Modeling and assessing effectiveness of intercropping as a sustainable agricultural practice for food security and air pollution mitigation

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FAO: to feed the fast growing population, we need to double our food supply by 2050

But, is the Earth ready for more agricultural activities?

Foley et al. (2011)

Cropland Expansion

Agriculture is the cause of 80% of deforestation worldwide

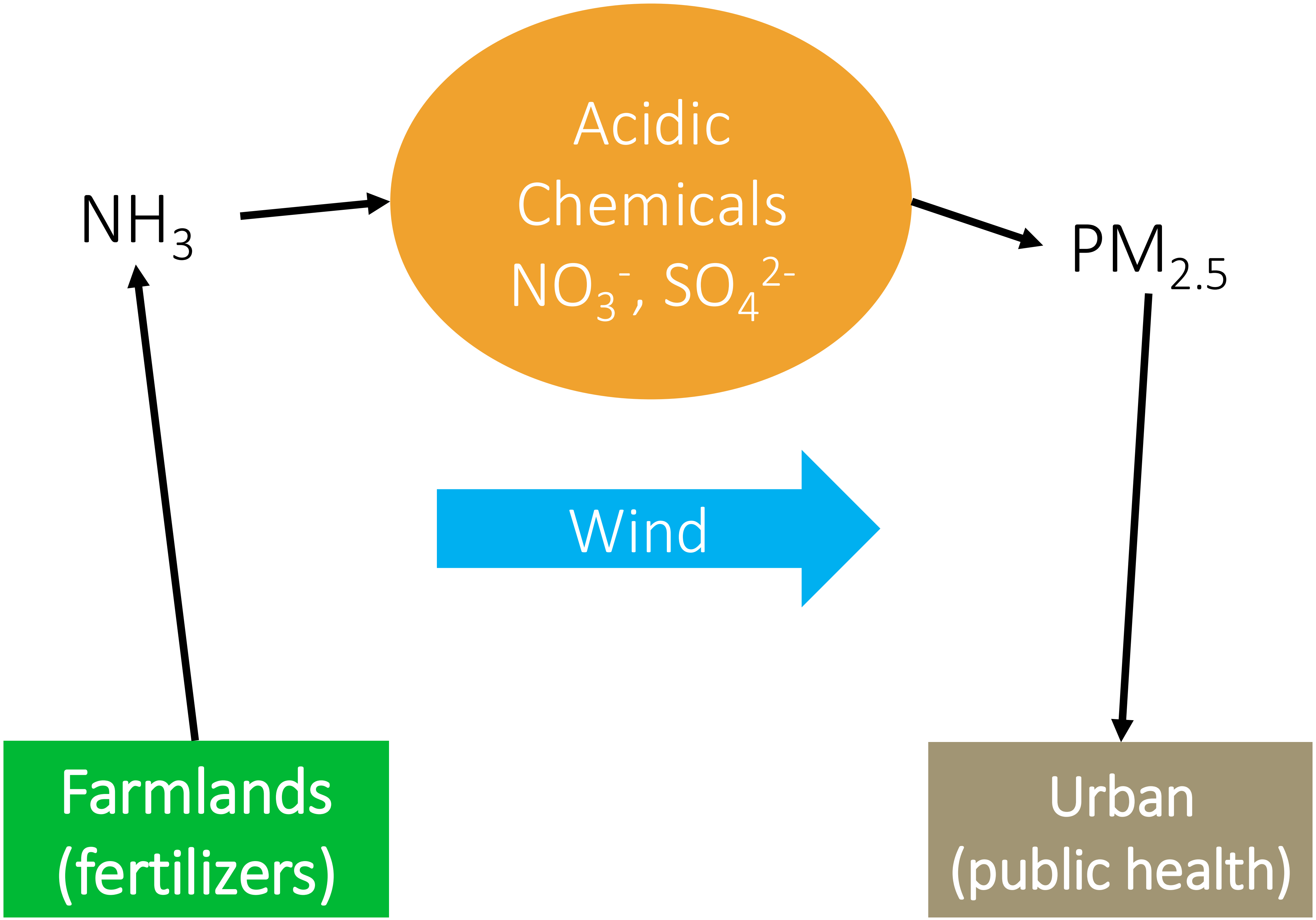
Intensified Farming

70% of fresh water is used for crops and livestock

Over-fertilization makes NH_3 emission an air pollution problem

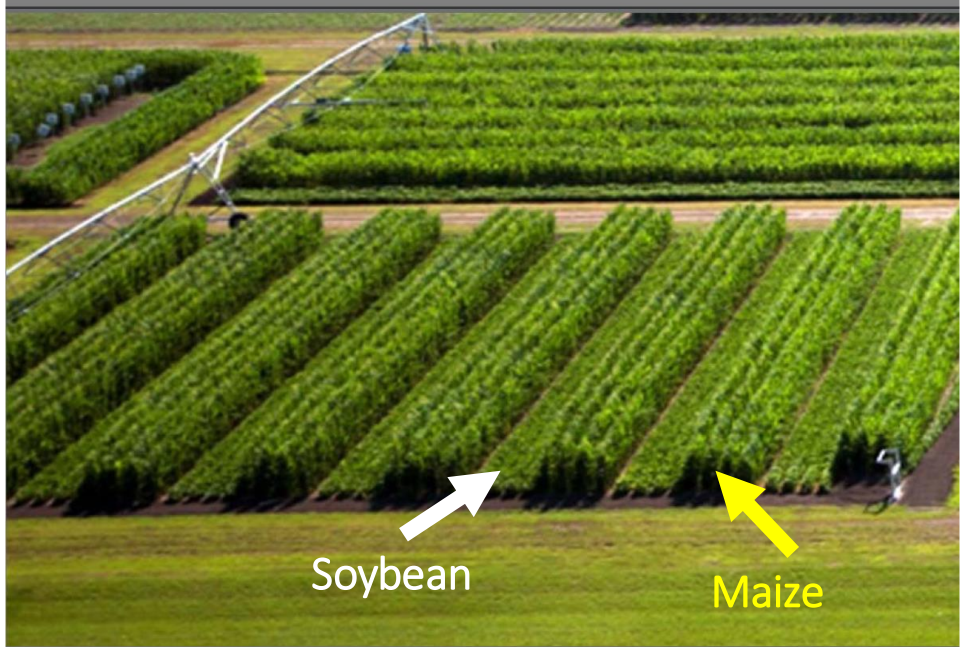
>90% of NH_3 in Europe & China are agricultural emissions and attributable to downwind $PM_{2.5}$

Gu et al. (2012)

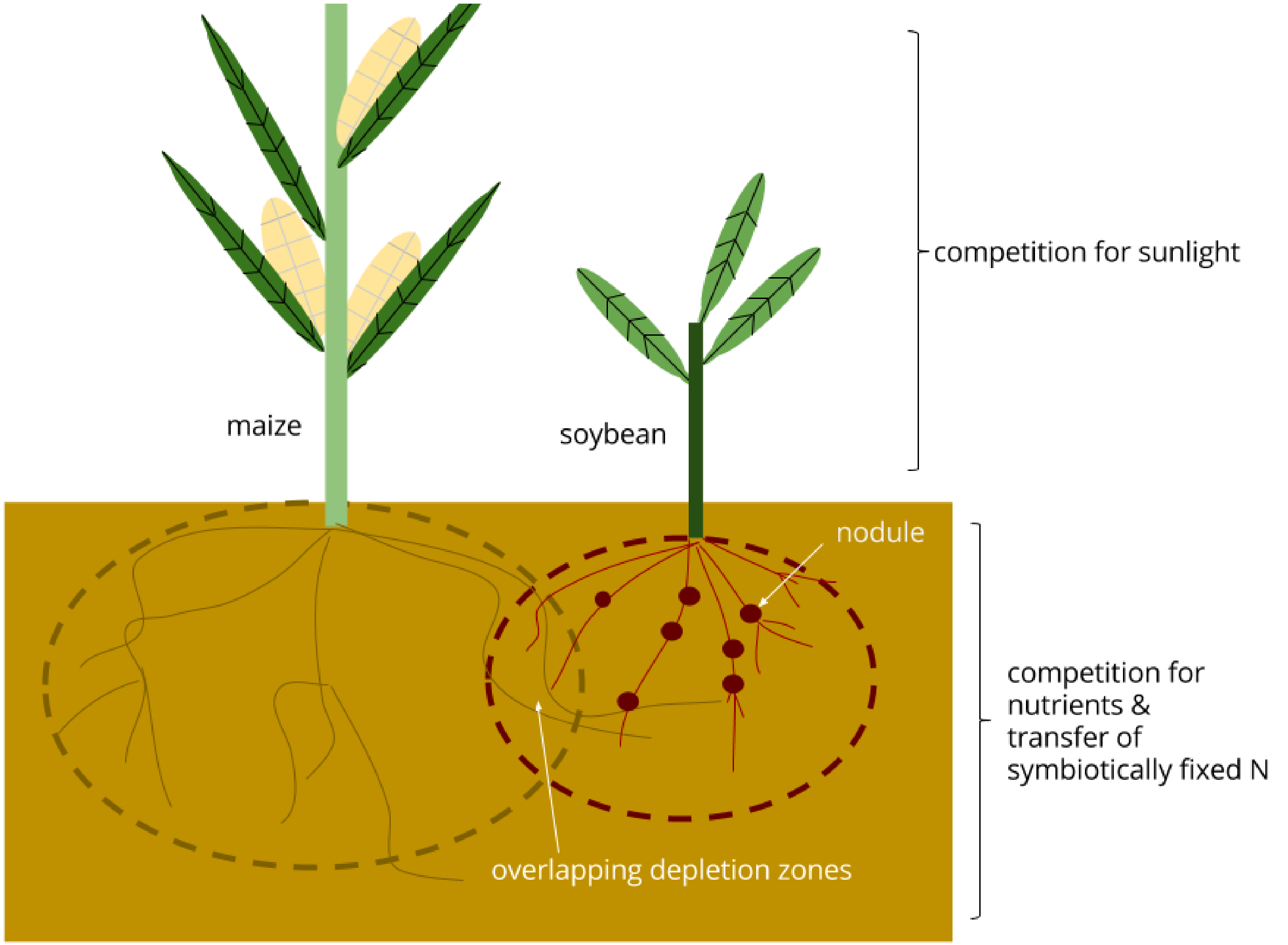


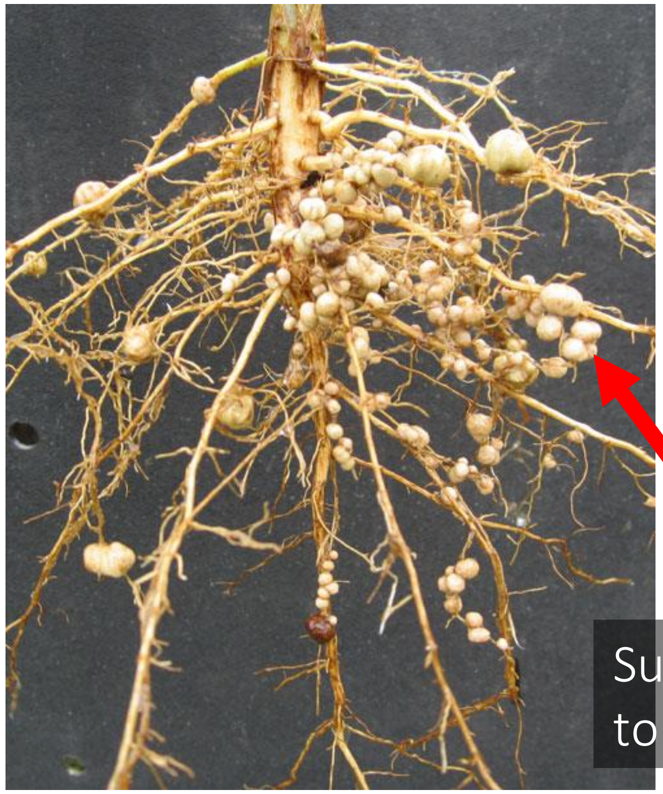
Intercropping could be a way-out to this food-environment dilemma

Two or more crops are planted in alternate strips with a time-delay



They are placed close enough to allow belowground competition





Nitrogen fixing nodules

Such competition triggers and enhances soybean to convert more atmospheric N to soil nutrients

To investigate its beneficial effects, we simulate a large-scale intercropping in China

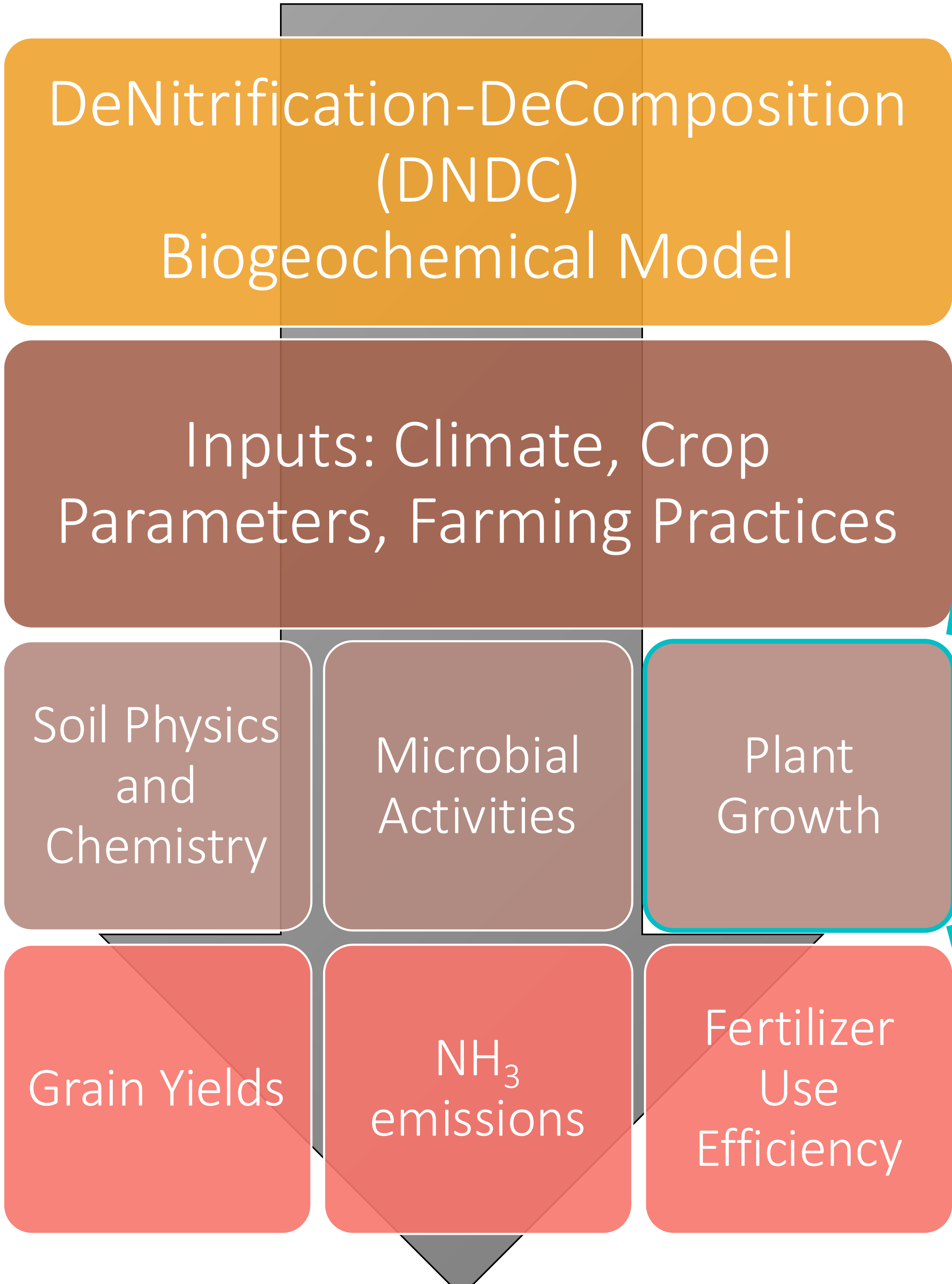
Adding intercropping into DeNitrification-DeComposition (DNDC) biogeochemical model

Simulating a nationwide conversion of the maize and soybean monoculture farmlands to intercropping in China

Predicting downwind $PM_{2.5}$ using GEOS-Chem 3-D global chemical transport model

Performing a cost-and-benefit analysis of such conversion of farmlands

We enable intercropping in DNDC by adding a new nutrient allocation algorithm



1. Fraction of non-nodulated roots:

$$f_{\text{uptake}} = \frac{N_{\text{uptake}}}{N_{\text{demand}}} = \frac{1}{\frac{N_{\text{demand}}}{N_{\text{uptake}}}} = \frac{1}{\frac{N_{\text{uptake}} + N_{\text{fix}}}{N_{\text{uptake}}}}$$

$$= \frac{1}{\text{N Fixation Index}}$$

2. Assuming size of depletion zone is proportional to root mass, competition factor is defined as:

$$CF_{\text{crop}} = \frac{\text{space occupied by crop}}{\text{space occupied by system}}$$

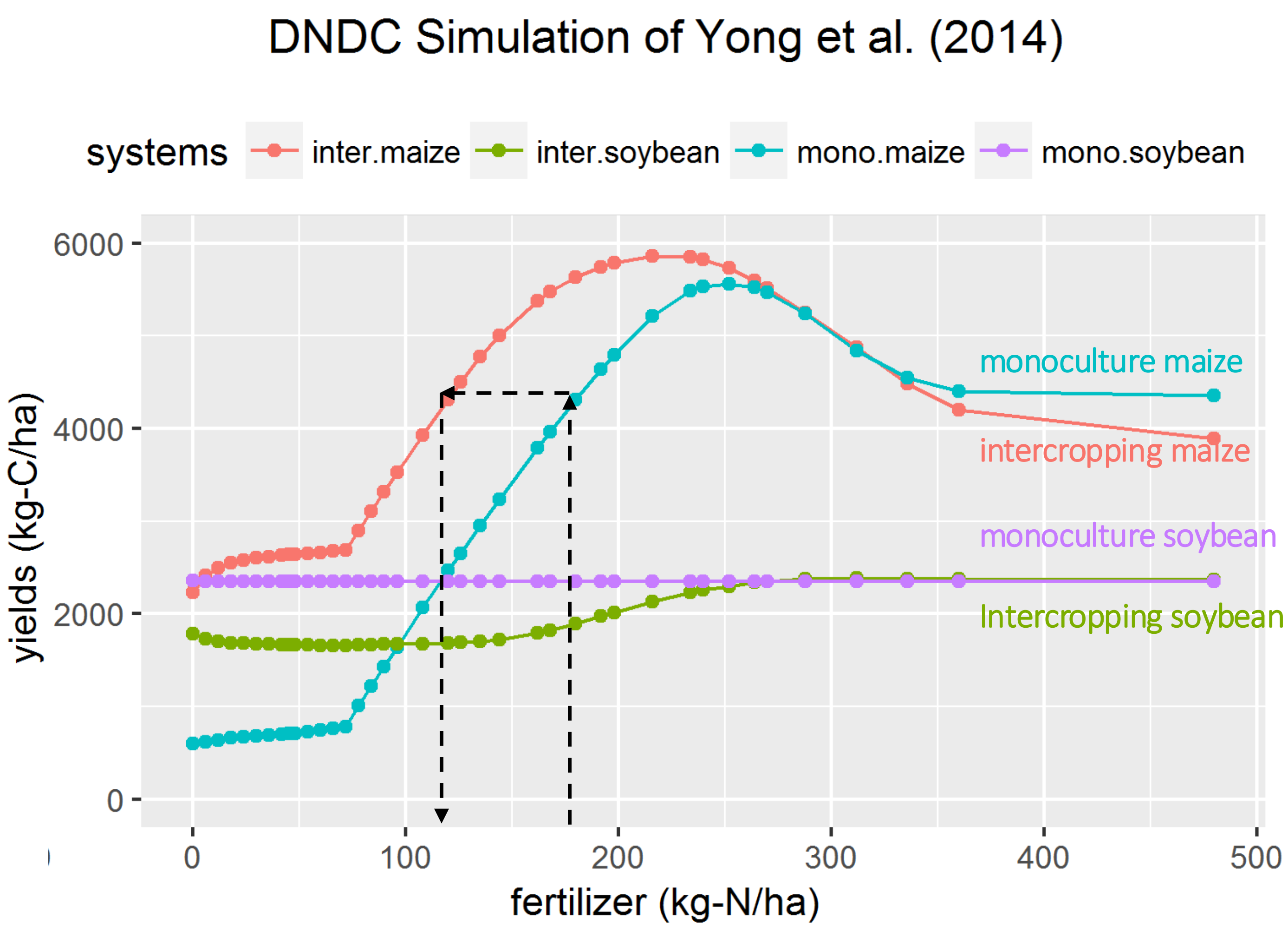
$$\approx \frac{mass_{\text{root,crop}} \cdot f_{\text{uptake,crop}}}{\sum_{crop} mass_{\text{root,crop}} \cdot f_{\text{uptake,crop}}}$$

3. In each iteration, the amount of N a crop could get from a soil layer:

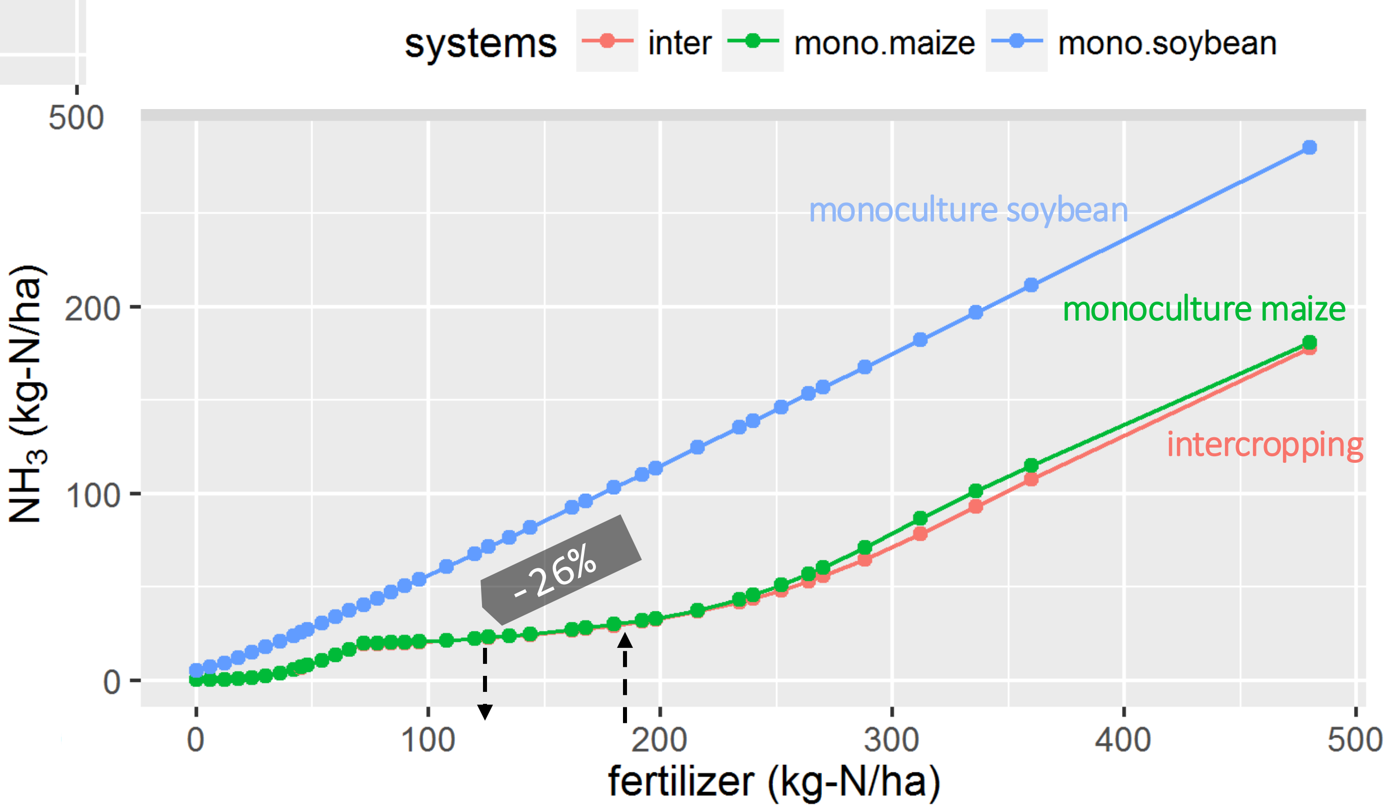
$$N_{\text{uptake,crop}} = \min\left(N_{\text{accessible,crop}}, N_{\text{demand,crop}}\right)$$

$$= \min(CF_{\text{crop}} \cdot N_{\text{soil}} , N_{\text{demand,crop}})$$

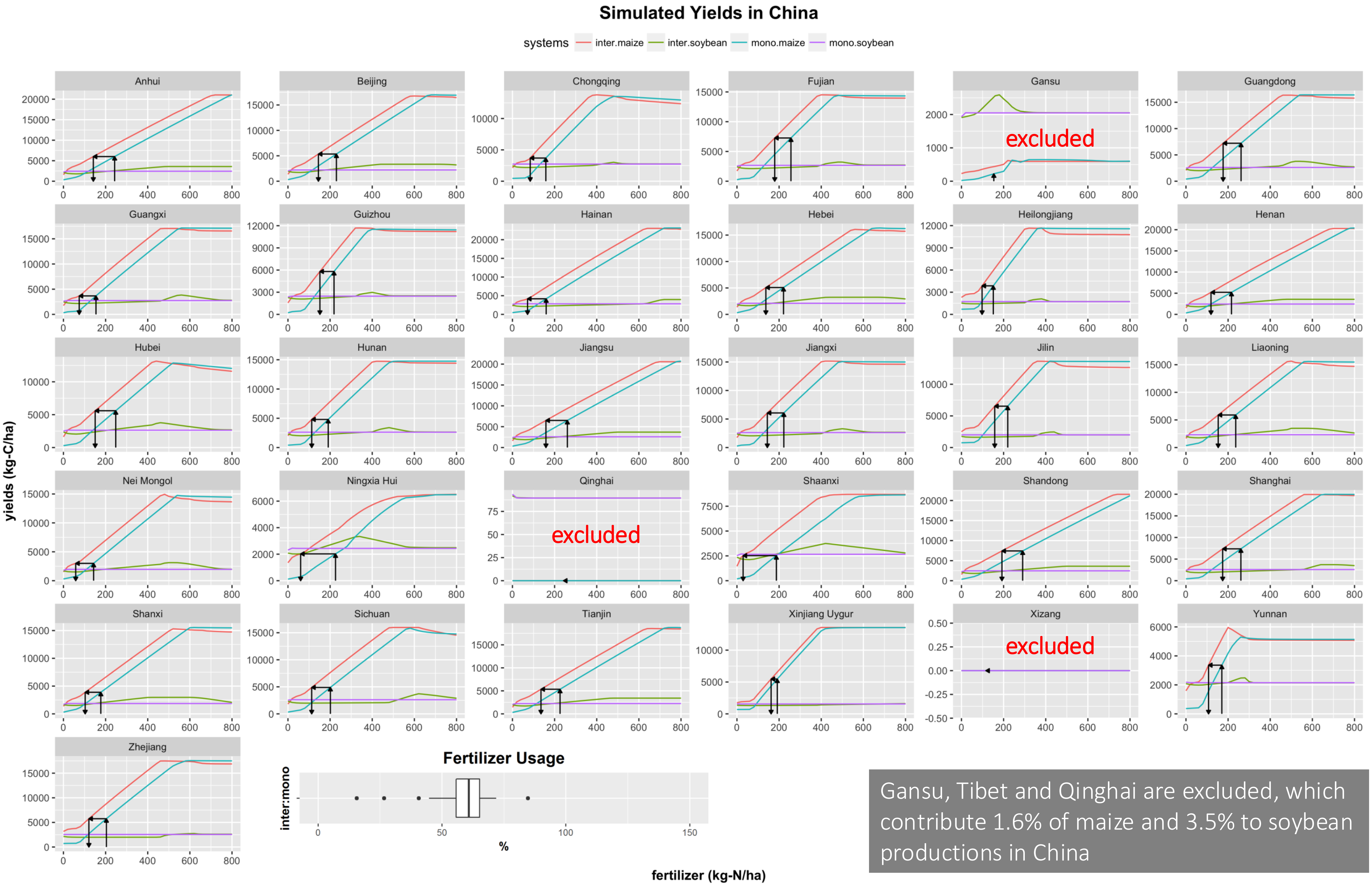
Using input data of a field experiment, our simulation shows that



1. Less fertilizer (-33%) to maintain maize yield
2. Extra batch of soybean produced



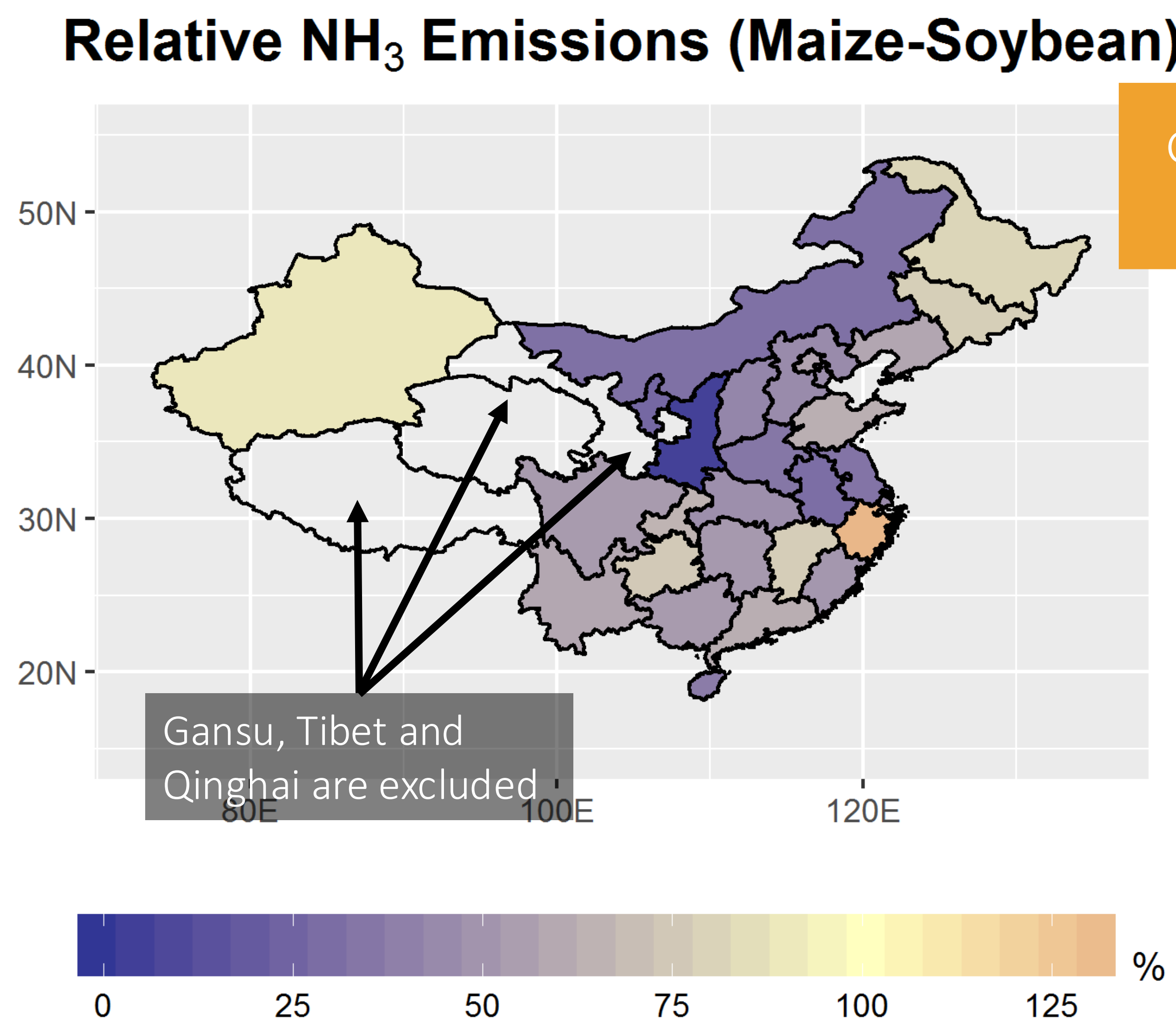
3. NH_3 emission is reduced by 26%



Gansu, Tibet and Qinghai are excluded, which contribute 1.6% of maize and 3.5% to soybean productions in China

On average, converting monoculture to intercropping in China could save 42% of fertilizer use while maintaining the maize production

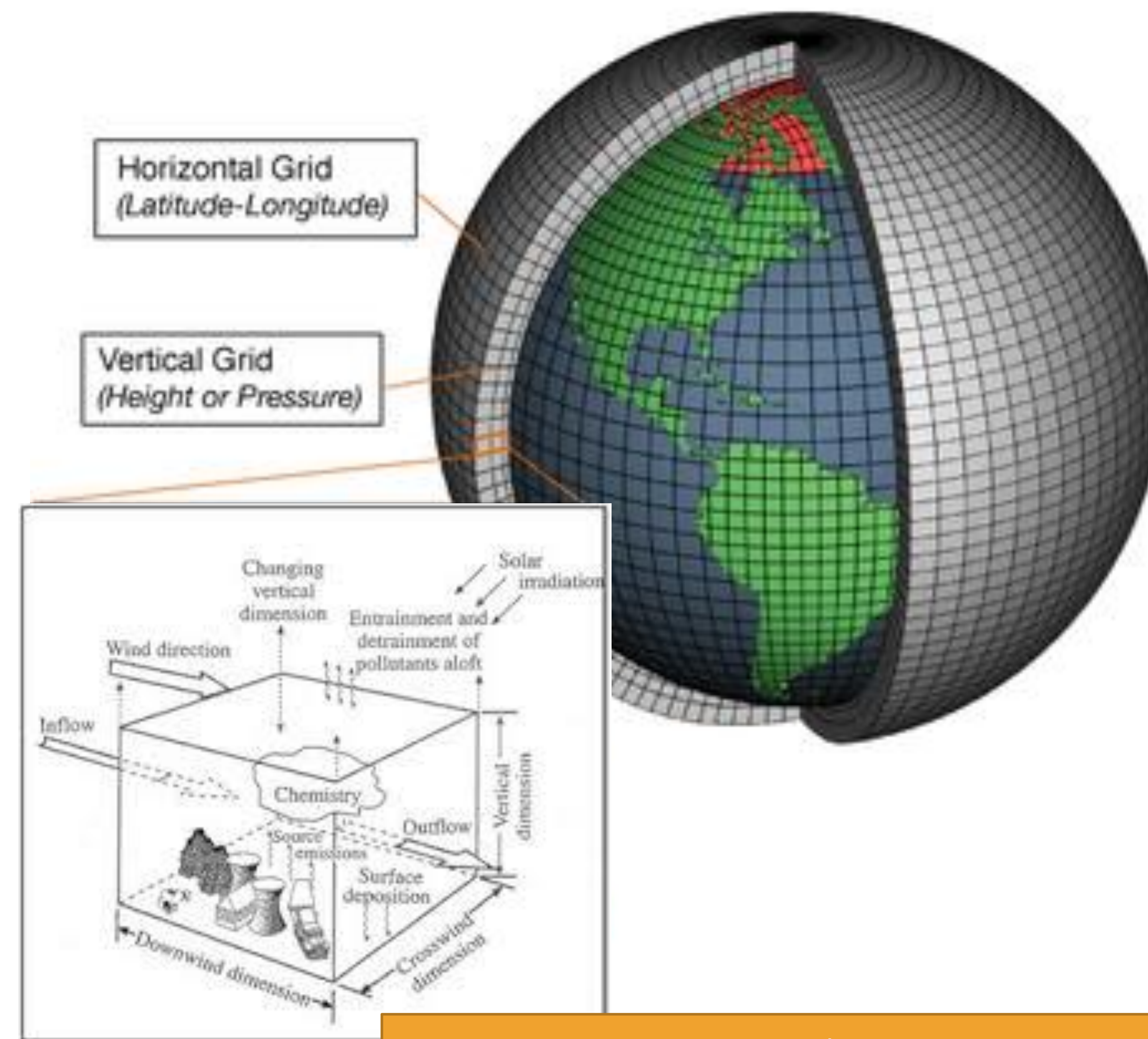
Correspondingly, NH_3 emission could be reduced by 45%



Grid-by-grid scaling

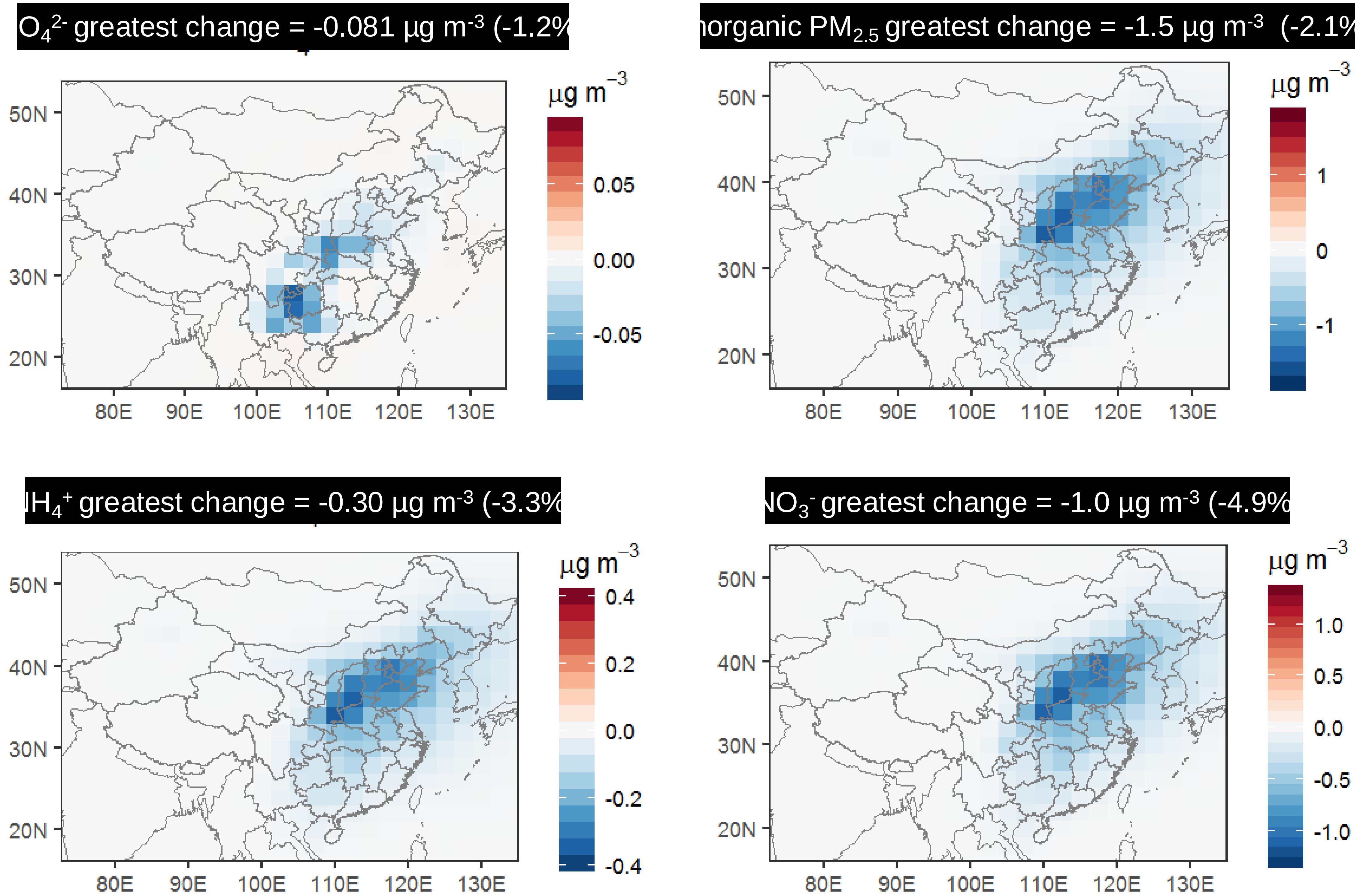
NH_3 Emission Inventory

(Magnitude And Seasonality of Agricultural Emissions; MASAGE)



GEOS-Chem
3-D Global Chemical Transport Model

GEOS-Chem predicts improvements in air quality after converting farmlands to intercropping

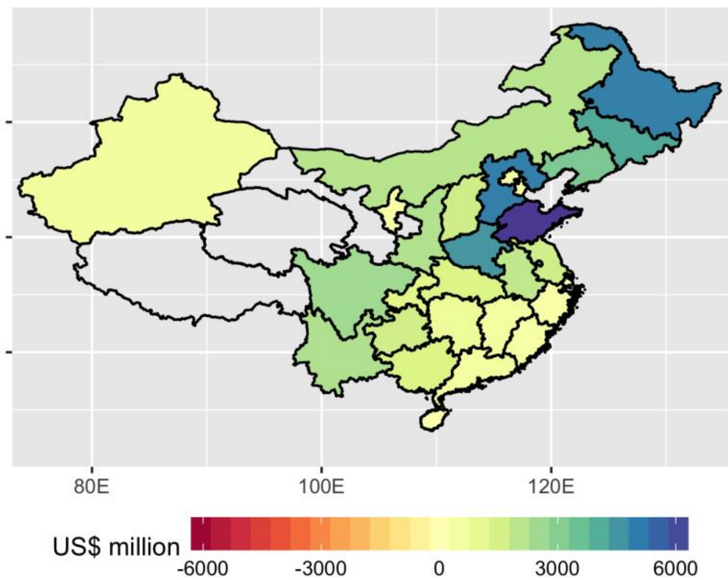


(% to local mean without intercropping)

Costs and benefits of converting monoculture to intercropping

Paulot & Jacob (2013)

Revenue from Grain Yields
(Sum = US$ 51,021 million)



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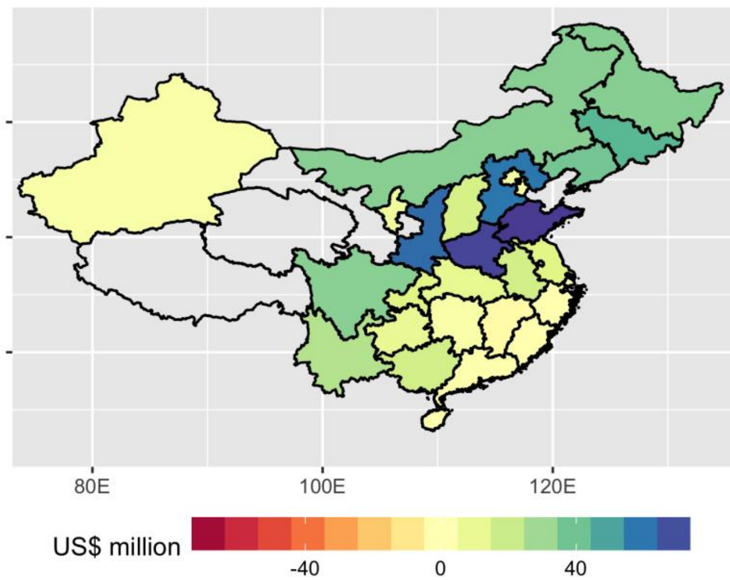
Saved Costs on Fertilizers
(Sum = US$ 610 million)



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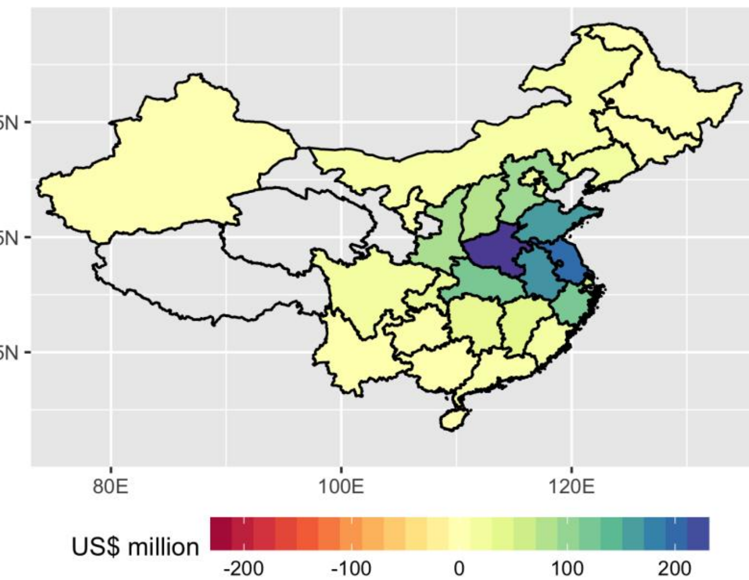
Saved Health Costs
(Sum = US$ 1,545 million)



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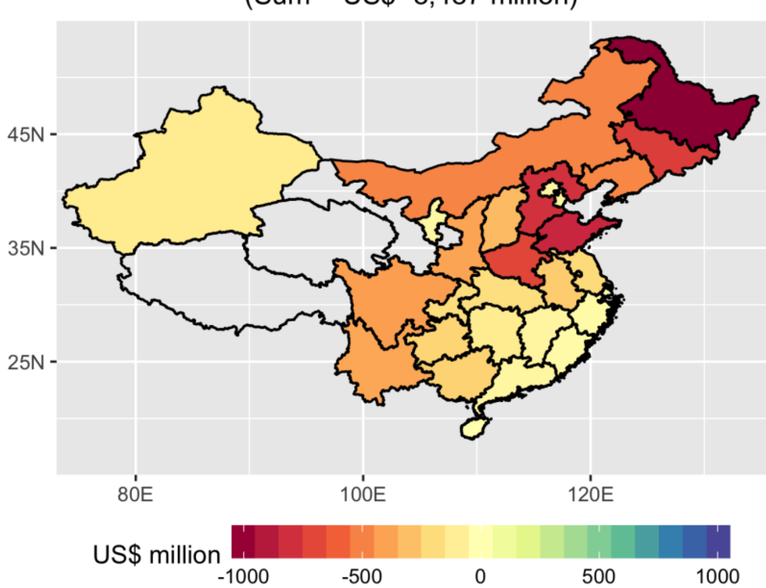
Saved Production Costs (Machinery & Labour)
(Sum = US$ -8,487 million)



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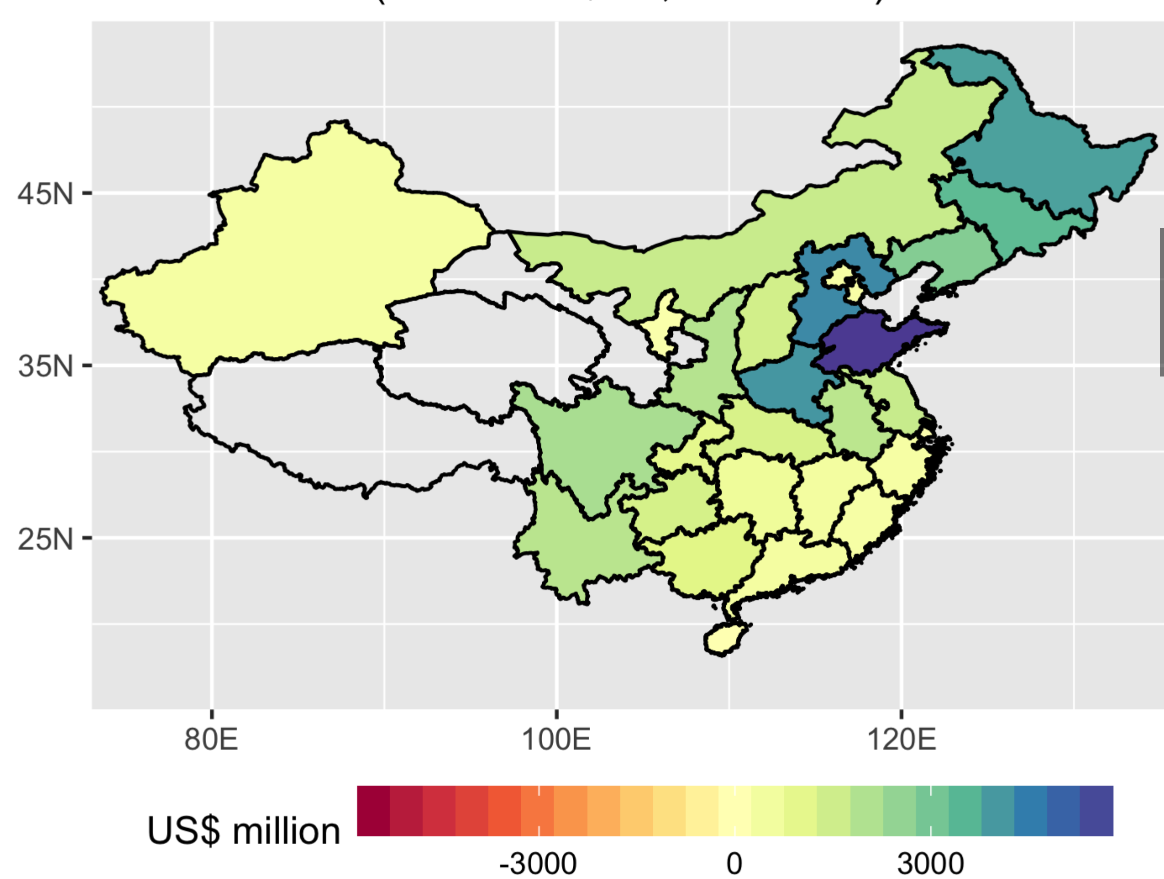
Net Gain with Intercropping (Maize-Soybean)
(Sum = US$ 44,689 million)



+85%

Item	Per Unit (US$)
Maize	0.410/kg
Soybean	0.798/kg
Urea	0.309/kg
NH_3	3.300/kg
Labor & Machinery	263.14/ha

Summary

Next: Intercropping and NH_3 emissions in the Community Land Model (CLM)

Land Use Efficiency
Multiple crops are produced on the same land over a single planting period

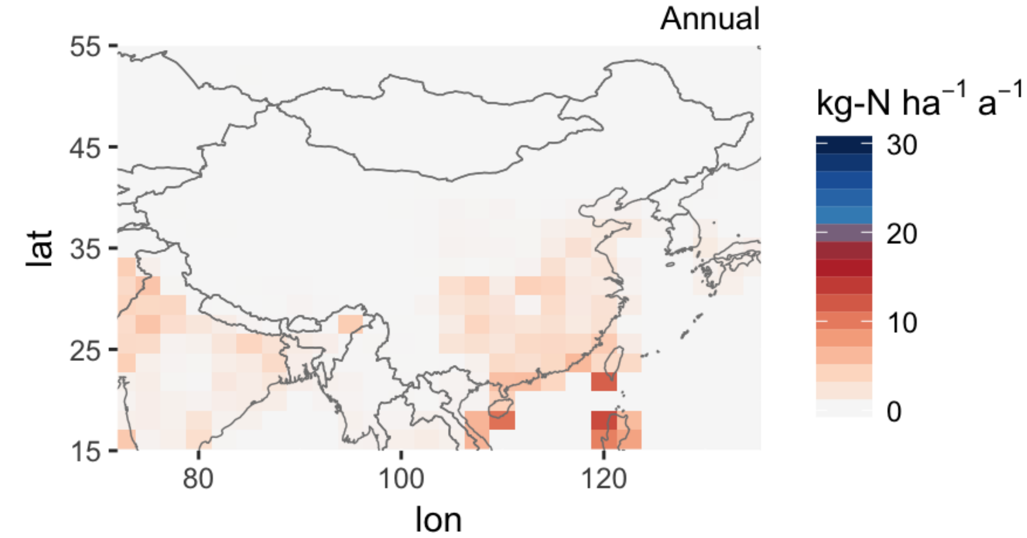
N Use Efficiency
Yield of maize is maintained and an extra crop of soybean is produced while saving 42% of fertilizer

Intercropping in China

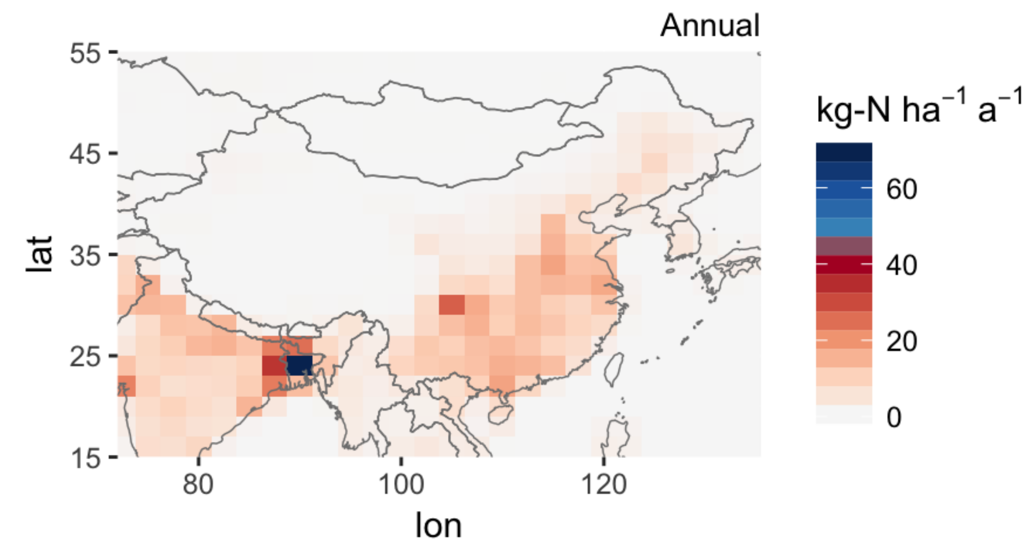
Environmental Sustainability
NH_3 emissions are reduced by 45% and $PM_{2.5}$ concentration is dropped by up to 2.1%

Profitability
Net economic benefits can be up to US$45b including US$1.5b health costs saved

CLM-NH3 (iter = 100)



MASAGE



Thank you!