td>
<td>153</td>
<td>8/1</td>
</tr>
<tr>
<td>LEDA3</td>
<td>140</td>
<td>14</td>
<td>154</td>
<td>10/1</td>
</tr>
<tr>
<td>LEDB1</td>
<td>131</td>
<td>23</td>
<td>154</td>
<td>6/1</td>
</tr>
<tr>
<td>LEDB2</td>
<td>136</td>
<td>17</td>
<td>153</td>
<td>8/1</td>
</tr>
<tr>
<td>LEDB3</td>
<td>139</td>
<td>14</td>
<td>153</td>
<td>10/1</td>
</tr>
</tbody>
</table>
## Photosynthetic characteristics of lettuce in different treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Photosynthesis rate (μ mol · m(^{-2} ) · s(^{-1}))</th>
<th>Transpiration rate (mol · m(^{-2} ) · s(^{-1}))</th>
<th>Stomatal conductance (mol · m(^{-2} ) · s(^{-1}))</th>
<th>Intercellular CO(_2) concentration (μ mol · mol(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEDA1</td>
<td>7.63bc</td>
<td>2.11cd</td>
<td>0.078d</td>
<td>247.8d</td>
</tr>
<tr>
<td>LEDA2</td>
<td>7.88b</td>
<td>3.863a</td>
<td>0.165b</td>
<td>332.8a</td>
</tr>
<tr>
<td>LEDA3</td>
<td>7.30c</td>
<td>2.42bc</td>
<td>0.098d</td>
<td>294.8b</td>
</tr>
<tr>
<td>LEDB1</td>
<td>7.57bc</td>
<td>1.88d</td>
<td>0.053e</td>
<td>275.9c</td>
</tr>
<tr>
<td>LEDB2</td>
<td>8.44a</td>
<td>3.62a</td>
<td>0.188a</td>
<td>270.2c</td>
</tr>
<tr>
<td>LEDB3</td>
<td>6.45d</td>
<td>2.58b</td>
<td>0.137c</td>
<td>295.2b</td>
</tr>
<tr>
<td>CK</td>
<td>5.70e</td>
<td>2.52b</td>
<td>0.086d</td>
<td>306.8b</td>
</tr>
</tbody>
</table>

(Wenjing etc, 2007)
2. Energy saving for light by using movable LED system
Treatments

A: CK; B: F-LED30; C: M-LED30; D: M-LED10; E: F-LED10

**Movable metal frame**

- **Fluorescent lamps**
  - Height: 15 cm
  - PPF: 150 μmol·m⁻²·s⁻¹
- **Cultivation boards** with seedlings:
  - Left
  - Right

**Movable metal frame**

- **LED panels**
  - Height: 15 cm
  - PPF: 150 μmol·m⁻²·s⁻¹
- **Cultivation boards** with seedlings:
  - Left
  - Right

**Moving direction of the frame**

**Moving direction of the LED panels**
### Electricity consumption of lighting, plant yield and light use efficiencies (LUEs) of lighting (movable LED, fixed-LED and FL)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Electricity consumption(^z) (kWh \cdot m^{-2})</th>
<th>Plant yields(^y) (g \cdot m^{-2})</th>
<th>LUEs(^x) (g \cdot kWh^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-LED10</td>
<td>61.2</td>
<td>625.9 ± 9.23(^w)</td>
<td>10.2 ± 0.15a</td>
</tr>
<tr>
<td>F-LED10</td>
<td>60.5</td>
<td>620.1 ± 35.76a</td>
<td>10.2 ± 0.59a</td>
</tr>
<tr>
<td>M-LED30</td>
<td>74.1</td>
<td>629.8 ± 13.17a</td>
<td>8.5 ± 0.18b</td>
</tr>
<tr>
<td>F-LED30</td>
<td>72</td>
<td>621.9 ± 6.37a</td>
<td>8.6 ± 0.09b</td>
</tr>
<tr>
<td>FL</td>
<td>105</td>
<td>438.7 ± 15.76b</td>
<td>4.2 ± 0.15c</td>
</tr>
</tbody>
</table>
3. Energy saving for cooling by introducing outside cold air

Outside cold air was introduced for cooling coordinated with an air conditioner.
Air exchanger (AE) system for introducing outside cold air to plant factory
COP of air exchanger (AE) affected by outdoor air temperature is much higher than air conditioner (AC)

Indoor air temperature: 25°C

Electric-energy use efficiency

\[ y = -0.94x + 15 \quad \text{R}^2 = 0.98 \]

\[ y = -0.18x + 8.4 \quad \text{R}^2 = 0.68 \]

<table>
<thead>
<tr>
<th>EUE</th>
<th>AE</th>
<th>AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>15.5</td>
<td>8.8</td>
</tr>
<tr>
<td>Average</td>
<td>14.2</td>
<td>8.2</td>
</tr>
</tbody>
</table>

Note: EUE-electric-energy use efficiency;
Hourly electric-energy consumption as affected by outdoor air temperature (T)

Electric-energy consumption during photoperiod (kWh)

- PFAL with AE
- PFAL without AE

\[ y = 0.04x + 0.37 \]
\[ R^2 = 0.63 \]

\[ y = 0.04x + 0.21 \]
\[ R^2 = 0.67 \]

Electric-energy consumption during dark period (kWh)

\[ y = 0.03x + 0.44 \]
\[ R^2 = 0.62 \]

\[ y = 0.03x + 0.26 \]
\[ R^2 = 0.68 \]

Table:

<table>
<thead>
<tr>
<th>Stages</th>
<th>( T_i )</th>
<th>( \eta_E )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photoperiod</td>
<td>25°C</td>
<td>24.6-63.0%</td>
</tr>
<tr>
<td>Dark period</td>
<td>15°C</td>
<td>2.3-33.6%</td>
</tr>
</tbody>
</table>

Note: \( T_i \) - indoor temperature; \( \eta_E \) - electric-energy saving effect.
4. Energy-saving using Solar energy power and LED in Plant factory

Solar cell components

battery
5. Quality control of vegetables

Nitrate
75~80%

Nitrate
20~25%

High nitrate → Cancers and diseases

Hemoglobin → methemoglobin
(carries oxygen) → (stop carrying oxygen)

(Cassens, 1997)
Reducing nitrate concentration with pre-harvest short-term continuous lighting

**Nitrate content**

![Nitrate content graph](image)

**Soluble sugar**

![Soluble sugar graph](image)

**Ascorbic acid**

![Ascorbic acid graph](image)

**Fig. 2** Changes of nitrate concentration in lettuce under 72h continuous light

**Fig. 3** Changes of soluble sugar content and Vc concentration in lettuce under 72h continuous light
R/B ratio during pre-harvest continuous lighting treatment

<table>
<thead>
<tr>
<th>Treatments</th>
<th>R/B ratio</th>
<th>Photon flux density of red and blue component (µmol·m⁻²·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Red</td>
</tr>
<tr>
<td>LED1</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td><strong>LED2</strong></td>
<td><strong>4</strong></td>
<td><strong>120</strong></td>
</tr>
<tr>
<td>LED3</td>
<td>8</td>
<td>133</td>
</tr>
<tr>
<td>LED4</td>
<td>--</td>
<td>150</td>
</tr>
</tbody>
</table>

(Zhou et al, 2013)
Reducing nitrate concentration by enriching selenium content in nutrient solution

Enrichment of selenite significantly decreased NO$_3^-$ content in roots and leaves.

(Lei et al, 2014)
7. Digital measurement and control

Control system

Model

Data Acquisition System

Dynamic Database

Measured values

compare

Simulations

Shany Ray Technologies Ltd.

Number of days analyzed: 7
Number of alarms: 4

DANGER!

My Computer
LPS #14
LPS #17
LPS #26
LPS #99

9:00-12:00     Air VPD > 2 kPa
12:00-15:00   Leaf T  > 34 C
Air VPD > 4 kPa
15:00-16:00    Air VPD > 2 kPa

Test # 1 negative
3.3 Researches on vertical cultivation and urban farming

Column cultivation
Vertical Cultivation
Multi-layer cultivation (leaf vegetable)
Multi-layer cultivation (fruit vegetable)

Sweet pepper

Tomato
Interesting Cultivation
Giant Cultivation

Pumpkin (150-500Kg)
Over-ground tuber production of sweet potato

(invented by IEDA in 2005)
Tuberous roots
Ecological house

The gate of a yard for Leisure & tourism
Ecological house
4. Facing Challenges of vertical farming (plant factory)
4.1 Facing Challenges of vertical farming (plant factory)

- High initial cost (construction & equipments)
- High energy consumption (light, air conditioning)
- Limited plant species (most of the plants is lettuce in PF with artificial light)
- Benefit (lower competition comparing with other vegetable production system, e.g. greenhouse and field)
Vegetable from greenhouse and field is very cheap, if the vegetable from VF or PF was put in the same market, it has lower competition, so it need to create special markets for high-end consumers.
One way—Old industry building (not used now) for plant factory (can decrease initial cost of construction)
Used for plant factory now

Dongguan city, Guangdong province, 2013)
4.2 Perspectives of vertical farming (plant factory) in China

◆ Priority areas for developing: Agri.sci.& tech.park, for demonstrating PF.
◆ Producing healthy and safe vegetables (fresh, clean, pesticide-free, and multi-function) for high-end consumers or local consumers in large cities, like Beijing, Shanghai.
◆ Multi-function utilization in special areas: family, building, supermarket, school, restaurant (Ubiquitous plant factory).
◆ Vertical farming (2-3 ongoing projects now)
Priority areas for developing PF

High-tech agricultural demonstrate park (over 6000 Agricultural Sci.& Tech. parks in China)

Vegetable Expo (April 20-May 30) in Shouguang, Shandong. The number of visitors in 2014 is up to 2.2 million.
Plant Factory for demonstration in Zhejiang

Bird eye view of the plant factory, 1600 m² (include PF with artificial light 880 m²)

Movable cultivation beds with LED light
Inside view of the plant factory

Plant factory with LED light (Zhejiang)
High quality vegetable production

High-end consumer groups increasing quickly in large cities (demands increasing for fresh, clean, pesticide-free vegetables)

Plant factory in Beijing

Plant factory in Shenyang, Liaoning province

Plant factory in Beijing
PF for producing healthy and safe vegetables (800m², Beijing)
Agri.sci.& tech.park(Xiaoshan,Zhejiang)

The area is about 40,000 m² (PF with artificial light and solar light)
Agri.sci.& tech.park(Sunqiao, Shanghai)

The area is about 50,000 m² (PF with artificial light and solar light)
PF for producing healthy and safe vegetables (Fuzhou, Fujian province)

The area is 250m², producing 260,000 heads of lettuce.
PF for producing healthy and safe vegetables (Shunde, Guangdong province)

The total area is 50000m² (PF with artificial light and solar light), haven’t finished now.
Low-carbon, intelligent, Plant Factory for Family, **Shanghai Expo 2010** (Concept of growing vegetables at your kitchen)
Mini-type plant factory for family
Mini-type plant factory for family
5. Projects on vertical farming and plant factory in China
## Research projects of Plant Factory in China

Research on intelligent plant factory production technology, national high sci.& tech. project (2013-2017; 50,000,000 ¥ RMB (8 million USD)) organized by Chinese Academy of Agricultural Sciences. 15 Uni., Insti., and Companies joined the project.

**Chief scientist:** Qichang Yang (CAAS)

<table>
<thead>
<tr>
<th><strong>1</strong></th>
<th><strong>Energy-saving LED light source and light environment intelligent control in plant factory</strong></th>
<th>Institute of Environment and Sustainable Development in Agriculture, CAAS; IEDA Ltd</th>
</tr>
</thead>
<tbody>
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<td><strong>2</strong></td>
<td><strong>Research on key technology and equipment of multilayer cultivation system in plant factory</strong></td>
<td>Beijing Agriculture Machinery Institute, China Agri. Uni.</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td><strong>Energy-saving environmental control technology based on light and temperature coupling in plant Factory</strong></td>
<td>Tech. Top photoelectric technology company, Nanjing agricultural university</td>
</tr>
<tr>
<td></td>
<td>Nutrient solution management and vegetable quality control technology research in plant Factory</td>
<td>Northwest A&amp;F University, CAAS</td>
</tr>
<tr>
<td>---</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>5</td>
<td>Key technologies research of intelligent system control based on the network management in plant factory</td>
<td>The National Engineering Research Center for Information Technology in Agriculture,</td>
</tr>
<tr>
<td>6</td>
<td>Integrated demonstration of solar light plant factory</td>
<td>Dushi Green Engineering Company, Shanghai, Tongji Uni., SAAS</td>
</tr>
<tr>
<td>7</td>
<td>Integrated demonstration technology of artificial light plant factory</td>
<td>Zhejiang University, CAAS</td>
</tr>
</tbody>
</table>
China-Europe cooperation project on vertical farming \& urban agriculture

◆ **Structure and cultivation systems** in vertical farming will be optimally designed for using vertical space efficiently.

◆ **Integrated environment control technologies** for producing high quality vegetables in vertical farming with zero fossil-fuel energy consuming

◆ **Innovations on resource** (wastewater, excess energy etc.) recovery and productive reuse

◆ **Energy-saving artificial light** in closed plant production systems for vegetable production

◆ **Hydroponic cultivation systems, nutrient solution’s recycling and controlling**
Thanks for your attention

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