Improving crop productivity and nutrient use efficiency simultaneously in intensive agriculture in China

Zhang FS, Fan MS, Zhang WF, Chen XP, Jiang RF

College of Resources and Environmental Sciences
China Agricultural University
Beijing, 100193, P.R.CHINA
zhangfs@cau.edu.cn
China

9.6 million km²
1.3 billion population
9% of world arable land
22% of world population
The population of China from 1952 to 2005

“Who will feed China?” is an important and disputed issue.

22% Population in world
9% arable land
Food security issue of China is always a global concern

Lester Brown

- **1994**
  - Who will Feed China?

- **2008**
  - Will China Starve the World?

- **2011**
  - Can the United States Feed China?
Outline

- Challenges and problems of food production and environmental protection
- Development of Integrated Soil-crop System Management technology (ISSM)
- Summary and prospects
Organic Agriculture Traces Back to China
---The First Publication on Organic Agriculture

“People in China, who with brain and brawn, have successfully and continuously sustained large families on small areas without impoverishing their soil.”

Secret of permanent agriculture in China:
• Feeling the plants
• Manuring the land
• System of multiple cropping

Published in 1911

Franklin Hiram King
(1848-1911)
Organic manure, intercropping and rotation were effective to maintain soil fertility and crop yield for about 5,000 years in China!
Organic farming was successful in feeding the Chinese in the past, but can not support the fast increasing population!
It took nearly 50 yrs to realize the dream of food sufficiency in China since 1949

(Data from the Statistic Bureau of China
Demand was estimated by using average grain demand of 400 kg/capita/year)
From 1949 to 2008:
Total grain production increased by 1054%,
Grain area increased by 38%,
Crop yield increased by 739%.

Data from National Statistic Bureau
30 years achievements in agriculture (1978=100)

数据来源：《中国统计年鉴》和《新中国五十年农业统计资料》
Questions

• What are major driving forces of China’s agriculture in the past?
  -- Institutional reform
  -- Agricultural technology
  -- Market liberalization
  -- ...

Institutional Reform
Total Factor Productivity for rice, wheat and maize in China, 1979-95

Institutional change (HRS) was major source of TFP growth in 1979-84

Source: Jin et al., 2002, AJAE
Agricultural Technology
Technology changes have been major sources of agricultural productivity growth after 1985 (Huang and Rozelle, 1996; Jin et al., 2002; Jun et al., 2008)

In 1985-97, TFP grew at about 3%
Topographic Map of China

About 1/3:
Intensive agriculture

About 2/3:
Low input, resource-limited agriculture

Use every piece of land, produce so much as possible!
Importance of upland crop production

– Contributed to 45% of total grain production
– Most poor and poverty relieve area
– Ecological protection zone for China
Grain Yield: ?

Sunshine: ?
Precipitation: ?
Evaporation: ?

Farmers field without water conservation measures
Rainwater harvesting system
Cisterns receiving water from runoff for crop production
Yield: 7000-11000 kg·ha⁻¹
WUE: 19-30 kg·ha⁻¹·mm⁻¹

Yield: 2000-3500 kg·ha⁻¹
WUE: 7-10 kg·ha⁻¹·mm⁻¹
Diversity of intercropping system in west of China

- Wheat/Maize
- Potato/Maize
- Flax/Maize
- Vegetable / Maize
- Pea/Maize
- Soybean/Maize
Intercropping Advantage of Several Intercropping Systems

<table>
<thead>
<tr>
<th>Intercropping system</th>
<th>Land equivalent ratio (LER)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat/maize</td>
<td>1.21-1.58</td>
</tr>
<tr>
<td>Wheat/soybean</td>
<td>1.23-1.26</td>
</tr>
<tr>
<td>Faba bean/maize</td>
<td>1.13-1.34</td>
</tr>
</tbody>
</table>

Interspecific interactions between species enhance productivity.
Increase crop yield with efficient nutrient use in intensive agriculture of China

Arable Land: 1217.2 million hm² (2008)
Grain production and resources input

Grain yield has been merely secured by much higher input of resources
Fertilizer Overuse and Misuse
China fertilizer consumption and grain production
(1980=100)

(WF Zhang et al., unpublished results)
Grain yield and N rate of rice crop

<table>
<thead>
<tr>
<th>Country</th>
<th>Grain yield* (t ha(^{-1}))</th>
<th>N rate (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>6.26</td>
<td>~200</td>
</tr>
<tr>
<td>Japan</td>
<td>6.42</td>
<td>70</td>
</tr>
<tr>
<td>South Korea</td>
<td>6.79</td>
<td>110</td>
</tr>
</tbody>
</table>

*FAO, 2004
Low nutrient use efficiency (NUE) --- Low PFP

Partial factor productivity: \( PFP_N = \text{kg harvest product per kg N applied} \)

Substantial decrease in \( PFP_N \) with increased rate of fertilization
The five key threats of excessive Nitrogen
Four fold increase in N inputs to estuaries since 1980

- Increased N inputs contribute to eutrophication, decreased fish production, and toxic algal bloom (red tides)
- The occurrence of red tides increased from 10/yr in the 1960s to 300/yr now (Norse and Zhu, 2004)

Blue alga attacked Tai lake again and Wuxi people are threatened by drink water shortage. Is it too naughty to be solved?

*China News, April 16, 2008*
Soil pH changes in major croplands in China (1980s-2000s)

(Guo et al., 2010, Science)
12 years fertilization experiment in Hunan Province (start in 1990 with initial soil pH at 5.7)

- M: pH 6.2
- NPKM: pH 6.1
- NPKS: pH 4.6
- PK: pH 5.3
- NK: pH 4.3
- NP: pH 4.5
- N: pH 4.2
- No fertilizer: pH 5.5

(Xu MG, PC)
Outline

- Challenges and problems of food production and environmental protection
- Development of Integrated Soil-crop System Management technology (ISSM)
- Summary and prospects
Challenges: Can we increase crop yield and nutrient use efficiency at the same time?
- Can food security and environment quality be ensured simultaneously?

At present (saving fertilizer)

1st step
15%-20%

Increase soil fertility

2nd step
30%-50%

(High-yield)
Cut down N fertilizer by 30-50% reduces N loss into the environment greatly without diminishing crop yield!

Wheat-Maize cropping system in NCP (Ju et al., 2009)
Reduction of $\text{NO}_3^-$ leaching, $\text{NH}_3$ and $\text{N}_2\text{O}$ emission by ISSM

Long-term field experiment

Monitoring sets

Reduction rate

- $\text{NO}_3^-$ leaching
  - wheat: 77%
  - maize: 96%
  - greenhouse tomato: 83%
  - greenhouse pepper: 35%

- $\text{NH}_3$ emission
  - wheat: 75%
  - maize: 56%
  - greenhouse tomato: 83%
  - greenhouse pepper: 36%

- $\text{N}_2\text{O}$ emission
  - wheat: 41%
  - maize: 73%
  - greenhouse pepper: 38%

(Zhu et al., 2005; Zhao et al., 2006; He et al., 2007; Gao, 2004; Ding, 2005; Zhao, 2006; Ren, 2007; Su et al., 2007)
Take all possible yield increase measures into consideration

<table>
<thead>
<tr>
<th>Year</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td></td>
</tr>
<tr>
<td>1975</td>
<td></td>
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<tr>
<td>1978</td>
<td></td>
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<td>1981</td>
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<td>1984</td>
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<td>1987</td>
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<td>1990</td>
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<td>1996</td>
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<tr>
<td>1999</td>
<td></td>
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<tr>
<td>2002</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td></td>
</tr>
</tbody>
</table>

Record yield of summer maize in China

- YD13 (1991-2000): 1407.3 (10^4 ha)
- YD22 (1997-2000): 85.9 (10^4 ha)

National average maize yield

Yield Gap
Result of increasing maize yield and NUE simultaneously

Summer maize yield increased by more than 30%, PFP doubled

<table>
<thead>
<tr>
<th>item</th>
<th>N rate (kg N/ha)</th>
<th>Grain yield (t/ha)</th>
<th>PFPN (kg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmers practice</td>
<td>250-300</td>
<td>7-8</td>
<td>27-32</td>
</tr>
<tr>
<td>INM</td>
<td>185</td>
<td>12.1</td>
<td>65</td>
</tr>
</tbody>
</table>

3 main technologies:  
Increased density of plants  
Better nutrient and water management  
Improved soil quality
Integrated soil-crop system management (ISSM)

1) Improve Soil Quality

2) Integrated nutrient management (INM)

3) Increase crop yield significantly
Why so much fertilizer?

Low quality of soils in China (>72%)
Relationship between achieved yields of rice, wheat and maize when NPK was applied and control yields with no fertilizer application. Rice (n=1300), Wheat (n=392), C Maize (n=562)

(Fan et al., unpublished)
Soil Fertility Contribution to Grain Yield in China: 52%
Lower 20% than that of USA

Tang and Huang, 2009
Best Cycle:
increase crop productivity, then more C and organic materials to improve soil quality and productivity

1) Higher yield
   higher C return
2) More straw return
   back into Soil
3) More organic manure
Increase crop NPP and soil productivity

Crop NPP increased

\[ y = 11.96x - 23341 \]

\( (R^2 = 0.98) \)

SOC: Green- Increased
Red- Decreased

With increased crop NPP in Chinese cropland from 1960s to 2000s, the soil organic C content increased by 27% from 1980s to 2000s (Huang et al., 2007)
Integrated Nutrient Management (INM)

1) Optimization of N input, take all possible sources of nutrient into consideration

2) Match soil supply to crop requirement spatially and temporally
Sources of nutrients

- Soil
- Manure
- Rain & atmospheric deposition
- Crop residues
- Irrigation water
- Biological N fixation
- Fertilizers

(Powlson, PC)
Nitrogen inputs from atmospheric deposition and irrigation water in NCP

(Ju et al., 2009, PNAS)
### Annual N input in wheat-maize rotation system in north China plain of China

<table>
<thead>
<tr>
<th></th>
<th>80s</th>
<th>now</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical N</td>
<td>150</td>
<td>532 (300~700)</td>
</tr>
<tr>
<td>Soil Nmin</td>
<td>30 (11-62)</td>
<td>191 (20-987)</td>
</tr>
<tr>
<td>Environmental N</td>
<td>22</td>
<td>90</td>
</tr>
<tr>
<td>total</td>
<td>202</td>
<td>713</td>
</tr>
</tbody>
</table>

(Cui et al., 2010)
Match application to crop requirement, apply when crop is growing fast

N uptake intensity

Seems obvious – but often ignored! Much was applied before/at planting time!
applying N in split doses with the largest amount applied during rapid growth stages

Farmers’ Practice: 425 kg N/hm$^2$

Pre-planting: 165 kg N/hm$^2$
Top-dressing: 260 kg N/hm$^2$

In-season N management
N rate: 128 kg N/hm$^2$
Pre-planting: 44 kg N/ha
Top-dressing: 84 kg N/ha
N uptake 125 kg N/hm$^2$

Advantages:
- Control total N rate (425/128)
- Splitting at right time (1:1.5/1:2.0)

(Cui et al., 2006; 崔振岭等，2005)
Integration of Genotype x Environment x Management for higher yield

Design of an integrated high-yielding maize production system
-- an example for Beijing

Variety: ZD958, GDD 1612
Planting date: Apr. 20
Planting density: 60,000 per ha

Yield potential (t ha⁻¹)

Planting date

Planting density

Comparison with farmers practice

High-yielding system

(Chen et al., PNAS, 2011)
Mean maize grain yield and modeled yield potential, N balance (fertilizer inputs-harvest outputs) and N applied per unit of grain produced for different management systems: integrated crop and soil system management approach (ISSM, \( n=66 \)), farmers’ practice (FP, \( n=4548 \)), and high-input, high-yielding studies (HY, \( n=43 \)).

<table>
<thead>
<tr>
<th>Variable</th>
<th>ISSM</th>
<th>HY</th>
<th>FP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize grain yield (t ha(^{-1}))</td>
<td>13.0 ± 1.6</td>
<td>15.2 ± 2.6</td>
<td>6.8 ± 1.6</td>
</tr>
<tr>
<td>Yield potential (t ha(^{-1}))</td>
<td>15.1 ± 1.9</td>
<td>16.8 ± 2.0</td>
<td>—</td>
</tr>
<tr>
<td>Yield potential (%)</td>
<td>86</td>
<td>91</td>
<td>—</td>
</tr>
<tr>
<td>N input from fertilizer and manure (kg ha(^{-1}))</td>
<td>237 ± 70</td>
<td>747 ± 179</td>
<td>257 ± 121</td>
</tr>
<tr>
<td>N removal in harvest (kg ha(^{-1}))</td>
<td>250 ± 31</td>
<td>292 ± 50</td>
<td>132 ± 31</td>
</tr>
<tr>
<td>Inputs minus harvest removals (kg ha(^{-1}))</td>
<td>-12 ± 56</td>
<td>457 ± 155</td>
<td>127 ± 42</td>
</tr>
<tr>
<td>Yield per unit fertilizer N applied (kg kg(^{-1}))</td>
<td>57 ± 13</td>
<td>21 ± 5</td>
<td>26 ± 20</td>
</tr>
</tbody>
</table>

(Chen et al., PNAS, 2011)
Outline

- Challenges and problems of food production and environmental protection
- Development of Integrated Soil-crop System Management technology (ISSM)
- Summary and prospects
Two-step-strategy to realize high crop yield, high efficiency of resource use, improving soil and environment quality simultaneously in China

At present (saving input)

The 1st step
15%-20%

Increase soil fertility

The 2nd step
30%-50%

(Doupling yield)

At present
National Soil Testing and Fertilizer Recommendation Project
(totally more than 6 billion RMB in 7 years)

- 200 Million Yuan covered 200 counties in 2005
- 500 Million Yuan covered 600 counties in 2006
- 900 Million Yuan covered 1200 counties in 2007
- 1150 Million Yuan covered 1861 counties in 2008
- 1500 Million Yuan covered all agric.counties 2009

Yield +11%
NUE +10%
Recovery from low nutrient use efficiency (NUE) --- PFP

Partial factor productivity: PFP = kg harvest product per kg N applied

\[ y = -0.3997x + 29.784 \]
\[ R^2 = 0.7357 \]

\[ y = 5.5735x + 93.417 \]
\[ R^2 = 0.9268 \]

(Zhang, et al., 2011)
Nutrient Imbalances in Agricultural Development

Nutrient additions to intensive agricultural systems range from inadequate to excessive—and both extremes have substantial human and environmental costs.

<table>
<thead>
<tr>
<th>Inputs and outputs</th>
<th>Western Kenya</th>
<th>North China</th>
<th>Midwest U.S.A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer</td>
<td>7</td>
<td>588</td>
<td>93</td>
</tr>
<tr>
<td>Biological N fixation</td>
<td></td>
<td></td>
<td>62</td>
</tr>
<tr>
<td>Total agronomic inputs</td>
<td>7</td>
<td>588</td>
<td>155</td>
</tr>
<tr>
<td>Removal in grain and/or beans</td>
<td>23</td>
<td>361</td>
<td>145</td>
</tr>
<tr>
<td>Removal in other harvested products</td>
<td>36</td>
<td>361</td>
<td>145</td>
</tr>
<tr>
<td>Total agronomic outputs</td>
<td>59</td>
<td>361</td>
<td>145</td>
</tr>
<tr>
<td>Agronomic inputs minus harvest removals</td>
<td>-52</td>
<td>+227</td>
<td>+10</td>
</tr>
</tbody>
</table>
Acknowledgments
NSFC, MoA, MoE, MOST

Thanks for your attention!