# 加强中微量元素研究，促进科学施肥

## Strengthening secondary/micro-elements research to promote better nutrient management

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# 报告提纲/Outline

- **为什么要加强中微量元素研究**
  **The importance of secondary/micro-elements research**

- **当前需要重点关注的几个中微量元素**
  **Key secondary/micro-elements need to be focused**

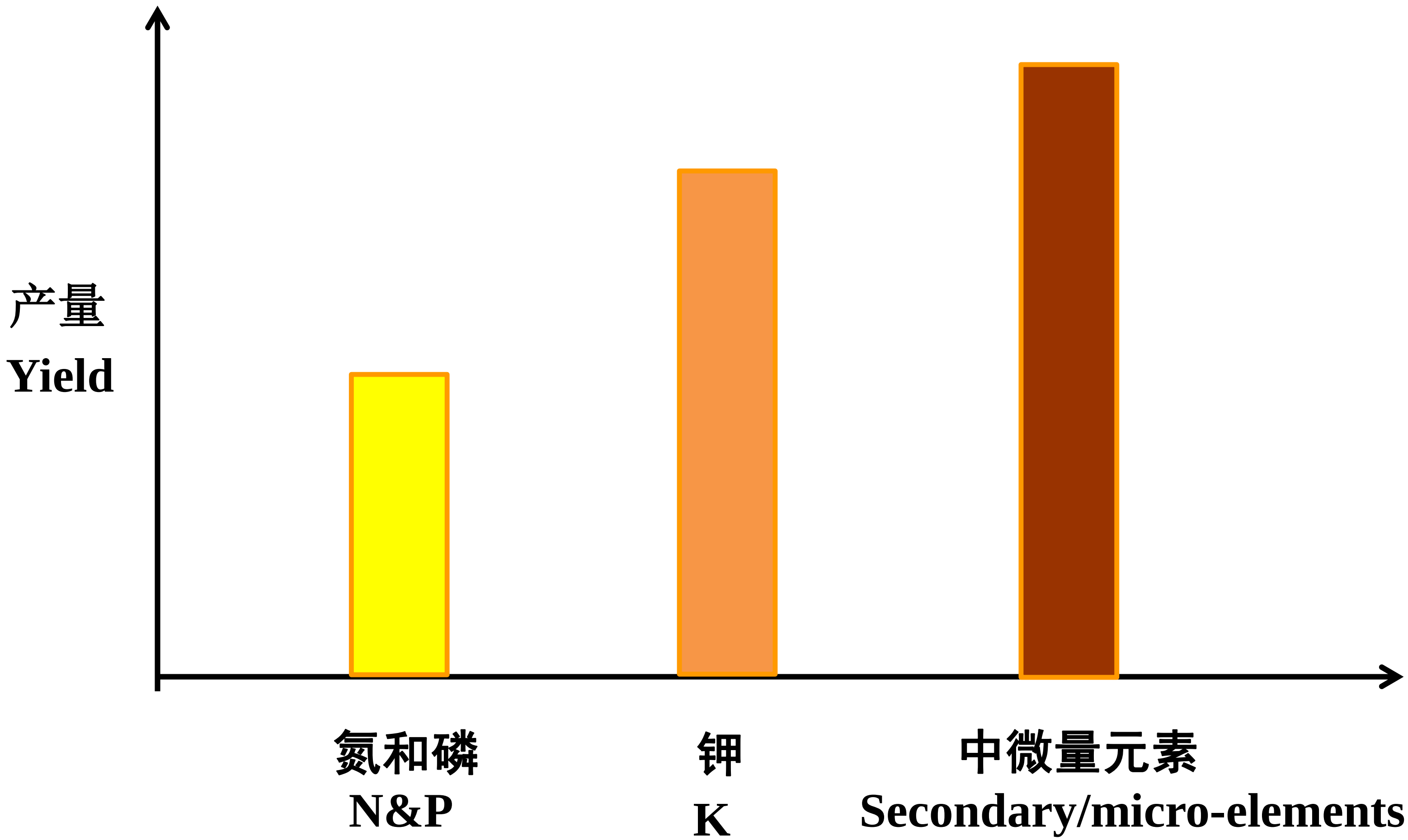
- **如何加强中微量元素营养与肥料的研究**
  **How to strengthen secondary/micro-elements research**

# 近三十年来施肥技术主要发展

## The development of fertilization technology during last three decades

**1、我国农田土壤养分缺乏程度：氮和磷 > 钾 > 中微量元素**

**Soil nutrient deficiency in Chinese croplands： N&P＞K＞secondary/micro-elements**



# 近三十年来施肥技术主要发展

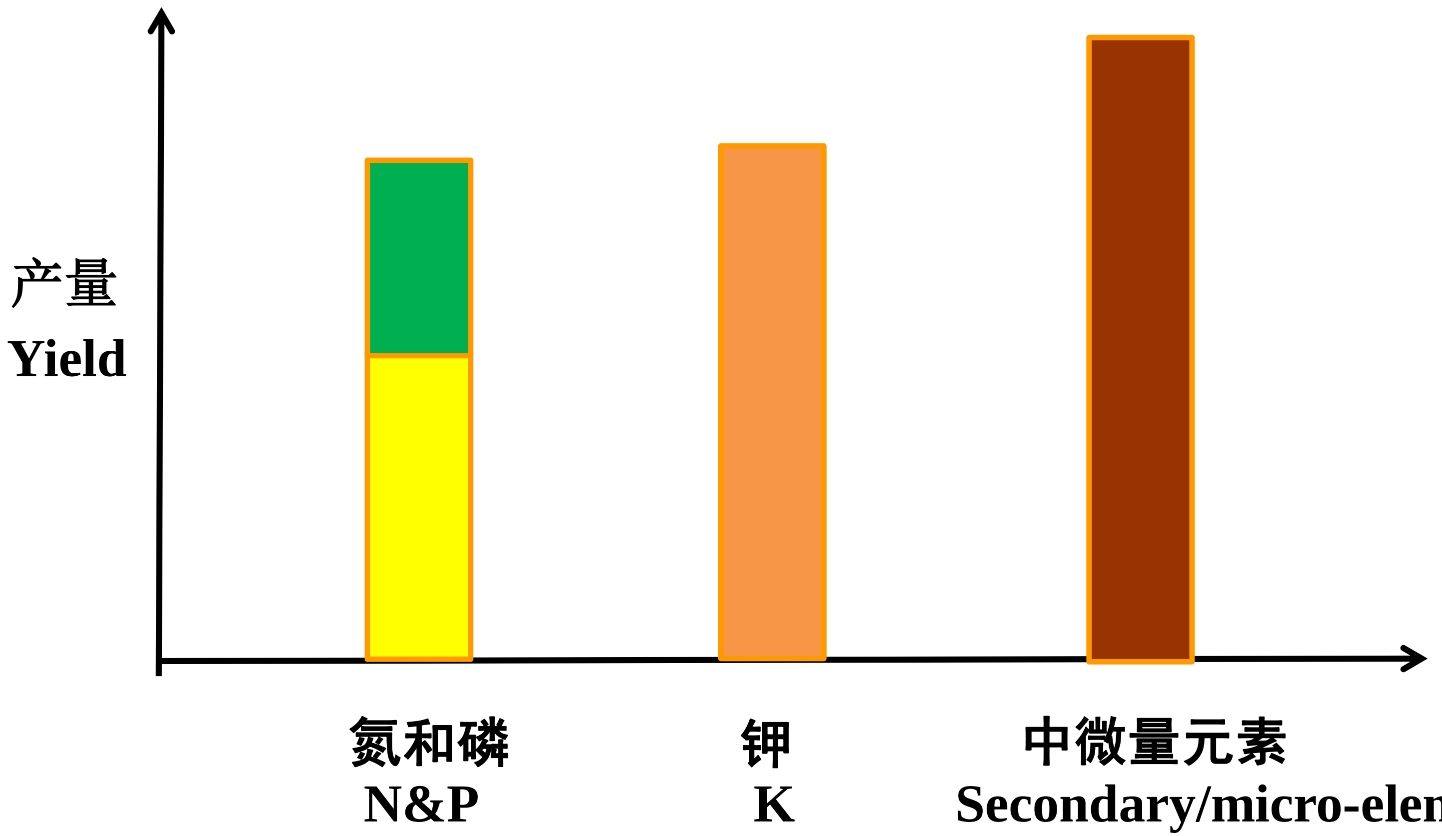
**The development of fertilization technology during last three decades**

**2、1980s-1990s，有效解决了氮、磷缺乏的问题**

重大行动：第二次土壤普查；关键产品：尿素、二铵

1980s-1990s, N&P deficiencies had been solved

Major action: 2nd National soil investigation; Key products: Urea and DAP



# 近三十年来施肥技术主要发展

**The development of fertilization technology during last three decades**

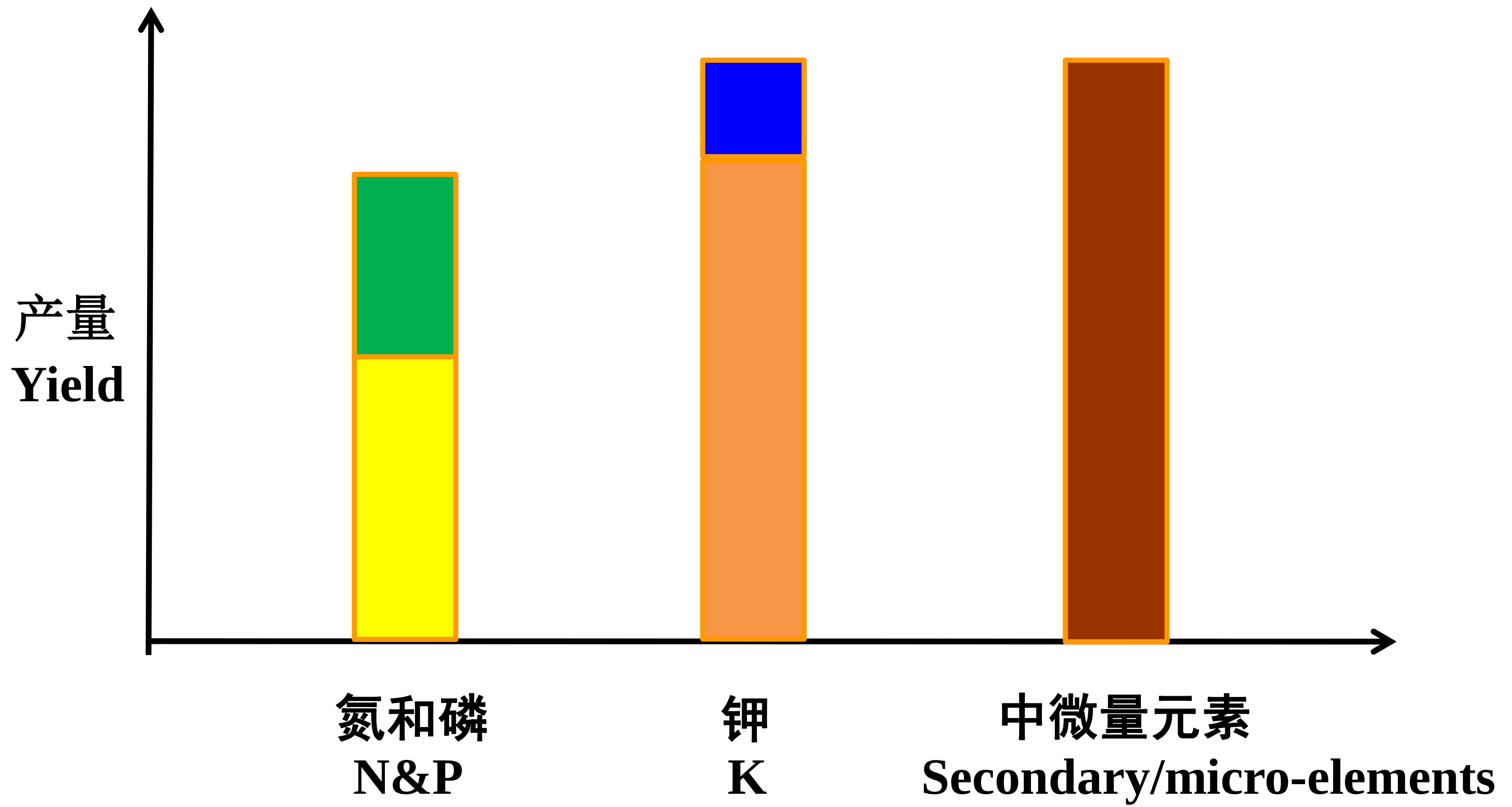
**3、1990s-2000s，缺钾问题得到基本解决**

**重大行动：测土配方施肥；关键产品：复合肥，配方肥**

1990s-2000s, K deficiency had been solved

Major action: National Soil Testing and Fertilization Program;

Key products: Compound fertilizer & Formula fertilizer



# 近三十年来施肥技术主要发展

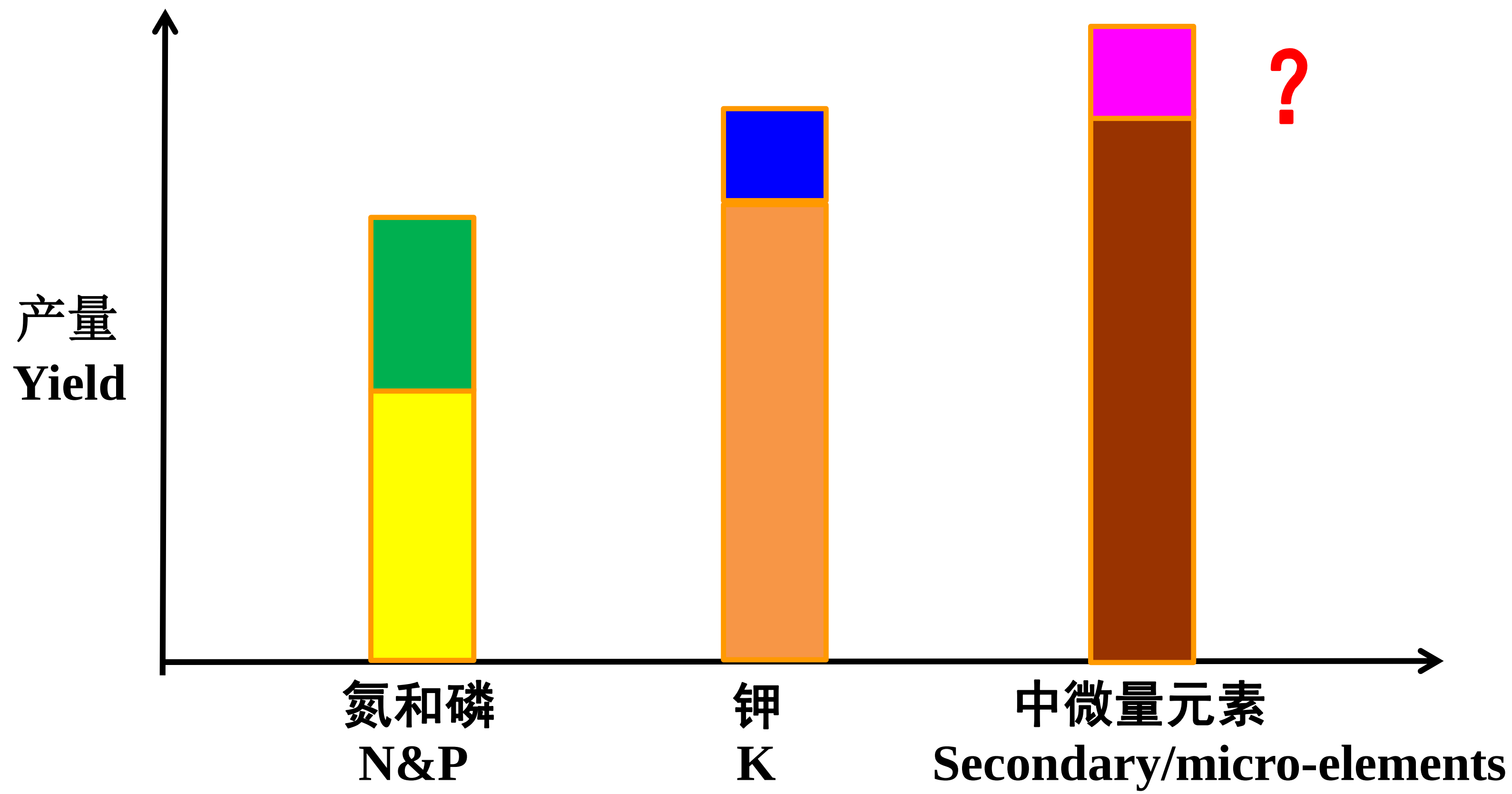
**The development of fertilization technology during last three decades**

**4、当前，中微量元素的问题受到关注**

重大行动？关键产品？

Secondary/micro-elements are getting more and more attention.

**Major action? Key products?**



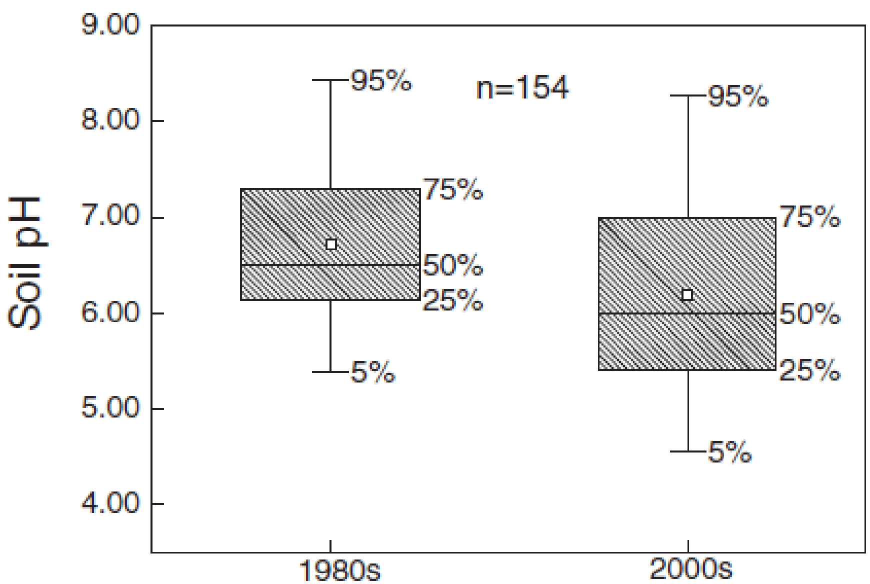
*(Science 2010, 327, 1008-1010)*

# Significant Acidification in Major Chinese Croplands

## 土壤酸化(Soil Acidification)：

**过去30年，我国农田土壤pH 值平均下降 0.5个单位，主要是由于不合理的氮肥施用造成的。**

**Overuse of N fertilizer contributes substantially to soil acidification in China.**




**Significant Acidification in Major Chinese Croplands**
J. H. Guo, *et al.*
*Science* **327**, 1008 (2010);
DOI: 10.1126/science.1182570

# 温室气体
# (GHG)

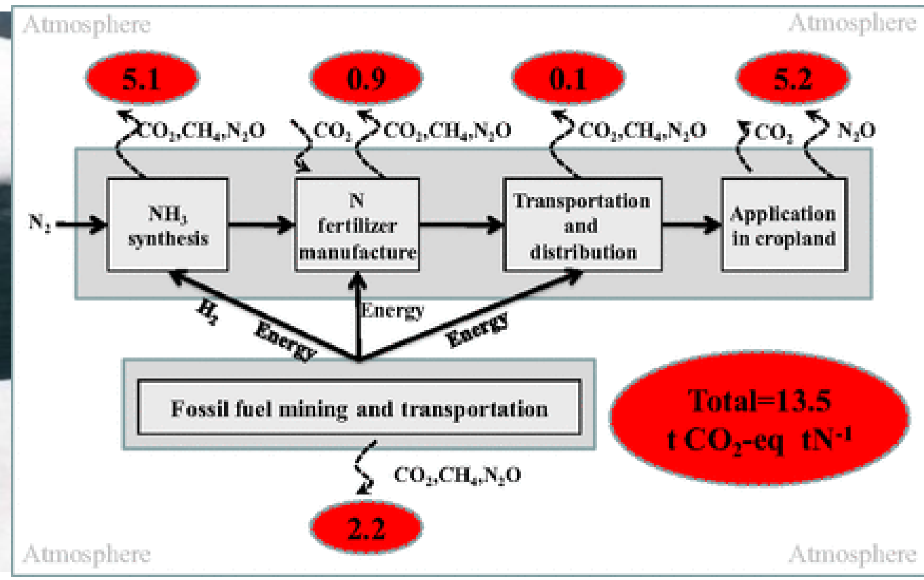
$N_2O$，$CH_4$，$CO_2$…

**每吨氮肥生产和施用造成的温室气体排放：欧洲9.7 t $CO_2$-eq；中国13.5 t $CO_2$-eq**

Emissions of GHG from fertilizer-N production and use per tonne: Europe, 9.7 t $CO_2$-eq ;China, 13.5 t $CO_2$-eq.

**中国当前氮肥生产和施用导致的总排放量（452 Tg $CO_2$-eq ）是80年代（ 131 Tg $CO_2$-eq ）的3倍。**

The total emissions due to fertilizer-N production and use (452 Tg $CO_2$-eq) is 3 times over than the 80's(131 Tg $CO_2$-eq )


(Zhang et al., 2013, PNAS)

**通过技术优化能减少氮肥相关的排放， 相当于102-357 Tg $CO_2$-eq，这相当于中国总GHG排放的2-6%。**

Fertilizer-N related emissions can be reduced by technology optimization, range at 102-357 Tg $CO_2$-eq, and that's the 2-6% of China's total GHG emissions.

# 大气污染(Air pollution)

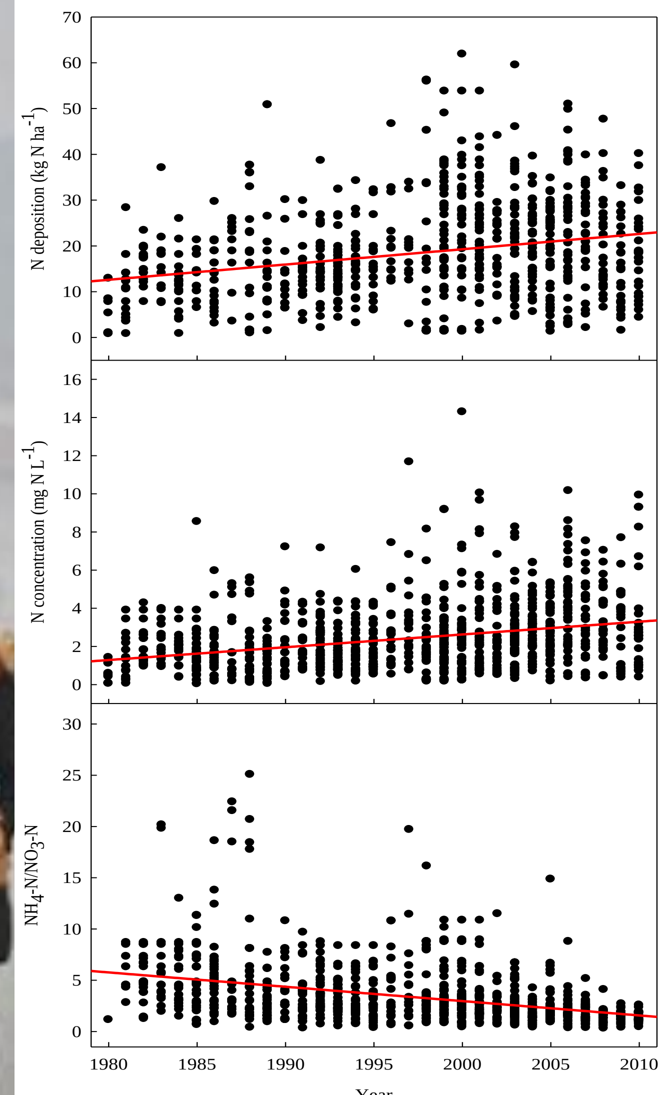
Trends in N deposition (a), N concentration (b), and ratio of $NH_4$-N to $NO_3$-N (c) in deposition from 1980 to 2010.

**Bulk N deposition**
**1980s: 14.3 kg N/ha/yr**
**2000s: 20.9 kg N/ha/yr**

**$NH_4$-N/$NO_3$-N in precipitation**
**1980s: 4.8**
**2000s: 2.0**

**$NH_3$-N/$NO_x$-N emissions**
**1980s: 5.0**
**2000s: 2.5**

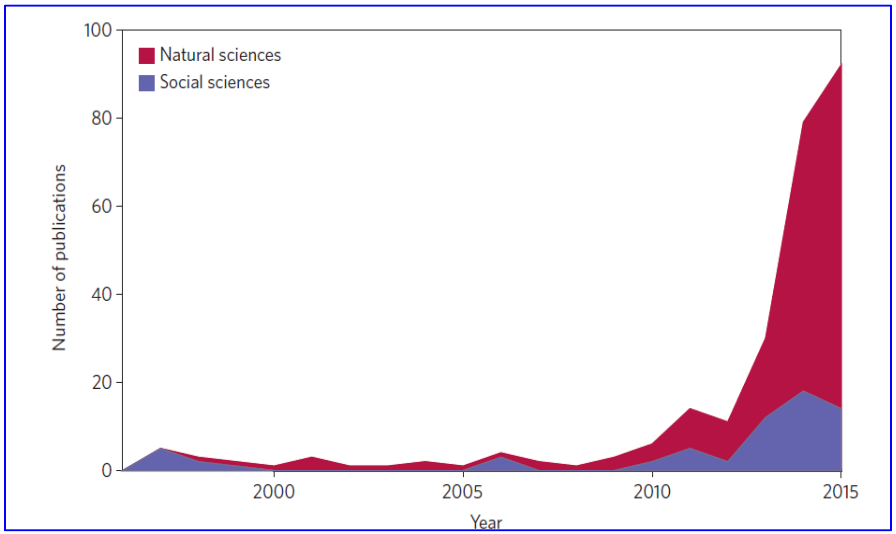
nature




(Liu et al., Nature, 2013)

# 可持续的集约化（Sustainable Intensification）

- **国际农业科学研究的热点；**
  Hotspot of international agricultural sciences
- **我国农业转型的唯一选择。**
  Only Choice for the transformation Chinese agriculture




(Gunton, 2016, Nature)

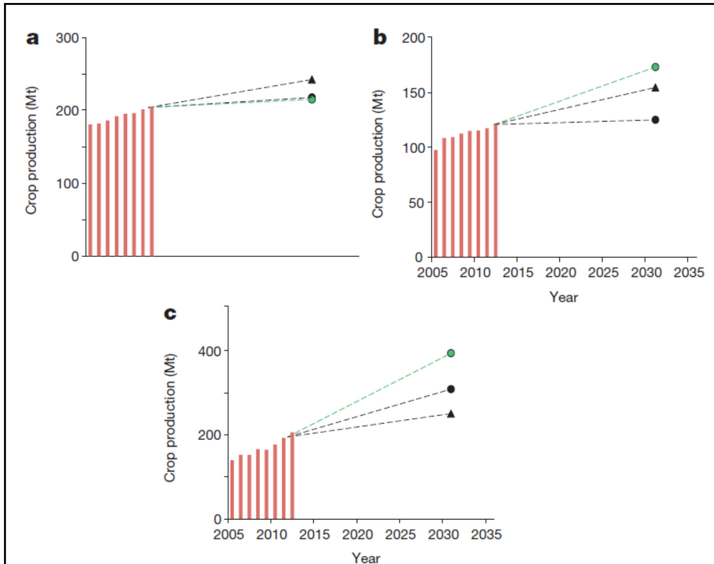



**Figure 3 | The projected demand of grain production for 2030 in China.** **a**, Rice; **b**, wheat; **c**, maize. Red bars, crop production from 2005 to 2012. Black circles, projected demand in 2030. Black triangles, increasing grain yield by the trend observed from 2005 to 2012, keeping planting area the same as in 2012. Green circles, grain yields that reach 80% of the level observed in our ISSM treatment, over the same planting area as in 2012. Note differences in scale for the different crops.

(Chen et al., 2014, Nature)

# 可持续集约化的养分资源管理(中国)
Nutrient management for sustainable intensification (China)

## 氮磷控制是核心(Core: controlling N&P)

**氮磷消费量大(可以控制)；环境问题突出(必须控制)**

Fertilizer-N&P consumptions are large (**can be controlled**)

Environmental problem is severe (**must be controlled**)

Annual average nutrient application ($N+P_2O_5+K_2O$) to arable land

| region | nutrient application kg $ha^{-1}$ |
|---|---|
| East Asia | 195 |
| industrialized countries | 118 |
| South Asia | 102 |
| Near East & N. Africa | 71 |
| Latin America | 56 |
| transition countries | 28 |
| sub-Saharan Africa | 5 |
| world | 92 |

(Bruinsma, 2003)

**大气污染 Air pollution**
(Liu et al., 2014, Nature)

**温室气体排放 GHG emissions**
(Zhang et al., 2013, PNAS)

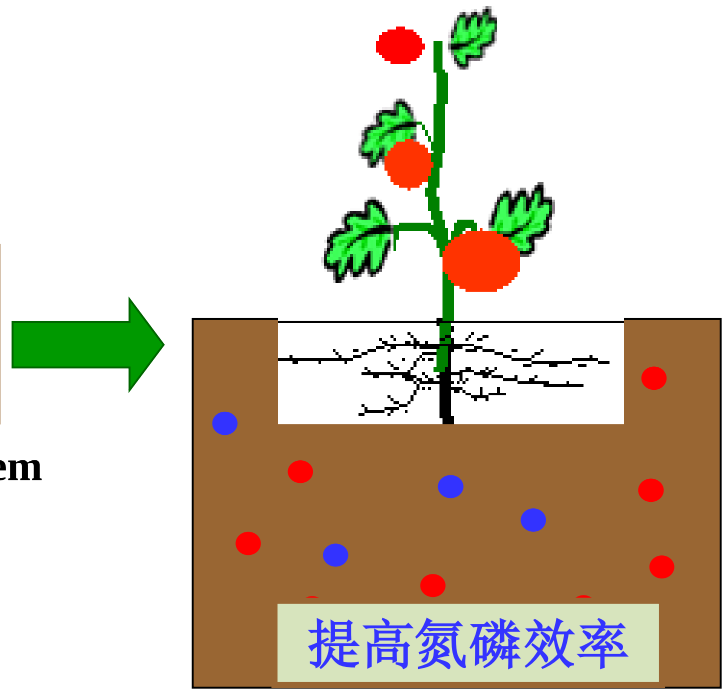
**土壤酸化 Soil acidification**
(Guo et al., 2010, Science)

**水体富营养化 Eutrophication**
(Conley et al., 2009, Science)

# 提高氮磷效率的主要途径
## Main approaches for improving N&P efficiency

土壤-作物系统综合管理

**Integrated Soil-crop System Management (ISSM)**

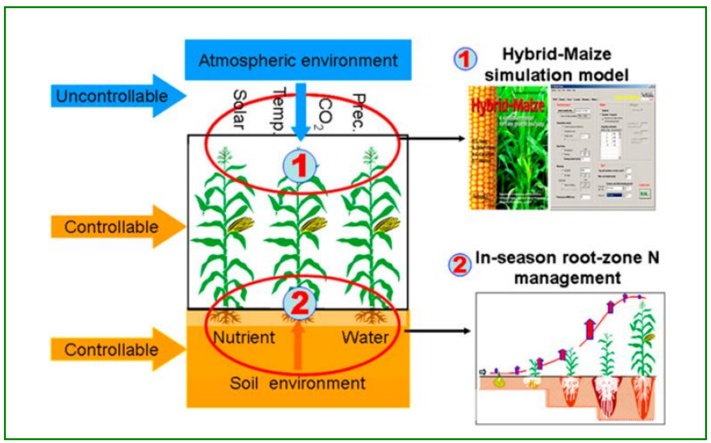



**Improving N&P efficiency**

# 土壤-作物系统综合管理(ISSM)在大幅度增产的同时，并不需要增加氮肥的投入，大幅度提高了氮肥的效率。

Integrated Soil-crop System Management (ISSM) significantly increased yield without more N input, therefor increasing N efficiency

**以根层养分调控为核心的土壤-作物系统综合管理理论模型**
**Conceptual framework for the ISSM approach**




**(Chen et al., 2011, PNAS.; Chen et al., 2014, Nature )**

**ISSM对小麦玉米水稻产量、氮肥用量、氮肥效率和氮素盈余的影响**
Effects of ISSM on grain yield, N application rate, $PFP_N$, Nr intensity and GHG intensity for rice, wheat and maize systems

| Crop | | Yield ($kg\ ha^{-1}$) | N rate ($Mg\ ha^{-1}$) | $PFP_N$ (%) | Nr intensity ($kg\ N\ Mg^{-1}$) | GHG intensity ($kg\ CO_2\ eq\ Mg^{-1}$) |
|---|---|---|---|---|---|---|
| Rice | ISSM | 8.5 | 162 | 54 | 4 | 1077 |
| | FP | 7 | 209 | 41 | 10 | 1574 |
| | **Δ** | **21** | **-22** | **32** | **-56** | **-32** |
| Wheat | ISSM | 8.9 | 220 | 41 | 6 | 463 |
| | FP | 5.7 | 210 | 33 | 12 | 671 |
| | **Δ** | **56** | **5** | **24** | **-50** | **-31** |
| Maize | ISSM | 14.2 | 256 | 56 | 9 | 329 |
| | FP | 7.6 | 220 | 43 | 17 | 621 |
| | **Δ** | **87** | **16** | **30** | **-50** | **-47** |

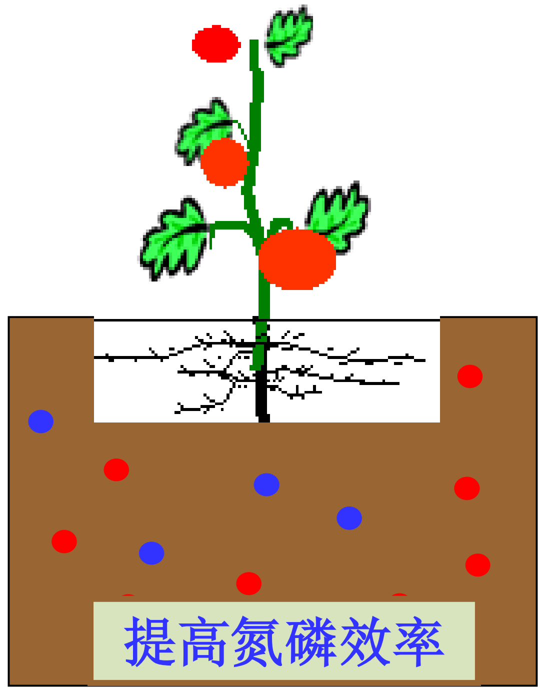
# 提高氮磷效率的主要途径
# Main approaches for improving N&P efficiency

土壤-作物系统综合管理

Integrated Soil-crop System Management (ISSM)

养分高效利用生物学潜力

Biological potential of nutrient use




Improving N&P efficiency

# 提高氮磷效率的主要途径

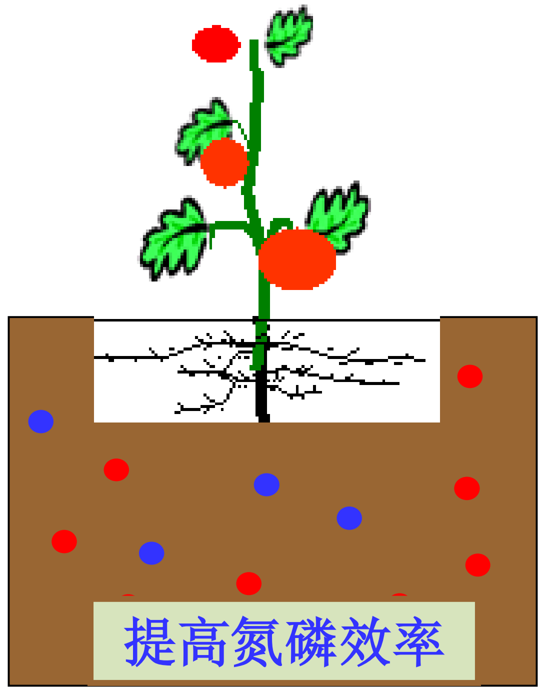
## Main approaches for improving N&P efficiency

土壤-作物系统
综合管理

**Integrated Soil-crop System Management (ISSM)**

养分高效利用
生物学潜力

**Biological potential of nutrient use**



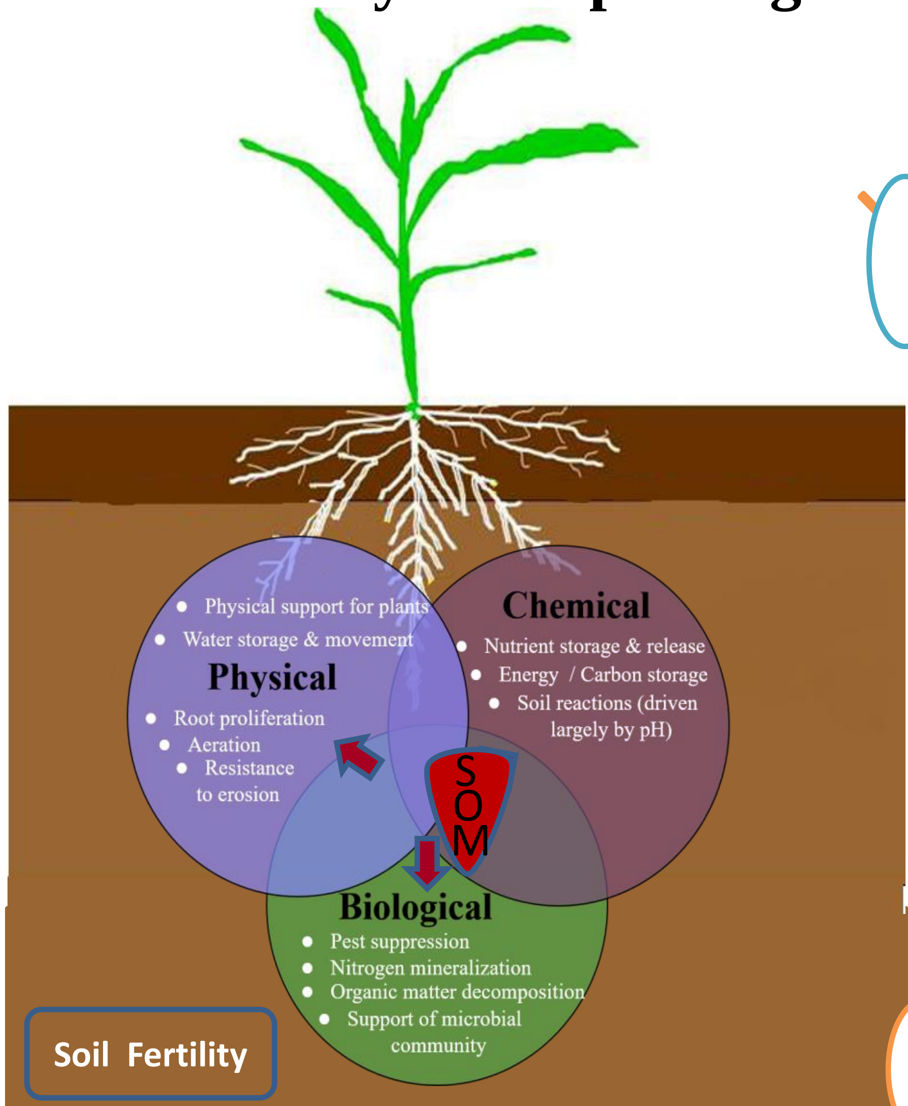

**Improving N&P efficiency**

提升土壤质量

**Soil quality improvement**

# 提升土壤质量的关键：土壤有机质

# The key for improving soil quality: Soil Organic Matter

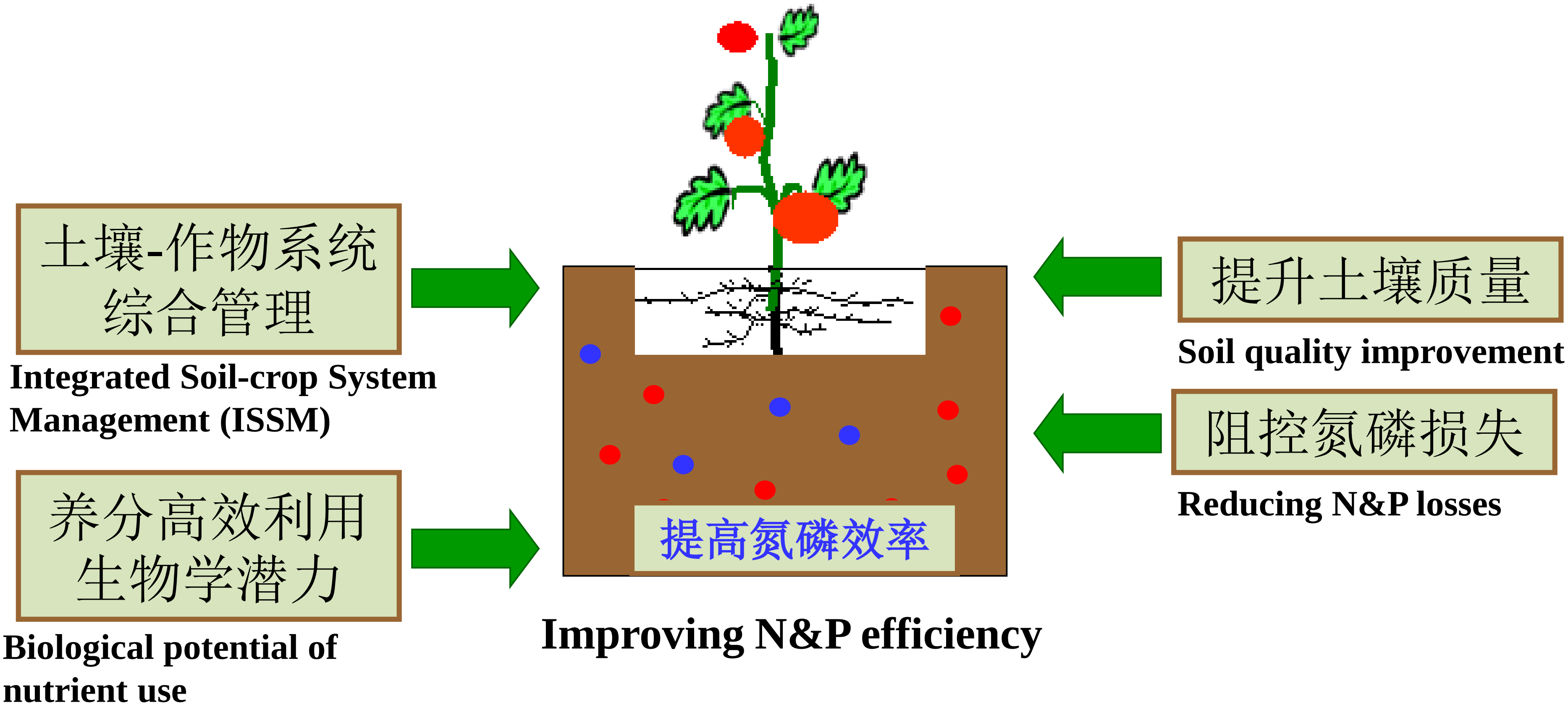



- 改善土壤结构，增加团聚体数量
  Improve soil structure, increase aggregates
- 保持土壤水分、防止养分流失
  Maintain soil moisture to prevent nutrient loss
- 促进根系伸展发育
  Promote root growth and extension
- 吸附农药和重金属残留
  Adsorption of pesticides and heavy metals
- 提高抗逆性，增加有益微生物活性
  Improve stress resistance, increase beneficial microbial activity
- 促进地上生长，提高作物产量
  Promote shoot growth, increase crop yield

（Chan Yin, 2008）

# 提高氮磷效率的主要途径

# Main approaches for improving N&P efficiency



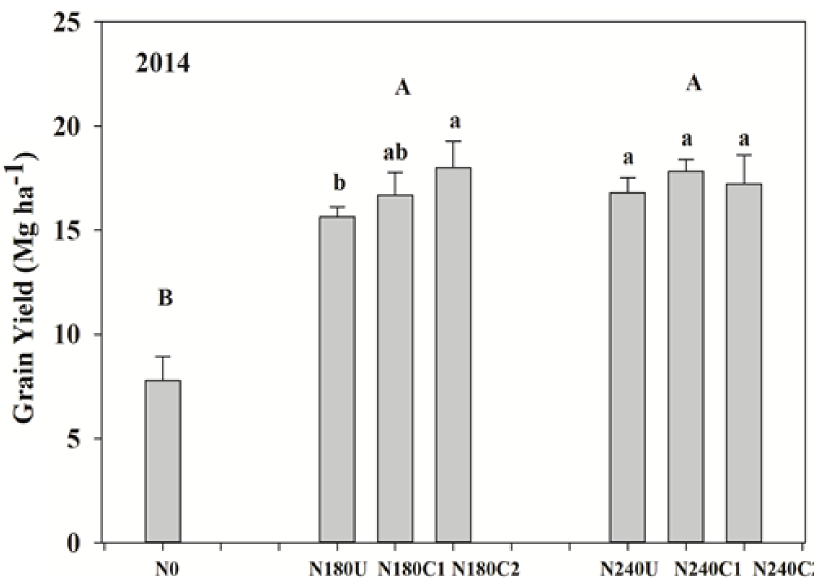
# 以新型肥料为抓手进行创新，改变肥料剂型，阻控氮素损失过程，减少氮磷损失，提高氮磷效率

# New products for reducing nutrients losses

## 大田作物：缓控释肥肥料应用

## Field crops: controlled-release fertilizer

对玉米产量的影响



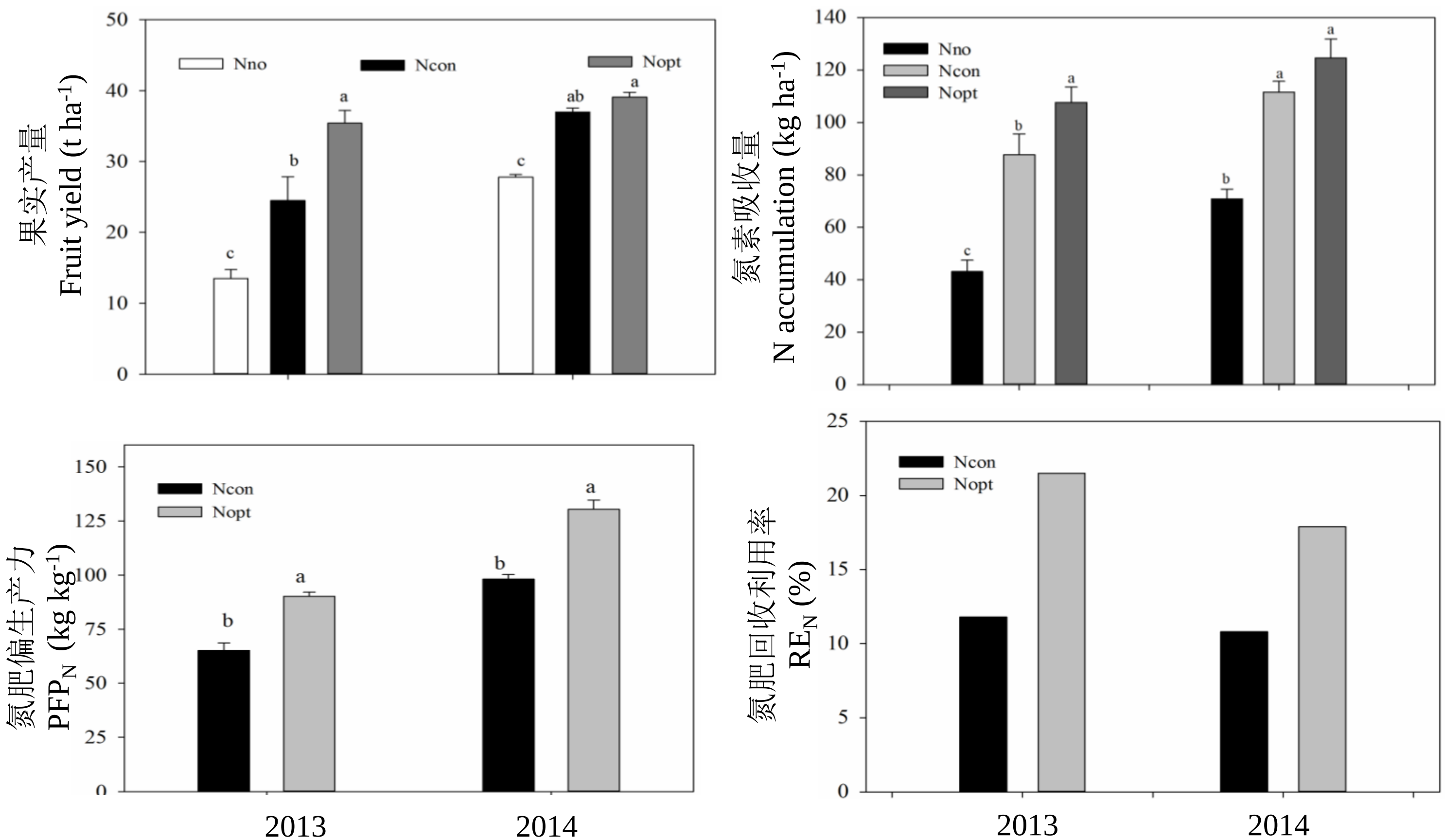

对玉米吸氮量、氮肥效率的影响

| Treatments | Aboveground N uptake (kg ha$^{-1}$) | $PFP_N$ (kg kg$^{-1}$) | $RE_N$ (%) | $AE_N$ (kg kg$^{-1}$) |
|---|---|---|---|---|
| N0 | 114 | - | - | - |
| N180U | 259a | 86.9b | 80.6a | 32.5b |
| N180C1 | 272a | 92.7ab | 87.8a | 37.1a |
| N180C2 | 296a | 99.9a | 101.1a | 42.5a |
| N240U | 294a | 70.0a | 75.0a | 37.5a |
| N240C1 | 302a | 74.3a | 78.3a | 41.7a |
| N240C2 | 289a | 71.8a | 72.9a | 39.2a |

(Guo et al., 2017, Field Crop Research)

# 经济作物：养分的形态调控、水肥一体化技术
## Cash crops: fertigation technology

139 kg N $ha^{-1}$ per growing season was lost by leaching with Ncon, this represented 36% of the N applied. With Nopt, leaching was reduced by 27.1% and yield was increased by 25.1%. Addition of nitrapyrin with Nopt helped maintain a high $NH_4^+/NO_3^-$ ratio in the soil and thereby helped reduce leaching.




(Zhang et al., 2017, AEE)

# 提高氮磷效率的主要途径

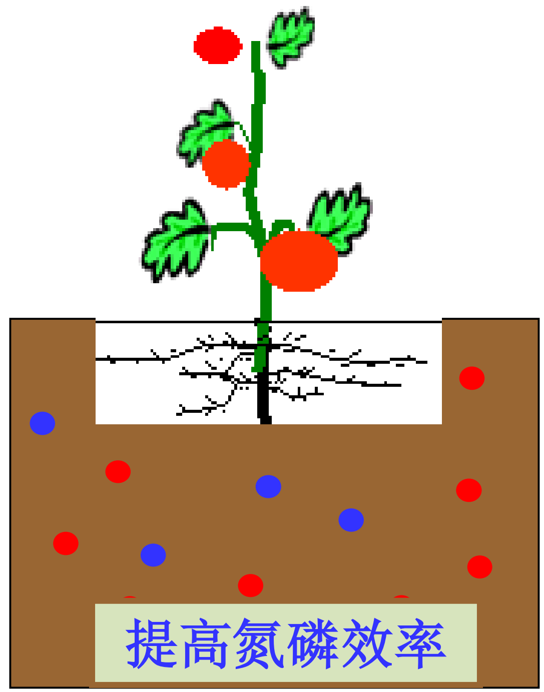
## Main approaches for improving N&P efficiency

土壤-作物系统综合管理

**Integrated Soil-crop System Management (ISSM)**

养分高效利用生物学潜力

**Biological potential of nutrient use**




**Improving N&P efficiency**

提升土壤质量

**Soil quality improvement**

阻控氮磷损失

**Reducing N&P losses**

中微肥料增效

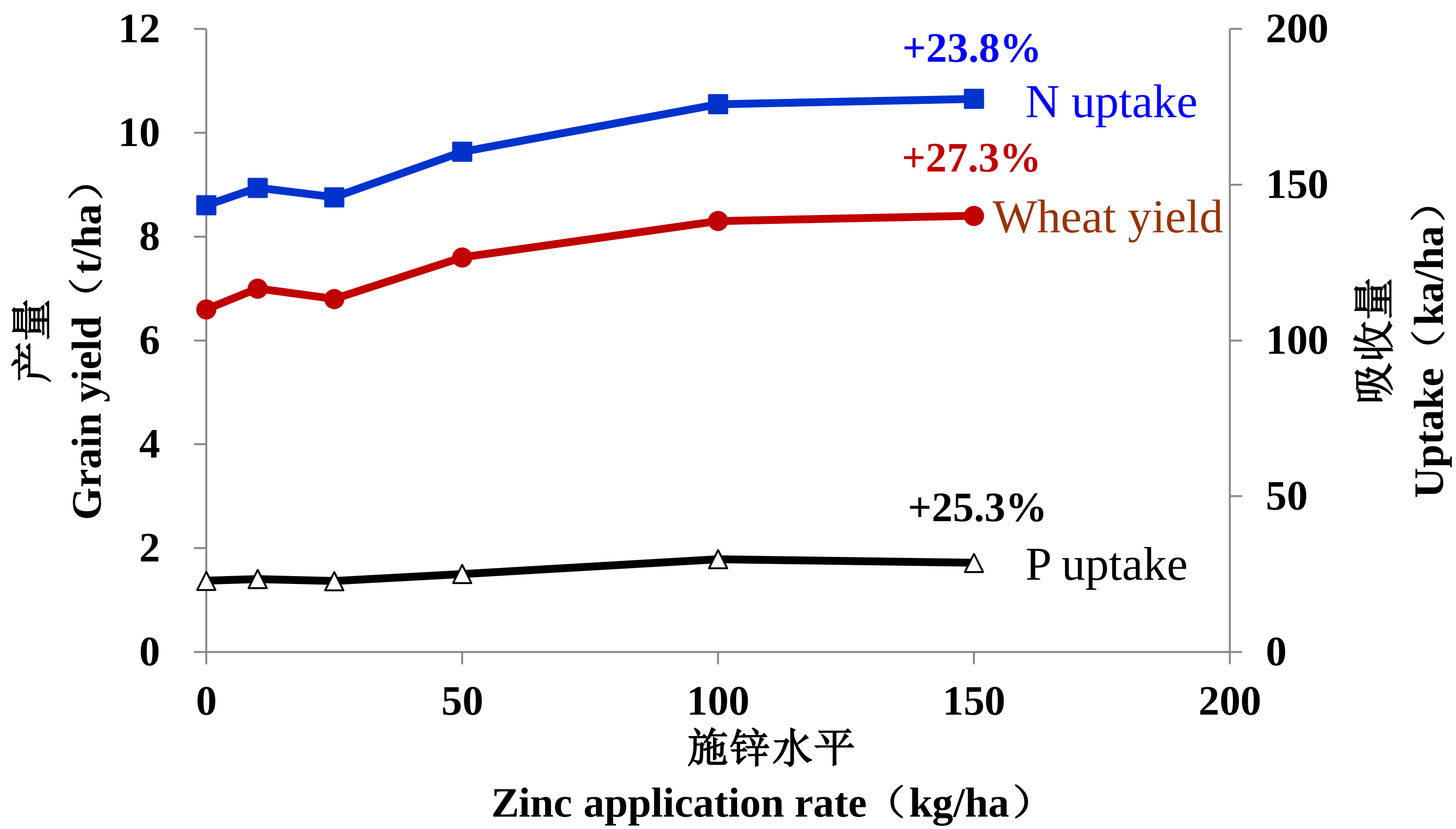
**Increasing efficiency by secondary/micro-elements application**

# 中微量元素应用，提高氮磷效率

# Increasing N&P efficiency by secondary/micro-elements application

**施锌水平对小麦籽粒产量和氮磷吸收的影响（曲周，2014）**

Zn application rate effects on grain yield, N and P uptake of wheat in 2014 (Quzhou)




注：纯氮肥施用量：225 kg/ha；$P_2O_5$施用量：75kg/ha

Note: N and $P_2O_5$ application rates are 225, 75 kg/ha, respectively.

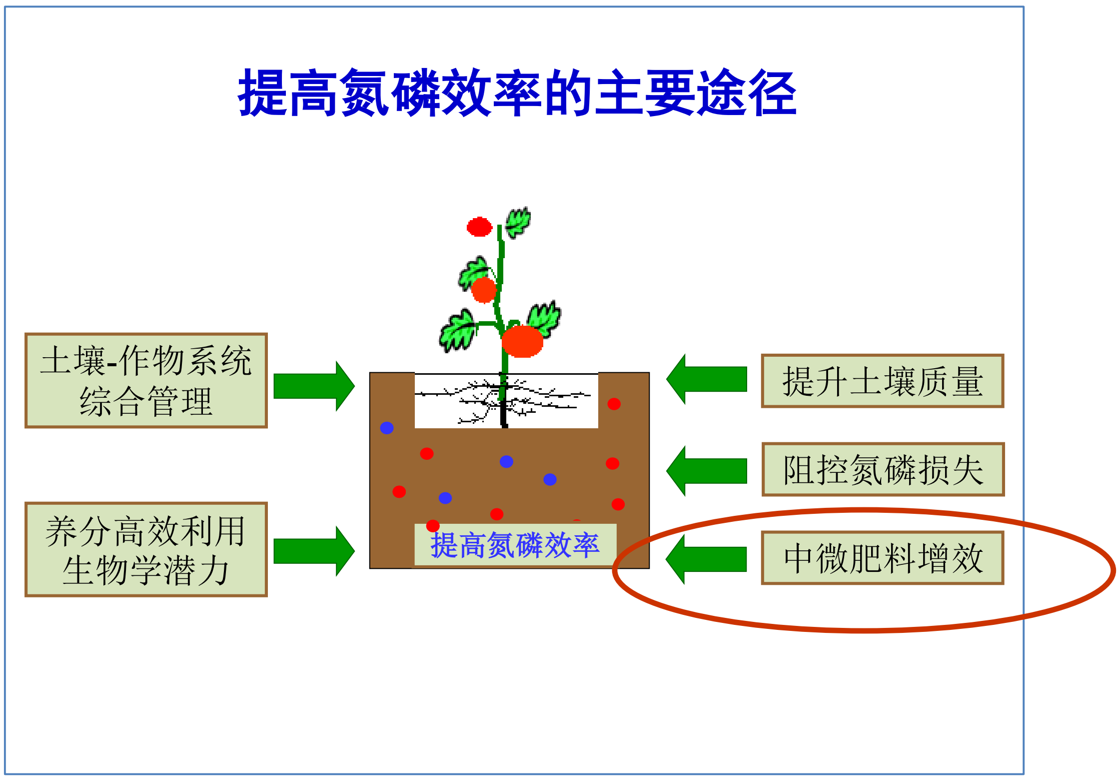
**（Liu Dunyi, Chen Xinping, Zou Chunqin et al, Plant & Soil, 2016）**

# 如何将中微量元素的研究与应用上升为国家行动？

How to push the research and application of secondary/micro-elements into national action?

# 中微量元素代表性、方向性的重大产品是什么？

What are the representative and directional products of secondary/micro-elements?




十三五国家行动：化肥零增长

**National thirteen five plan:**
Zero growth of fertilizer

十三五科技行动：肥药双减，绿色增产，面源污染防控

**Scientific thirteen five plans:**
Fertilizer and pesticide reduction;
Green production;
Non-point source pollution control

# 报告提纲/Outline

- **为什么要加强中微量元素研究**
  **The importance of secondary/micro-elements research**

- **当前需要重点关注的几个中微量元素**
  **Key secondary/micro-elements need to be focused**

- **如何加强中微量元素营养与肥料的研究**
  **How to strengthen secondary/micro-elements research**

# 中国镁地球化学图

## Geochemical Map of Magnesium in China

西北栗钙土、棕钙土中高达3%以上

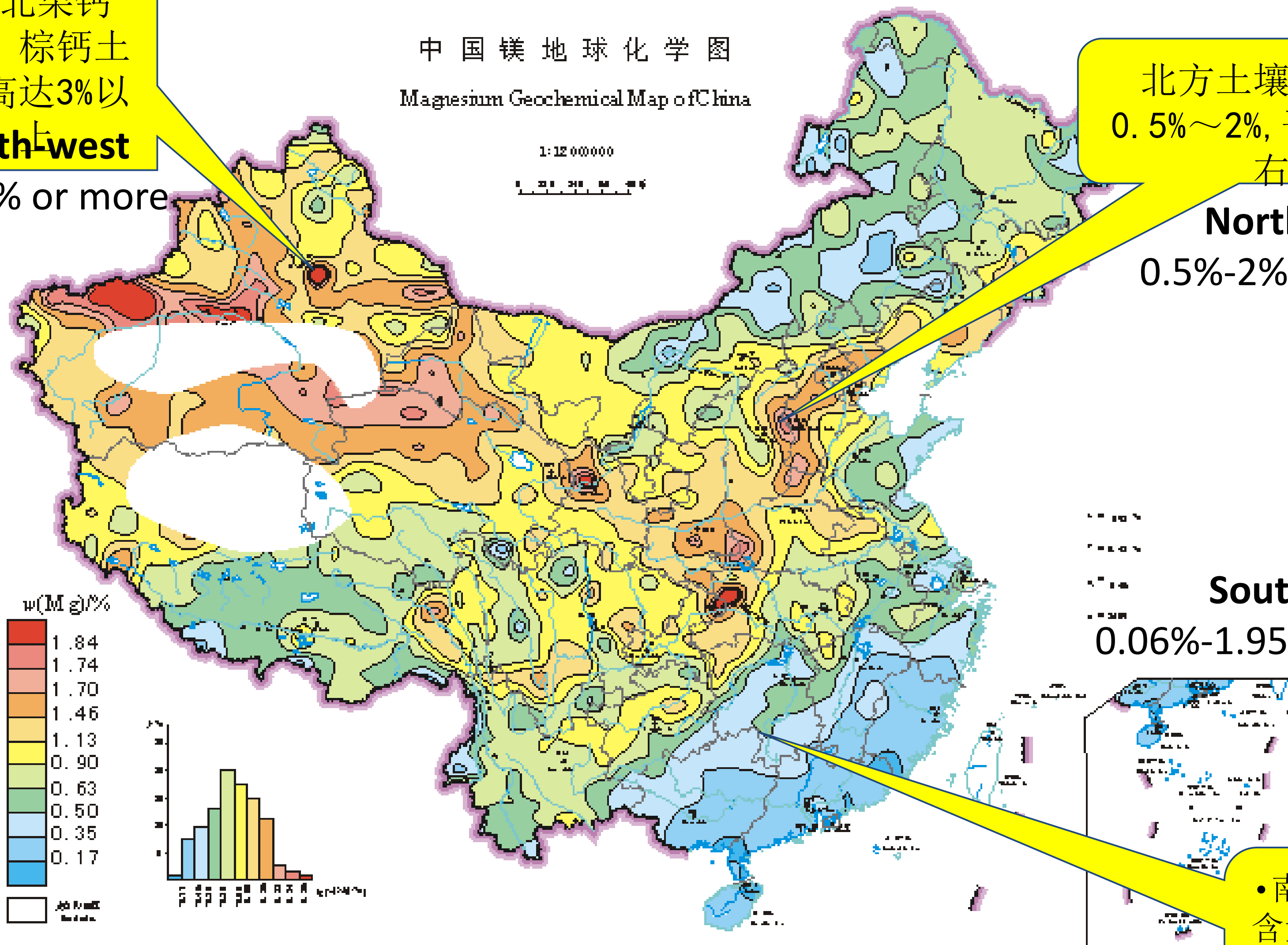
**North-west**

Over 3% or more

北方土壤一般为0. 5%～2%, 平均1%左右

**North China**

0.5%-2%, main:1%




**South China**

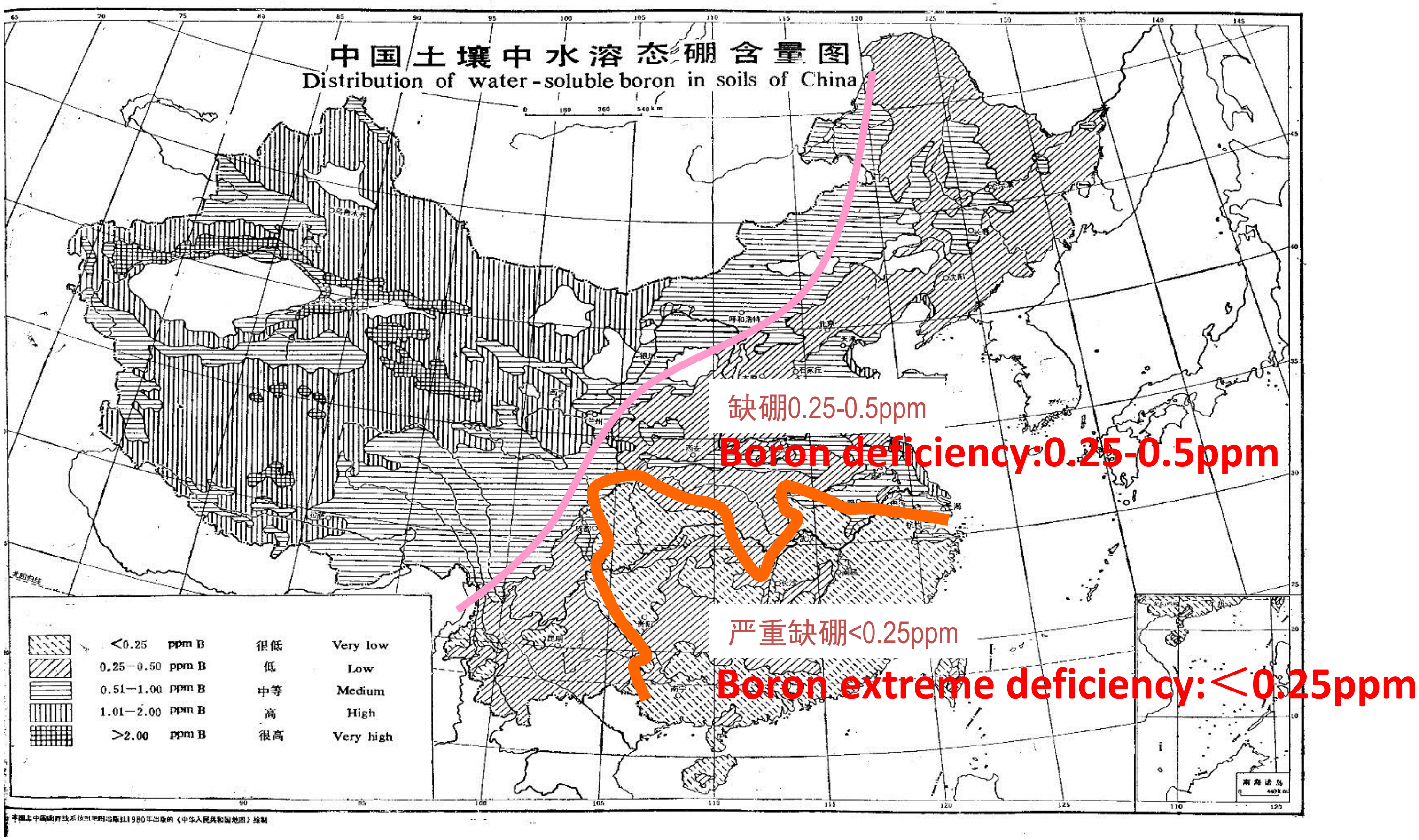
0.06%-1.95%, main:0.5%

- 南方地区全镁含量一般是0. 06%～1. 95%, 平均0. 5%左右,

我国土壤含镁量自北向南、自西向东逐渐降低

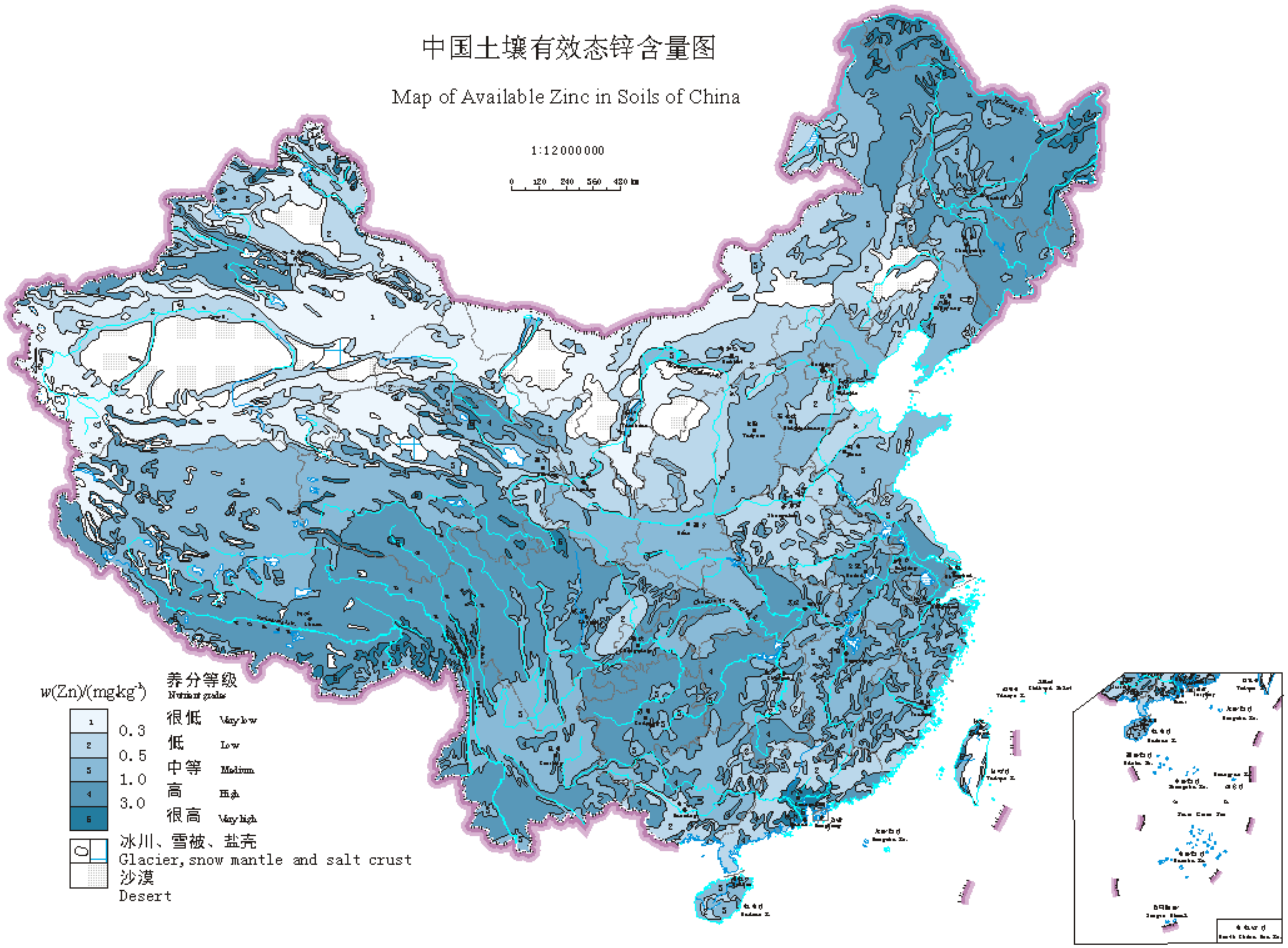
# 中国土壤水溶性硼含量图

# The map of soil water-soluble boron in China



# 中国土壤有效锌含量图

## The map of soil available zinc in China



**大体而言，中微量元素可以分为两类：**

Generally, secondary/micro-elements can be divided into two categories：

**一类是土壤中总量不高：降雨量、成土母质，如镁、硼等**

Low content in soil: magnesium, boron, because of soil parent material and rainfall

**一类是养分有效性受到限制：pH 值，如锌、铁等**

Low availability: Zinc, iron, due to soil pH and other reasons

**钙：南方是土壤含量问题，北方是有效性问题**

Calcium: North, availability; South, low content

**此一特点，必须在中微量元素的施肥技术和肥料研发中予以充分考虑。**

This unique property must be considered fully during the research and development

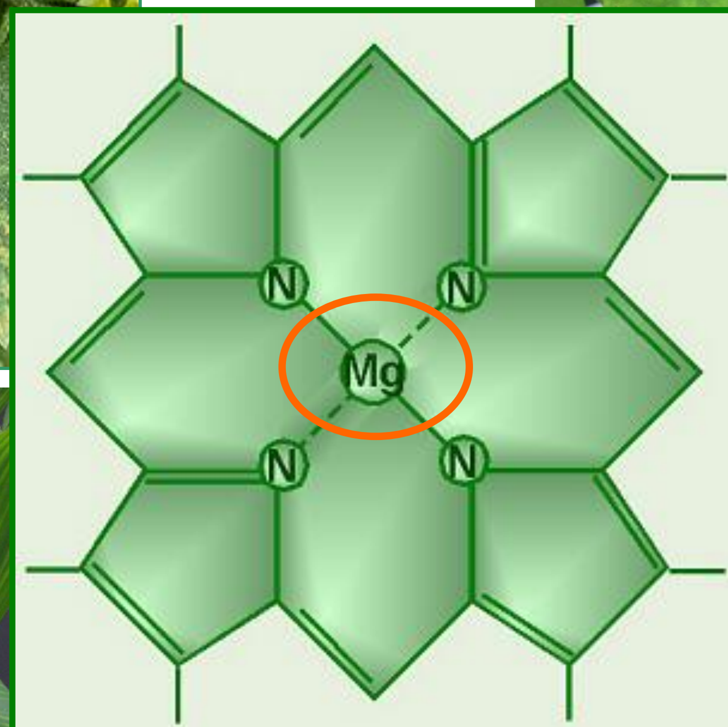
# 镁(Mg)–作物增产的关键
## Magnesium(Mg)- The key to increase crop yield

- ✓ 叶绿素的重要组分**(Chlorophyll)**
- ✓ 碳水化合物的运输**(Carbohydrate transportation)**
- ✓ 影响根系生长**(Root growth)**
- ✓ 提高作物对高温、辐射的抗性
  **(Resistance to high temperature and radiation)**
- ✓ 提高酶的活性**(Enzyme activities)**
- ✓ 影响**RNA**的合成**(RNA synthesis)**

# 作物缺镁症状 (Mg deficiency symptom)

## 镁是叶绿素的中心，缺镁导致叶片黄化

## Mg serves as the central atom of chlorophyll




(Source: Cakmak, 2016)

# 豇豆缺镁症状
# Mg deficiency symptom in Cowpea

（张白鸽，广州 **2015**）

**（Zhang Baige, Guangzhou, 2015）**

# 果树缺镁的典型症状及敏感程度
# Mg deficiency symptom in Fruit trees

**缺镁敏感作物一般果蔬作物多于大田作物，果树中葡萄、柑橘、桃、苹果较易发生。**
**Sensitivity: Fruit & Vegetabl＞Field crop; grape, citrus, peach, apple**


(张跃强，2016)

(Zhang Yueqiang, 2016)

# 中国土壤镁的状况
## Magnesium status in soils of China

**44% 的土壤有效镁低于50mg/kg**

Exchangeable magnesium is under 50mg/kg in 44% of soils

| Grades | Exchangeable Mg（mg/kg） | Samples | Proportion（%） |
|---|---|---|---|
| **1** | >500 | 38452 | **13.83** |
| **2** | 300-500 | 53263 | **10.71** |
| **3** | 200-300 | 52083 | **8.95** |
| **4** | 100-200 | 75956 | **13.42** |
| **5** | 50-100 | 54507 | **9.31** |
| **6** | 25-50 | 42528 | **7.64** |
| **7** | <25 | 98820 | **36.14** |

43.8%

*Data from national soil testing and fertilizer recommendation program*

(Li, 2016)

# 报告提纲/Outline

- **为什么要加强中微量元素研究**
**The importance of secondary/micro-elements research**

- **当前需要重点关注的几个中微量元素**
**Key secondary/micro-elements need to be focused**

- **如何加强中微量元素营养与肥料的研究**
**How to strengthen secondary/micro-elements research**

# 加强中微量元素营养和肥料研究

**Strengthening secondary/micro-elements research**

## 1、中微量元素的生理需求

**Physiological demands of secondary/micro-elements**

# 1、中微量元素的生理需求

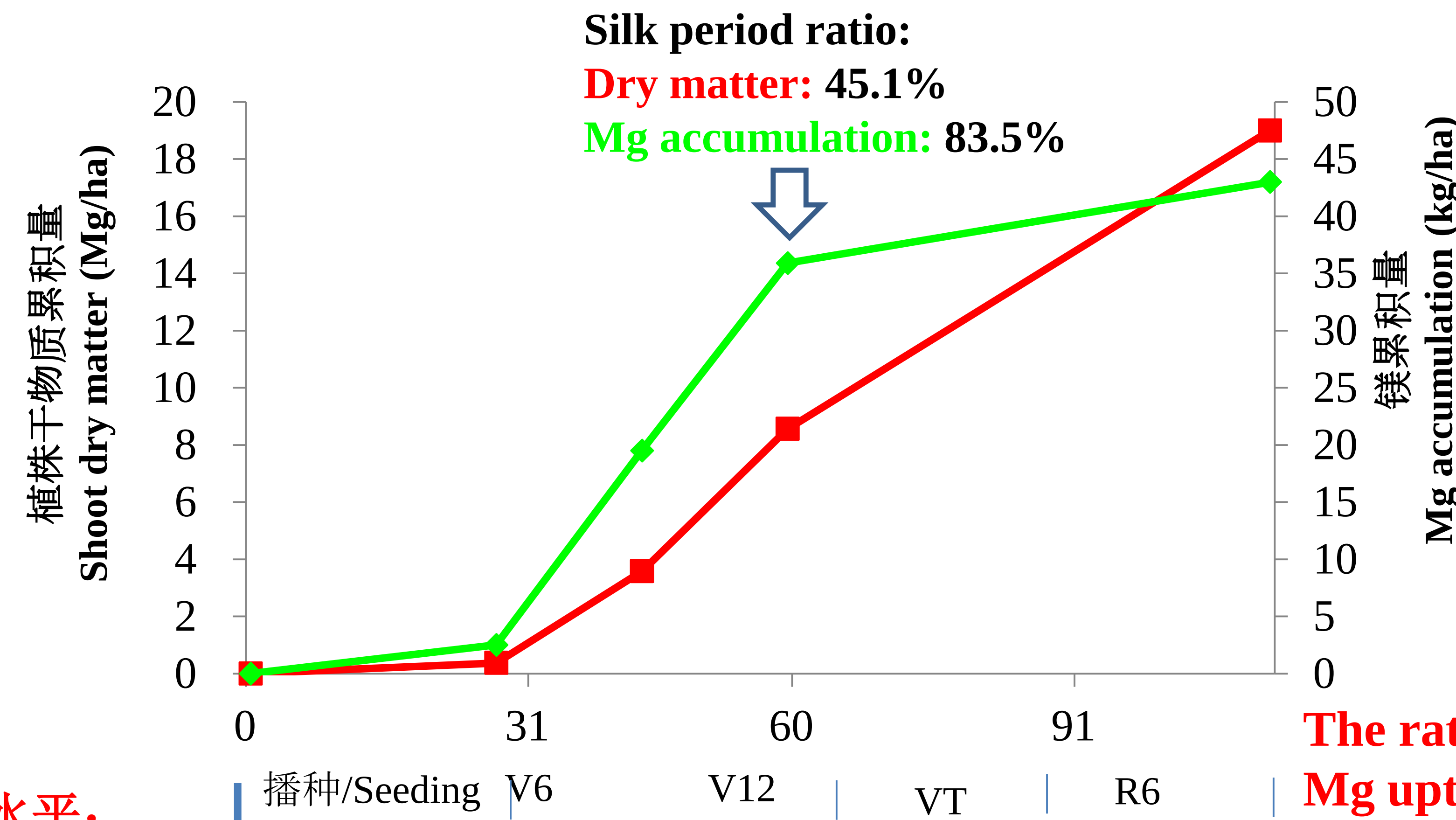
Physiological demands of secondary/micro-elements

**不同产量水平下各作物养分吸收量 Nutrients uptake(kg/ha)**

| 作物 Crop | 产量 Yield(t/ha) | N | P | K | Ca | Mg | 数据来源 Data sources |
|---|---|---|---|---|---|---|---|
| Maize 玉米 | 10.0 | 194 | 24 | 149 | 39 | 43 | 2014年数据 |
| Wheat 小麦 | 8.6 | 207 | 28 | 140 | 29 | 21 | 2014年数据 |
| Barley 大麦 | 3.7 | - | - | 63 | 20 | 14 | Jakobsen, 1992 |
| Pepper 辣椒 | 47.1 | 186 | 27 | 260 | 84 | 39 | 刘 彬等，2016 |
| Tomato 番茄 | 126 | 275 | 65 | 345 | 239 | 69 | 蔡绍珍等，1983 |
| Cucumber 黄瓜 | 107 | 193 | 74 | 239 | 318 | 86 | 蔡绍珍等，1993 |
| Banana 香蕉 | 34.5 | 152 | 28 | 582 | 58 | 10 | 于俊江等，2010 |
| Strawberry 草莓 | 20.5 | 97 | 18 | 100 | 41 | 21 | 雷伟伟等，2015 |
| Apple 苹果 | 40.2 | 217 | 16 | 139 | 50 | 10 | 王 建等，2014 |

（Guan Xilin & Chen Xinping , unpublished）

# 玉米生育期内干物质及镁累积规律
# Accumulation of dry matter and Mg in maize growth period

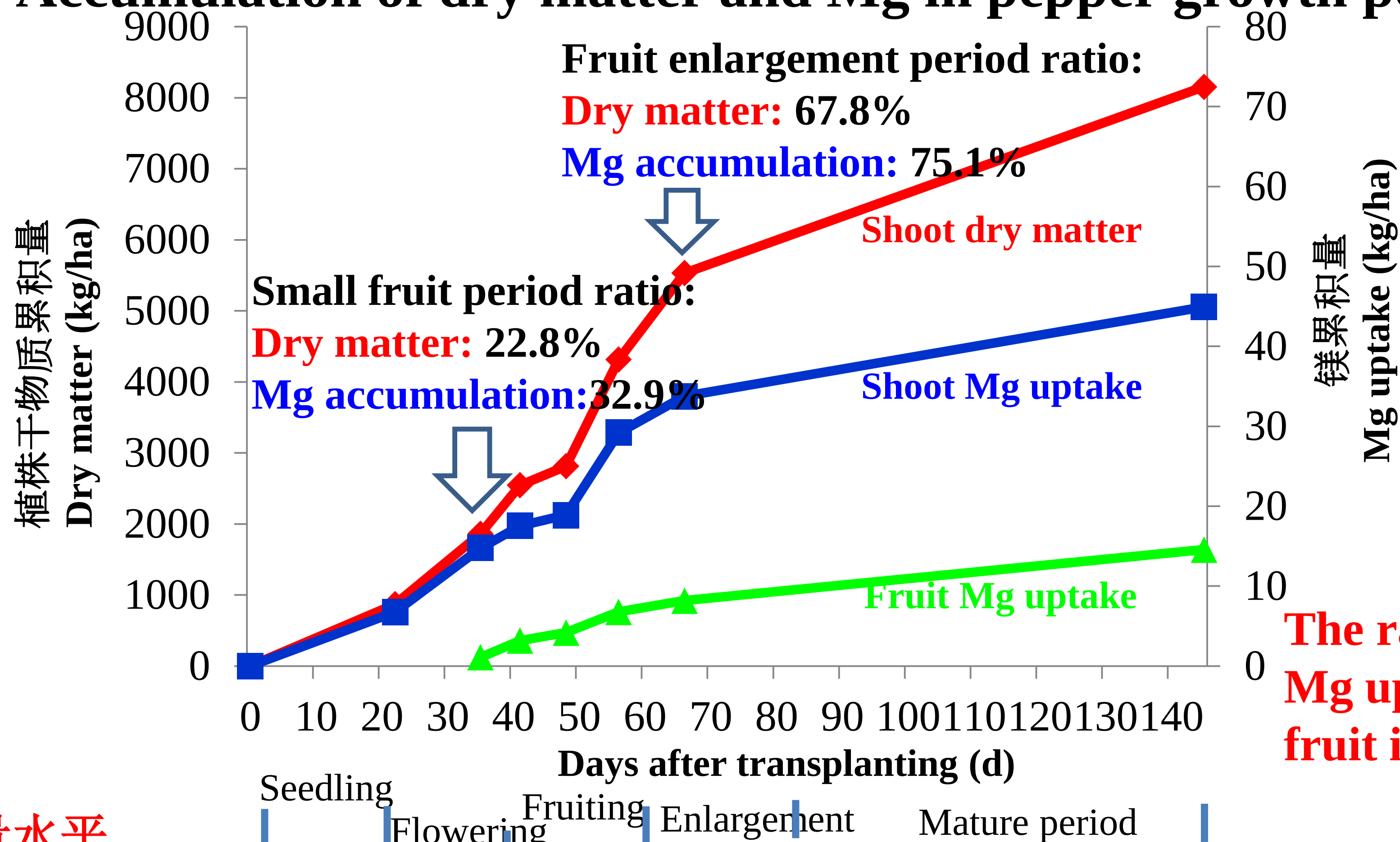



**产量水平：**
**Production:10t/ha**


**The ratio of Mg uptake in grain is 24.7%**

**(Unpublished)**

# 辣椒生育期内干物质及镁累积规律
# Accumulation of dry matter and Mg in pepper growth period



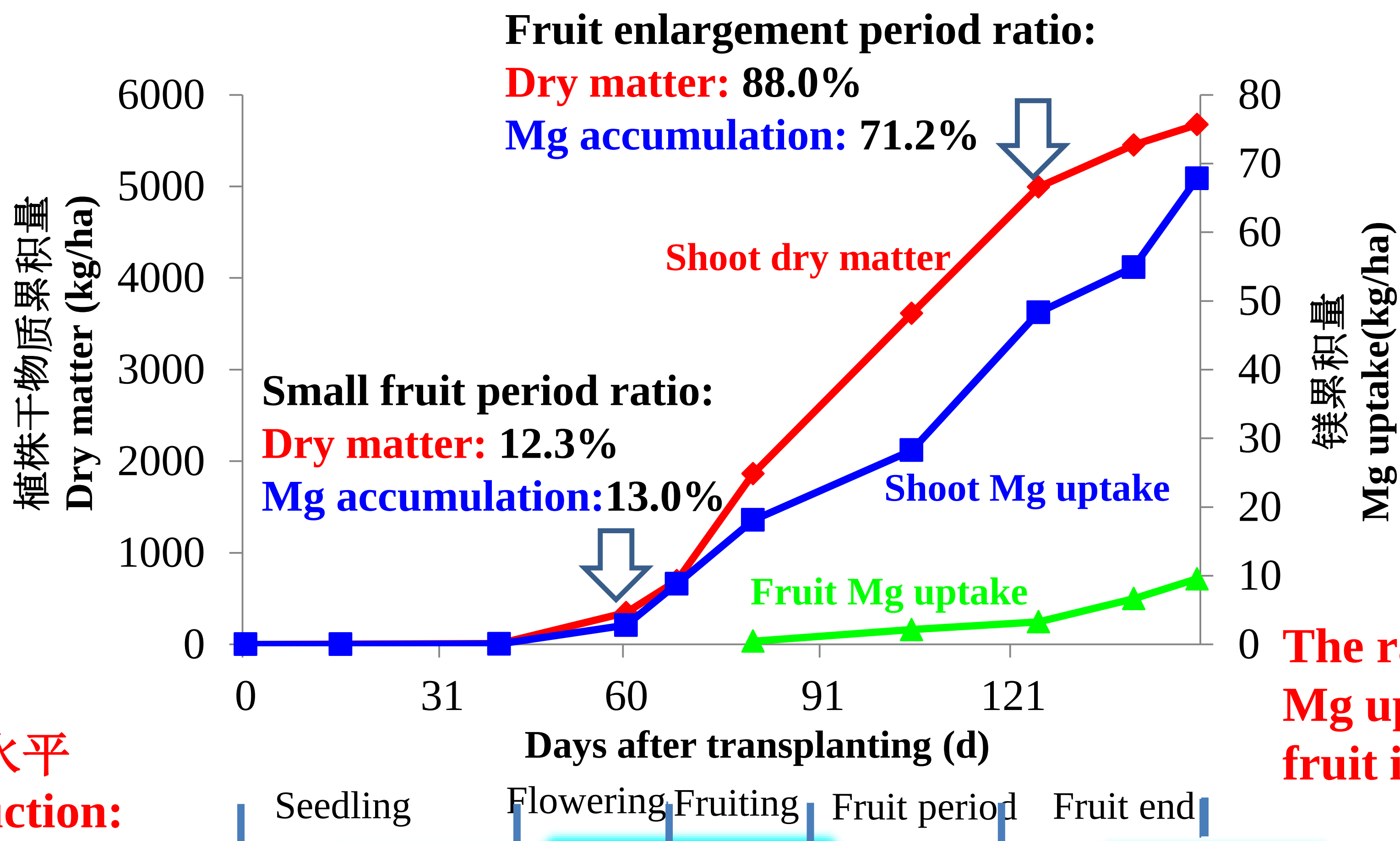

**The ratio of Mg uptake in fruit is 33.3%**

**产量水平**
**Production: 47.1t/ha**

**(Unpublished)**

# 樱桃番茄生育期内干物质及镁累积规律

# Accumulation of dry matter and Mg in cherry tomato growth period




**The ratio of Mg uptake in fruit is 14.1%**

**产量水平**
**Production: 28.9t/ha**

**(Unpublished)**

# 加强中微量元素营养和肥料研究
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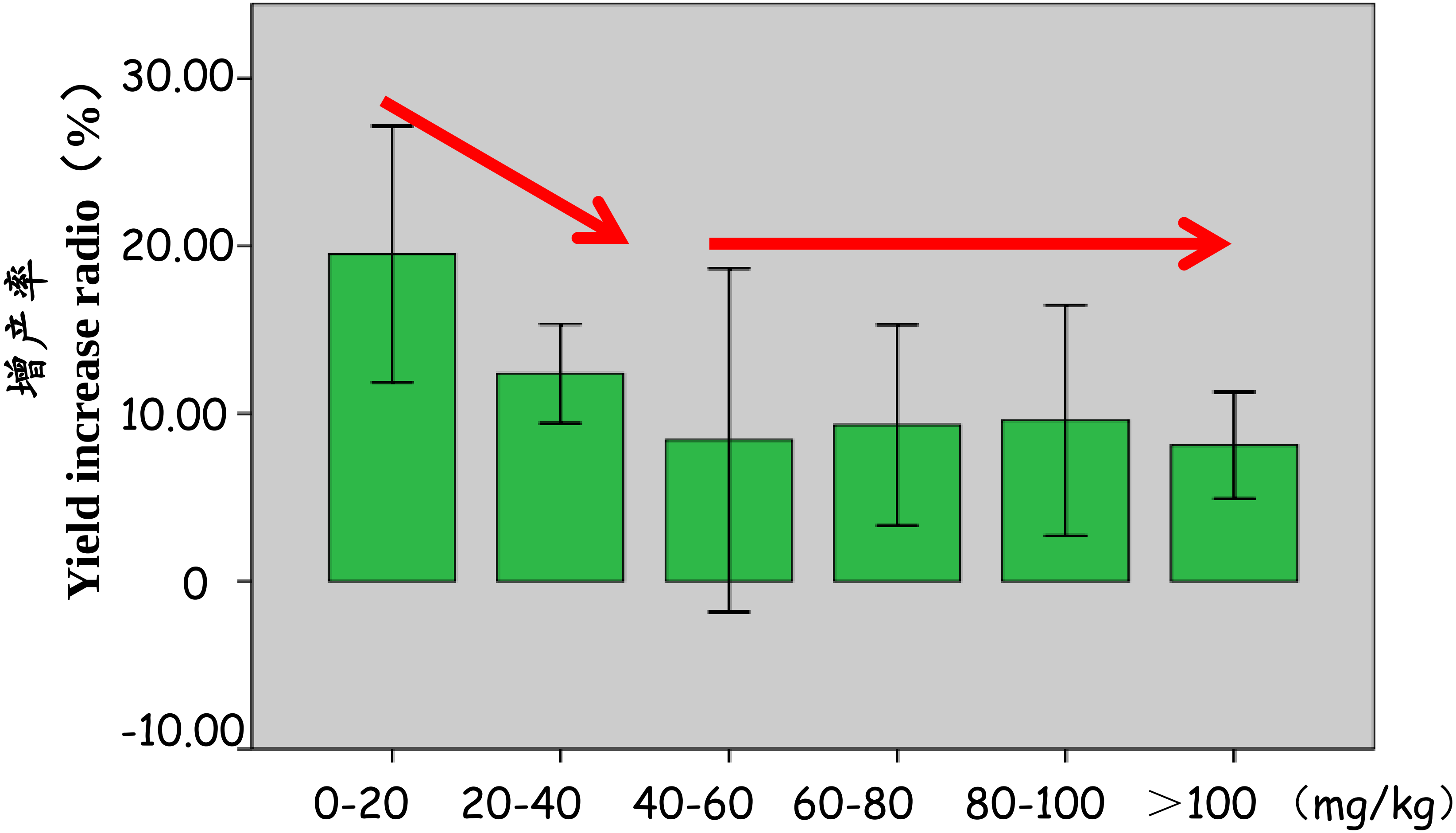
## 2、中微量元素的土壤状况
**Secondary/micro-elements in soils**

# 土壤有效镁的临界值

Critical value of soil exchangeable Mg




土壤最适交换性镁浓度：**40-60mg/kg。**

Optimum exchangeable Mg: **40-60mg/kg**

**（Wu Liangqian et al, unpublished）**

# 农田镁的淋失量
# Mg leaching in cropland

| | Crop system | Precipitation (mm) | Leaching amount （kg/ha） | literature sources |
|---|---|---|---|---|
| | Forest | | 9.5 | Boysen, 1977 |
| | Arable land | | 20 | Boysen, 1977 |
| | Grass | 558 | 17.4 | Di and Cameron, 2004 |
| precipitation | Winter wheat | 512 | 19 | Jakobsen, 1992 |
| | Winter wheat | 715 | 35 | Jakobsen, 1992 |
| | Winter wheat | 808 | 42 | Jakobsen, 1992 |
| region | Maize | 867 | 44 | Jakobsen, 1992 |
| | Maize | 1040 | 45 | Poss and Saragoni,1992 |
| species | Fallow | 542 | 35 | Ylaranta et al., 1996 |
| | Barley | 542 | 87 | Ylaranta et al., 1996 |
| | Grass | 542 | 38 | Ylaranta et al., 1996 |
| | Oilseed rape | 808 | 42 | Jakobsen, 1992 |
| | Soybean | 814 | 45 | Jakobsen, 1992 |

**（Guan Xilin & Chen Xinping, unpublished）**

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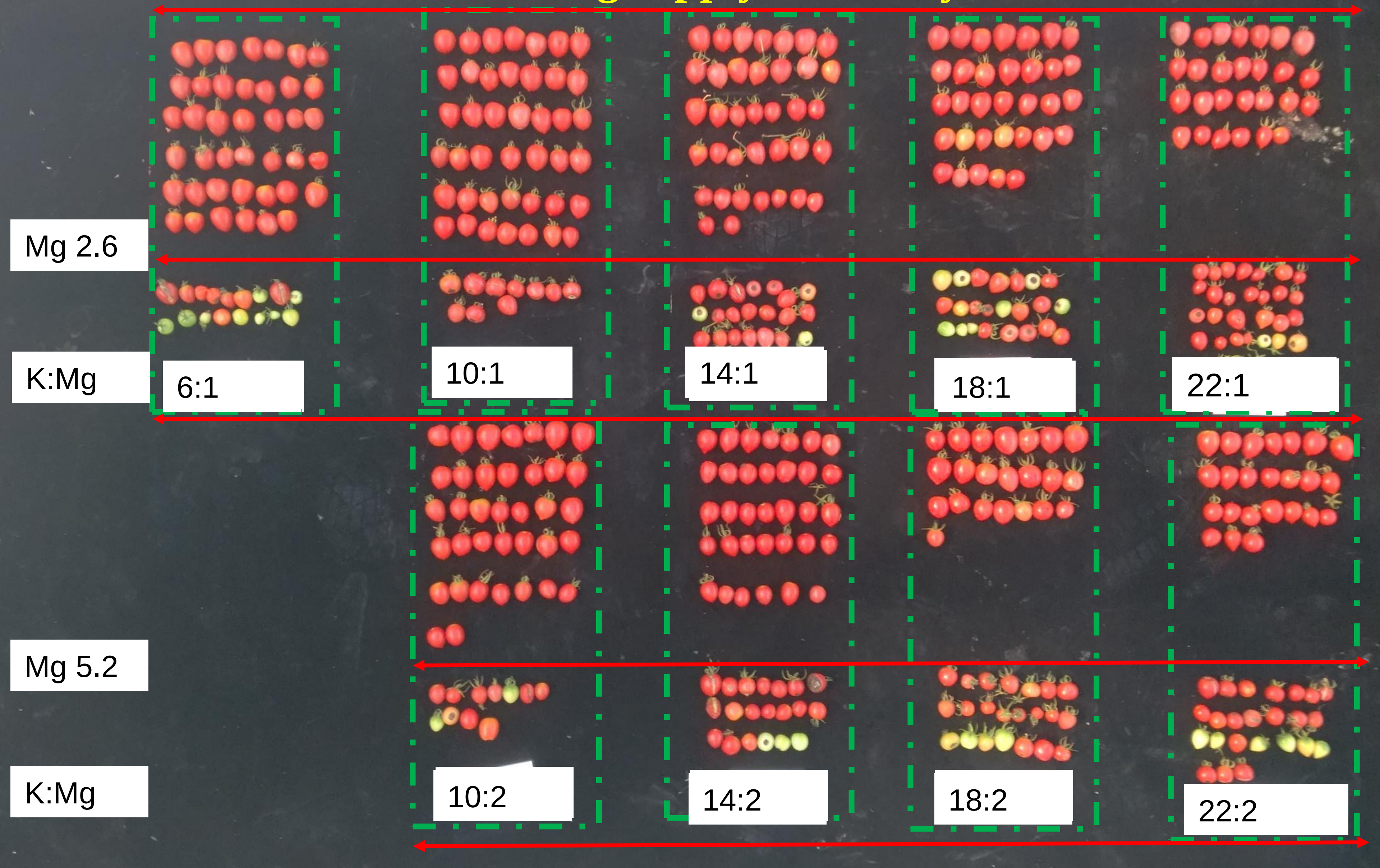
3、中微量元素的养分互作关系

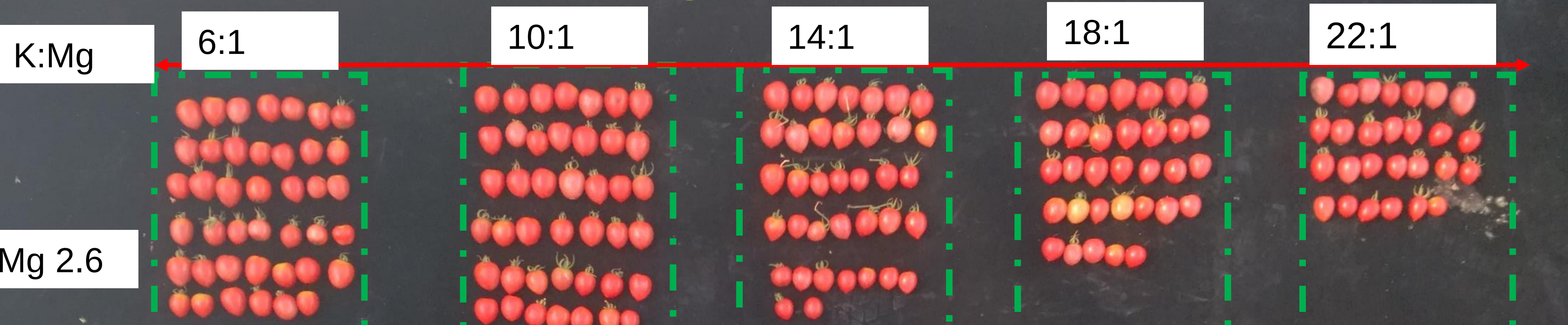
**Interaction between nutrients**

# 不同钾镁比对樱桃番茄的影响
# Effects of K/Mg supply on cherry tomato

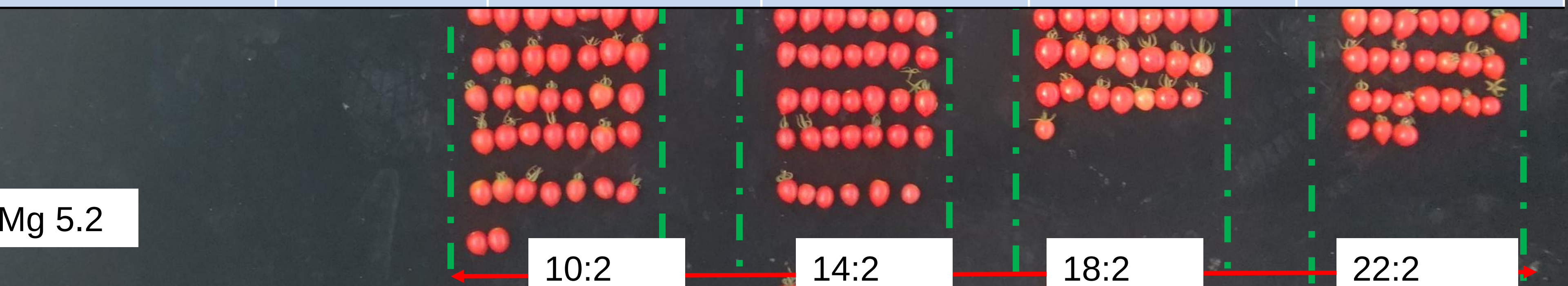



(Unpublished)

# Effects of K/Mg supply on cherry tomato




| K/Mg radio in leaf | 6.3 | 8.0 | 12.4 | 14.2 | 15.3 |
|---|---|---|---|---|---|
| Yield (g/plant) | 552.0 | 578.5 | 499.3 | 493.3 | 463.1 |
| Commodity fruit rate (%) | 86.1 | 92.4 | 87.0 | 85.6 | 84.9 |




| K/Mg radio in leaf | 7.5 | 10.0 | 12.5 | 14.8 |
|---|---|---|---|---|
| Yield (g/plant) | 518.1 | 492.4 | 457.5 | 354.7 |
| Commodity fruit rate (%) | 84.6 | 83.3 | 77.6 | 74.7 |

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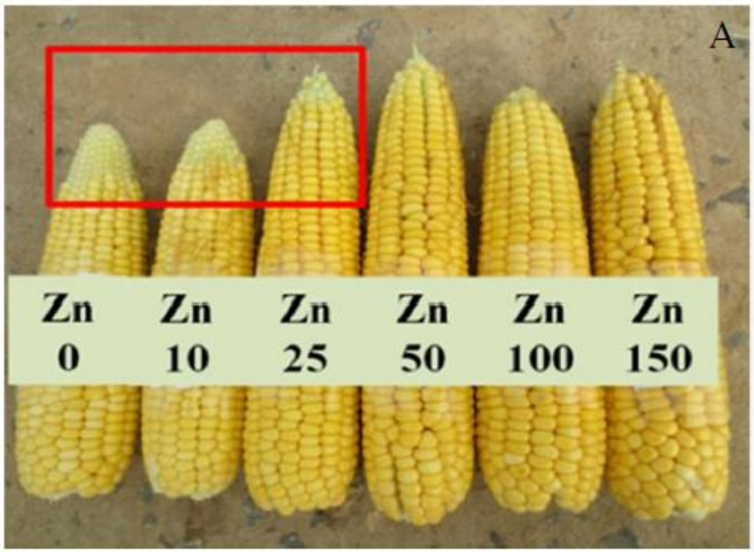
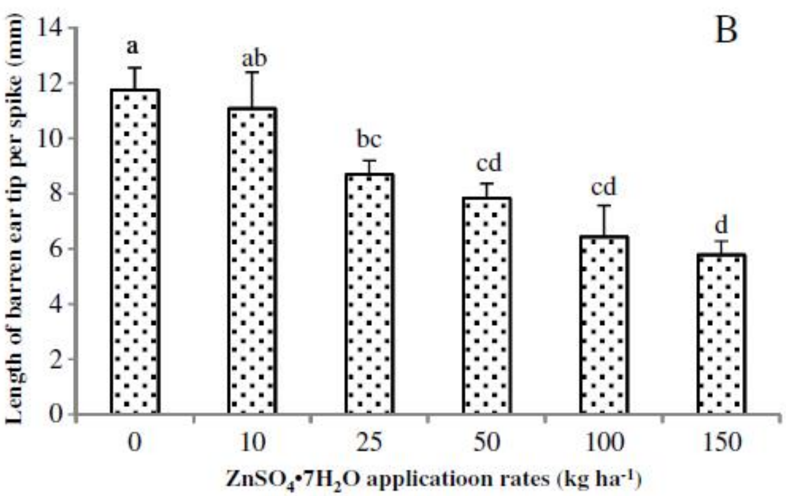
**4、中微量元素肥料有效施用条件**

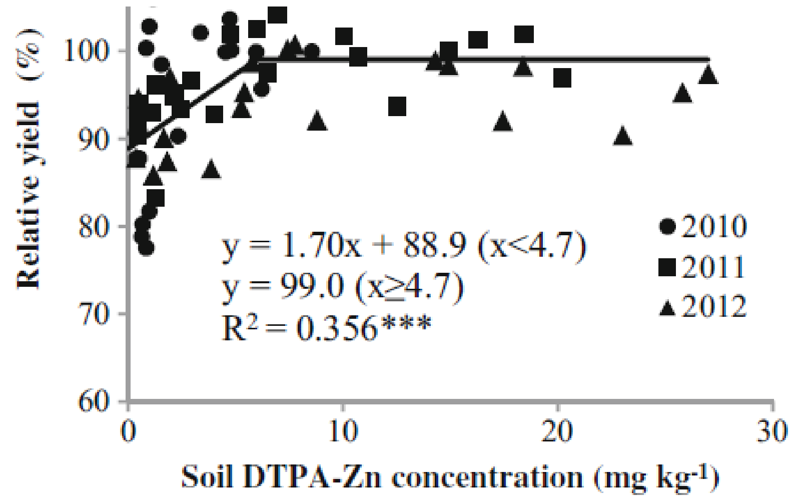
**Application conditions**

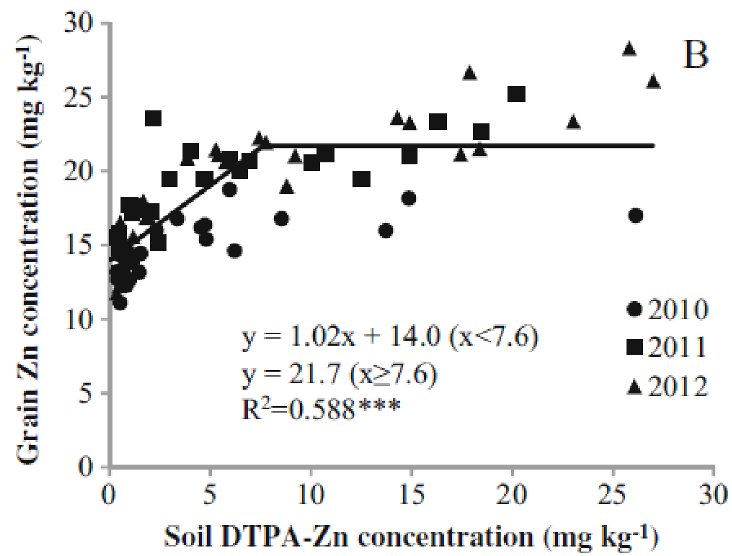
# Soil application of zinc fertilizer could achieve high yield and high grain zinc concentration in maize

Dun-Yi Liu • Wei Zhang • Peng Yan • Xin-Ping Chen •
Fu-Suo Zhang • Chun-Qin Zou



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## 5、中微量元素肥料新产品

**New products of secondary/micro-elements fertilizer**

# 中微量元素肥料新产品
## New products of secondary/micro-elements fertilizer

考虑不同元素、不同区域、不同作物上的施肥方式：
Fertilization methods in difference regions and crops

- ✓ 土施：单独施用/添加到复合肥、配方肥

**Soil application:** separately or add to compound fertilizer, formula fertilizer

- ✓ 滴灌：复配水溶肥，形态与有效性、元素互作

**Drip irrigation**: Mixed with water soluble fertilizer; form and availability, interaction among elements

- ✓ 叶面：形态与有效性

**Foliar application**: form and availability.

# 近十年来我国科学施用水平显著提高

## Fertilization has been significantly improved in recent years

**2004年到2013年，我国粮食增产了28.2%，同期我国化肥用量增长了27.5%，这是自上世纪六十年代我国开始大范围施用化肥以来，粮食增产速度首次跑赢肥料增长速度，同期，我国蔬菜总产增加了33.5%，水果总产增加了63.6%。**

From 2004 to 2013, China's grain production increased by 28.2%, over the same period China's fertilizer consumption increased by 27.5%. Meanwhile, total vegetable production increased by 33.5%, and fruit production increased by 63.6%.

## 下一个十年：期待中微量元素的显著贡献?

Next decade: Significant contributions be expected from secondary/micro-elements?

谢谢！

Many thanks!