Nutrient Management
For Food Security And Environment Quality

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China Agricultural University

September. 16, 2013, Beijing

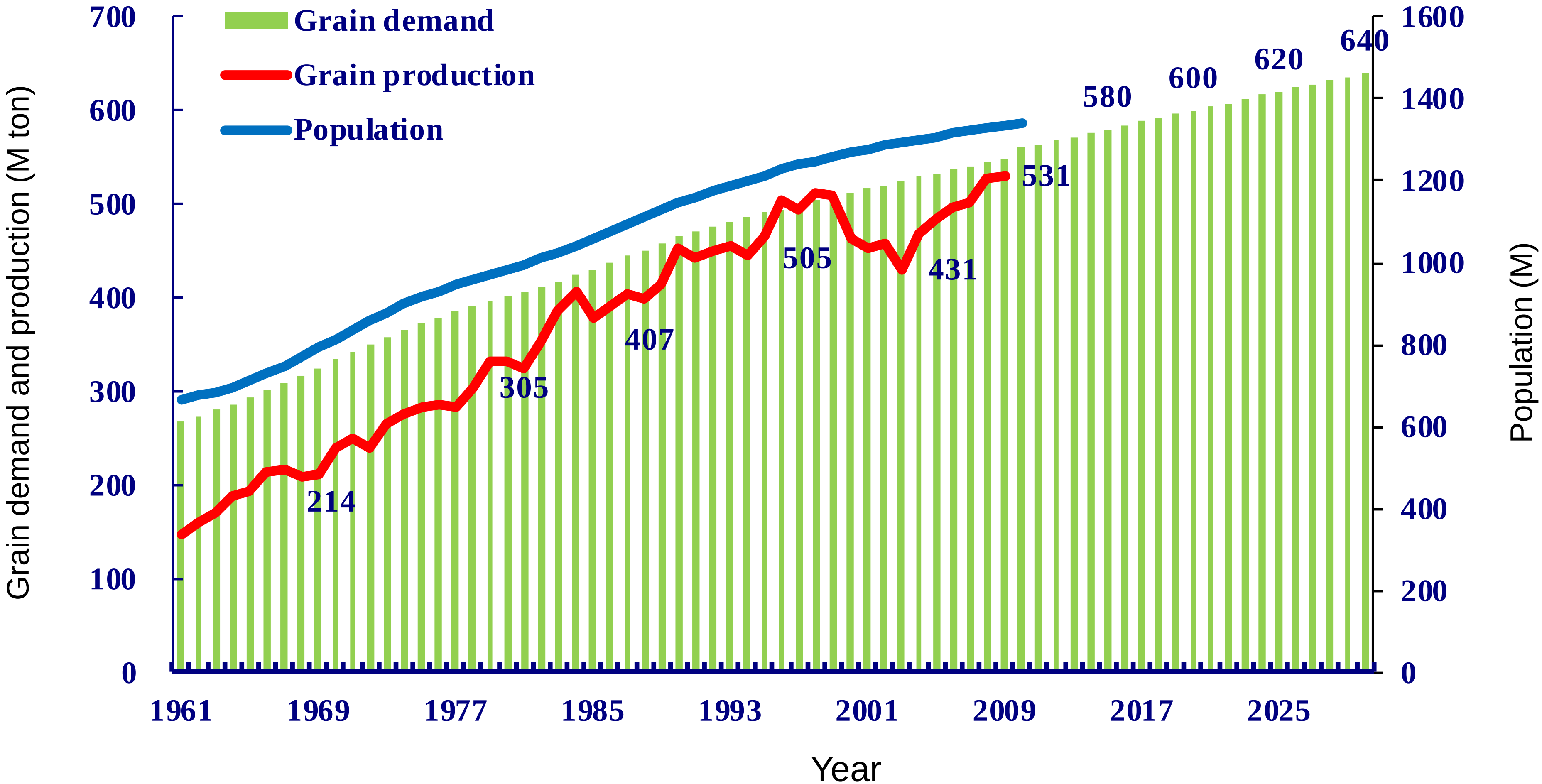
Outline

- **Problems and Challenges**
- **Strategy of Nutrient Management and It's Impact**
- **Prospects**

China

9.6 million km2
1.3 billion population
9% of world arable land
22% of world population

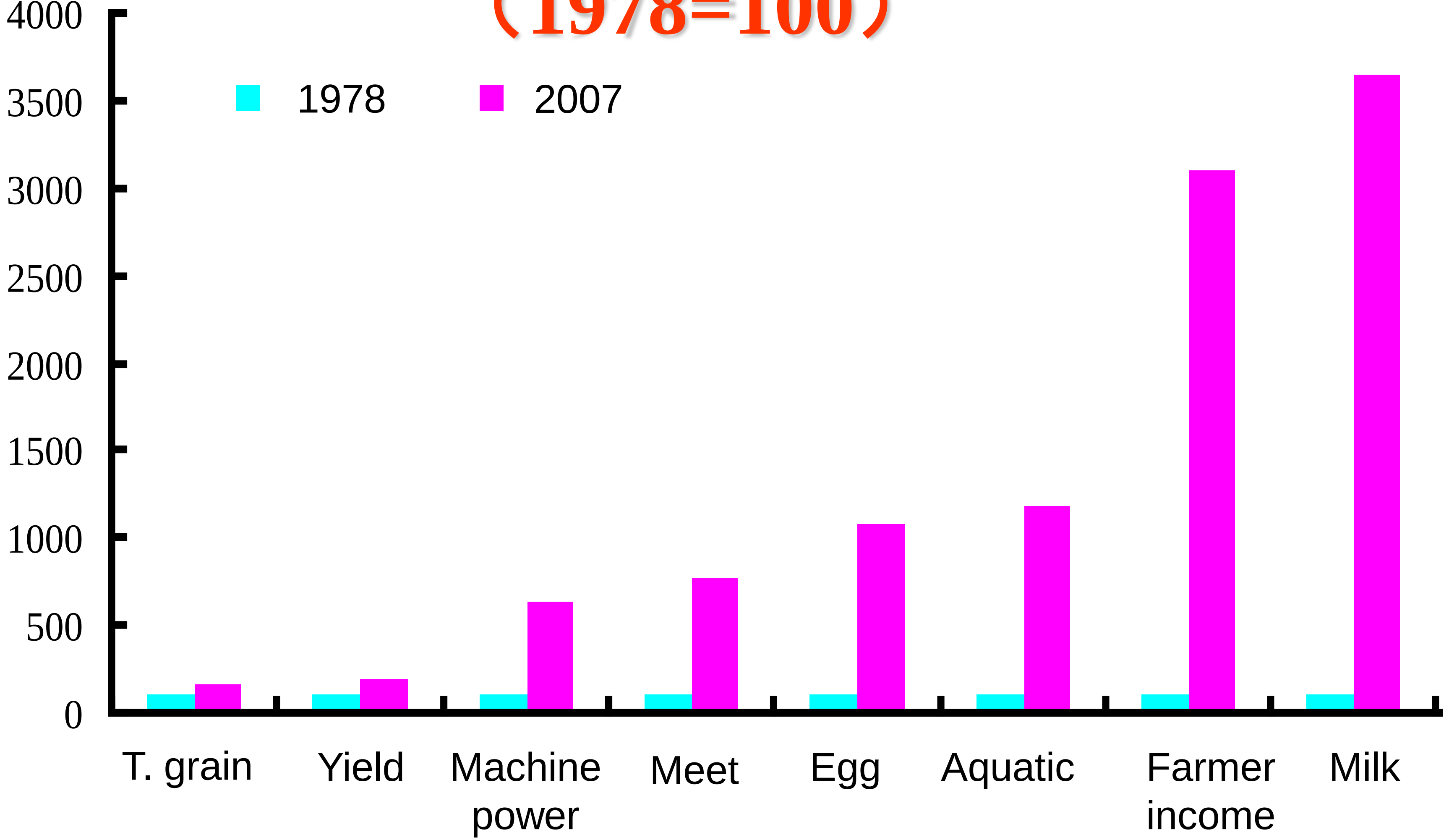
It took several hundred years to realize the dream of food sufficiency in China



(Data from the Statistic Bureau of China

Demand was estimated by using average grain demand of 400 kg/capita/year)

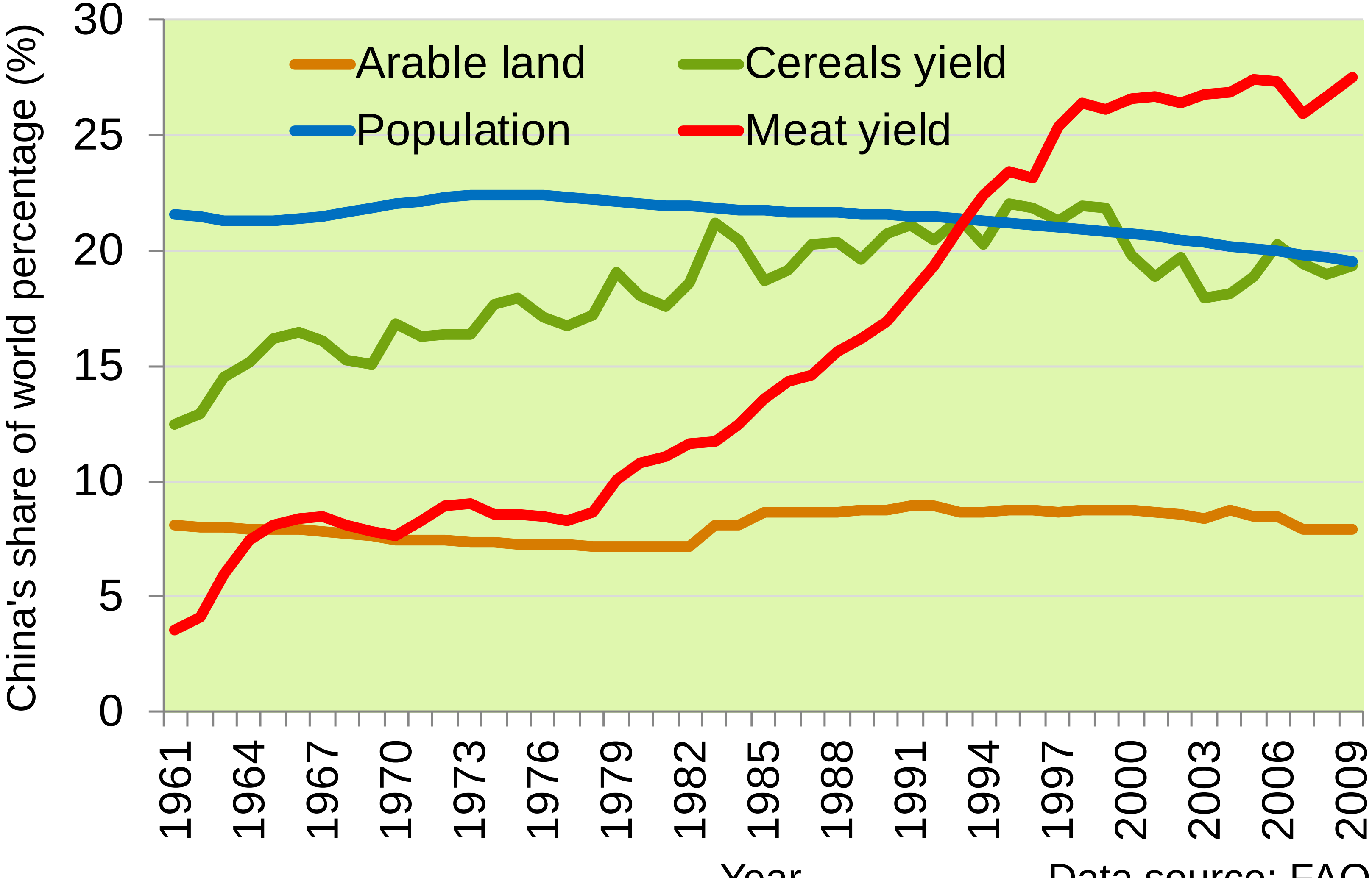
30 years achievements in agriculture
（1978=100）



Data from：China Statistical Yearbook and China agricultural statistical yearbook 1949-1999

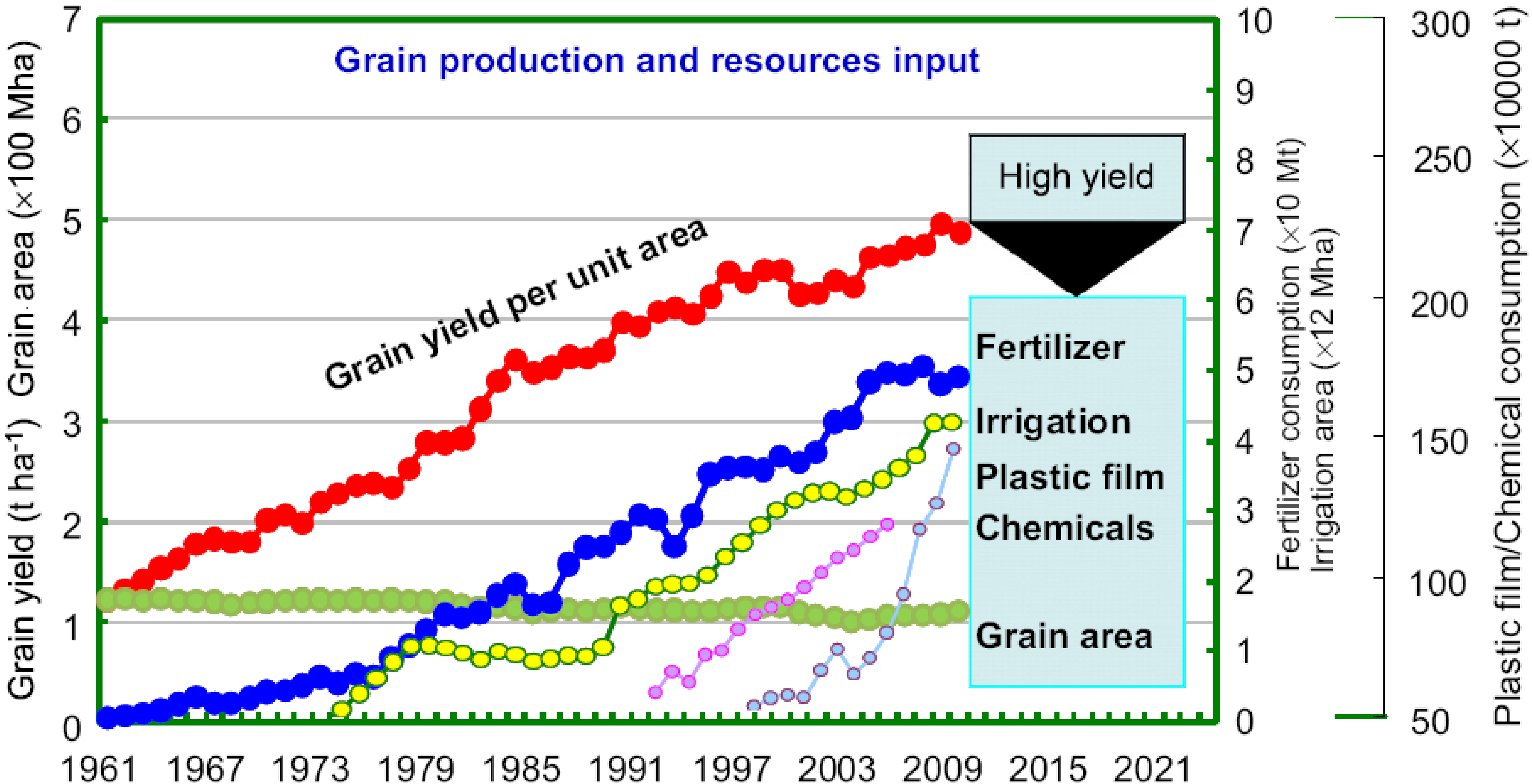
Remarkable contribution to the world

8% arable land, 20% cereals , 28% meat , 20% population



Data source: FAO and UN

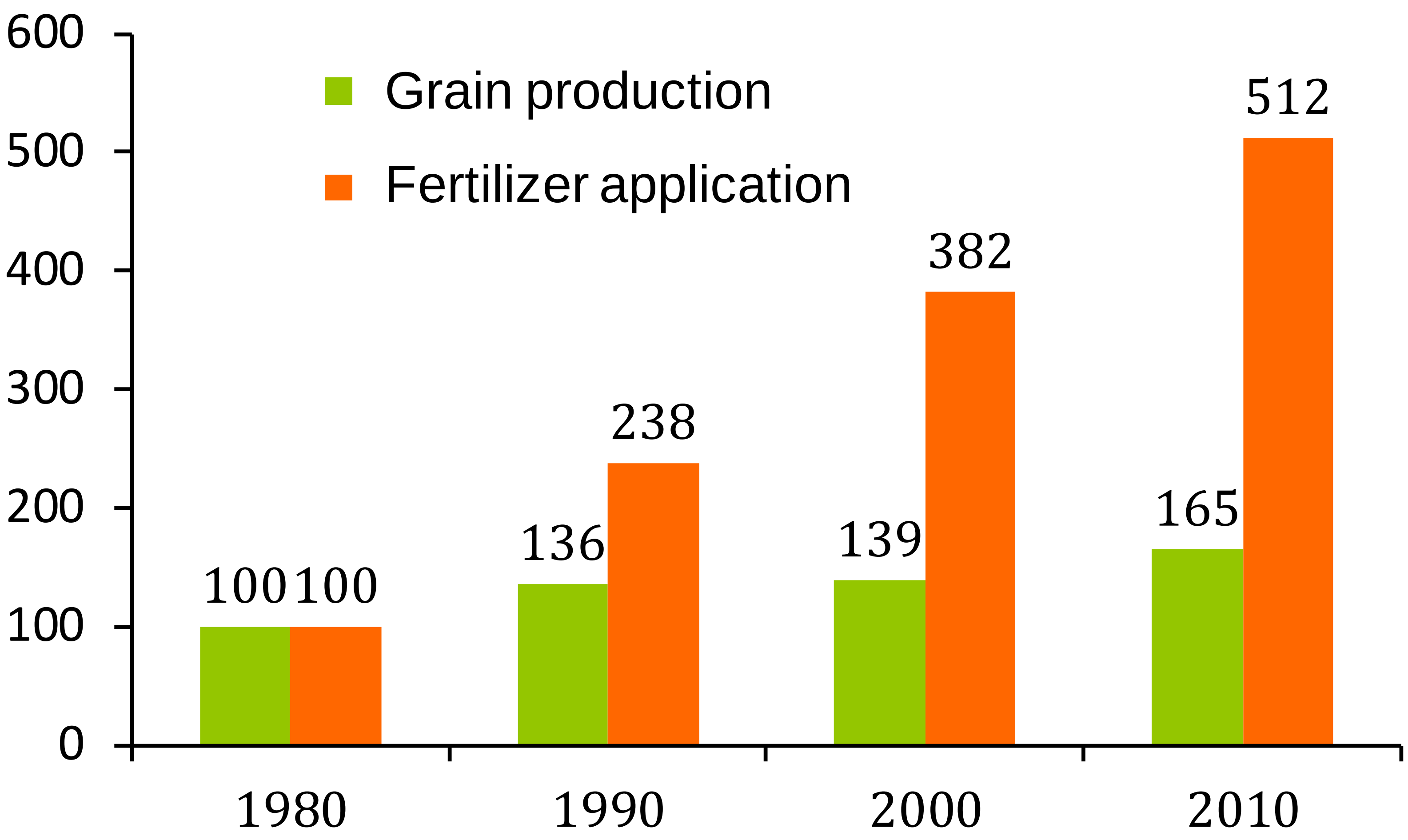
Grain production and resources input



Cereal grain yield in China has been merely secured by much higher input of resources including fertilizer, irrigation, plastic film and other chemicals. Data are based on the China statistic yearbook (national bureau of statistics of china, 1961-2010. Zhang et al., 2011)

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(WF Zhang et al., unpublished results)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

Country	Grain yield* (t ha^{-1})	N rate (kg ha^{-1})
China	6.26	~200
Japan	6.42	70
South Korea	6.79	110

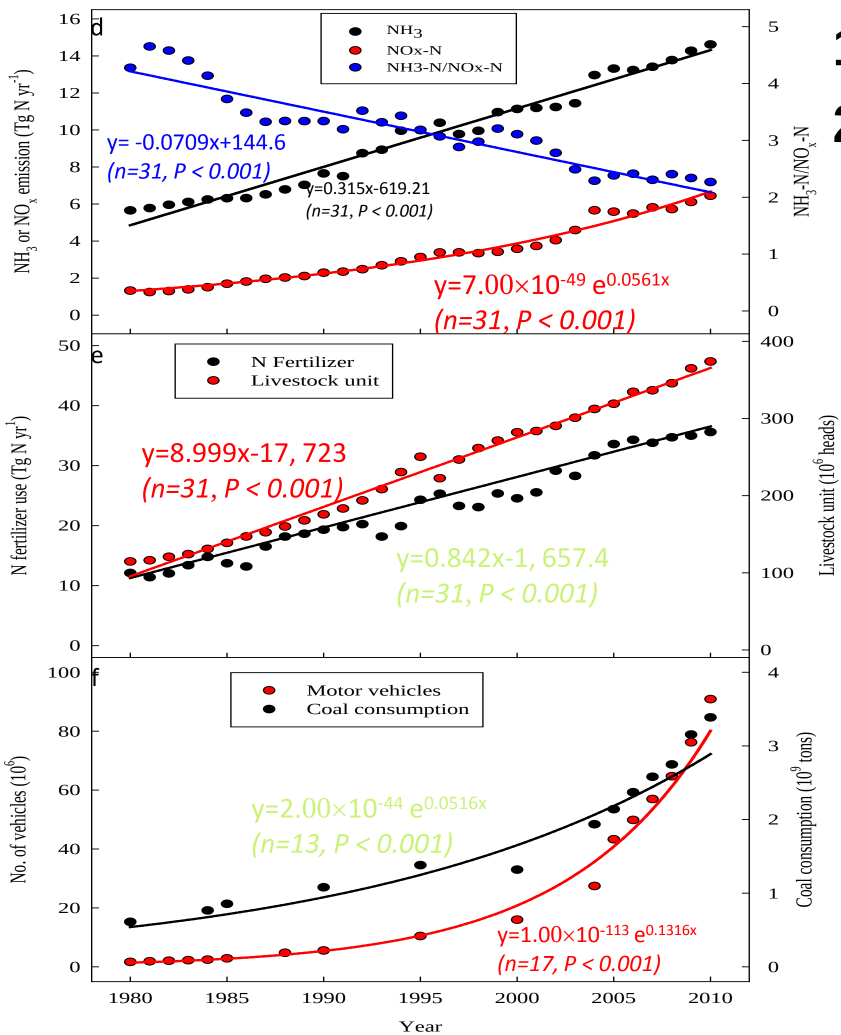
*FAO, 2004

Eutrophication

LETTER NATURE (Liu et al.,2013) doi:10.1038/nature11917

Enhanced nitrogen deposition over China

Xuejun Liu[1]*, Ying Zhang[1]*, Wenxuan Han[1], Aohan Tang[1], Jianlin Shen[1], Zhenling Cui[1], Peter Vitousek[2], Jan Willem Erisman[3,4], Keith Goulding[5], Peter Christie[1,6], Andreas Fangmeier[7] & Fusuo Zhang[1]



1980s: 13.2 kg N/ha

2000s: 21.1 kg N/ha

60% of increase

Air pollution in Beijing

Nature China20100304 - ACDSee v3.1

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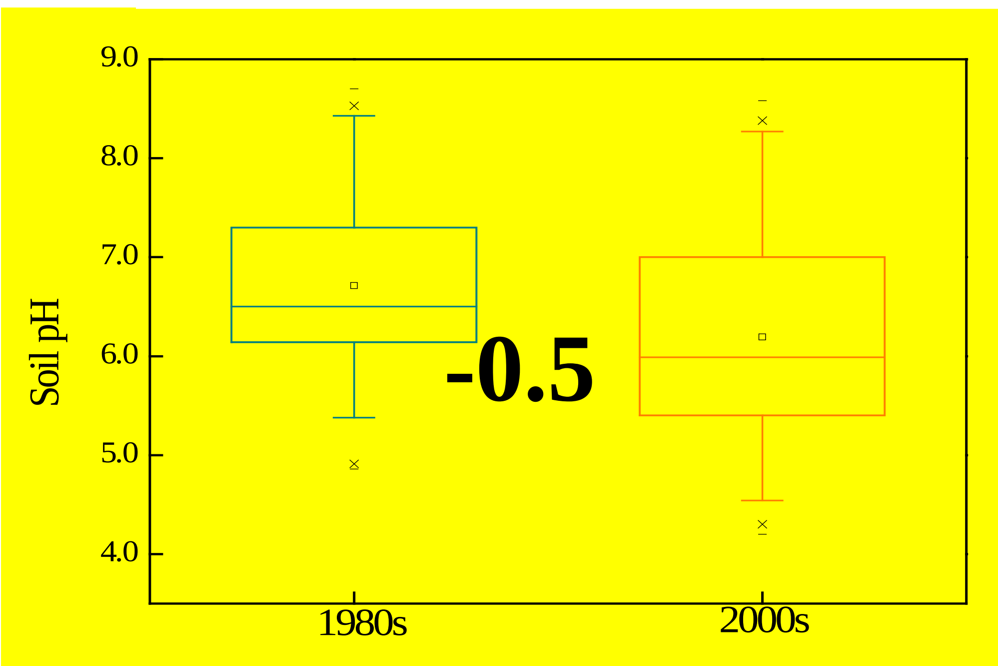
Science AAAS

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

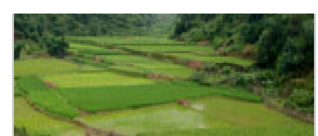
Soil pH has been declined by 0.5 unit since 1980s

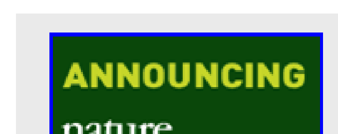


Significant Acidification in Major Chinese Croplands

J. H. Guo,[1*] X. J. Liu,[1*] Y. Zhang,[1] J. L. Shen,[1] W. X. Han,[1] W. F. Zhang,[1] P. Christie,[1,2] K. W. T. Goulding,[3] P. M. Vitousek,[4] F. S. Zhang[1]†

Soil acidification is a major problem in soils of intensive Chinese agricultural systems. We used two nationwide surveys, paired comparisons in numerous individual sites, and several long-term monitoring-field data sets to evaluate changes in soil acidity. Soil pH declined significantly ($P < 0.001$) from the 1980s to the 2000s in the major Chinese crop-production areas. Processes related to nitrogen cycling released 20 to 221 kilomoles of hydrogen ion (H^+) per hectare per year, and base cations uptake contributed a further 15 to 20 kilomoles of H^+ per hectare per year to soil acidification in four widespread cropping systems. In comparison, acid deposition (0.4 to 2.0 kilomoles of H^+ per hectare per year) made a small contribution to the acidification of agricultural soils across China.

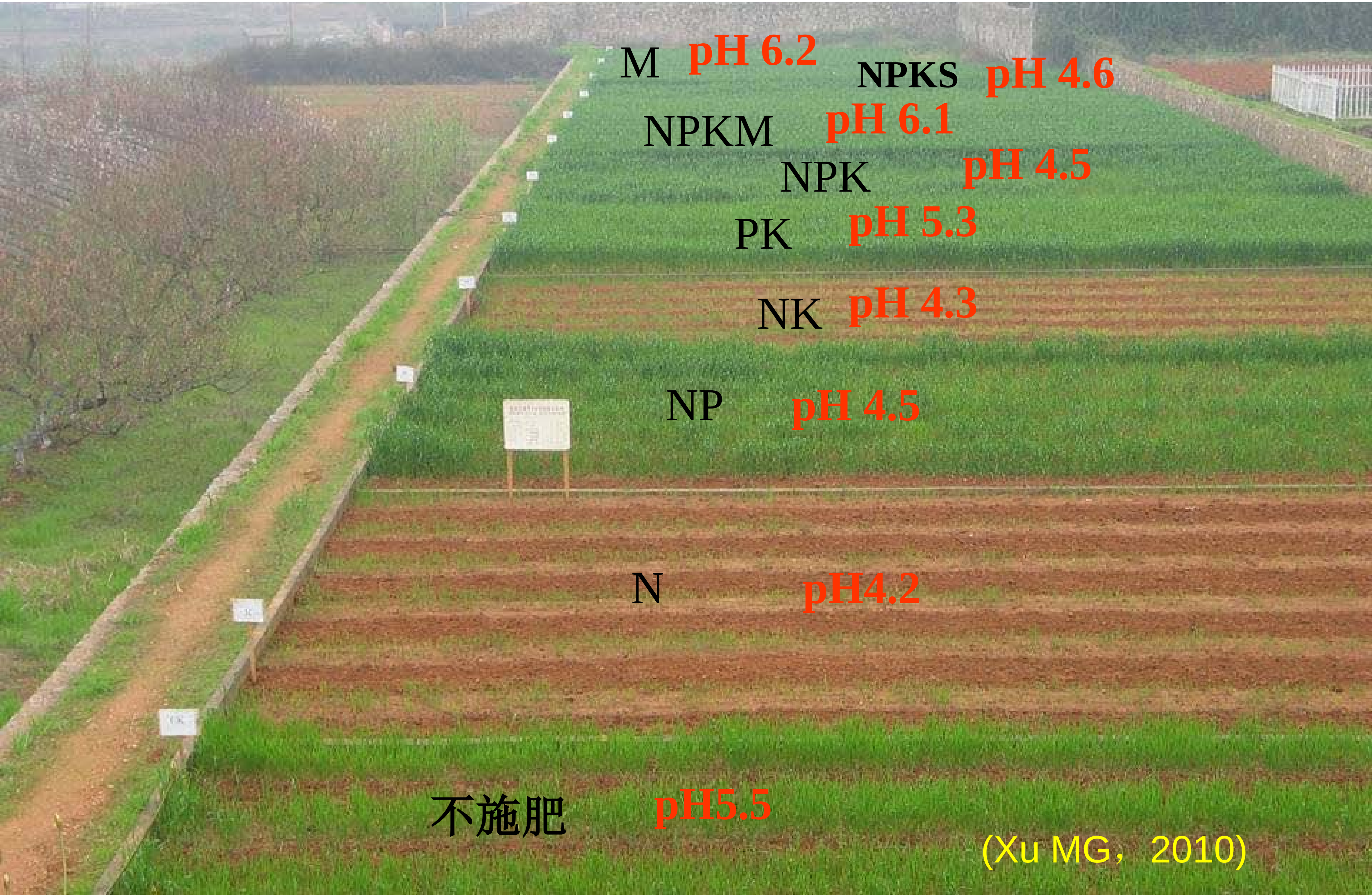




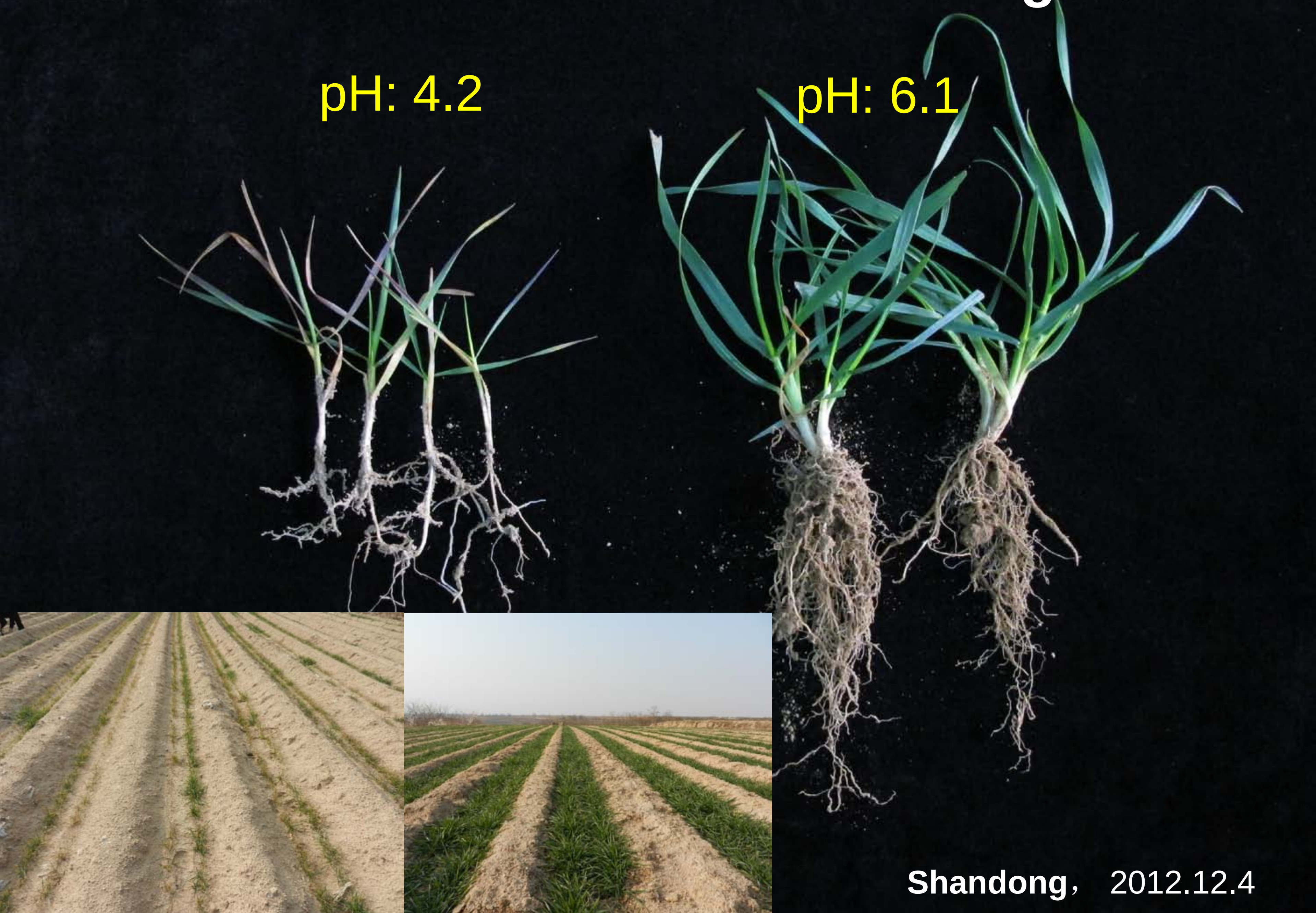
national soil surveys that the excess use of chemical

3/10 Nature China20100304 487.0 KB 1263x1386x32b png 100%

Soil pH declined significantly after 12-yr annual N input of 150 kg N/ha (Initial soil pH in 1990 was 5.7)

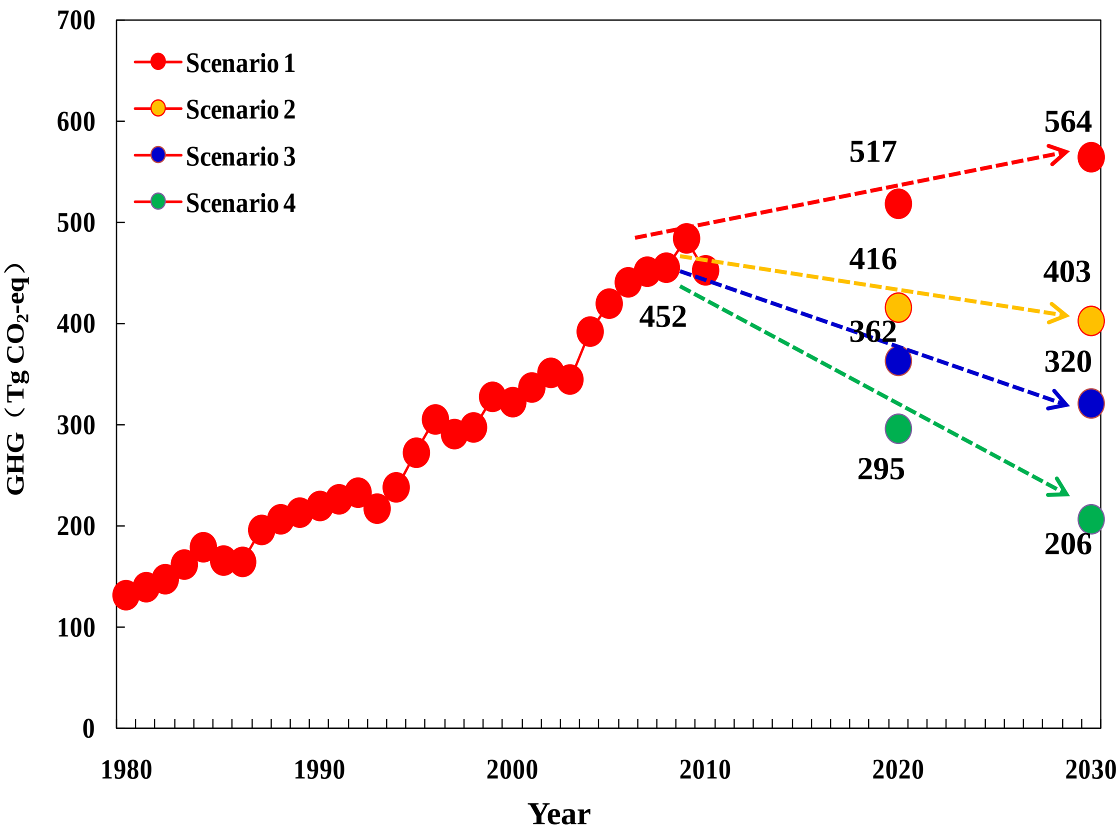


Effect of soil acidification on wheat growth



New technologies reduce greenhouse gas emissions from nitrogenous fertilizer in China

Wei-feng Zhang[a,1], Zheng-xia Dou[b,1], Pan He[a], Xiao-Tang Ju[a], David Powlson[c], Dave Chadwick[d], David Norse[e], Yue-Lai Lu[f], Ying Zhang[a], Liang Wu[a], Xin-Ping Chen[a], Kenneth G. Cassman[g], and Fu-Suo Zhang[a,2]



Industry management

- CH_4 recovery in coal mining
- Improve Energy efficiency in fertilizer plants
- N_2O abatement in Nitric acid production
- Control N fertilizer export

Soil-Crop System management

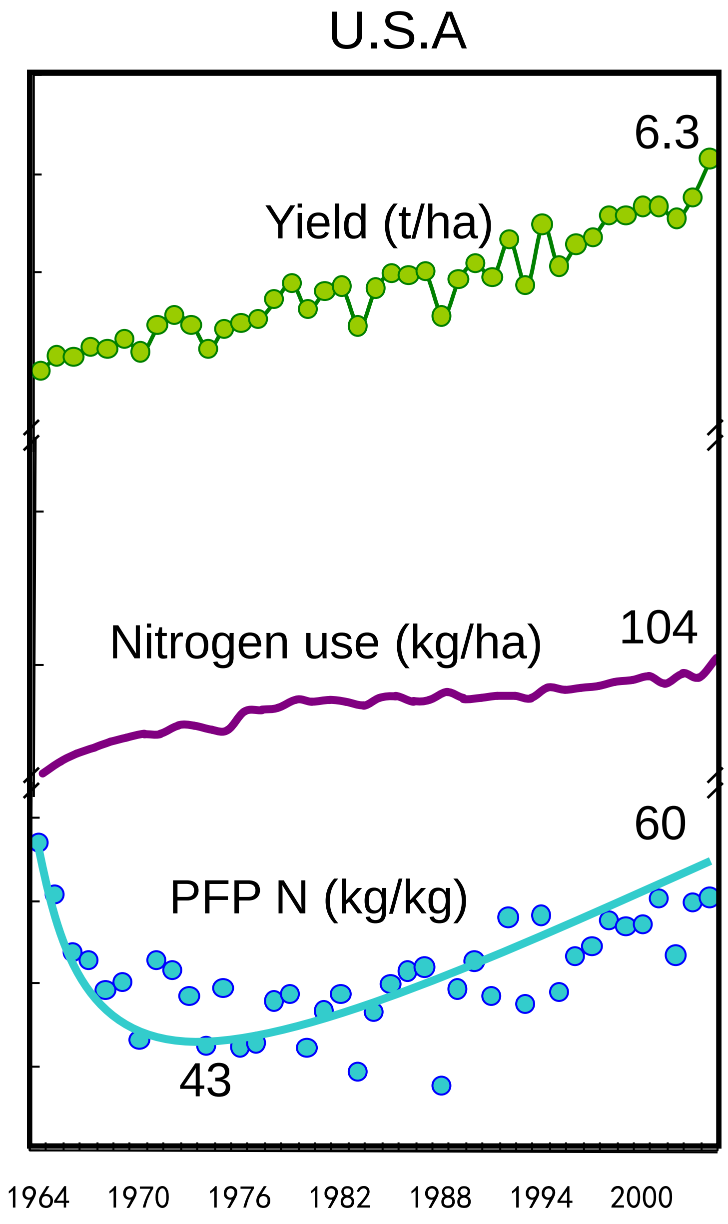
- Right amount-balance crop demand
- Right place-Deep placement
- Right time-use in crop fast growth period
- Right products- in cooperate NH_3 and NO_3
- Recycling organic nutrients

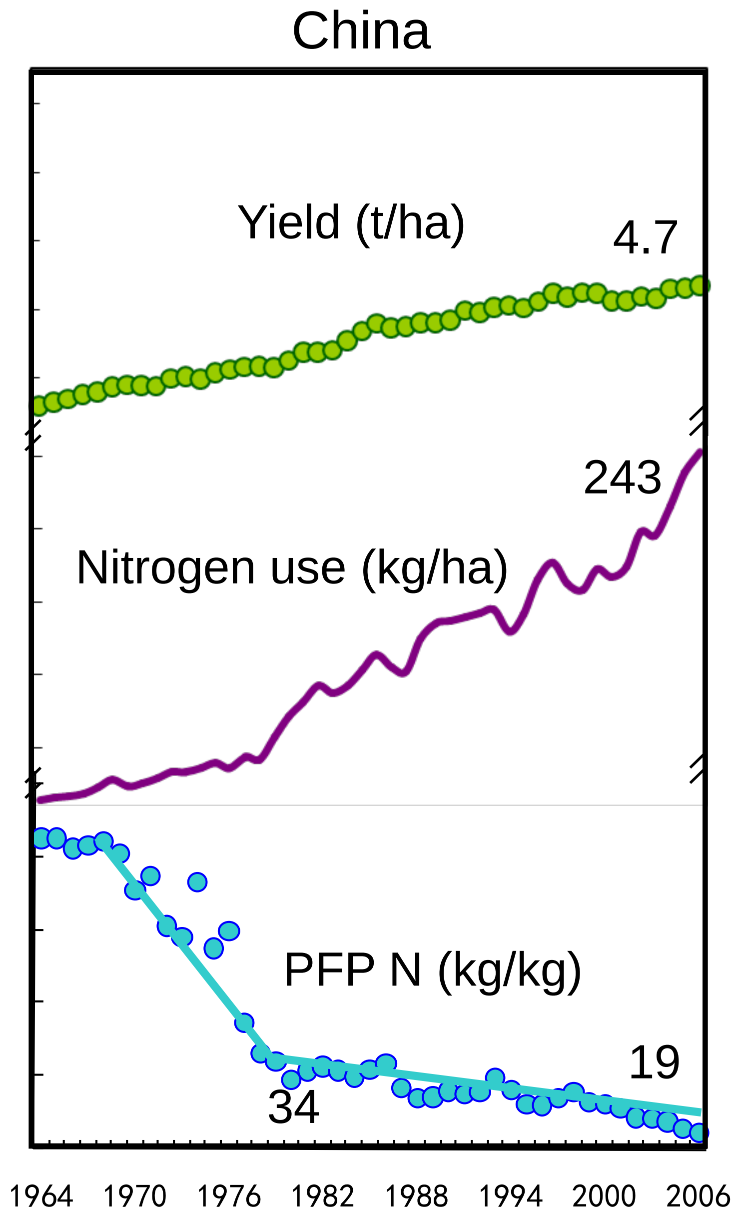
Integrated industry and Soil-Crop management

70% of agricultural emission!
7% of national total emission!
New technologies and policies could cut 2-6% of total emission!

(Zhang et al., PNAS, 2013)

How to Increase both Crop Yield and NUE Simultaneously?





Outline

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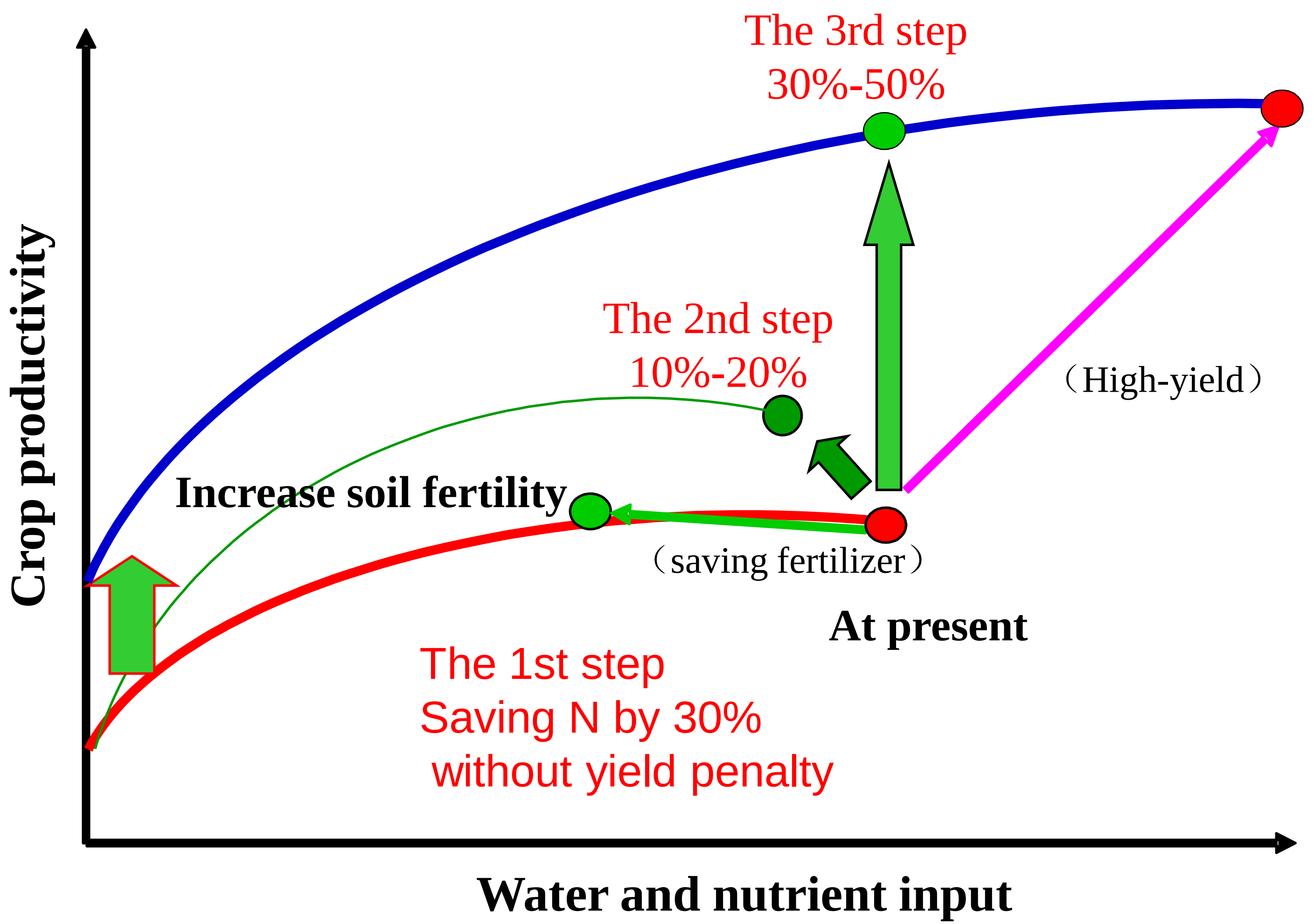
- Prospects

Three-Step Strategy to increase crop yield and nutrient use efficiency by developing and using INM technology

- For ensure both food security and environment quality simultaneously

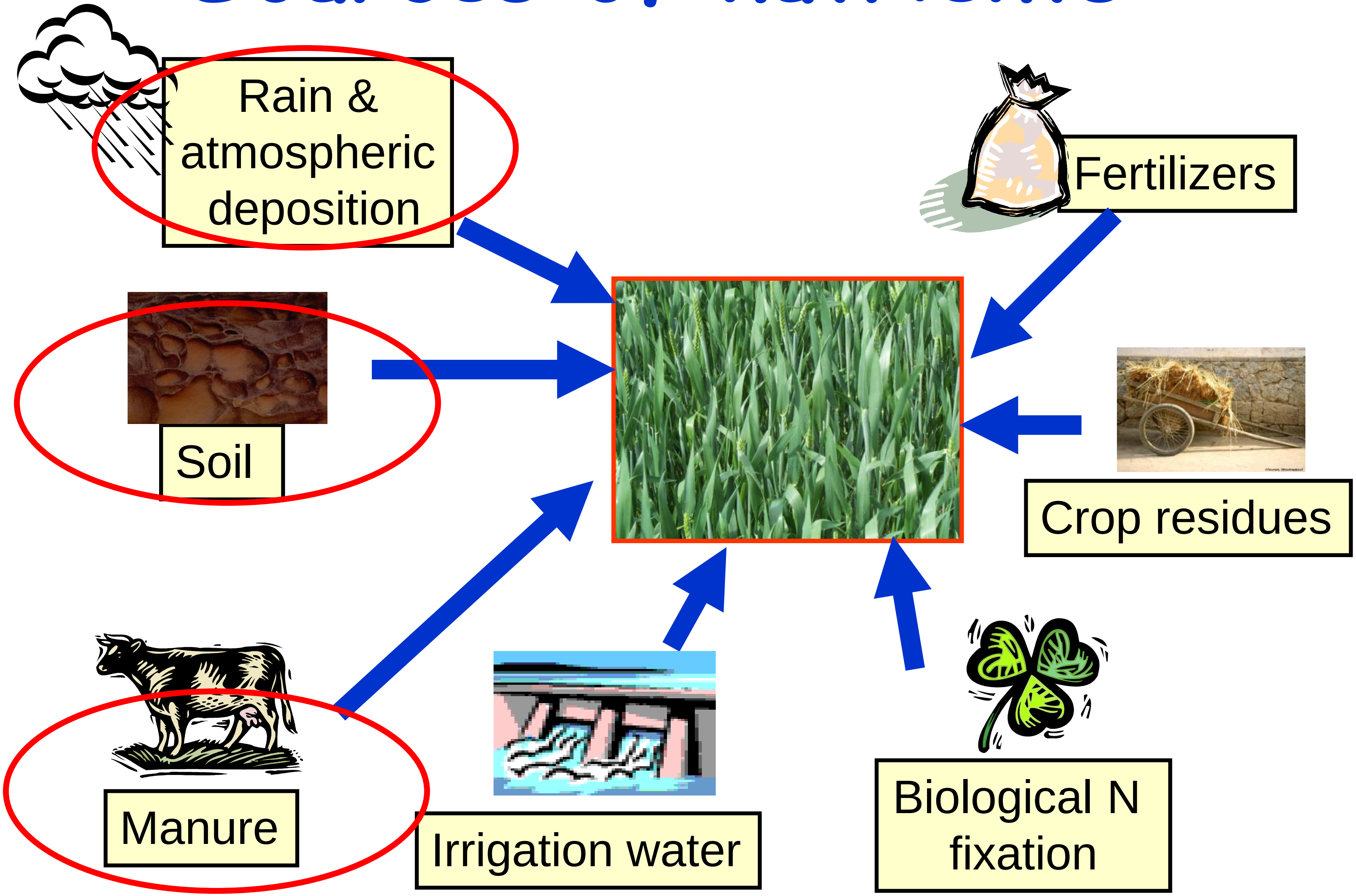


First step of Integrated Nutrient Management (INM,1993-2003)

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

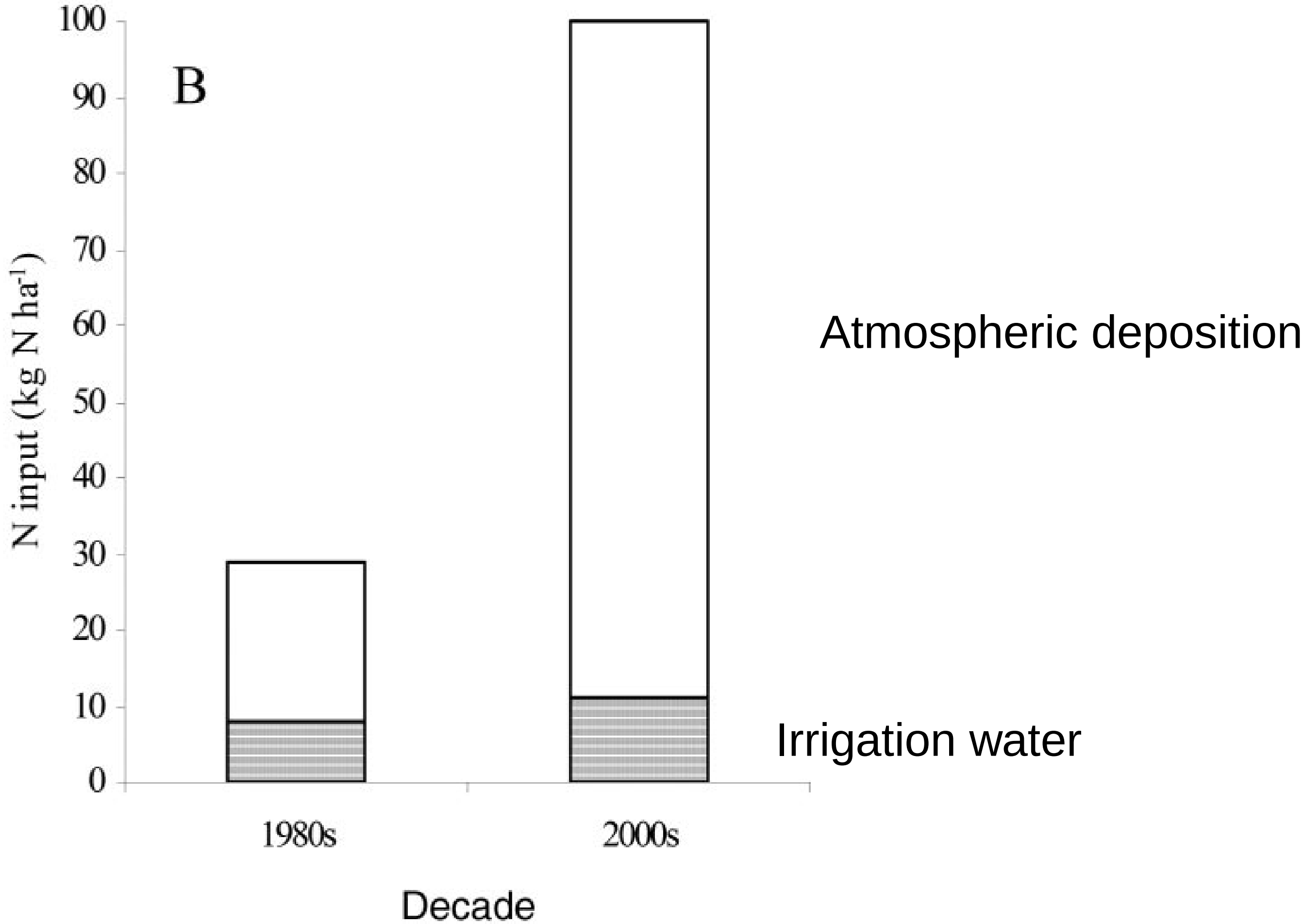
2) Match soil supply to crop requirement spatially and temporally

Sources of nutrients



(Powlson,PC)

Nitrogen inputs from atmospheric deposition and irrigation water in NCP



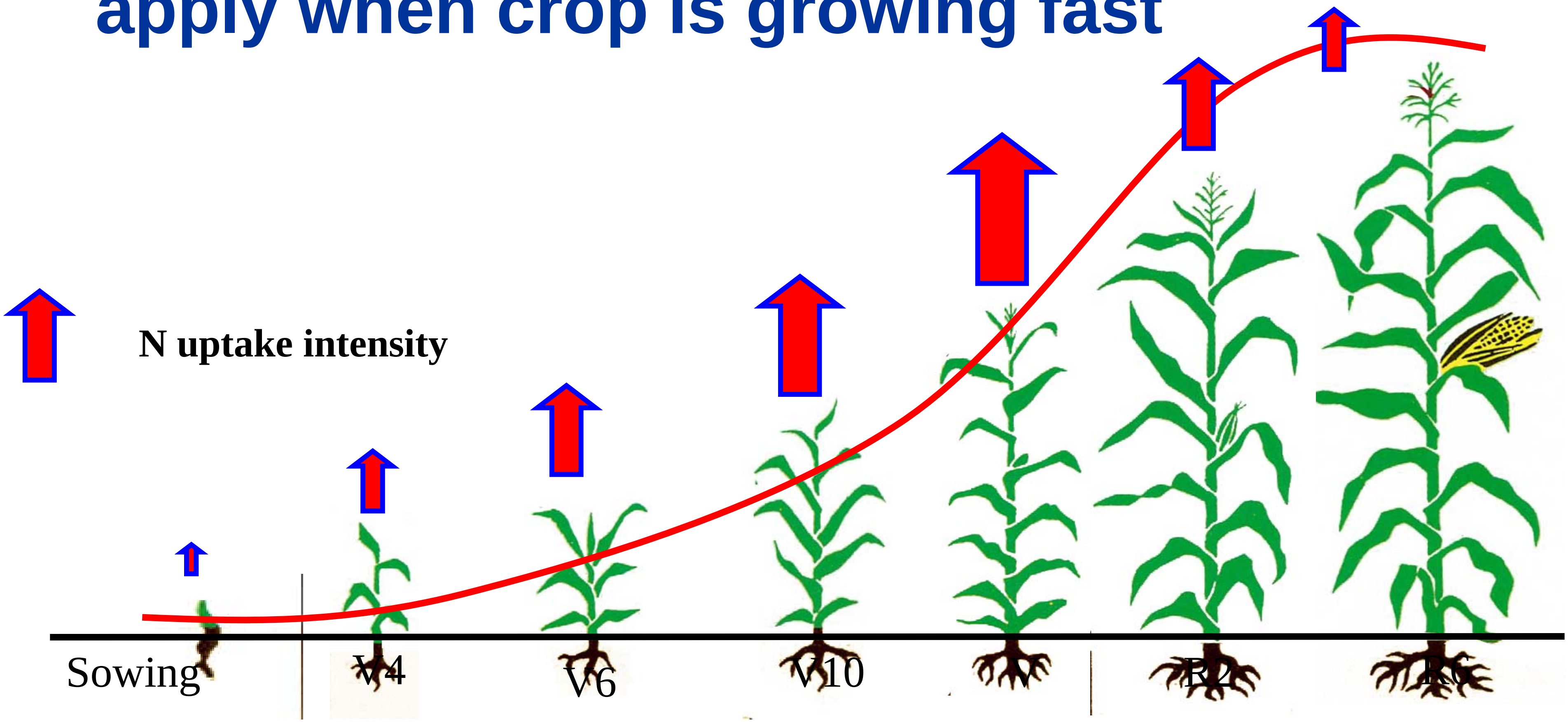
(Ju et al., 2009,PNAS)

Annual N input in wheat-maize rotation system in north China plain of China

	80s	now
Chemical N	150	532 (300~700)
Soil Nmin	30 (11-62)	191 (20-987)
Environmental N	22	90
total	202	713

(Cui et al.,2010)

Match application to crop requirement, apply when crop is growing fast



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

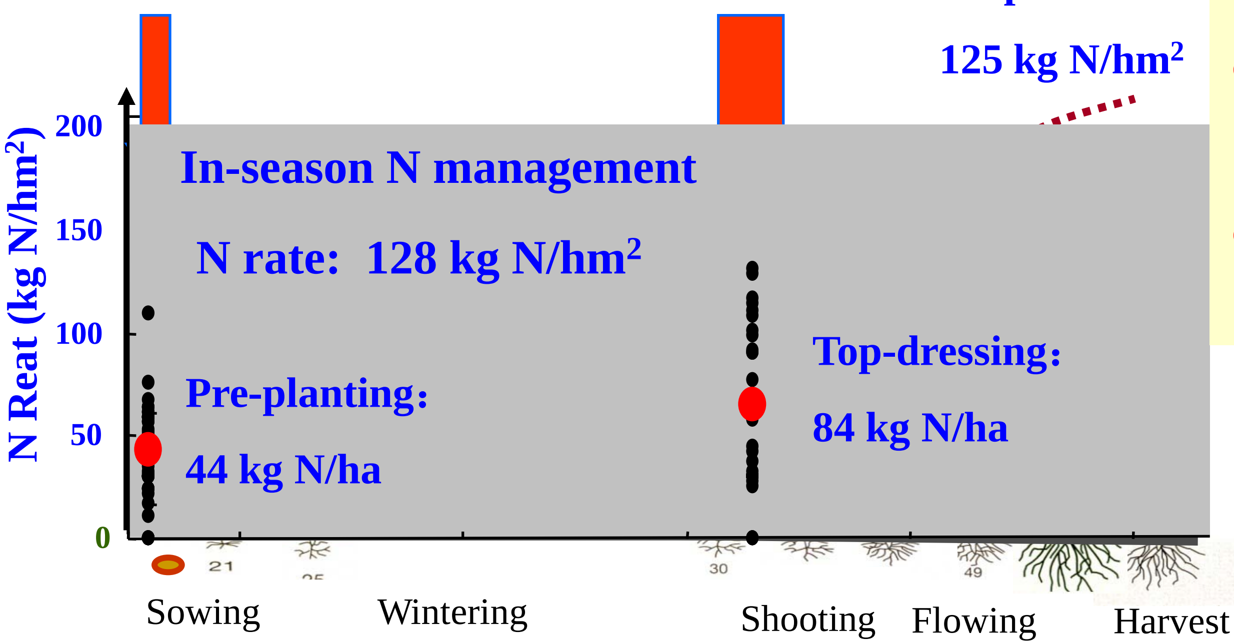
Farmers' Practice: 425 kg N/hm^{2n}

(n = 460)

Pre-planting: 165 kg N/hm^2

Top-dressing: 260 kg N/hm^2

N uptake 125 kg N/hm^2



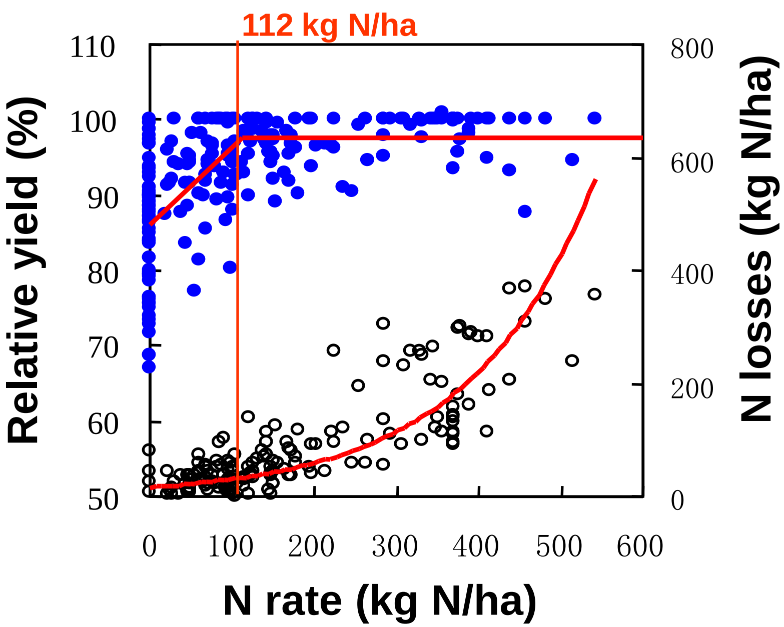
Advantages:

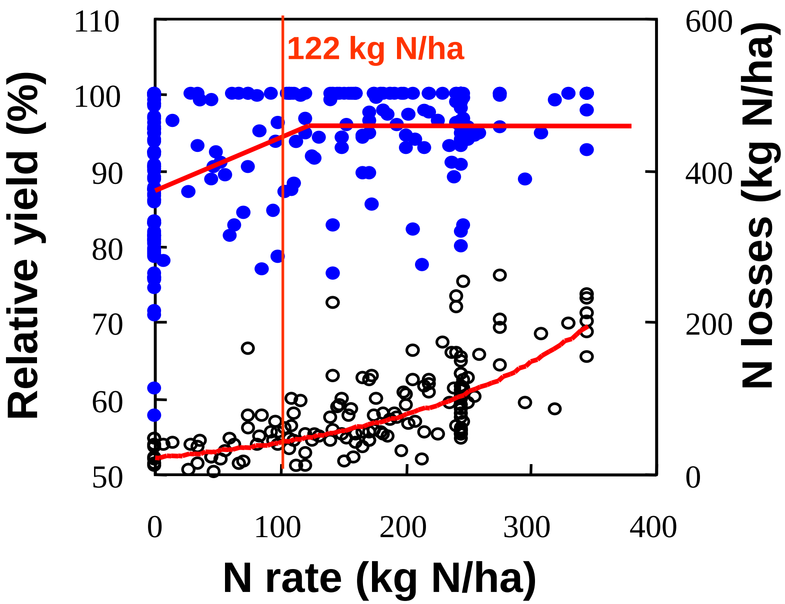
- **Control total N rate (425/128)**
- **Spliting at right time (1:1.5/1:2.0)**

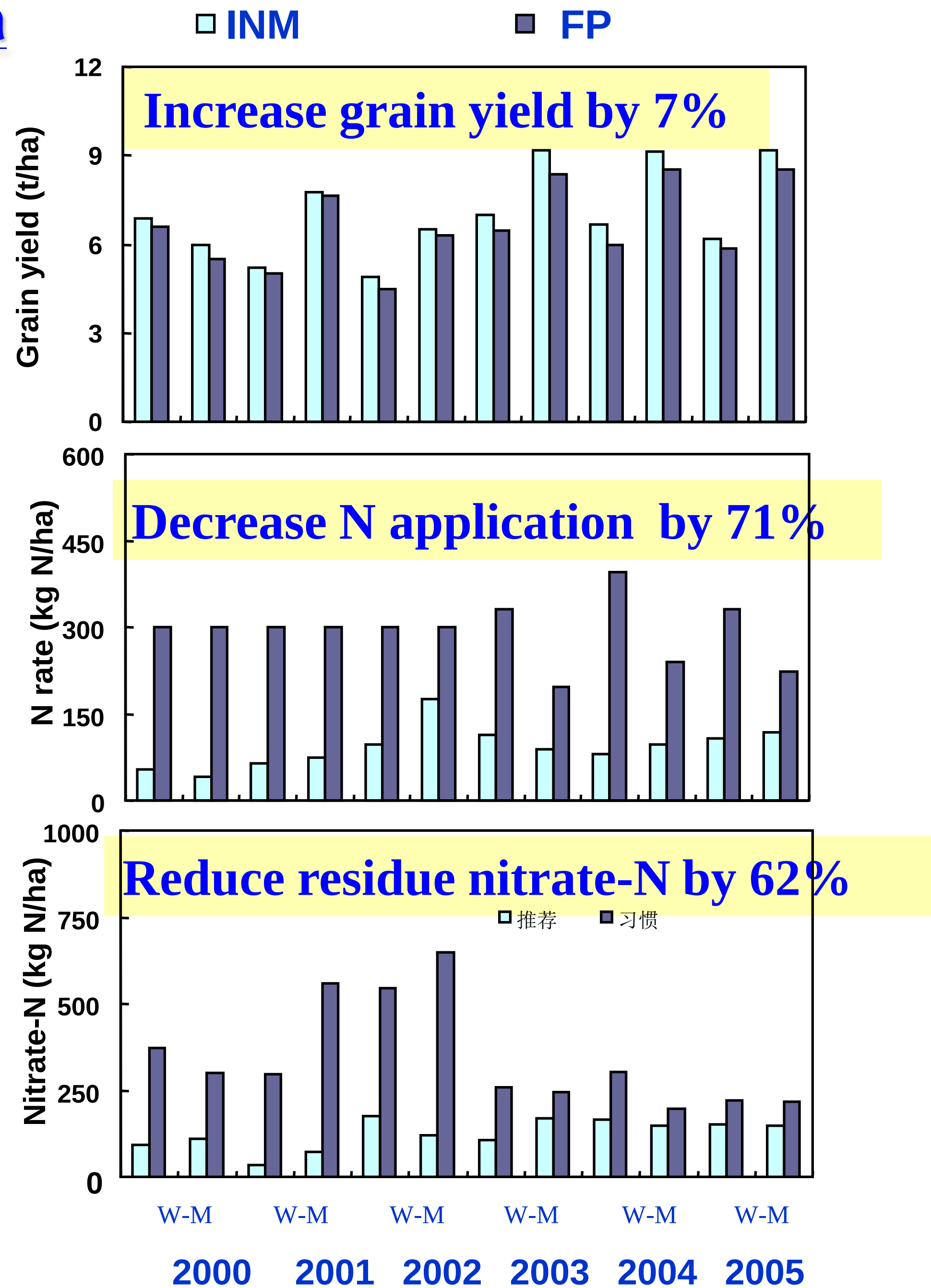
（Cui et al., 2006; 崔振岭等，2005）

Wheat-Maize Rotation System

（n =156, six years)







Reducing environmental risk by improving N management in intensive Chinese agricultural systems

2009

Xiao-Tang Ju[a,1], Guang-Xi Xing[b], Xin-Ping Chen[a], Shao-Lin Zhang[b], Li-Juan Zhang[c], Xue-Jun Liu[a], Zhen-Ling Cui[a], Bin Yin[b], Peter Christie[a,d], Zhao-Liang Zhu[b], and Fu-Suo Zhang[a,1]

Table 2. Different N loss pathways expressed as a percentage (mean ± SD) of N application rate in farmers' N practices (Field Study 3, Lysimeter Study)

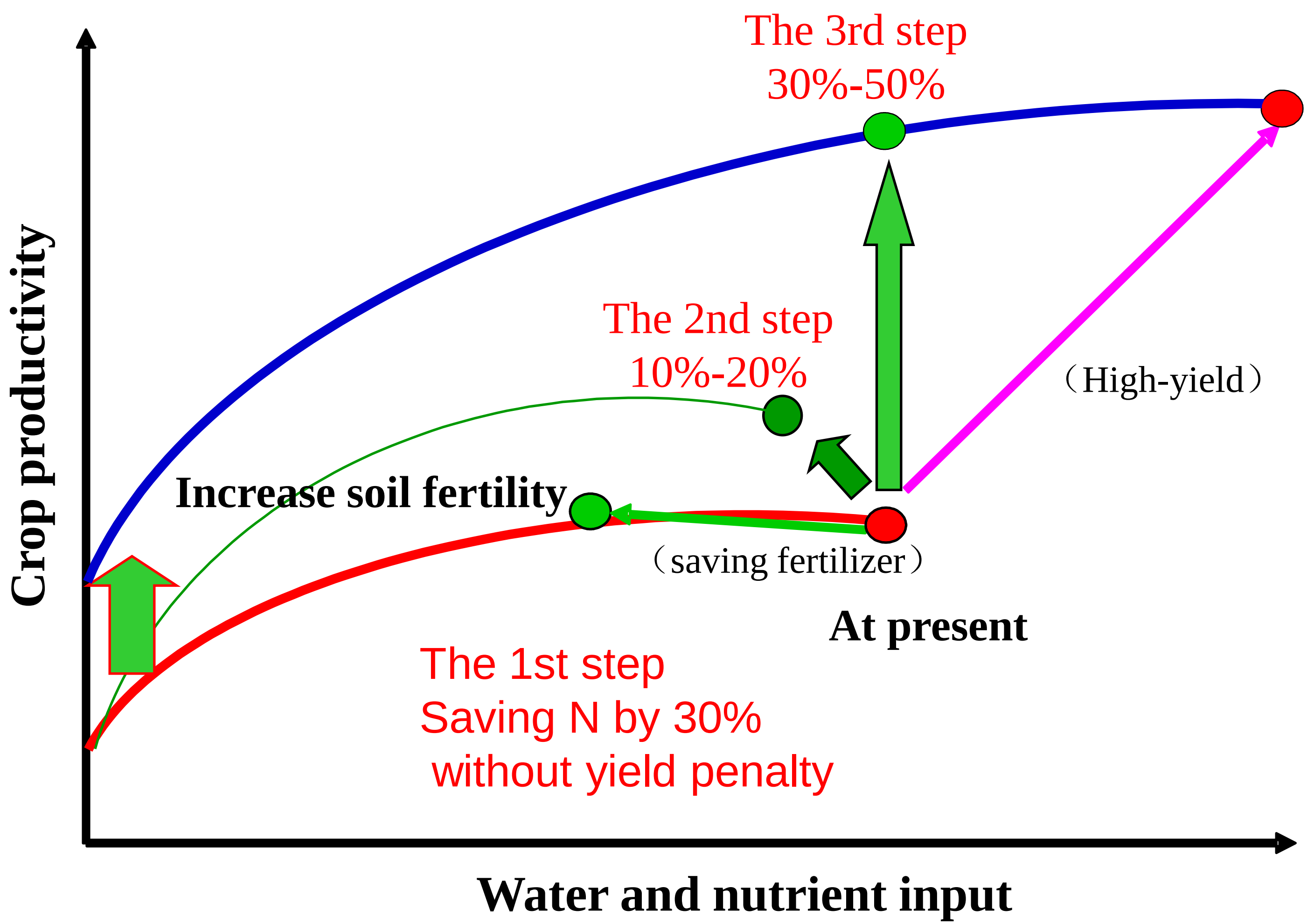
		Taihu region		North China Plain	
Component		Rice	Wheat-south	Wheat-north	Maize
N rate (kg of N per hectare)		300	250	325	263
Recovery rate (%)*		29.6 ± 4.9	18.4 ± 6.3	31.0 ± 3.6	25.5 ± 5.2
Retention rate (%)*		21.7 ± 5.1	28.5 ± 4.6	45.7 ± 5.4	33.9 ± 2.3
Loss pathway	NH_3 volatilization (%)	11.6 ± 4.7	2.1 ± 1.4	19.4 ± 5.2	24.7 ± 5.6
	Leaching out of 1 m soil depth (%)	0.3 ± 0.5	3.4 ± 2.1	2.7 ± 2.6	12.1 ± 8.5
	Denitrification (%)	36.4†	43.5†	0.1 ± 0.04	3.3 ± 1.6

*Measured from corresponding ^{15}N field experiments.
†Calculated by difference method.

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

Three-Step Strategy to increase crop yield and nutrient use efficiency by developing and using INM technology

- For ensure both food security and environment quality simultaneously



Second step of
Integrated Nutrient Management
(INM, 2003-2008)

1) Increase crop yield significantly through Integrated Crop Management

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

3) Match soil supply to crop requirement spatially and temporally

Model-, recorded- and experimental-based yield gaps (YG_M, YG_R, and YG_E) and the ratio between the average farmers' yield and the modeled yield potential, recorded yield, and experimental yield in China.

		Region				China
		Northeast China	North China Plain	Northwest China	Southwest China	
Yield gaps	YG_M (Mg ha^{-1})	6.6	10.3	12.2	7.1	**8.6**
	YG_R (Mg ha^{-1})	6.5	9.0	10.0	5.3	**7.6**
	YG_E (Mg ha^{-1})	4.3	4.9	6.0	3.0	**4.5**
The ratio						
Average farmers' yield/Yield potential	(%)	58	41	37	44	**48**
Average farmers' yield/Recorded yield	(%)	59	45	42	52	**51**
Average farmers' yield/Experimental yield	(%)	68	60	55	66	**64**

(Meng et al., 2013, Field Crops Research)

Result of increasing maize yield and NUE simultaneously

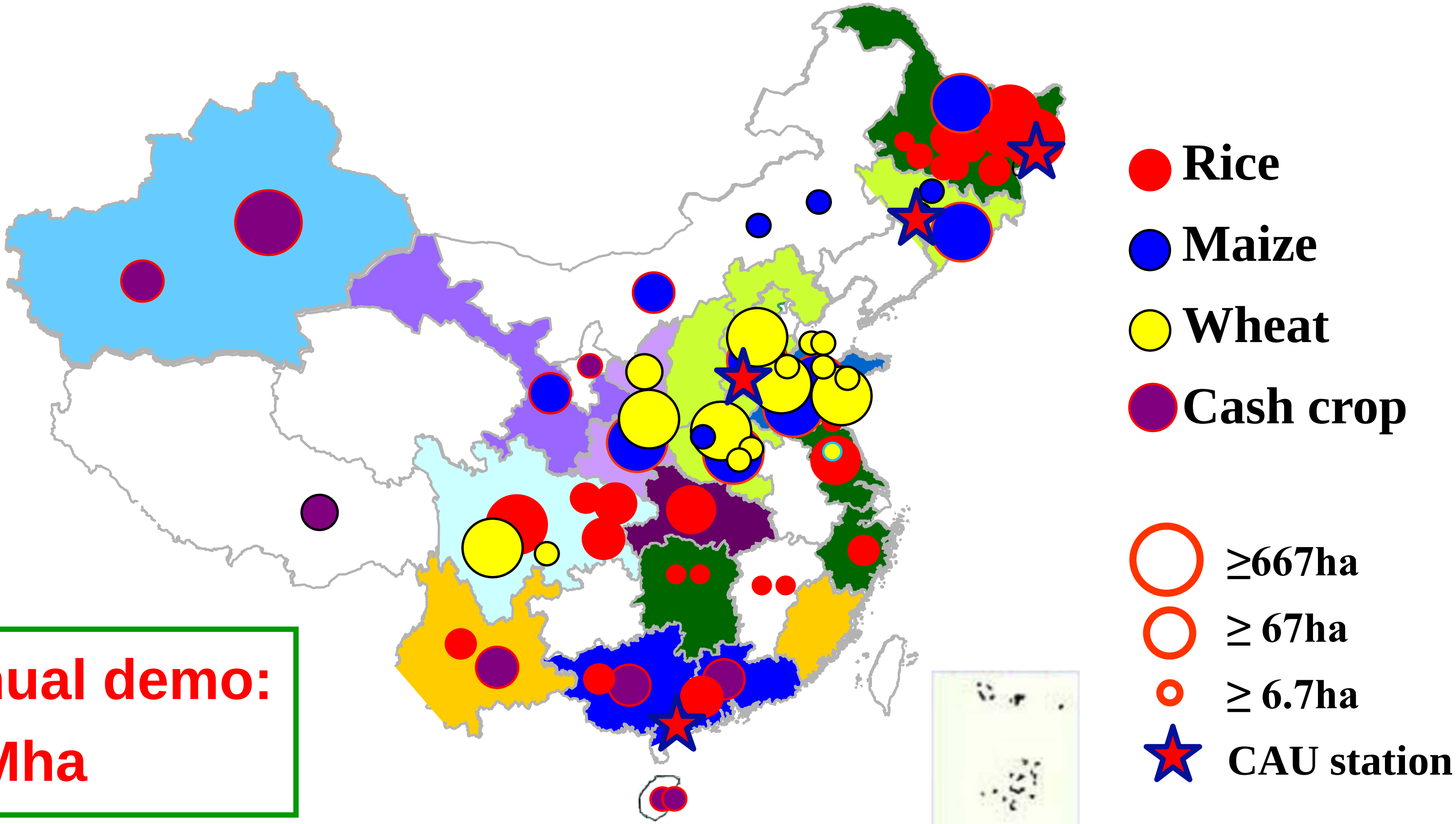
Summer maize yield increased by more than 30%， PFP doubled

item	N rate (kg N/ha)	Grain yield (t/ha)	PFPN (kg/kg)
Farmers practice	250-300	7-8	27-32
INM	185	12.1	65

2 main technologies: Increased density of plants
Better nutrient and water management

On farm demos

- 23 bases in form of STBY
- 185 demo bases by more than 36 collaborative institutions
- 110 counties in collaboration with NATESC of MOA
- 24 counties in 11 provinces in collaboration with fertilizer companies

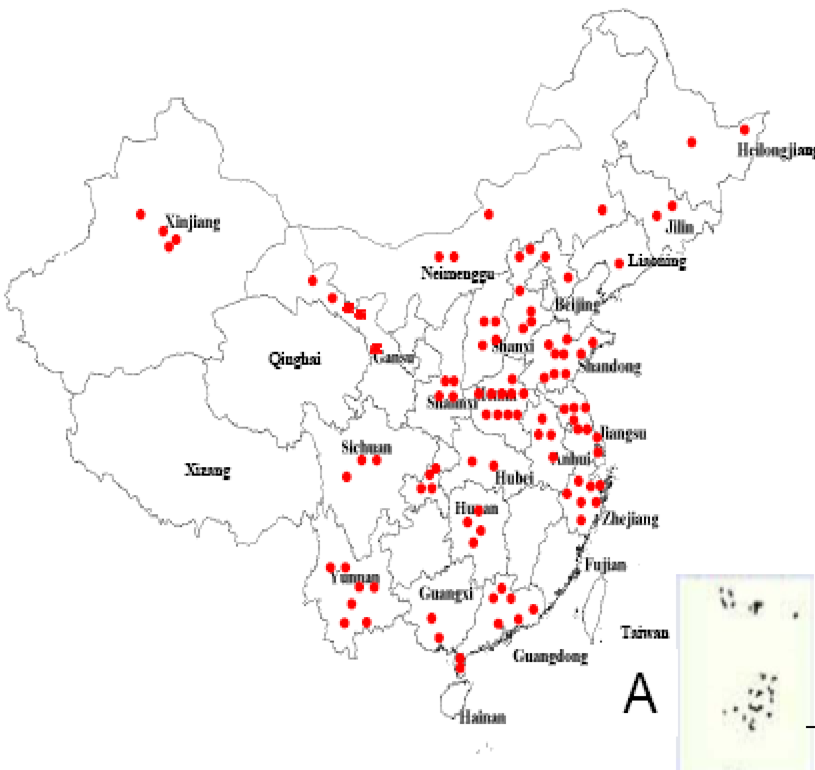


Annual demo: 4Mha

Network on Integrated Soil-crop System Management（NISSM）

Performance of INM in China.

Across all 5147 sites, on average, reduce N fertilizer inputs by 24%, increase grain yield by 12%, and increased net farming income by $ 132 per ha



Crops	*n*	Δ yields (%)	Δ N rate (%)	Δ net income ($ ha^{-1})
Wheat	558	10	29	92
Maize	2100	16	25	111
Rice	1861	8	21	99
Vegetable	310	6	39	397
Fruit	57	13	28	775
Rape	239	12	8	196
Cotton	22	7	36	164
average	5147	12	24	132

B

(Zhang et al., 2012, Adv. Agron.)

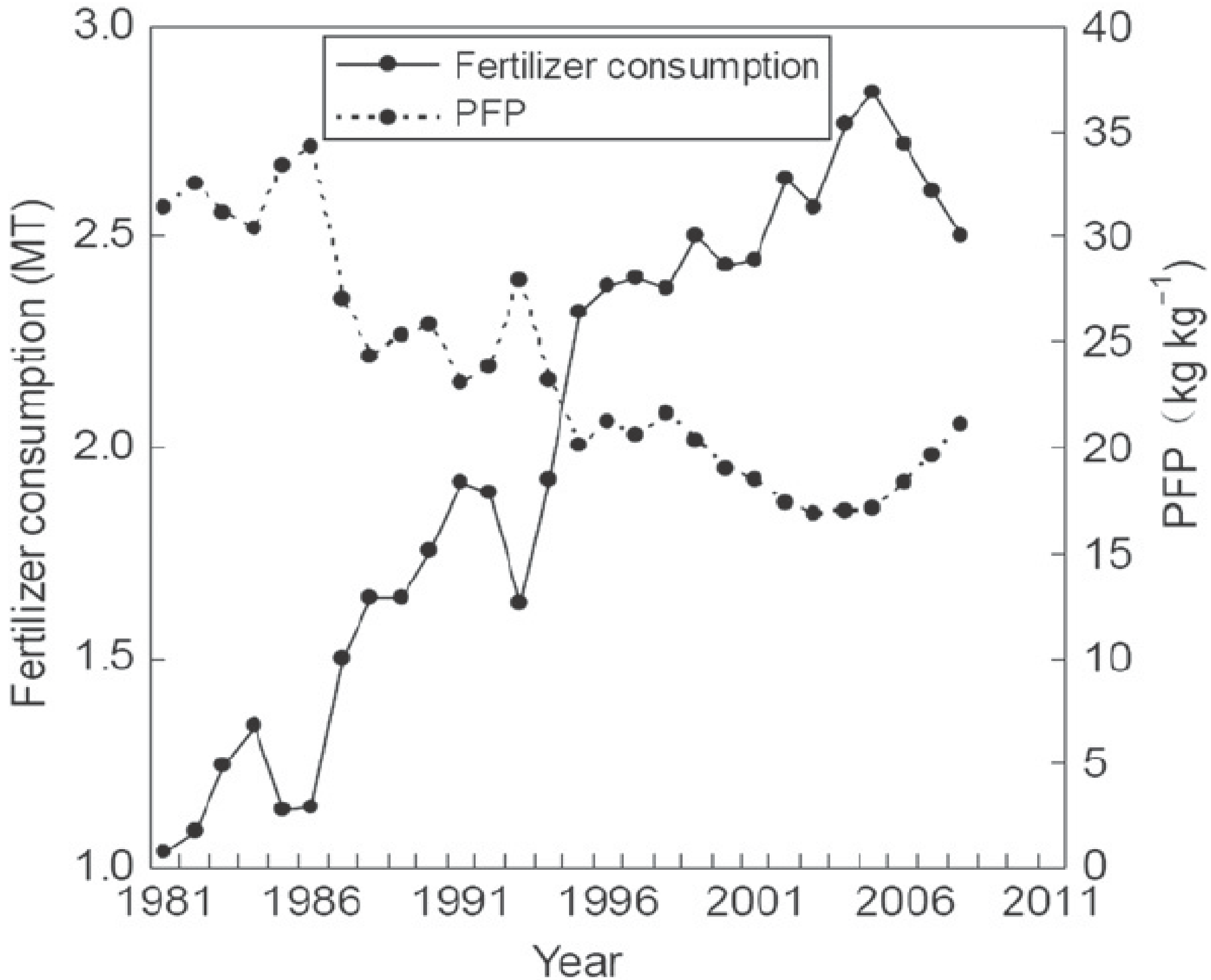


Figure 13 Trends in fertilizer consumption for cereal crop and partial factor productivity for fertilizer (PFP) in China from 1981 to 2008. The PFP was defined the ratio of crop yield per unit of applied chemical fertilizer. Modified from Zhang *et al.* (2011).

(Zhang et al., 2012, Adv. in Agronomy)

Third step of INM(2003-2013) Integrated Soil-crop System Management (ISSM)

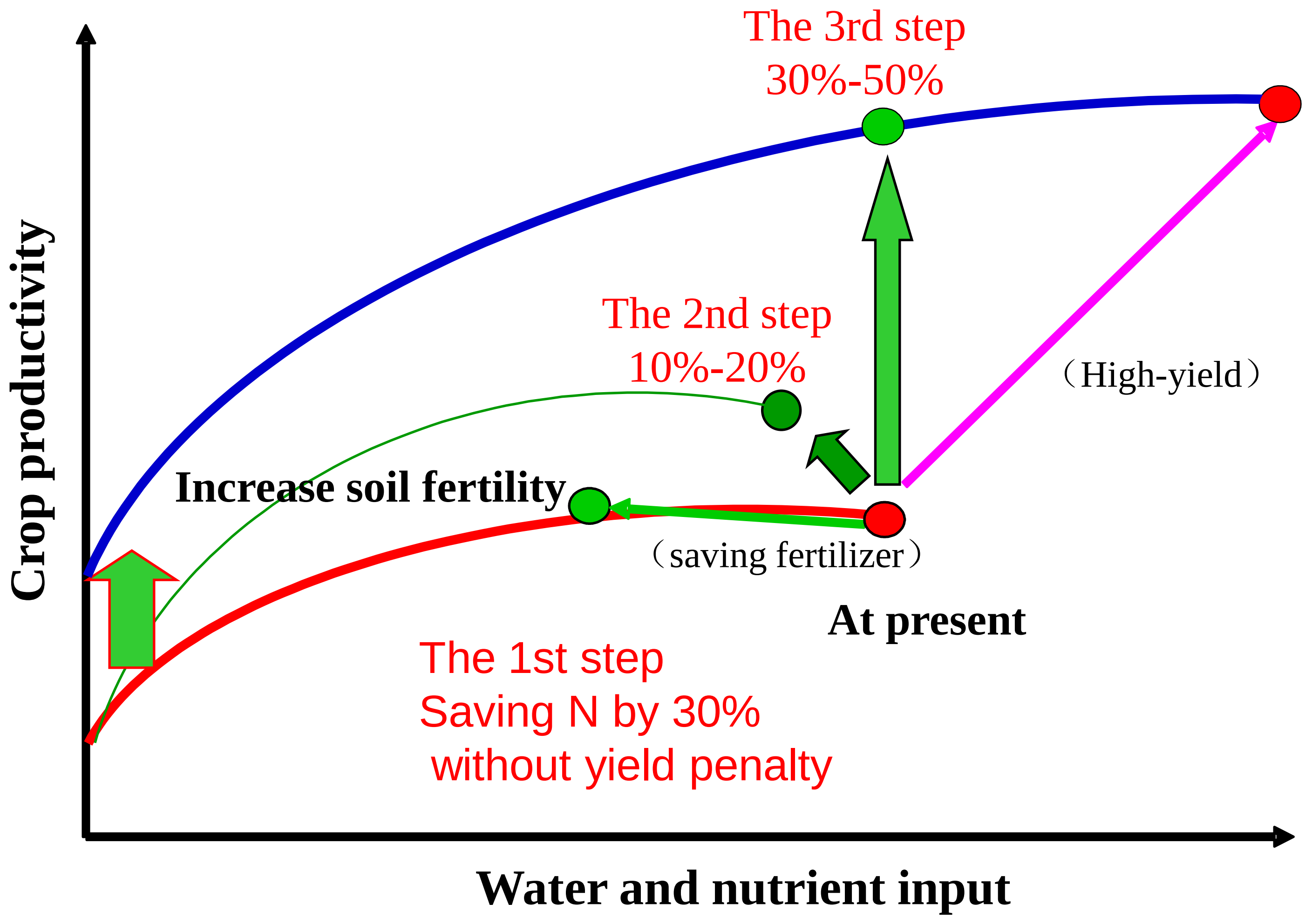
1) Improve Soil Quality

2) Increase crop yield significantly

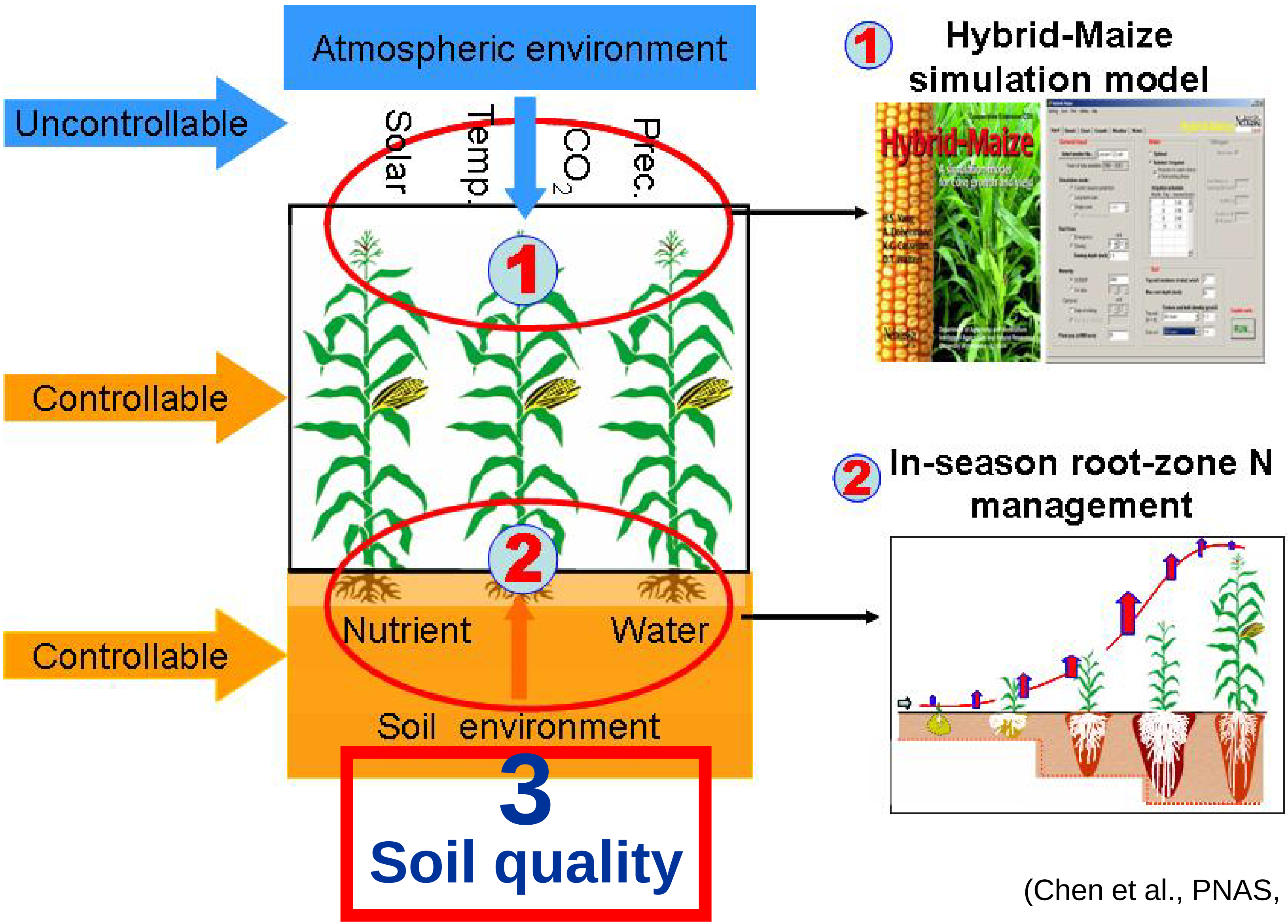
3) Integrated nutrient management (INM)

Three-Step Strategy to increase crop yield and nutrient use efficiency at the same time

- For ensure both food security and environment quality simultaneously



Conceptual model illustrating the soil-crop system management strategies for realizing the high yield and high N efficiency



(Chen et al., PNAS, 2011)

Integrated soil–crop system management for food security ----Increase yield and NUE by 30-50%

Xin-Ping Chen[a,1], Zhen-Ling Cui[a,1], Peter M. Vitousek[b,2], Kenneth G. Cassman[c], Pamela A. Matson[d], Jin-Shun Bai[a], Qing-Feng Meng[a], Peng Hou[a], Shan-Chao Yue[a], Volker Römheld[e], and Fu-Suo Zhang[a,2]

[a]College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, China; [b]Department of Biology, Stanford University, Stanford, CA 94305; [c]Department of Agronomy and Horticulture, University of Nebraska, Lincoln, NE 68583; [d]School of Earth Sciences, Stanford University, Stanford, CA 94305; and [e]Institute of Plant Nutrition, Hohenheim University, 70593 Stuttgart, Germany

Contributed by Peter M. Vitousek, February 15, 2011 (sent for review October 25, 2010)

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).

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

(Chen et al., PNAS, 2011)

National action of The Best Cycle to improve Soil Quality(80millyuan/Yr)

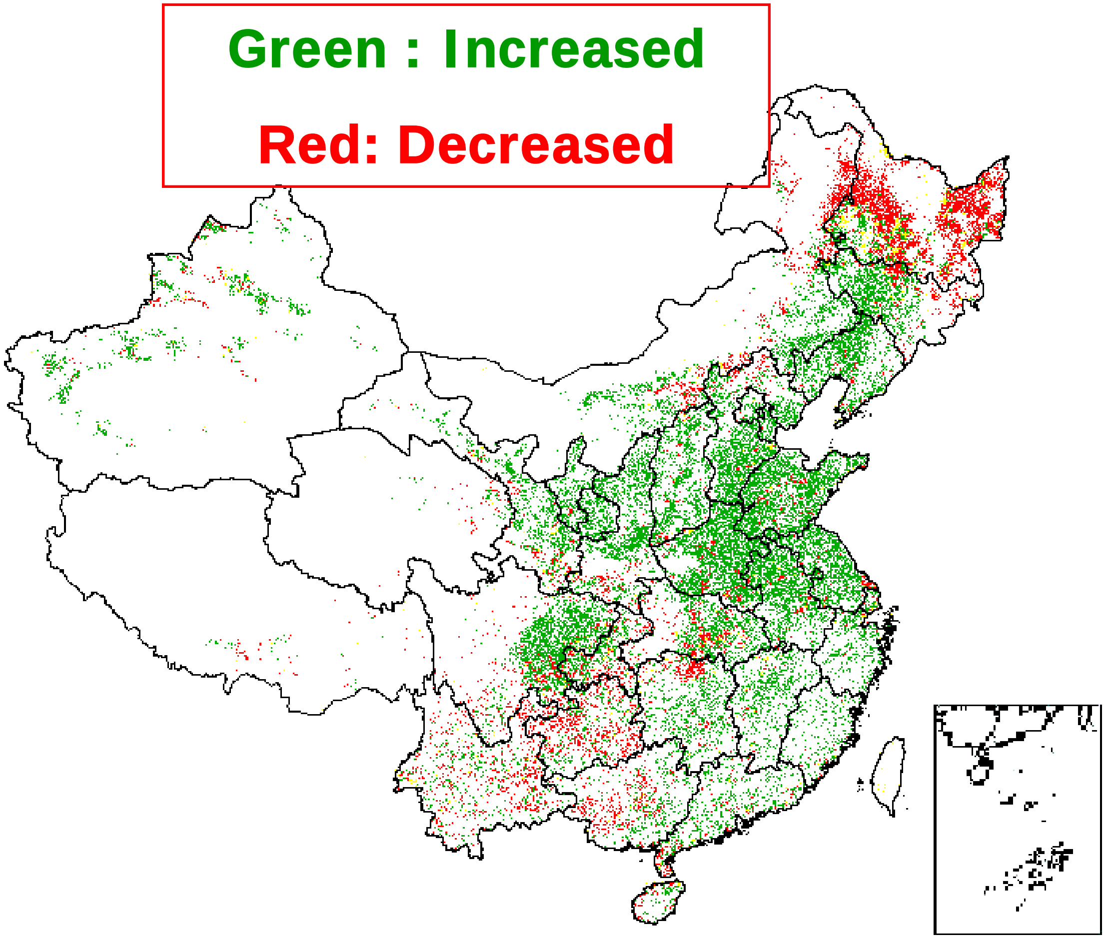
increase crop productivity, then more C and organic materials to improve soil quality and productivity

1) Higher yield
   higher C return

2) More straw return
   back into Soil

3) More organic
   manure

SOM concentration change in Chinese cropland since 1980s



Crop system		Change in SOM (g/kg)
Wheat	Northwest China (Winter wheat)	2.0** (±1.4)
	North China (Winter wheat)	4.7** (±2.2)
Maize	North China (Summary Maize)	
	North east China (Spring maize)	-2.0 (±3.9) no
Rice	Yangtze River Basin (Single R)	3.2** (±4.0)
	South China (Early Rice)	3.3* (±4.7)
	South China (Later Rice)	

*: p=0.01-0.05; **: p<0.001; Average (±std deviation)

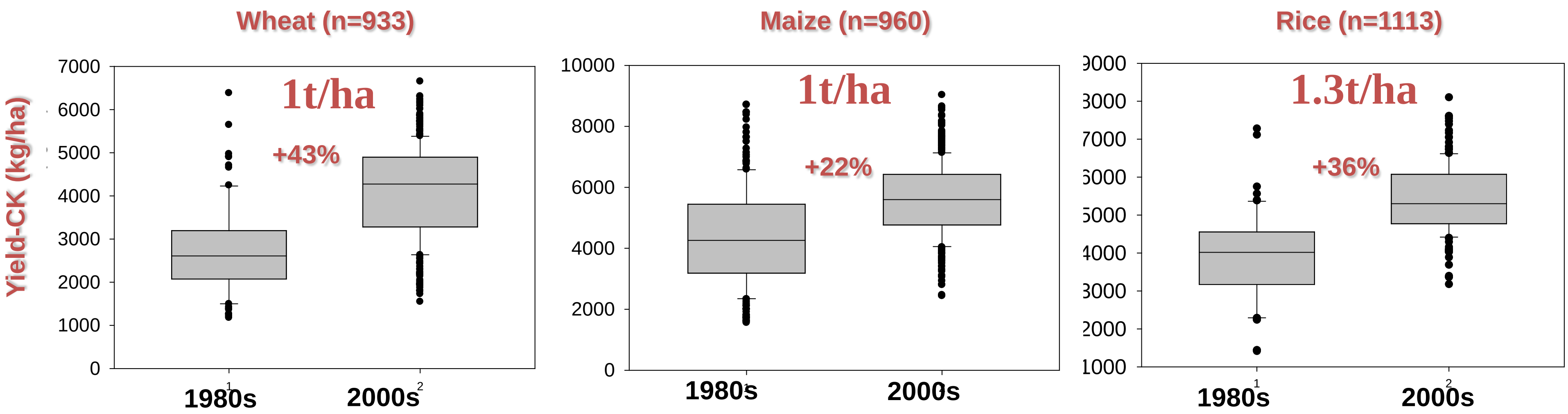
Data were summarized from national inventory (80 published documents, > >140,168 Sites/samples)

(Fan et al.,2013)

Assessment of changes in soil productivity

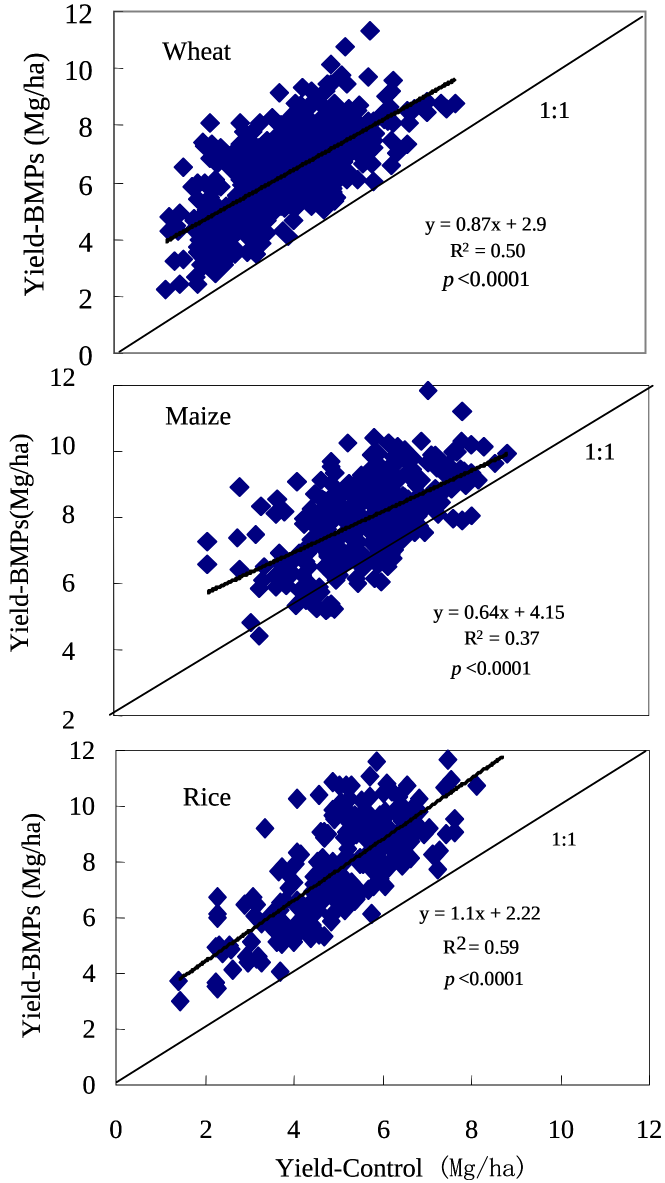
<u>"on farm trails"</u>

between 1980s and 2000s by Plant based method



Yield-CK: grain yield in without chemical NPK and any organic amendment on-Farm trails during the 1 to 2-year experimental period in 1980s or 2000s.

(Fan et al.,2013)



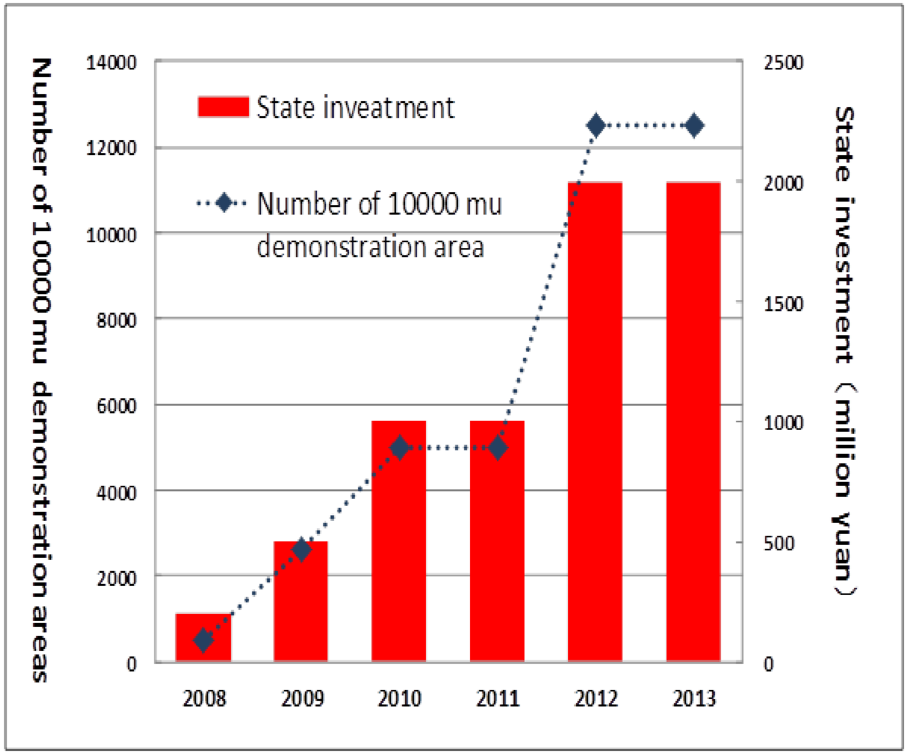
Relations between grain yields of wheat, maize and rice without fertilizer addition (Yield-Control) and yields in best management practices (Yield-BMPs) on-farm trails in major cereal-based cropping systems in China. Note: Paired sites involved in 933 for wheat, 530 for maize (only summer maize in north) and 1113 sites for rice.

The better soil quality, the better response of crop yield to fertilizer application!

(Fan et al.,2013)

National action of high yielding grain, cotton, oil and sugar crop production (since 2008-)

In last 6 years, totally 6.7 billion RMB has been invested in to set up 12500 "10000 mu demonstration areas".



Unit (t/ha)

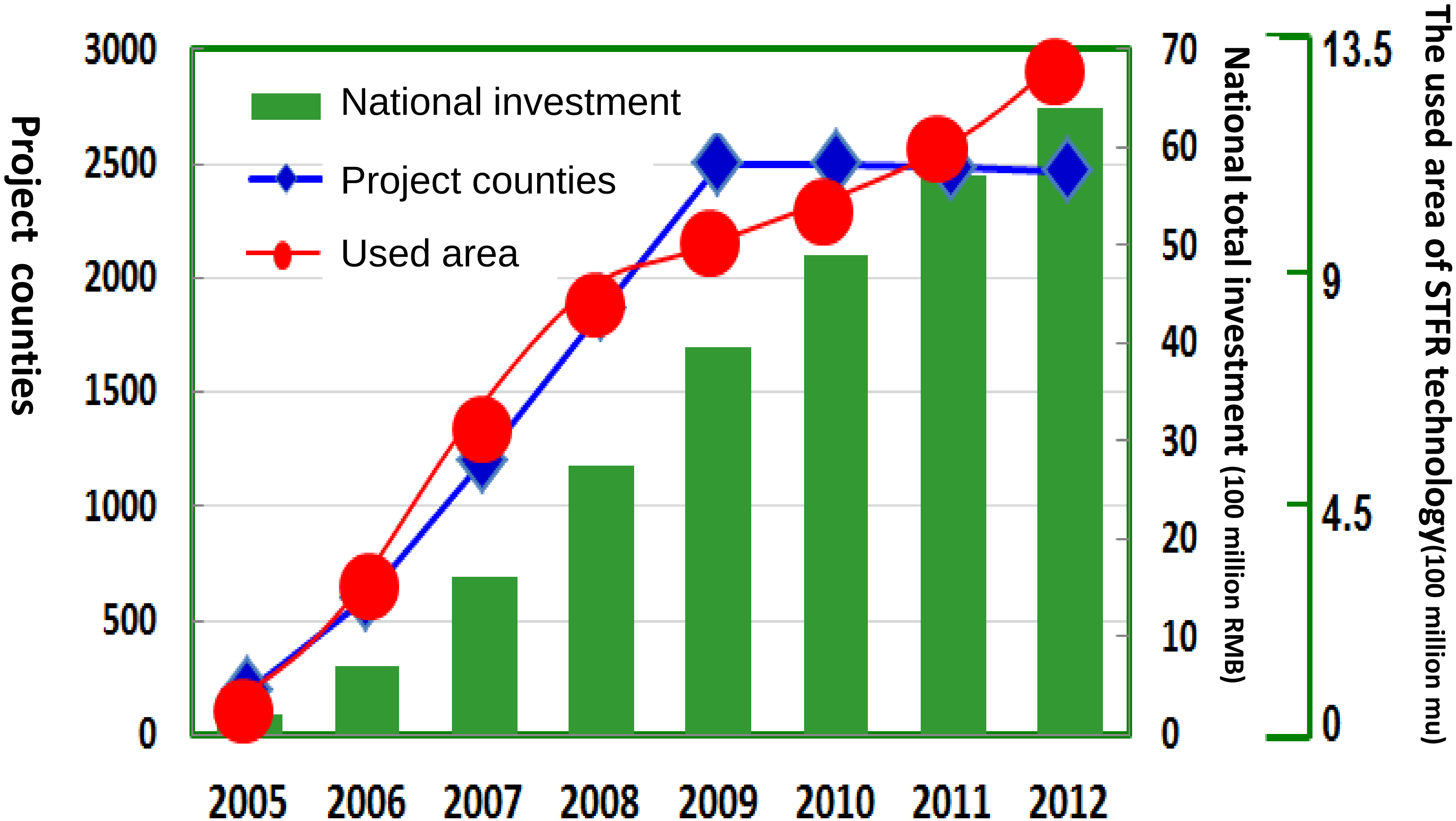
Crops	Target yield	Farmers' pratice	Increase rate(%)
Spring maize	12	7.6(1118)	58%
Summer maize	10.5	6.9(1709)	52%
Single rice	10.5	7.9(927)	33%
Double rice	13.5	12.6(1159)	7%
Irrigated wheat	9	6.6(1252)	36%
Dryland wheat	6	3.7(1192)	62%

Note:10000 mu=667 hectare; Farmers' practice from farmer survey, including 7357 households in 2008-2009.

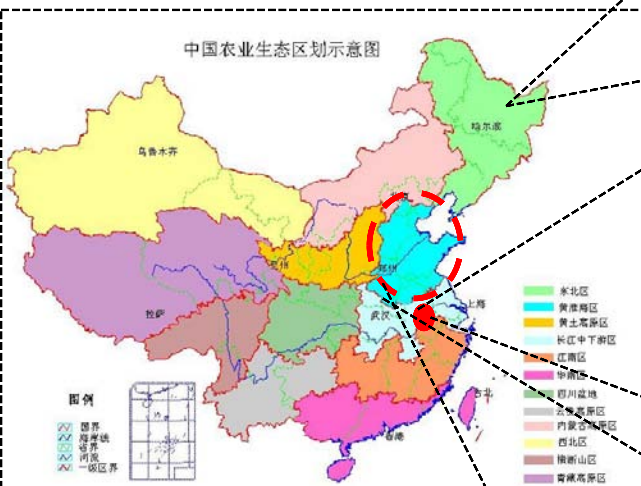
National action of nutrient management

(started from 2005 till now)

In last 8 years, totally 6.4 billion RMB has been invested to cover all agricultural areas (totally 2498 counties). The technology has been used on more than 9 million ha cropland

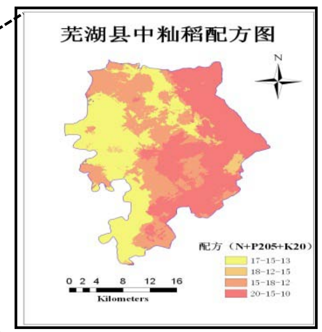


Concept to develop crop/site specific fertilizer in China, in collaboration of 200 fertilizer companies



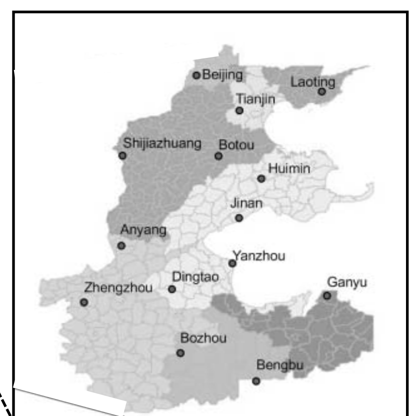
Scale： farms

Implementation Ways： BB fertilizers



Scale： counties

Implementation Ways： Small and medium fertilizer enterprise ＋ BB fertilizers

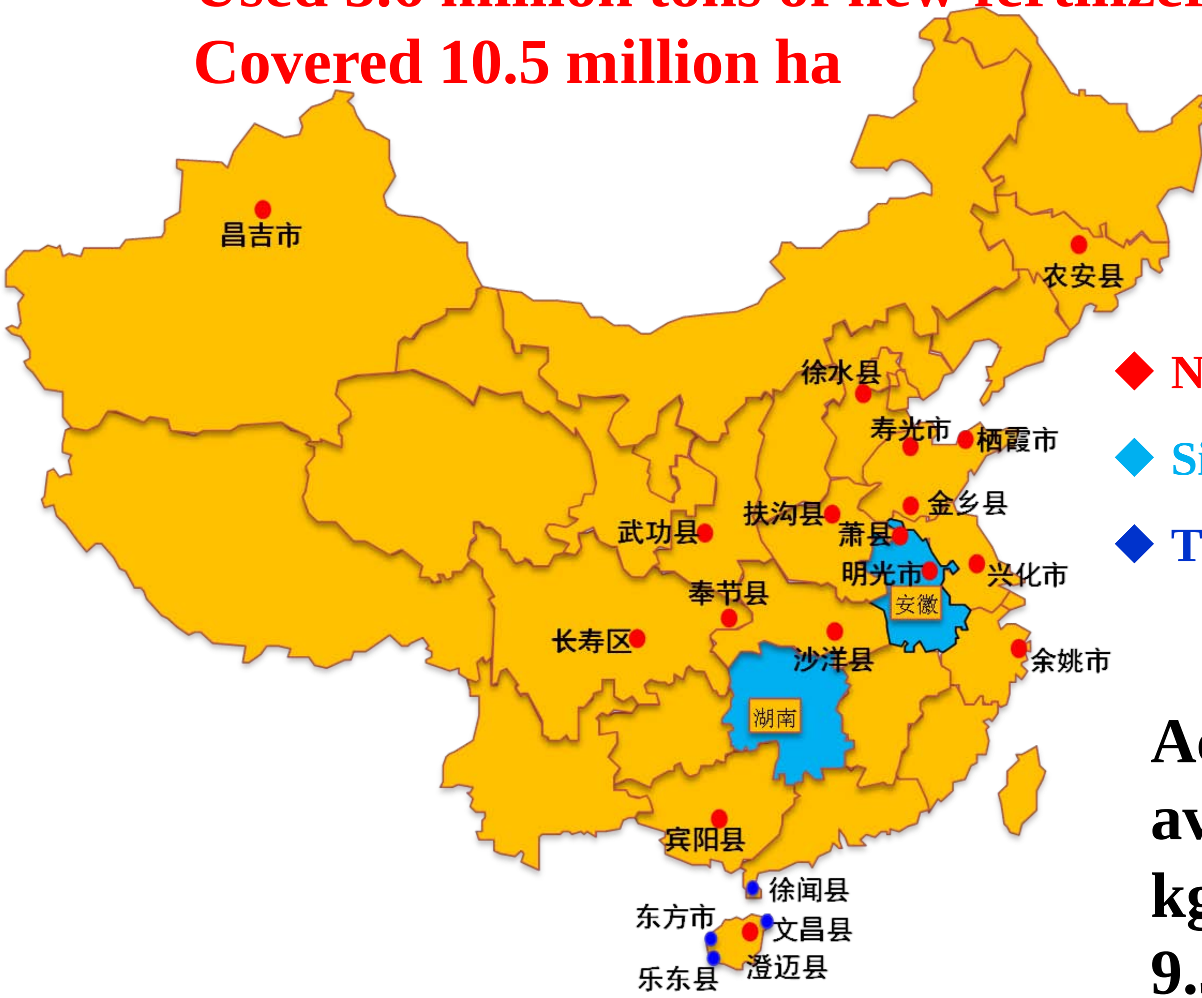


Scale： agro-ecological regions

Implementation Ways： large fertilizer enterprise＋compound fertilizers

Network of new fertilizer development and demonstration: 42 counties, 22 cropping systems

Used 5.6 million tons of new fertilizer
Covered 10.5 million ha

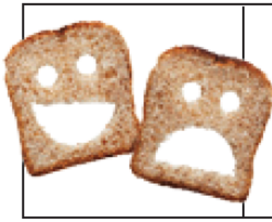


Across all 241 sites, on average, saved N 60 kg/ha， increased yield 9.3%， PFP_N +31.2%，income +470 dollar/ha.

Outline

- Problems and Challenges
- Strategy of Nutrient Management and It's Impact
- Prospects

An experiment for the world

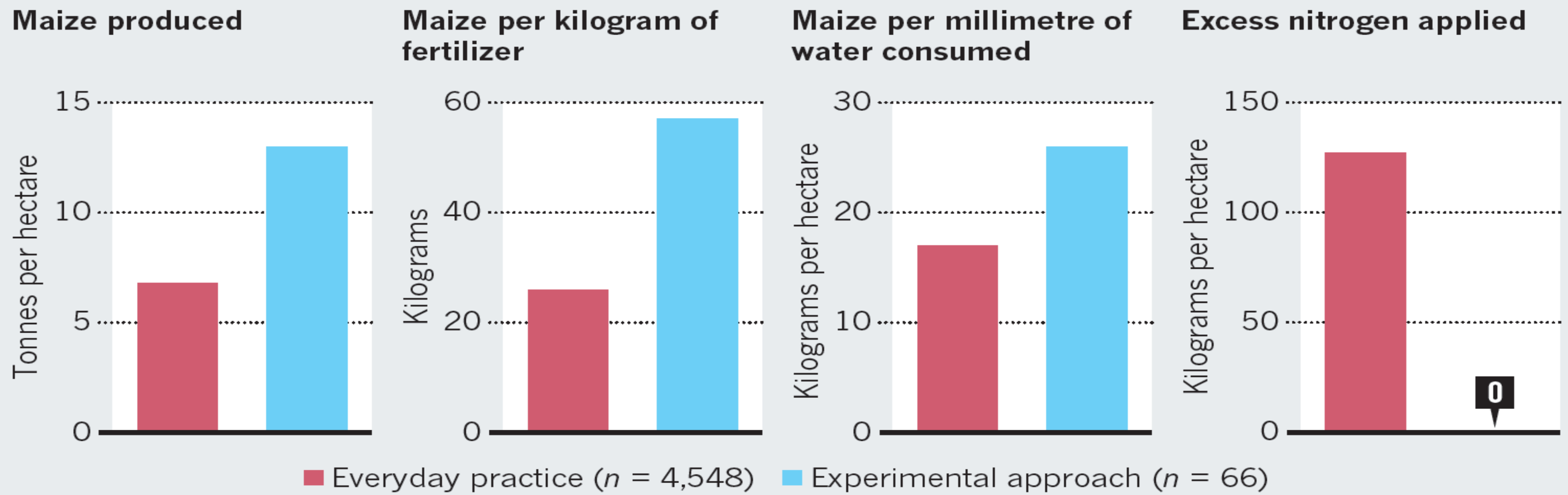


GM CROPS: PROMISE & REALITY
A *Nature* special issue
nature.com/gmcrops

China's scientists are using a variety of approaches to boost crop yields and limit environmental damage, say **Fusuo Zhang**, **Xinping Chen** and **Peter Vitousek**.

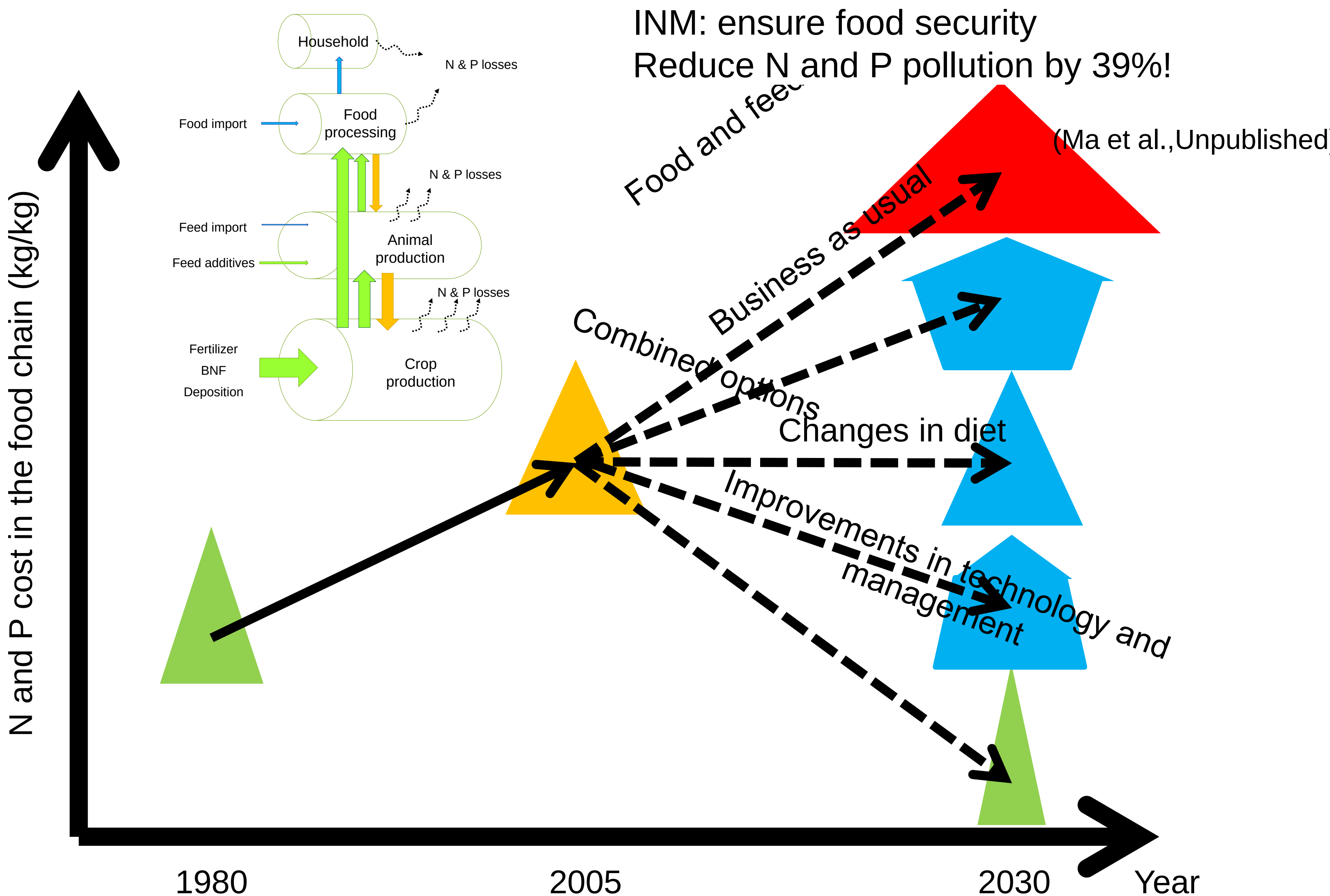
MORE FOR LESS

Using farm designs informed by modelling, Chinese agricultural researchers are increasing yields in experimental plots and in farm studies while reducing the amount of resources used and nutrients lost.



(Zhang et al., 2013, Nature)

N and P cost in the food chain of China



Acknowledgments

NSFC, MoA , MoE, MOST

Thanks

for your attention !