International Symposium on Improvement of Nutrient Use Efficiency in China under Zero Growth of Chemical Fertilizers, Beijing, March 16-18, 2016

An Integrated Soil-Crop System Approach

-- Producing More Grain with Lower Environmental Costs in China

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Outline

- Background
- Results and discussion
  - Yield and yield potential
  - Nitrogen use
  - Environmental costs
- Summary

The demand of yield increasing

World:

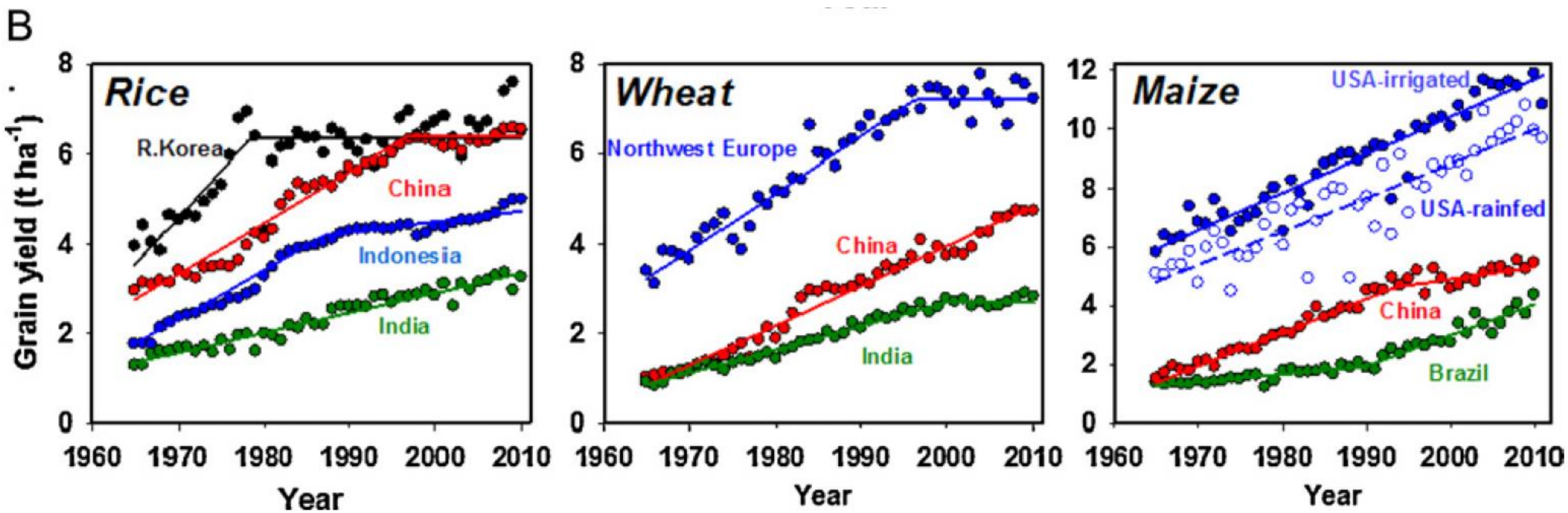
Increasing cereal production by 70%, doubling the output of developing countries must be required for lifting a billion people out of poverty and feeding an extra 2.3 billion by 2050 (World Summit, 2009).

Global demand for crop calories would increase by 100% ± 11% and global demand for crop protein would increase by 110% ± 7% from 2005 to 2050. (Tilman et al., 2011, PNAS)

China:

Looking towards 2030, it is suggested that annual crop production should be increased to around 580 Mt and that yield should increase by at least 2% annually. (Fan et al., 2012, JXB) (need increase by 30-50%)

Examples of major rice, wheat and maize producing countries with yield trends.



(Ittersum and Cassman, 2013)

Across 24–39% of maize-, rice-, wheat- and soybean-growing areas, yields either never improve, stagnate or collapse. This result underscores the challenge of meeting increasing global agricultural demands.

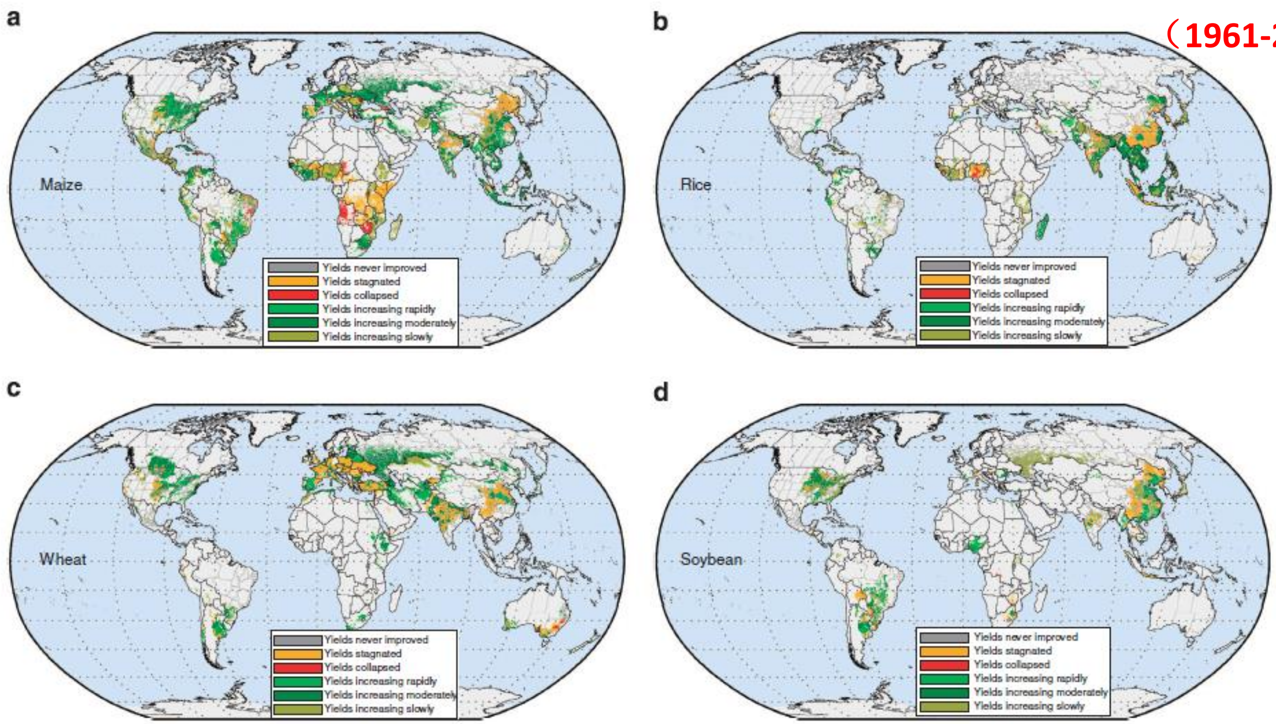


Figure 2 | Global maps of current crop yield trends. At each political unit where (**a**) maize, (**b**) rice, (**c**) wheat and (**d**) soybean crop yields were tracked globally, we determined the status of their current yield trend. The trends were divided into the six categories and colour coded. We show in the maps only those areas in the political unit where the crop was harvested.

ARTICLE

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Recent patterns of crop yield growth and stagnation

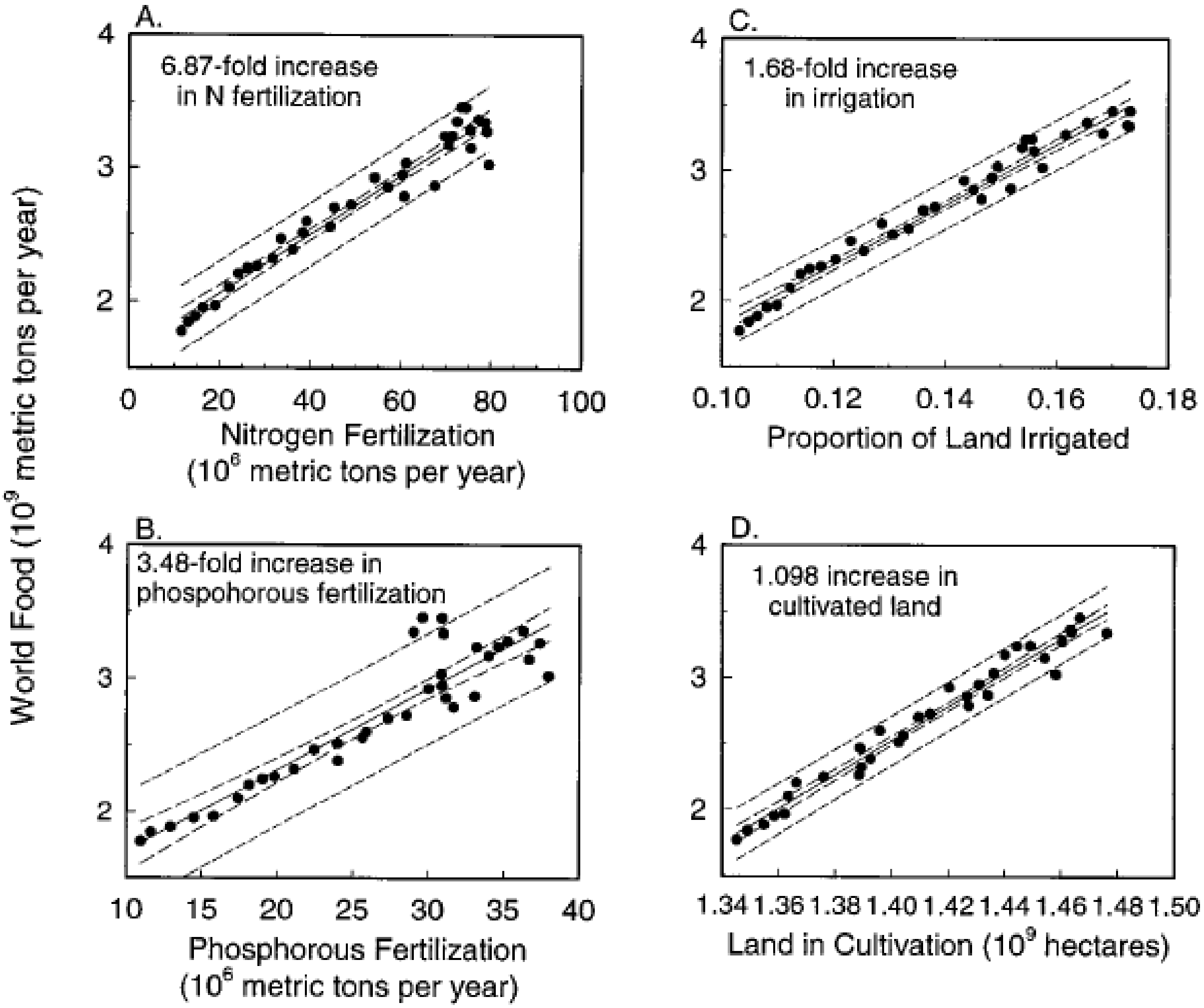
Deepak K. Ray[1], Navin Ramankutty[2], Nathaniel D. Mueller[1], Paul C. West[1] & Jonathan A. Foley[1]

nature COMMUNICATIONS

Question 1:

Can we increase crop yield by 2% annually in next decades? How much potential we will have for three staple crops?

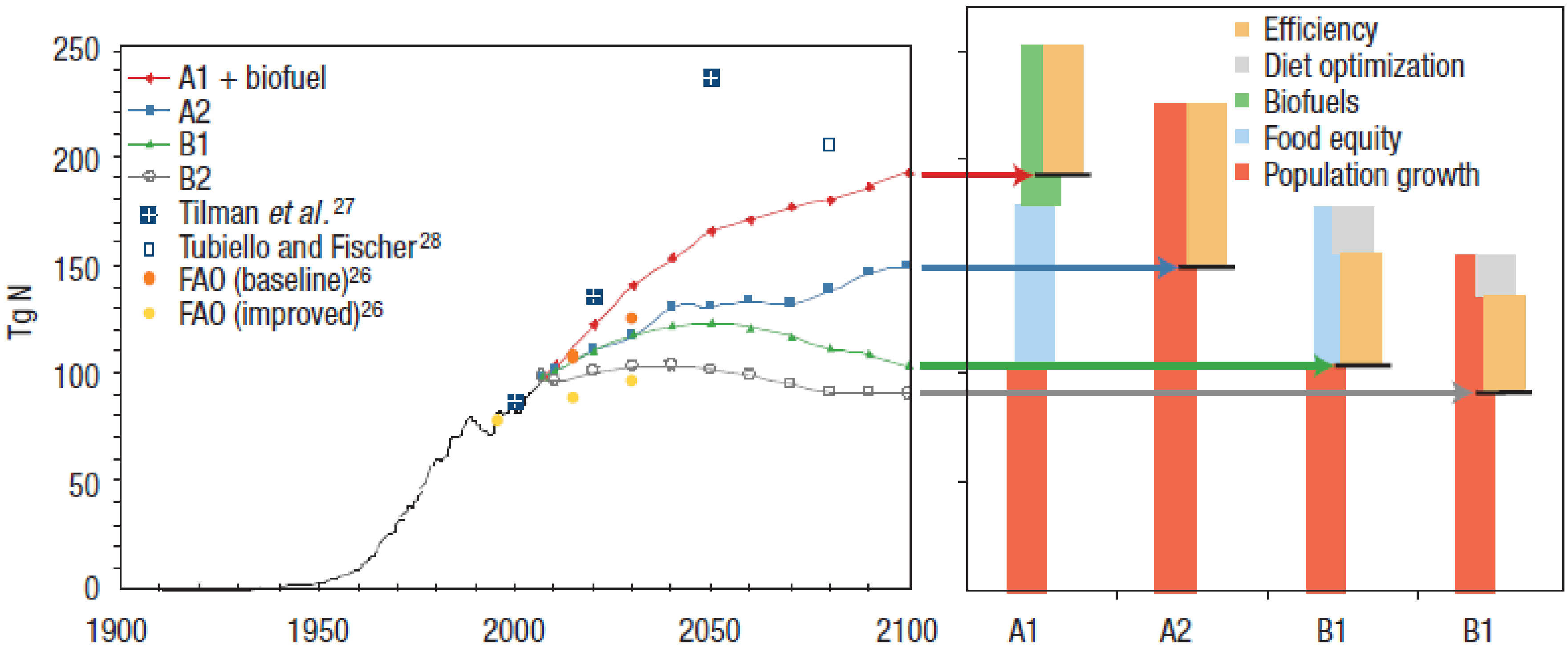
The doubling of agricultural food production during the past 35 years (1961-1995) was associated with a 6.87- fold increase in nitrogen fertilization, a 3.48- fold increase in phosphorus fertilization, a 1.68- fold increase in the amount of irrigated cropland, and a 1.1- fold increase in land in cultivation.



Based on a simple linear extension of past trends, the anticipated next doubling of global food production would be associated with approximately 3-fold increases in nitrogen and phosphorus fertilization rates, a doubling of the irrigated land area, and an 18% increase in cropland.

Tilman, PNAS,1999

The global fertilizer N consumption is still expected to dramatically increase in the future because of continuing increased population and food requirement.



Erisman, et al., 2008

Question 2:

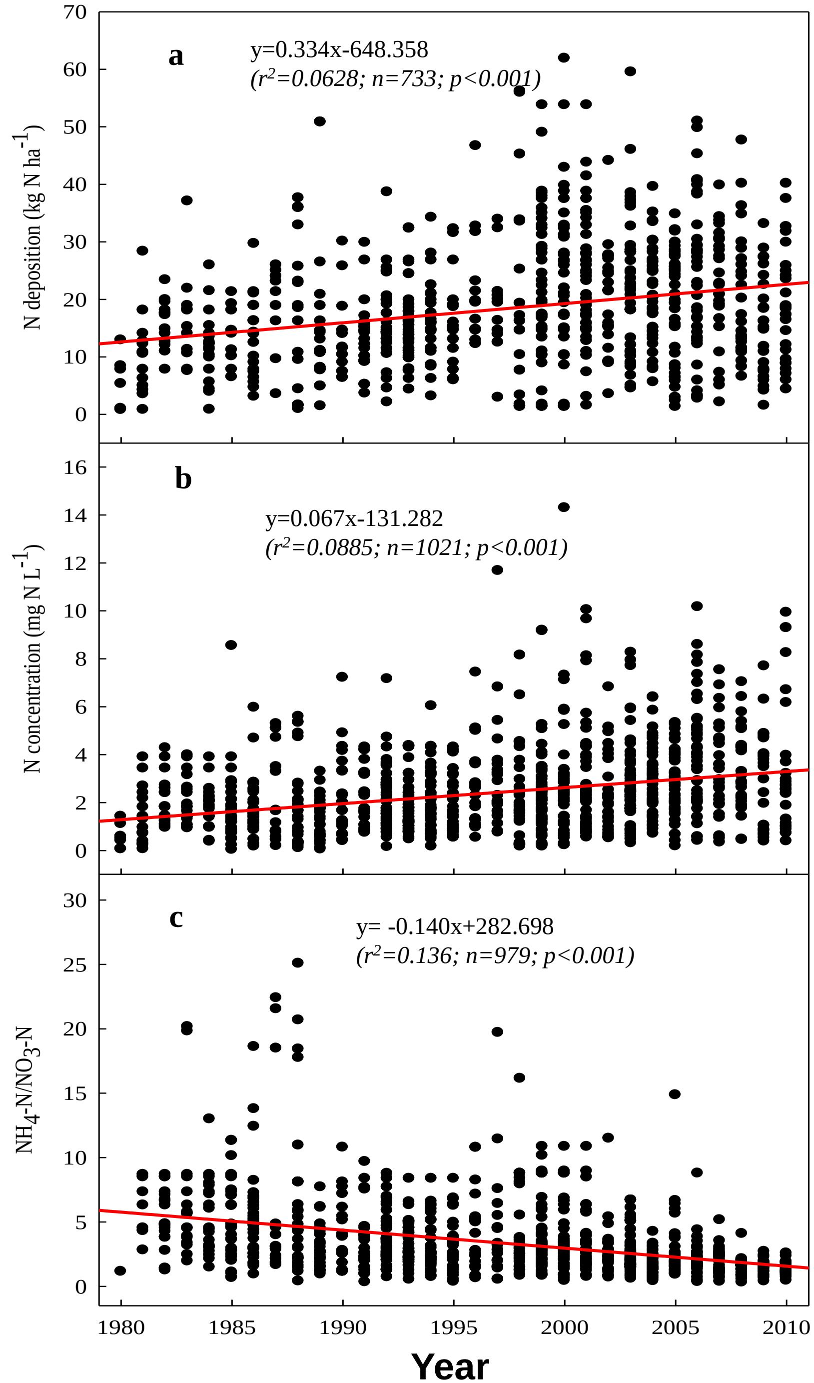
How many N should be used for yield increasing in next decades?

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.

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

NH_4-N/NO_3-N
1980s: ~ 5.0
2000s: ~ 2.0

(Liu et al., Nature, 2013)



For every ton of N fertilizer manufactured and used, 13.5 tons of CO2-equivalent (eq) (t CO2-eq) is emitted, compared with 9.7 t CO2-eq in Europe. Emissions in China tripled from 1980 [131 terrogram (Tg) of CO2-eq (Tg CO2-eq)] to 2010 (452 Tg CO2-eq). N fertilizer-related emissions constitute about 7% of GHG emissions from the entire Chinese economy.

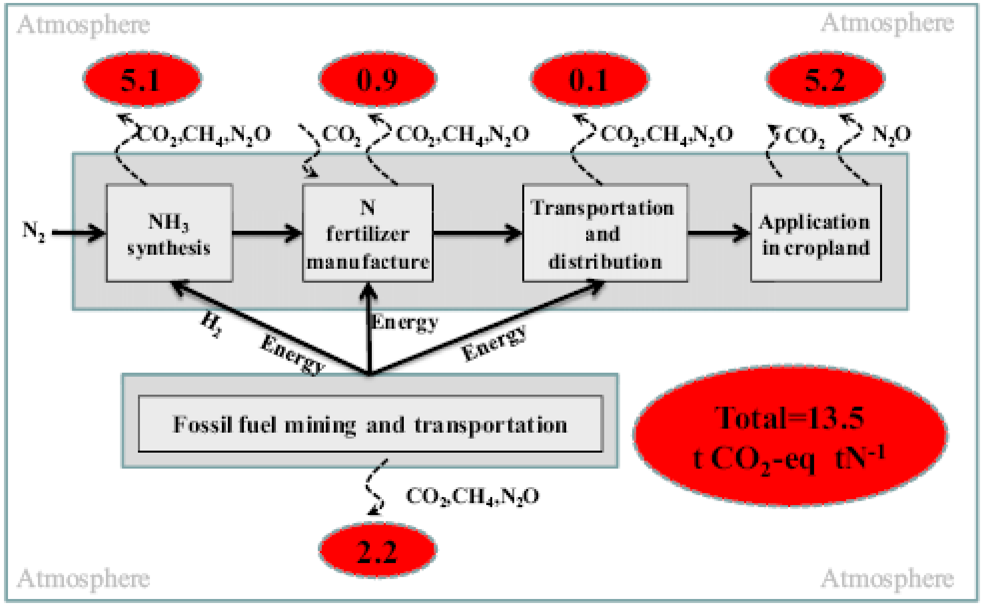


Fig. 1. Life cycle assessment of GHG emissions from manufacturing and field use of N fertilizer in China and weighted emission factors of main processes (system boundaries are described in the main text). Atmospheric nitrogen (N_2) is combined with hydrogen using energy from fossil fuels. The produced NH_3 is reacted with CO_2, nitric acid, hydrochloric acid, or phosphoric acid to produce different N fertilizer products. These fertilizers are transported by various means before being applied to croplands. The solid line represents the materials and N fertilizer flow. The broken line represents GHG exchanges between the fertilizer chain and the atmosphere.

(Zhang et al., 2013, PNAS)

Question 3:

How about the environmental costs for yield increasing in the future?

AGRICULTURE

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.

P. M. Vitousek,[1]* R. Naylor,[2] T. Crews,[3] M. B. David,[4] L. E. Drinkwater,[5] E. Holland,[6] P. J. Johnes,[7] J. Katzenberger,[8] L. A. Martinelli,[9] P. A. Matson,[10] G. Nziguheba,[11] D. Ojima,[12] C. A. Palm,[11] G. P. Robertson,[13] P. A. Sanchez,[11] A. R. Townsend,[14] F. S. Zhang[15]

	Nutrient balances by region (kg ha $^{-1}$ year $^{-1}$)					
Inputs and outputs	Western Kenya		North China		Midwest U.S.A	
	N	P	N	P	N	P
Fertilizer	7	8	588	92	93	14
Biological N fixation					62	
Total agronomic inputs	7	8	588	92	155	14
Removal in grain and/or beans	23	4	361	39	145	23
Removal in other harvested products	36	3				
Total agronomic outputs	59	7	361	39	145	23
Agronomic inputs minus harvest removals	-52	+1	+227	+53	+10	−9

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Essay

Input Subsidies to Improve Smallholder Maize Productivity in Malawi: Toward an African Green Revolution

Glenn Denning*, Patrick Kabambe, Pedro Sanchez, Alia Malik, Rafael Flor, Rebbie Harawa, Phelire Nkhoma, Colleen Zamba, Clement Banda, Chrispin Magombo, Michael Keating, Justine Wangila, Jeffrey Sachs

Table 1. Malawi's National Maize Production, Food Self-Sufficiency, and the Malawi Maize Production Index, 2000–2001 to 2006–2007

Indicator	Season 2000–2001	2001–2002	2002–2003	2003–2004	2004–2005	2005–2006	2006–2007
National average yield (t/ha) [9]	1.18	1.05	1.28	1.05	0.76	1.59	2.04
National production (million t) [9]	1.71	1.56	1.98	1.61	1.23	2.58	3.44
Food requirement met (%) [9,49]	88	78	97	83	57	118	153
MMPI (deviation from 100%) [50]	5	7	7	−2	−19	8	12

MMPI, Malawi Maize Production Index.
doi:10.1371/journal.pbio.1000023.t001

A total of 132,000 t fertilizer and 6,000 t of improved maize seed were made available.

the Millennium Development Goals Centre for East and Southern Africa,
Earth Institute at Columbia University

LETTER

doi:10.1038/nature13809

Productivity limits and potentials of the principles of conservation agriculture

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One of the primary challenges of our time is to feed a growing and more demanding world population with reduced external inputs and minimal environmental impacts, all under more variable and extreme climate conditions in the future[1–4]. Conservation agriculture represents a set of three crop management principles that has received strong international support to help address this challenge[5,6], with recent conservation agriculture efforts focusing on smallholder farming systems in sub-Saharan Africa and South Asia[7]. However, conservation agriculture is highly debated, with respect to both its effects on crop yields[8–10] and its applicability in different farming contexts[7,11–13]. Here we conduct a global meta-analysis using 5,463 paired yield observations from 610 studies to compare no-till, the original and central concept of conservation agriculture, with conventional tillage practices across 48 crops and 63 countries. Overall, our results show that no-till reduces yields, yet this response is variable and under certain conditions no-till can produce equivalent or greater yields than conventional tillage. Importantly, when no-till is combined with the other two conservation agriculture principles of residue retention and crop rotation, its negative impacts are minimized. Moreover, no-till in combination with the other two principles significantly increases rainfed crop productivity in dry climates, suggesting that it may become an important climate-change adaptation strategy for ever-drier regions of the world. However, any expansion of conservation agriculture should be done with caution in these areas, as implementation of the other two principles is often challenging in resource-poor and vulnerable smallholder farming systems, thereby increasing the likelihood of yield losses rather than gains. Although farming systems are multifunctional, and environmental and socio-economic factors need to be considered[14–16], our analysis indicates that the potential contribution of no-till to the sustainable intensification of agriculture is more limited than often assumed.

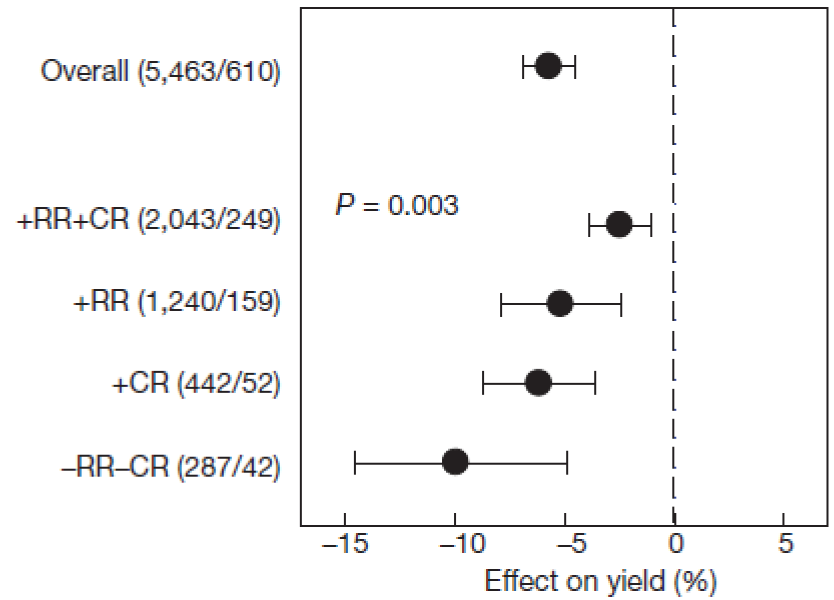

Figure 1 | Comparison of yield in no-till versus conventional tillage systems in relation to the other two principles of conservation agriculture. Results are shown for the entire data set (overall) and for subcategories of studies which indicated the presence or absence of residue retention and crop rotation for both no-till and conventional tillage systems: +RR+CR (residue retention + crop rotation), +RR (residue retention), +CR (crop rotation), or –RR–CR (without residue retention or crop rotation). The number of observations and total number of studies included in each category are displayed in parentheses. Error bars represent 95% confidence intervals. Significant differences between categories are indicated by *P* values based on randomization tests.

LETTER

doi:10.1038/nature11069

Comparing the yields of organic and conventional agriculture

Verena Seufert[1], Navin Ramankutty[1] & Jonathan A. Foley[2]

Numerous reports have emphasized the need for major changes in the global food system: agriculture must meet the twin challenge of feeding a growing population, with rising demand for meat and high-calorie diets, while simultaneously minimizing its global environmental impacts[1,2]. Organic farming—a system aimed at producing food with minimal harm to ecosystems, animals or humans—is often proposed as a solution[3,4]. However, critics argue that organic agriculture may have lower yields and would therefore need more land to produce the same amount of food as conventional farms, resulting in more widespread deforestation and biodiversity loss, and thus undermining the environmental benefits of organic practices[5]. Here we use a comprehensive meta-analysis to examine the relative yield performance of organic and conventional farming systems globally. Our analysis of available data shows that, overall, organic yields are typically lower than conventional yields. But these yield differences are highly contextual, depending on system and site characteristics, and range from 5% lower organic yields (rain-fed legumes and perennials on weak-acidic to weak-alkaline soils), 13% lower yields (when best organic practices are used), to 34% lower yields (when the conventional and organic systems are most comparable). Under certain conditions—that is, with good management practices, particular crop types and growing conditions—organic systems can thus nearly match conventional yields, whereas under others it at present cannot. To establish organic agriculture as an important tool in sustainable food production, the factors limiting organic yields need to be more fully understood, alongside assessments of the many social, environmental and economic benefits of organic farming systems.

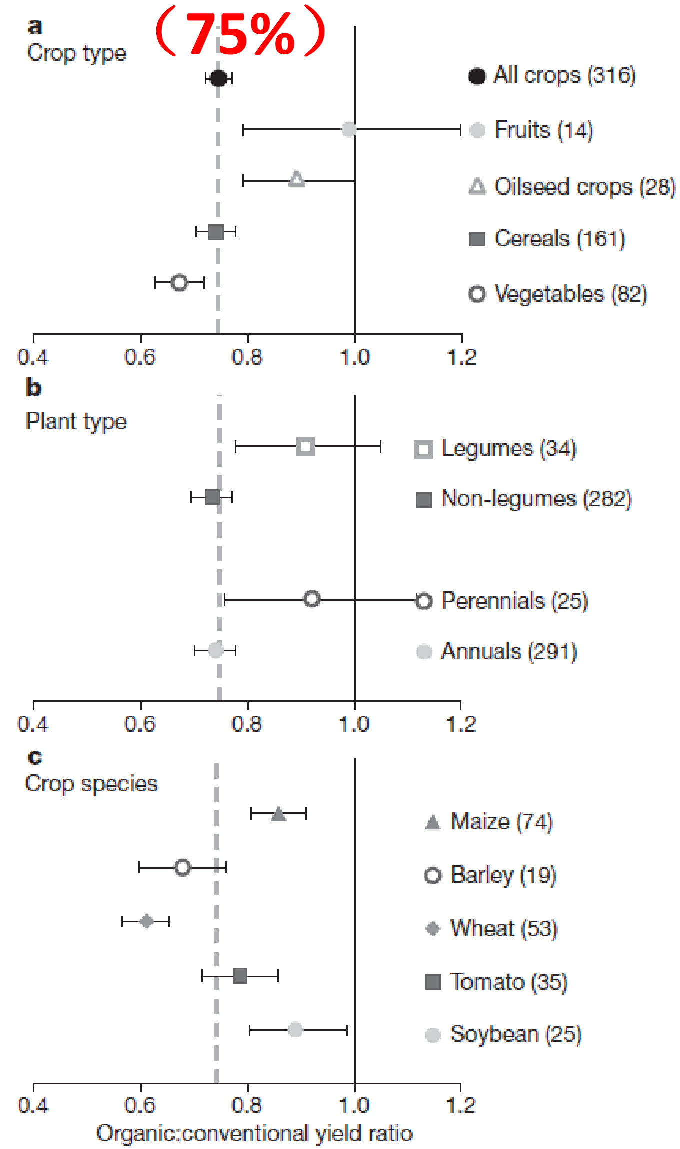

Figure 1 | Influence of different crop types, plant types and species on organic-to-conventional yield ratios. a–c, Influence of crop type (a), plant type (b) and crop species (c) on organic-to-conventional yield ratios. Only those crop types and crop species that were represented by at least ten observations and two studies are shown. Values are mean effect sizes with 95% confidence intervals. The number of observations in each class is shown in parentheses. The dotted line indicates the cumulative effect size across all classes.

The biggest challenge for agricultural sciences and technologies today come from the rapidly developing economies. This is because:

1) After great success in yield increasing from green-revolution during 1960s-1980s, rate of gain in cereal yields have slowed markedly in the past 10-20 years, even thought their agricultural inputs such as nitrogen (N) and phosphorus (P) continuously increased.

2) Environmental pollution problems such as eutrophication, greenhouse gas emissions, soil acidification, have become so severe in such rapidly developing countries, because of continuously increasing the use of limiting resources (nitrogen, phosphorus).

3) Crops are produced by hundreds of millions of farmers on small parcels of land , it makes agricultural technologies more difficult and significant different than in most developed countries.

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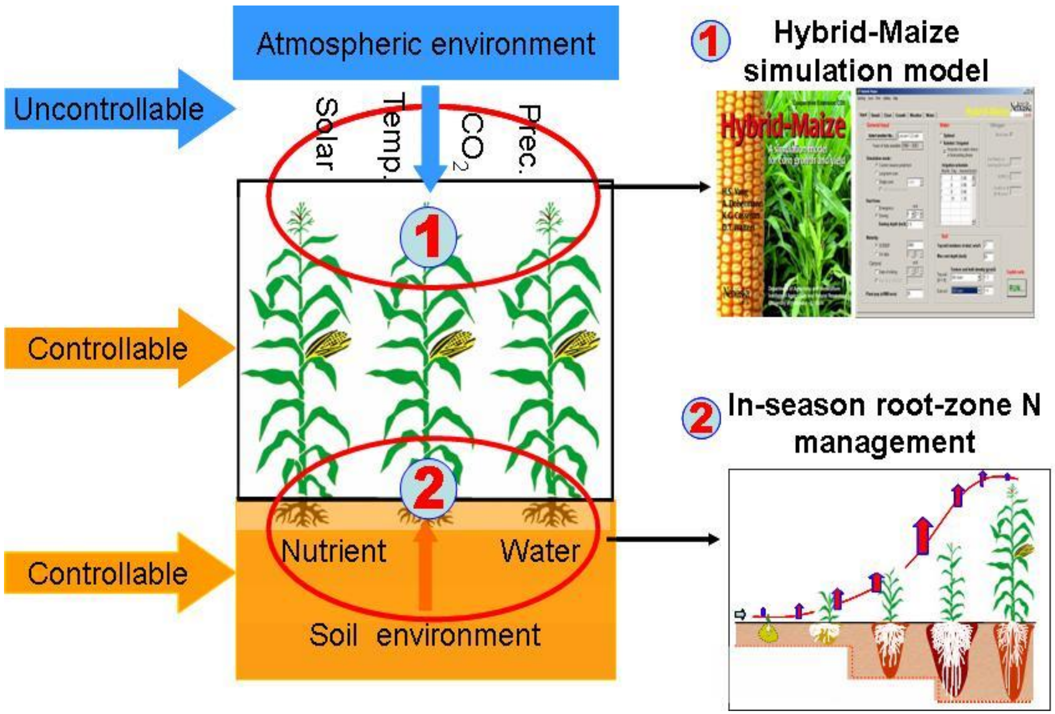
Conceptual model of the integrated soil-crop system management



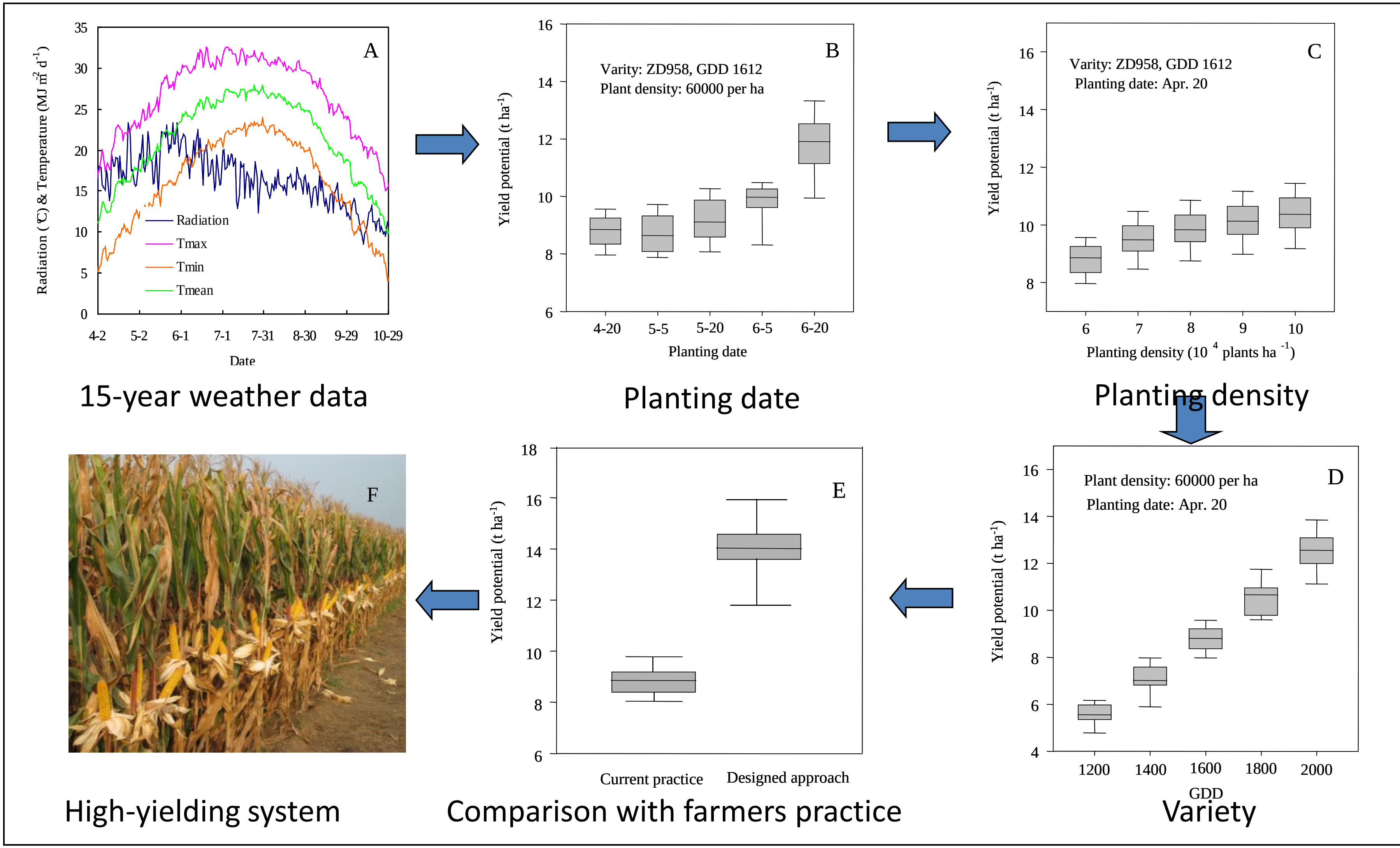
1. Designing cropping system to adopt local ecological conditions, to make use of solar radiation and periods with favorable temperatures to the maximum possible extent, and thereby increase crop productivity.

2. Establishing an in-season root zone nutrient management strategy for high-yielding cropping system.

(Chen et al., 2011, Proc. Natl. Acad. Sci. USA.)

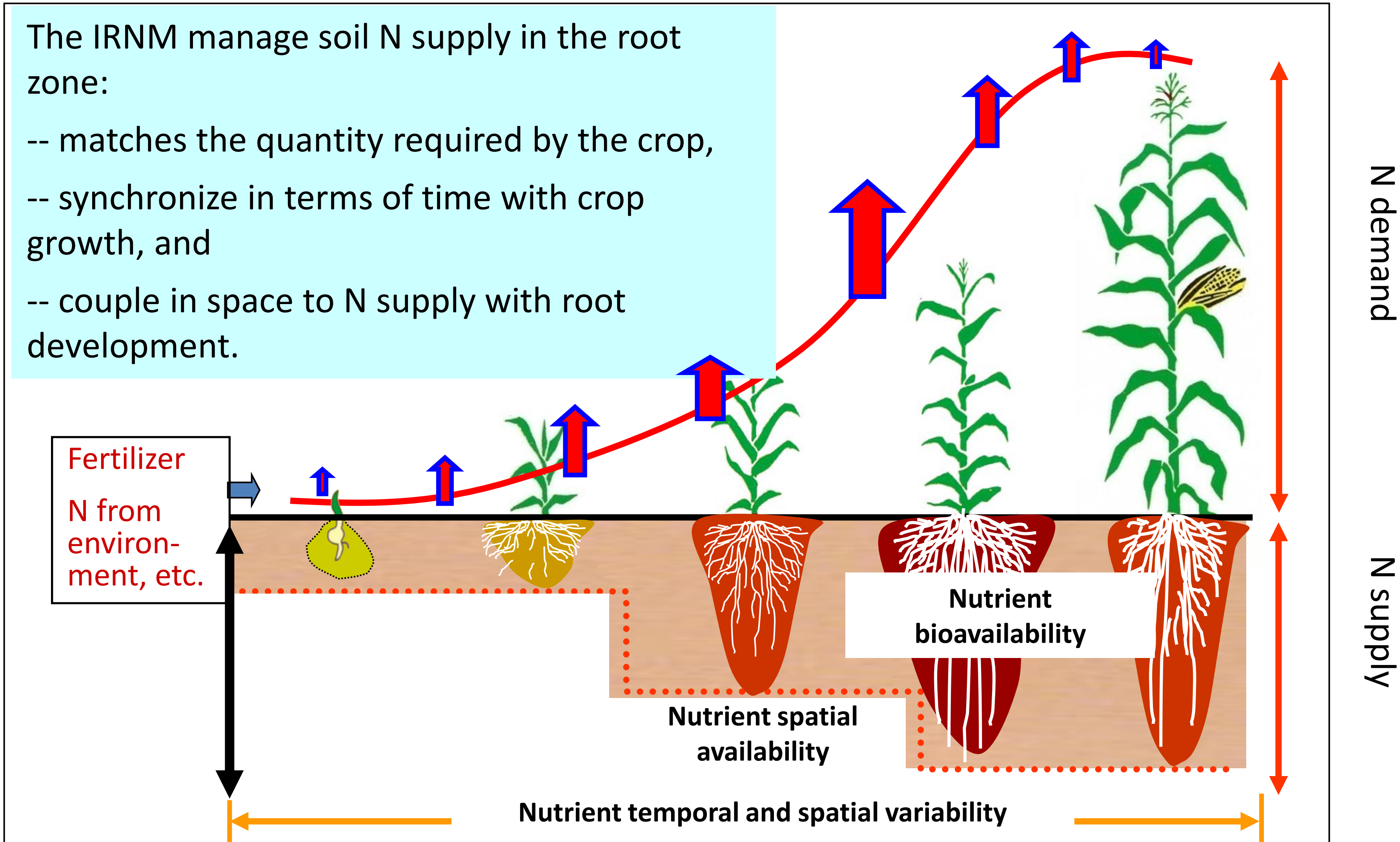
Design a high-yielding maize production system by understanding the interaction between crop and radiation / temperature resources

-- an example for Beijing suburb



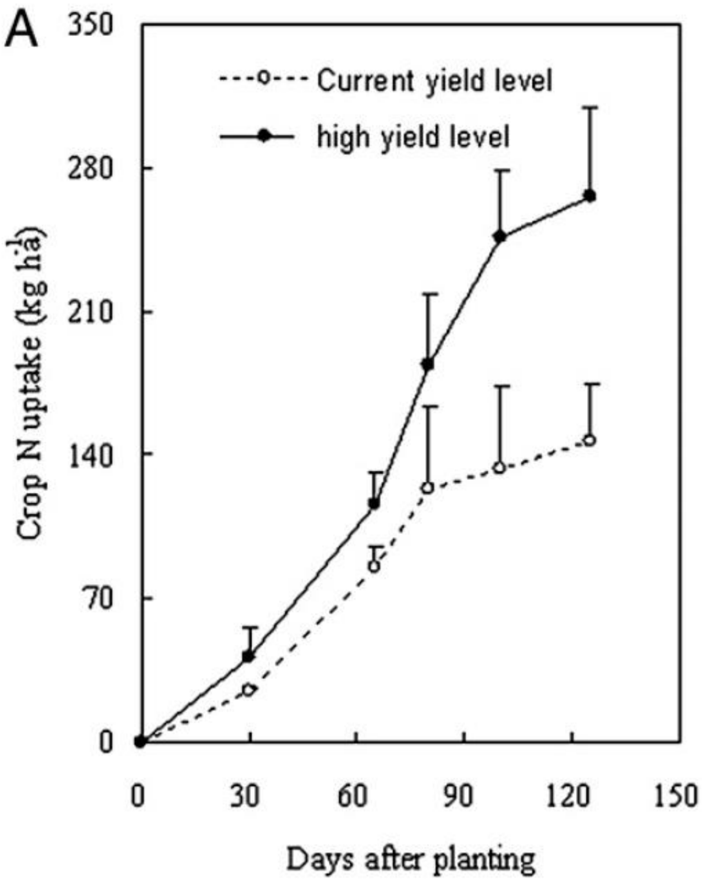
(Chen et al., 2011, Proc. Natl. Acad. Sci. USA.)

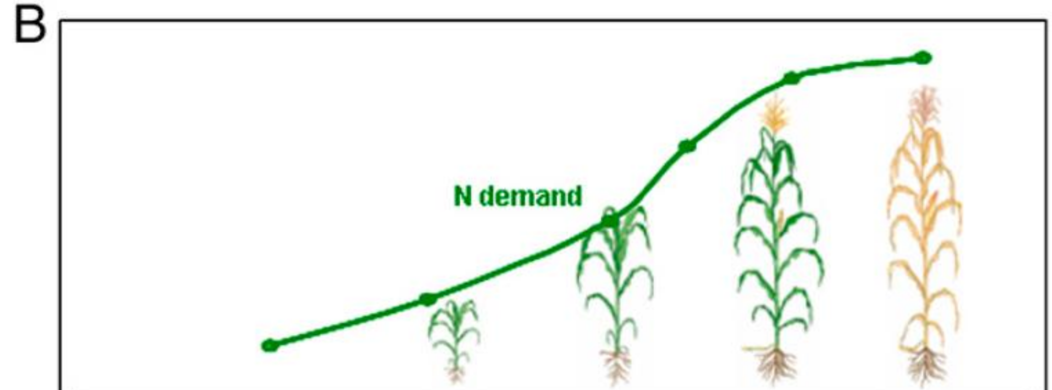
Conceptual model illustrating the in-season root zone nitrogen management strategies (IRNM) for realizing the high yield and high efficiency



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

N uptake dynamic in different yield levels of maize and in-season root-zone nitrogen management strategy





Growing stage	Planting-V_6	V_6-V_{10}	V_{10}-R_1	R_1-R_2	R_2-R_6
Depth of root-zone (cm)	0-30	0-60	0-90	0-90	0-90
Target N value (kg N ha^{-1})	80	130	130	140	120
N fertilizer rate (kg N ha^{-1})	68	52	30	30	45

(Chen et al., 2011, Proc. Natl. Acad. Sci. USA.)

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., 2011, Proc. Natl. Acad. Sci. USA.)

Experimental design

Treatment 1: Current Practice (CP)

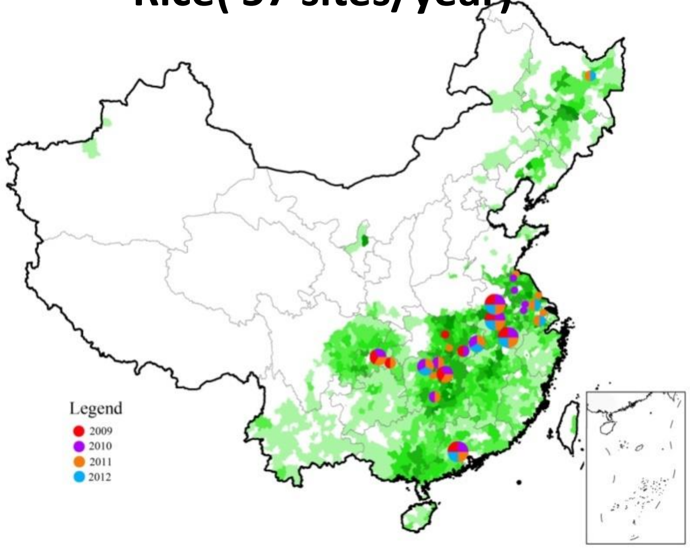
Treatment 2: Improved Practice (IP)

Treatment 3: High Yield system (HY)

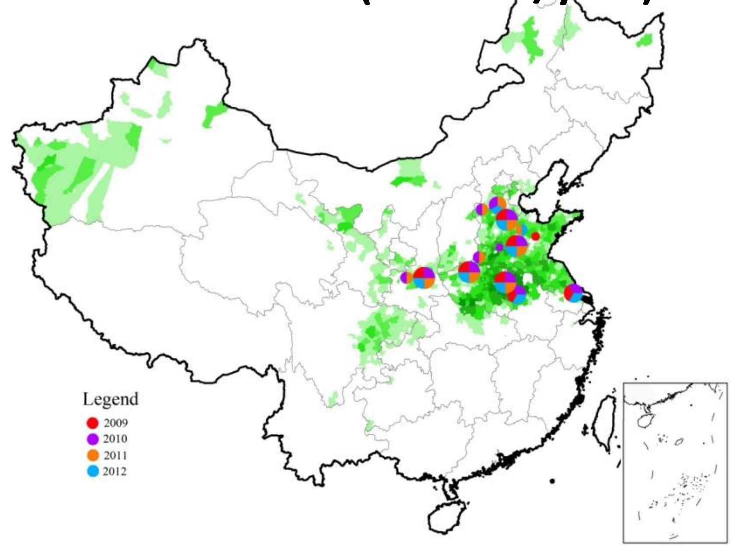
Treatment 4: Integrated Soil-Crop System Management (ISSM)

Experiments for rice, wheat and maize

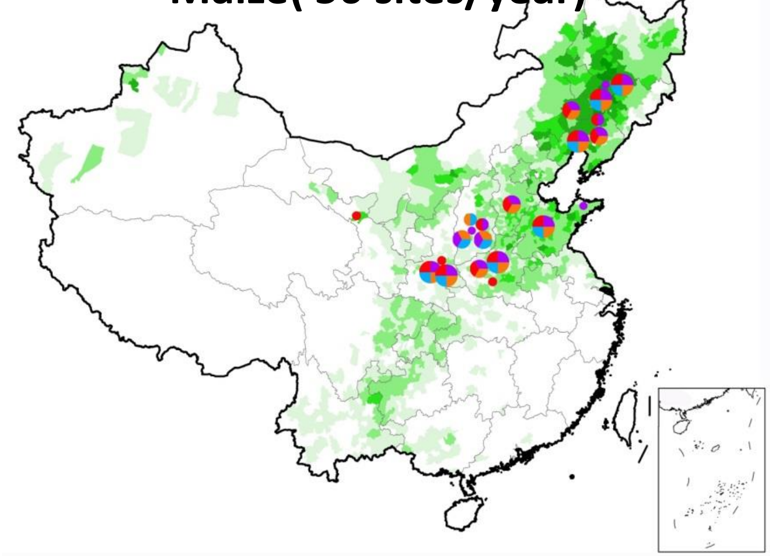
Rice(57 sites/year)



Wheat(40 sites/year)



Maize(56 sites/year)



(Chen et al., 2014, Nature)

Yield increasing by 30-50% is possible

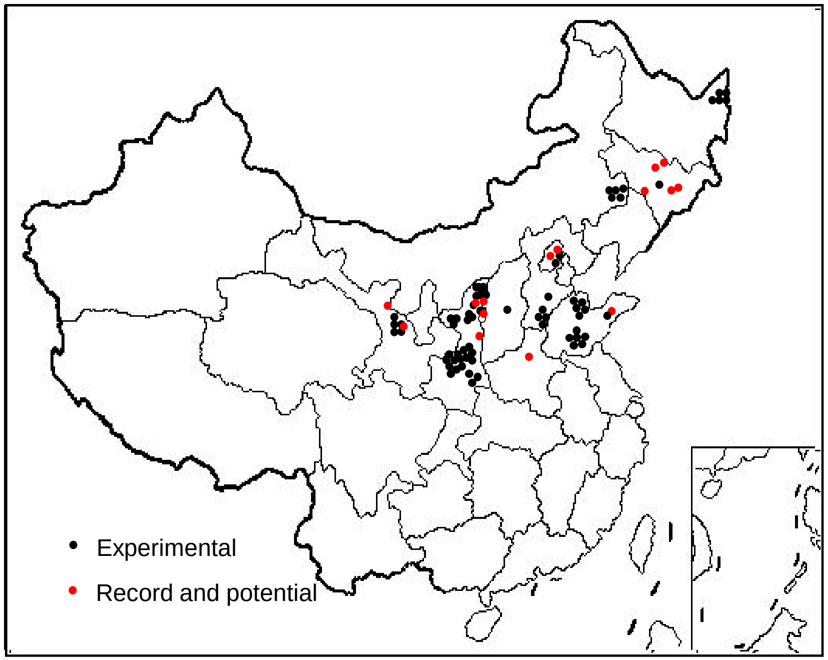
Table 1 | Grain yield, nitrogen application rate, PFP_N and nitrogen surplus for rice (*n* = 57), wheat (*n* = 40) and maize systems (*n* = 56) for the four management treatments in field experiments compared with farmers' practice from a total of 18,938 farmers

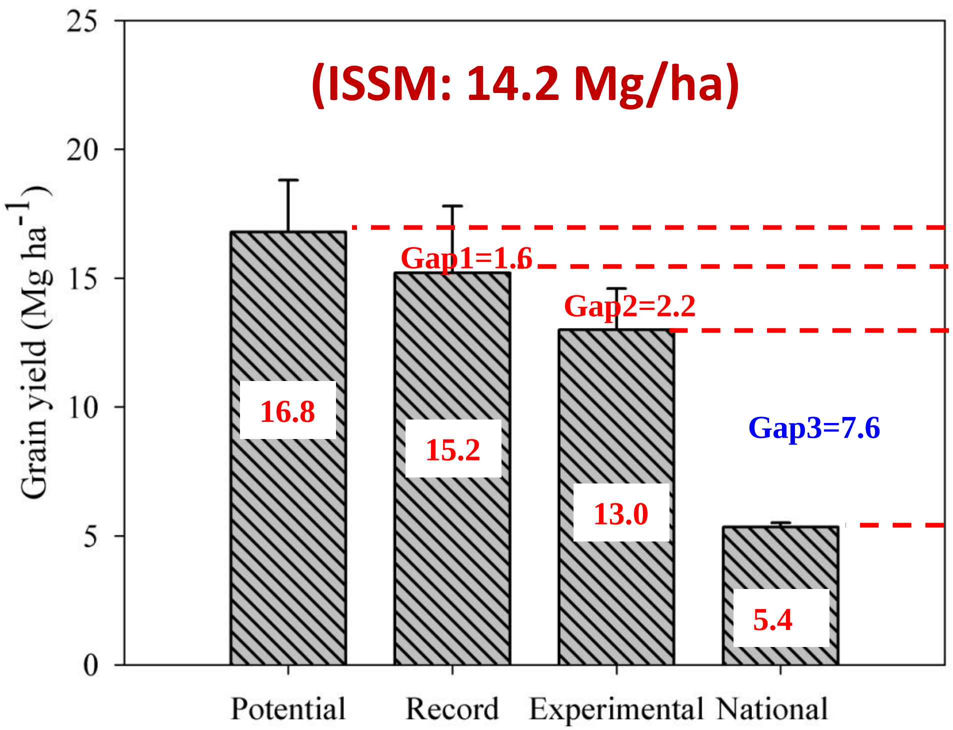
Crops	Treatment	Yield (Mg ha^{-1})	N rate (kg N ha^{-1})	PFP_N (kg kg^{-1})	N surplus (kg N ha^{-1})
Rice					
	Current practice	7.2 ± 1.1‡	181*	41§	58*
	Improved practice	8.1 ± 1.1†	146‡	57*	7‡
	High-yielding system	8.8 ± 1.2*	192*	47‡	38†
	ISSM	8.5 ± 1.2*†	162†	54†	16‡
	Farmers' practice (*n* = 6,592)	7.0 ± 1.5	209	41	82
Wheat					
	Current practice	7.2 ± 1.4‡	257†	28‡	74*
	Improved practice	8.3 ± 1.7†	192§	44*	−9†
	High-yielding system	9.2 ± 1.9*	283*	33†	50*
	ISSM	8.9 ± 1.7*†	220‡	41*	2†
	Farmers' practice (*n* = 6,940)	5.7 ± 1.3	210	33	74
Maize					
	Current practice	10.5 ± 1.6‡	266†	40†	72†
	Improved practice	12.6 ± 2.2†	214‡	59*	−8‡
	High-yielding system	14.4 ± 2.4*	402*	37†	140*
	ISSM	14.2 ± 2.6*	256†	56*	8‡
	Farmers' practice (*n* = 5,406)	7.6 ± 1.5	220	43	72

Means ± s.d. for yield. The same footnote symbol(s) within each column among the four experimental treatments for each crop are not significantly different at $P < 0.05$.

(Chen et al., 2014, Nature)

Maize yield gaps in China





n=60 n=60 n=66

Meng et al., 2013, FCR

Potential: potential yield simulated by Hybrid-Maize model
Record: average highest record yields
Experimental: average yield at different experimental sites
National: average yield

Yield potential: the climatic-genetic yield potential by planting elite germplasm on the optimal planting date and with optimal population density

Yield increasing: biomass *vs* HI

Crops	Treatment	Biomass Mg ha^{-1}	HI	Crop N uptake kg Nha^{-1}
Rice	CP	11.7b	0.52a	123c
	IP	12.8ab	0.54a	138b
	HY	14.1a	0.54a	155a
	ISSM	13.4ab	0.54a	147ab
Wheat	CP	13.4c	0.46b	183b
	IP	14.8bc	0.48ab	201b
	HY	16.7a	0.48ab	234a
	ISSM	15.8ab	0.49a	218ab
Maize	CP	18.4c	0.49b	194 c
	IP	20.8b	0.52a	222b
	HY	23.7a	0.52a	261a
	ISSM	23.3a	0.52a	249ab

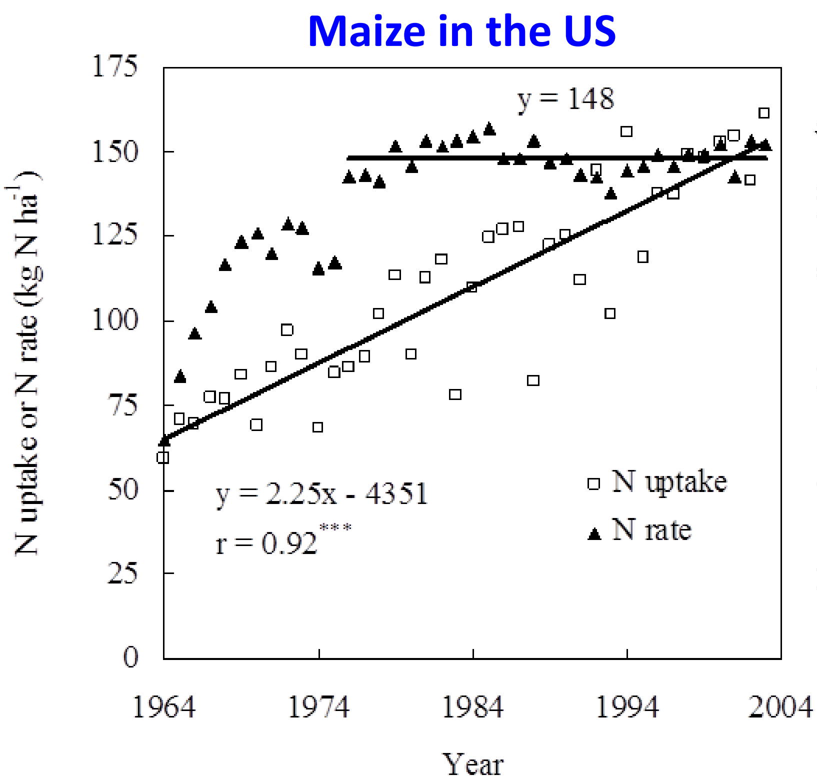
(Chen et al., 2014, Nature, SI)

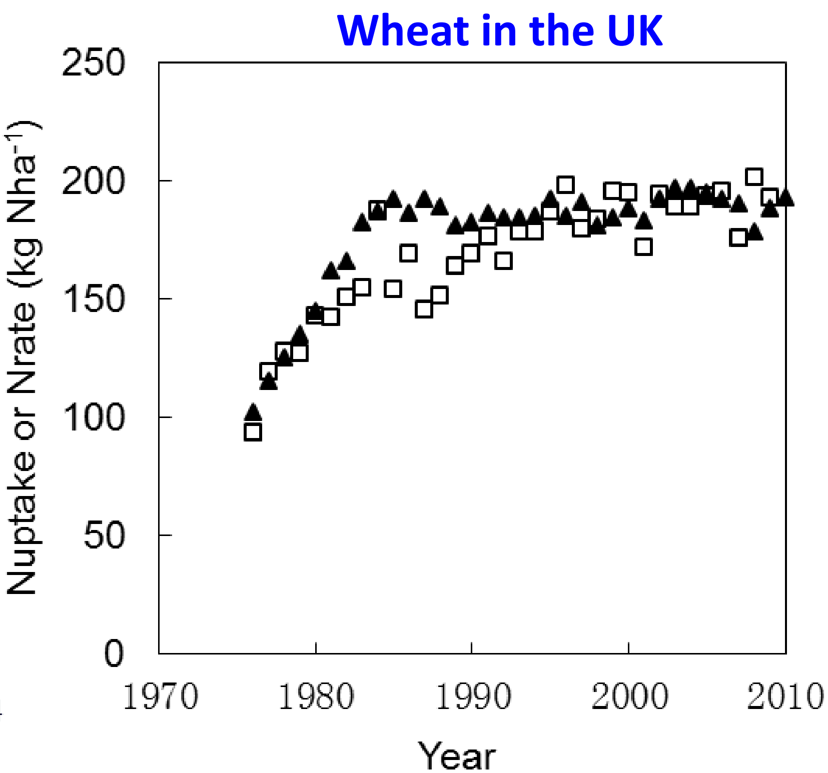
N use: needn't more

Crops	Treatment	N rate kg N ha^{-1}	PFP_N kg kg^{-1}	N surplus kg N ha^{-1}
Rice (n=57)	CP	181 a	41 d	58 a
	IP	146 c	57 a	7 c
	HY	192 a	47 c	38 b
	ISSM	162 b	54 b	16 c
	FP (n=6592)	209	41	82
Wheat (n=40)	CP	257b	28c	74 a
	IP	192d	44 a	-9 b
	HY	283 a	33 b	50 a
	ISSM	220 c	41 a	2 b
	FP (n=6940)	210	33	74
Maize (n=56)	CP	266b	40b	72b
	IP	214c	59a	-8 c
	HY	402 a	37 b	140 a
	ISSM	256b	56a	8 c
	FP(n=5406)	220	43	72

(Chen et al., 2014, Nature)

Comparison with maize in the US and wheat in the UK



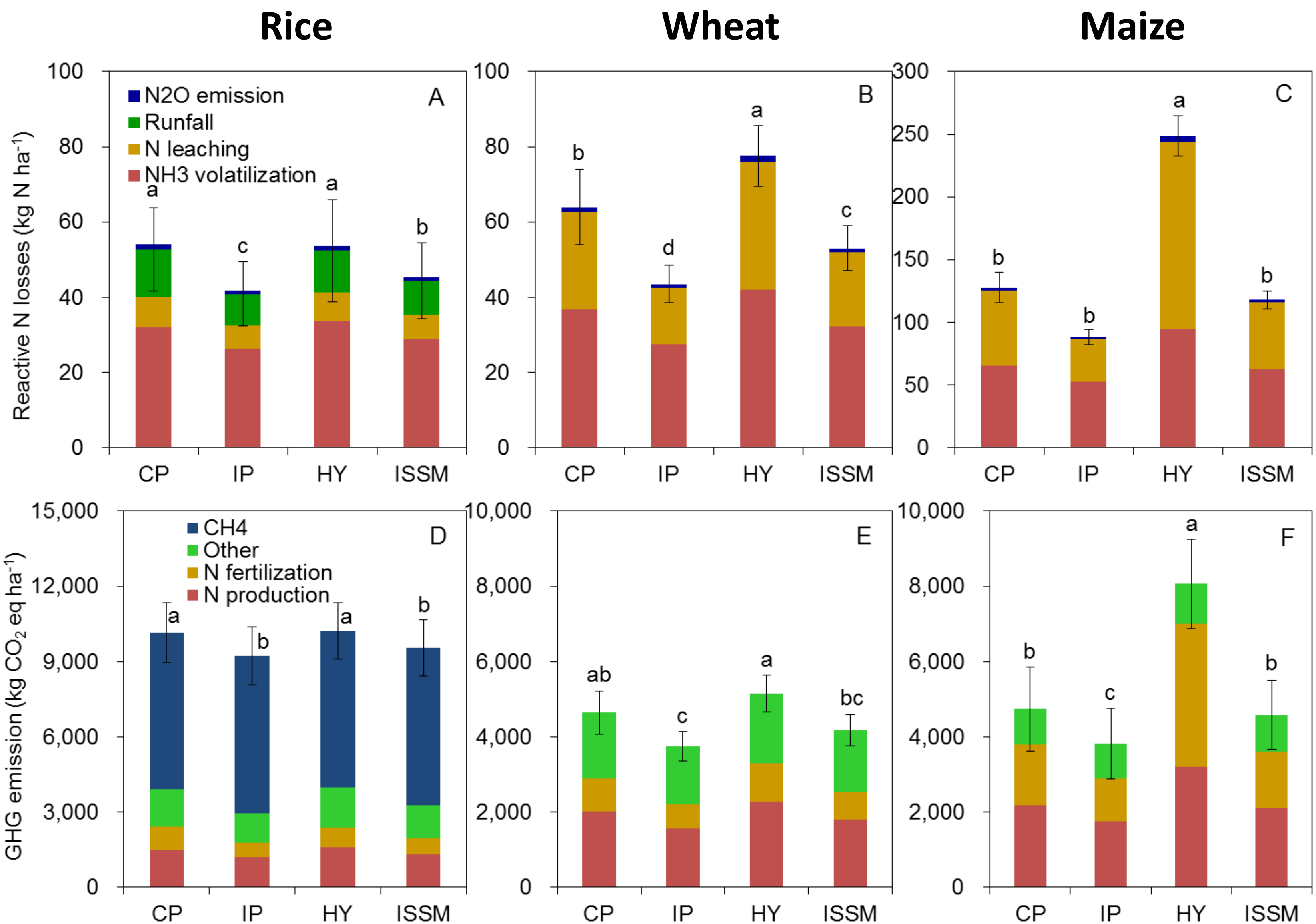


	Yield(Mg/ha)	N(kg/ha)	PFPn(kg/kg)
USA(2000-2009)	9.2	136	68
IP	12.6	214	59
ISSM	14.2	14.2	56

	Yield(Mg/ha)	N(kg/ha)	PFPn(kg/kg)
UK(2000-2009)	7.8	190	41
IP	8.3	192	44
ISSM	8.9	220	41

(Chen et al., 2014, Nature, SI)

Reactive N losses and GHG emissions



Lower environmental costs for food production

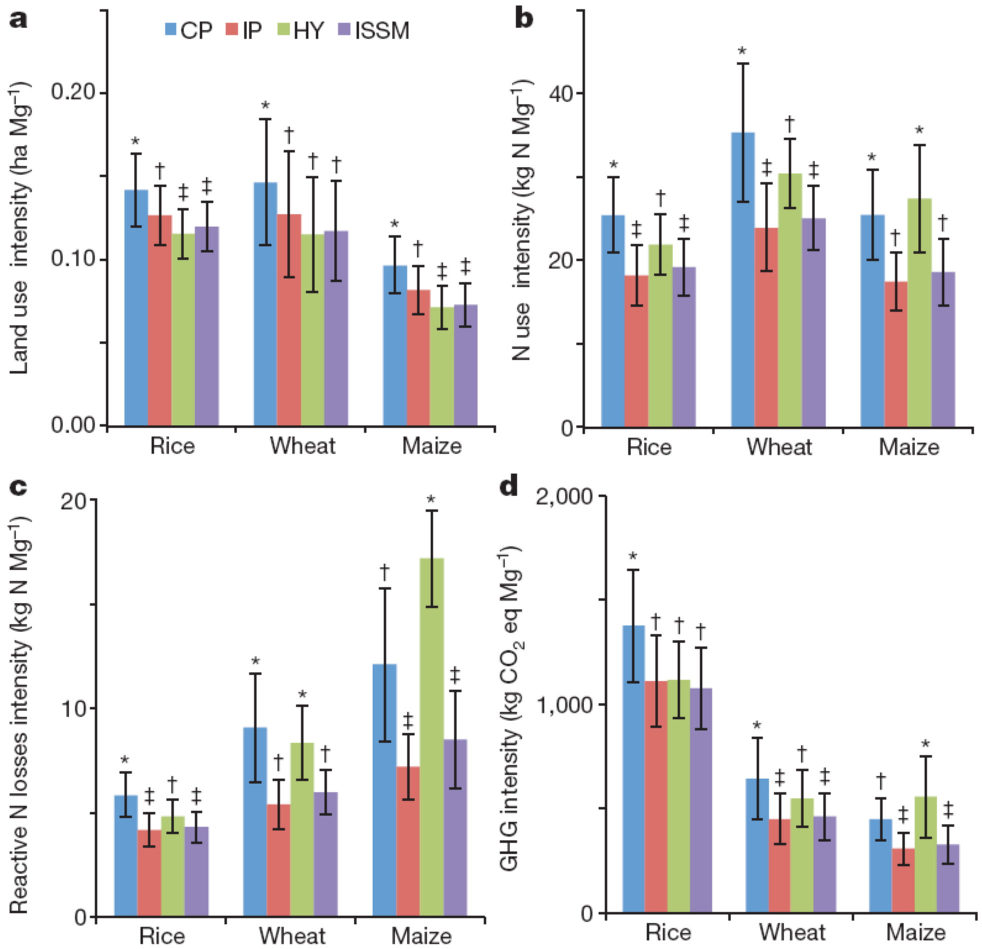


Figure 2 | Substantially increased yields can be produced with lower inputs of nitrogen fertilizer, and so lower human and environmental costs. The intensity of land use (**a**), nitrogen use (**b**), reactive nitrogen losses (**c**) and GHG emissions (**d**) needed to produce 1 Mg of grain, for three crops and four management treatments. Means followed by the same footnote symbol(s) for each crop are not significantly different at $P < 0.05$.

80% of ISSM: meet national demand

The human population of China is projected to reach a peak of 1.47 billion around 2030. Projected demand for rice, wheat and maize in 2030 for China will be 218, 125 and 315 Mt, respectively, for a total of 658 Mt for the three crops.

If farmers could achieve grain yields of 80% of the yield level in our ISSM treatment by 2030, using the same planting area as in 2012, total production will be enough to meet the demand for direct human consumption and domestically produced animal feed.

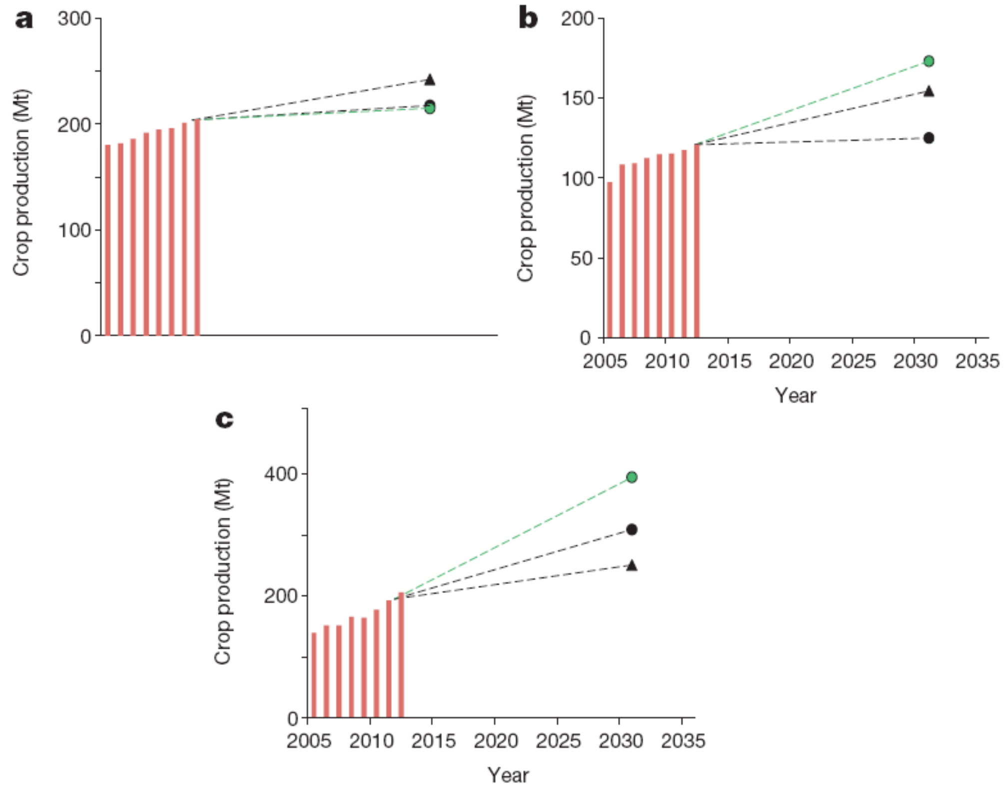


Figure 3 | The projected demand of grain production for 2030 in China. **a**, Rice; **b**, wheat; **c**, maize. Red bars, crop production from 2005 to 2012. Black circles, projected demand in 2030. Black triangles, increasing grain yield by the trend observed from 2005 to 2012, keeping planting area 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)

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- Results and discussion
  - Yield and yield potential
  - Nitrogen use
  - Environmental costs
- Summary

Summary

Yield potentials exist, but are different among crops. Maize has largest potential. Under an ISSM approach, N use in high yielding system could be optimized. The reactive N losses and the GWP per area and as well as per products will not increase (even decrease) with the yield increasing.

Integrated Soil-Crop System Management can make significant contribution for food security and as well as sustainable development (sustainable agricultural intensification).

ISSM needs greater understanding of interactions among soil, crop, and environment, including processes governing the relationships among agricultural inputs, soil quality, climate, and crop productivity.

Thanks

for your attention !