High efficient utilization of water and fertilizer in Greenhouse Vegetable production

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Content

1. Bottle neck in high use efficiency of water and fertilizer in greenhouse vegetable production
2. Fertigation: basic demand to improve high UE of water and fertilizer
3. High efficient Utilization of water and fertilizer: Soil health and crop health
4. Summary
China is also the largest country of protected-field vegetable production

The planting area of protected-field vegetable was 5.01 million ha, 22.6% of total area in China in 2016

Low temperature and soil barriers from continuous planting caused very poor root system and low P uptake rate, consequently high phosphate is needed in rootzone soil solution.
Special micro-environmental condition in greenhouse

Soil quality change:

- Nutrient leaching and soil acidification
- High nutrient accumulation and secondary salinity
- Low ratio of C/N, low soil biodiversity and more fungi disease
- Nematode etc

Diagram:

- High temperature
- Low light
- Irrigation
- Manure
- Chemical fertilizer
- Rootzone
- N\textsubscript{min} buffer
- Continuous planting
- Mineralization—immobilization
- DOC TN leaching
- N\textsubscript{2}O, NH\textsubscript{3}, CO\textsubscript{2}
Conventional water and nutrient input. Maximum yield is the goal of farmer's nutrient management, however, this will increase nutrient loss.

Shallow root system needs frequent irrigation/fertilization with low rate.

Water and nutrient supply.
Environmental implications of low nitrogen use efficiency in excessively fertilized hot pepper (Capsicum frutescens L.) cropping systems

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Nitrogen rates (kg ha$^{-1}$) distribution balance for a cropping season.

![Diagram of Drainable Lysimeter](image)

```
<table>
<thead>
<tr>
<th>Green-use m</th>
<th>N inputs</th>
<th>Total</th>
<th>N outputs</th>
<th>Soil mineral N$^a$ variation</th>
<th>Unaccounted N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mineral fertilizer</td>
<td>Organic fertilizer</td>
<td>Irrigation water</td>
<td>Rate</td>
<td>%</td>
</tr>
<tr>
<td>1</td>
<td>325</td>
<td>68</td>
<td>8</td>
<td>2</td>
<td>144</td>
</tr>
<tr>
<td>2</td>
<td>190</td>
<td>30</td>
<td>170</td>
<td>27</td>
<td>268</td>
</tr>
<tr>
<td>3</td>
<td>493</td>
<td>38</td>
<td>310</td>
<td>24</td>
<td>482</td>
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<tr>
<td>4</td>
<td>207</td>
<td>31</td>
<td>154</td>
<td>23</td>
<td>300</td>
</tr>
<tr>
<td>5</td>
<td>501</td>
<td>58</td>
<td>190</td>
<td>22</td>
<td>169</td>
</tr>
<tr>
<td>6</td>
<td>504</td>
<td>39</td>
<td>185</td>
<td>14</td>
<td>603</td>
</tr>
<tr>
<td>7</td>
<td>300</td>
<td>57</td>
<td>166</td>
<td>32</td>
<td>59</td>
</tr>
<tr>
<td>8</td>
<td>328</td>
<td>56</td>
<td>186</td>
<td>32</td>
<td>73</td>
</tr>
<tr>
<td>9</td>
<td>391</td>
<td>34</td>
<td>240</td>
<td>21</td>
<td>523</td>
</tr>
<tr>
<td>Average</td>
<td>360</td>
<td>46</td>
<td>179</td>
<td>22</td>
<td>298</td>
</tr>
</tbody>
</table>
```

$^a$ Variation in soil mineral N content (100 cm depth).

**Fig. 3-1** Drainable lysimeter

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Song, et al., 2009
Unsustainable **Bottle necks:**

- **Soil borne diseases**
  - Crop rotation
  - Disease resistance compost types (?)
  - Soil sterilization

- **Nematodes**
  - Rootstocks
  - Crop rotation
  - Bio-fumigation (?)
  - Soil acidification
Comparison of soil pH change between cereal and vegetable fields in Shouguang, n=20

Lei, 2008
Comparison of soil ratio of carbon to nitrogen between cereal and vegetable field in Shouguang, n=20

Lei, 2008
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Drip irrigation is the most efficient way of delivering water & fertilizers

- FERTIGATION

Regardless your injection devices
You must have a very good **irrigation uniformity**
Design, a good product, **maintenance**
Irrigation Management Measurement Methods

- Human Observations
  - Crop Appearance
  - Hand Feel of Soil
  - When Your Neighbor Irrigates
  - Personal Calendars
  - 4 users

- Field Sampling Observations
  - Neutron Probe
  - Gypsum Block (Watermark)
  - Turgor Pressure Sensor (leaf)
  - Dendrometer (trunk diameter)
  - Infrared Thermometers
  - 1 user

- Real-time In-situ Monitoring
  - Tensiometers
  - Capacitance Sensors
  - Time-Domain Reflectometry

Human Observation Methods Used at 4 Times the Rate of ALL Other Methods for Irrigation Management by California Growers
Key1: Soil nutrient concentration in rootzone

Different crops need different nutrient concentrations, which depend on the uptake ratio of N-P-K-Ca -Mg

It should keep optimum nutrient supply in rootzone, otherwise it will cause nutrient lose or yield reduction due to too high or too low level.

<table>
<thead>
<tr>
<th>Nutrient uptake pattern in greenhouse tomato (%DW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laminae</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>P</td>
</tr>
<tr>
<td>S</td>
</tr>
<tr>
<td>K</td>
</tr>
<tr>
<td>Ca</td>
</tr>
<tr>
<td>Mg</td>
</tr>
<tr>
<td>Dry matter</td>
</tr>
</tbody>
</table>

Nutrient uptake of year round tomato crops-W. Voogt
氮肥分施：根据生育期决定

N fertilizer splitting: crop growth pattern

影响因素：光、温  
Factors: Light, temperature

露地番茄 Open field tomato
光照、温度条件好 Light, temperature conditions are good

设施秋冬茬 Facilities for Autumn and Winter
光照条件逐渐变差, 温度逐渐降低 Light down, temperature down

设施冬春茬 Facilities for winter and spring
光照条件逐渐转好, 气温逐渐升高 Light up, temperature up
Weekly N uptake pattern of tomato in different growth seasons in North China Plain

Winter-spring season in greenhouse
Data from Tang (2004); Liu (2004, 2005), et al

Autumn-winter season in greenhouse
Data from Tang (2004); Liu (2004, 2005), et al

Open field
Data from Cai, 1997
Soil index for P (or K) recommendation

(Example: Correlation between relative yield in the control plot without P supply with soil available P level)

\[ y = 30.96 \ln(x) - 13.498 \]

\[ R^2 = 0.8194 \]
Based on the responses of P and K fertilizers application, P and K recommendation “maintainence” can be used

<table>
<thead>
<tr>
<th>Soil Olsen-P (mg/kg)</th>
<th>Soil exchangeable-K (mg/kg)</th>
<th>Index</th>
<th>P$_2$O$_5$/K$_2$O recommendation*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open field</td>
<td>Greenhouse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0~20</td>
<td>0~50</td>
<td>0~80</td>
<td>L</td>
</tr>
<tr>
<td>1.8-2.0 times of crop removal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20~60</td>
<td>50~120</td>
<td>80~150</td>
<td>M</td>
</tr>
<tr>
<td>1.3-1.5 times of crop removal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;60</td>
<td>&gt;120</td>
<td>&gt;150</td>
<td>H</td>
</tr>
<tr>
<td>0.8-1.0 times of crop removal</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Organic manure recommendation: open field 30-45 m$^3$/hm$^2$; protected field 60-90 m$^3$/hm$^2$.)
Key2: Relative proportion of nutrient supply in rootzone

- It needs balanced nutrient supply.
- Excessive NH$_4^+$ supply can cause the Ca$^{2+}$, K$^+$ deficiency
- Excessive K$^+$ supply easily cause the Mg$^{2+}$ deficiency
- Excessive PO$_4^{3-}$ supply easily cause the Zn$^{2+}$ deficiency

过量施用铵态氮造成K、Ca、Mg的缺乏

Nitrate nitrogen: N (NO$_3^-$) (anion)  
Ammonium nitrogen: N (NH$_4^+$) (cation)  
Nitrate carries calcium with it  
Ammonium reduces calcium uptake
Key 3: Optimized soil environment in rootzone

- Select appropriate raw material and N form; Adjust the soil pH; Reduce fertilizer use and soil salinity
- Appropriate formula can promote crop root development, increase soil nutrient reserves, and reduce the possibility of nutrient loss
- Increase soil CEC and organic matter content in rootzone
- Reduce soil diseases, and straw return increase the microbial activity
Key4: Spatial match of root and water-fertilizer supply in rootzone

How to concentrate the effective water and nutrient on the root zone, and realize the time and space effectiveness?

• **IrrigAid**
  It should consider the use of IrrigAid in liquid water-soluble fertilizer formula, increasing irrigation area and achieving water retention is the key to improve nutrient use efficiency.

• **Fertigation**
  Integrate irrigation and fertilizer, supply water and fertilizer for crops timely, precisely, accurately, and in balanced synchronous.

(Ren, Personal communication)
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• Phosphorus fertilizer produced in China was 16.4 million t, accounting for 48.7% of the global production.

• Excessive fertilizer P input resulted in the high legacy P in soils of China.

• Chinese government has promoted the projects of reduced chemical fertilizer application and encouraged organic manure utilization since 2015.

Trends of soil available P in China from 1990 to 2012. (Ma et al. 2016)
Focusing on soil legacy P in vegetable fields

The P-imbalance in vegetable field
P application exceeded P removal by 13.0-fold in greenhouse and 4.7-fold in open field; Over 50% of applied P derived from manure (Yan et al., 2013)

95% of protected-field existed the high risk of P mobility

- Agronomic threshold: 46-57 mg P kg\(^{-1}\) in open field; ~90 mg P kg\(^{-1}\) in protected field
- Environmental threshold: 50-60 mg P kg\(^{-1}\) (Jiang et al., 2008; Qin et al., 2010; Zhang et al., 2012; Wang et al., 2006)
Why high legacy phosphorus?

The levels and forms of soil legacy P indicated the availability to crop or the mobility to environment.

(Wither et al., 2014)
Chelates activated soil legacy P through combination/dissolution with phosphate metals in soil

\[ \text{H}^+ + \text{Metal-P} \rightarrow \text{H}^+ + \text{M} + \text{PO}_4^{3-} \]

Different Chelate Treatments in Batch Experiment

(Wang et al., Unpublished)
生物刺激素的促根和抗逆效应提高养分和水分的有效性

**Biostimulants:**

农业天然物质，其他于肥料和农药

- **Biological fertilizers,**
- Humic acids,
- Amino acids,
- Alginic acid,
- Chitin,
- PGPR (plant growth-promoting rhizobacteria), …

健康根区微生态环境

天然生物刺激素是肥料和农药之外的农用天然物质，它可改善作物营养和健康状况，提高作物的抗病能力，提高农药药效和肥料的利用率
Increasing rootzone P availability through fertigation accompanied strategy to utilize legacy P in soil

No P fertilizer sidedressing with fertigation

Biologically active substances to stimulate root growth and/or chelating metals, i.e., amino acid, fulvic acid, and citrate were selected as synergistic component in liquid water soluble fertilizers for drip irrigation.
促进根系发育，优化根系结构，改善土壤物理、化学和生物过程，提高土壤水分、养分资源利用效率
Factors on root growth in vegetable field:

**caused by:**
- low/high temperature
- soil compaction
- root pathogens
- excessive nutrient status
- soil secondary salinity

The physical root volume limitations may have caused secondary water or nutrient limitations.

CARLOS A. M. PORTAS*

Plant and Soil 39, 507-518 (1973)
Localized supply of $\text{PO}_4^{2-}$, $\text{NO}_3^-$, $\text{NH}_4^+$, or $\text{K}^+$ and the architecture of barley root growth

Supply $\text{PO}_4^{2-}$, $\text{NO}_3^-$, $\text{NH}_4^+$, or $\text{K}^+$ when barley root growth

---

<table>
<thead>
<tr>
<th>Control</th>
<th>Phosphate</th>
<th>Nitrate</th>
<th>Ammonium</th>
<th>Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

+ - portion of root system receiving complete nutrient solution
根系统的一部分吸收到完全营养液

- - Part of the root system receiving the solution deficient in specified nutrient
根系统的一部分吸收到缺乏某种营养的营养液

Drew (1975) New Phytol. 75 : 461-478
Biostimulant materials for functional liquid WSF

减少土壤传播病害

Add organic matter

增加生物活性 (多样性)

Group aggregate increases

分解

Humus and other growth-promoting substances

Detoxification of harmful substances

Nutrient release

Plant Health

Improve tillage and water storage

Improve the pore structure

Reduce soil diseases

提高耕性和蓄水

改善孔隙结构

腐殖质和其他促生长物质

有害物质解毒

有机碳、糖、海藻酸、氨基酸、腐殖酸/菌剂等

有机物质 添加

Detoxification of harmful substances

Improve tillage and water storage

Improve the pore structure

Reduce soil diseases

Add organic matter

Increase the biological activity

Improve tillage and water storage

Improve the pore structure

Reduce soil diseases

Add organic matter

Increase the biological activity

Improve tillage and water storage

Improve the pore structure

Reduce soil diseases

Add organic matter

Increase the biological activity

Improve tillage and water storage

Improve the pore structure

Reduce soil diseases
Strategies to improve greenhouse soil quality and productivity
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Innovative product and related techniques

• **High efficiency**: Meeting crop demand, time and labor saving, high efficiency;

• **Complex**: the inorganic complex; organic and inorganic complex; bio-organic compound; pesticides, hormones and herbicides compound

• **Wide-function**: Soil quality, root growth and seedling health, weeding-cleaning, flowers and fruit,

• **Low-carbon**: reduce greenhouse gas emissions.
Thanks for your attention