Large-scale adoption of intercropping for securing global food supply and air quality – a model study using CLM 4.5

Ka Ming FUNG (kamingfung@link.cuhk.edu.hk)

Graduate Division of Earth and Atmospheric Sciences
Faculty of Science
The Chinese University of Hong Kong

Advisors: Amos Tai (CUHK), Eri Saikawa (Emory)

CESM LMWG Meeting
February 5th, 2018

EMORY UNIVERSITY

香港中文大學
The Chinese University of Hong Kong

Damages done by agricultural emissions are comparable to those caused by industrial sectors

Gu et al. (2012)

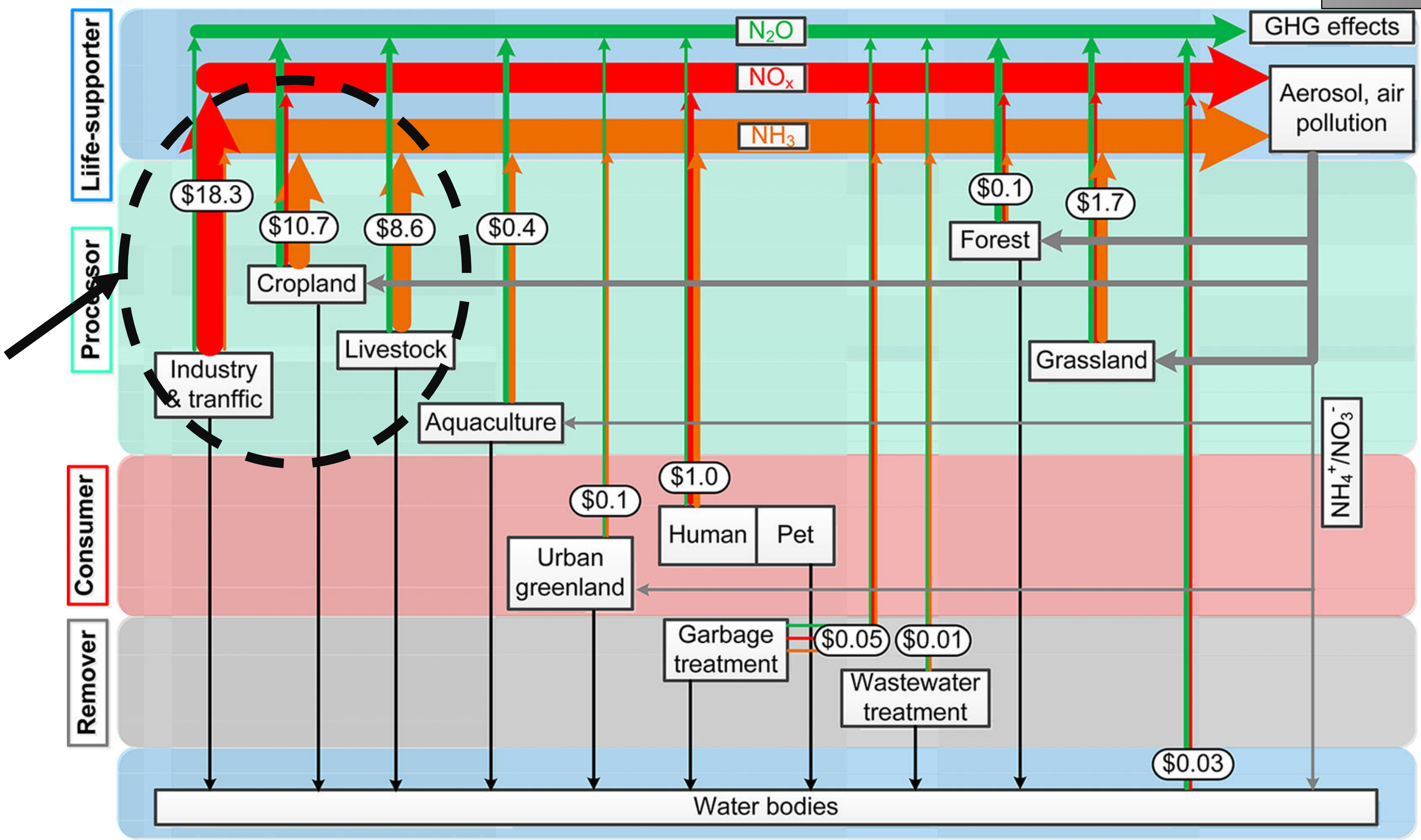
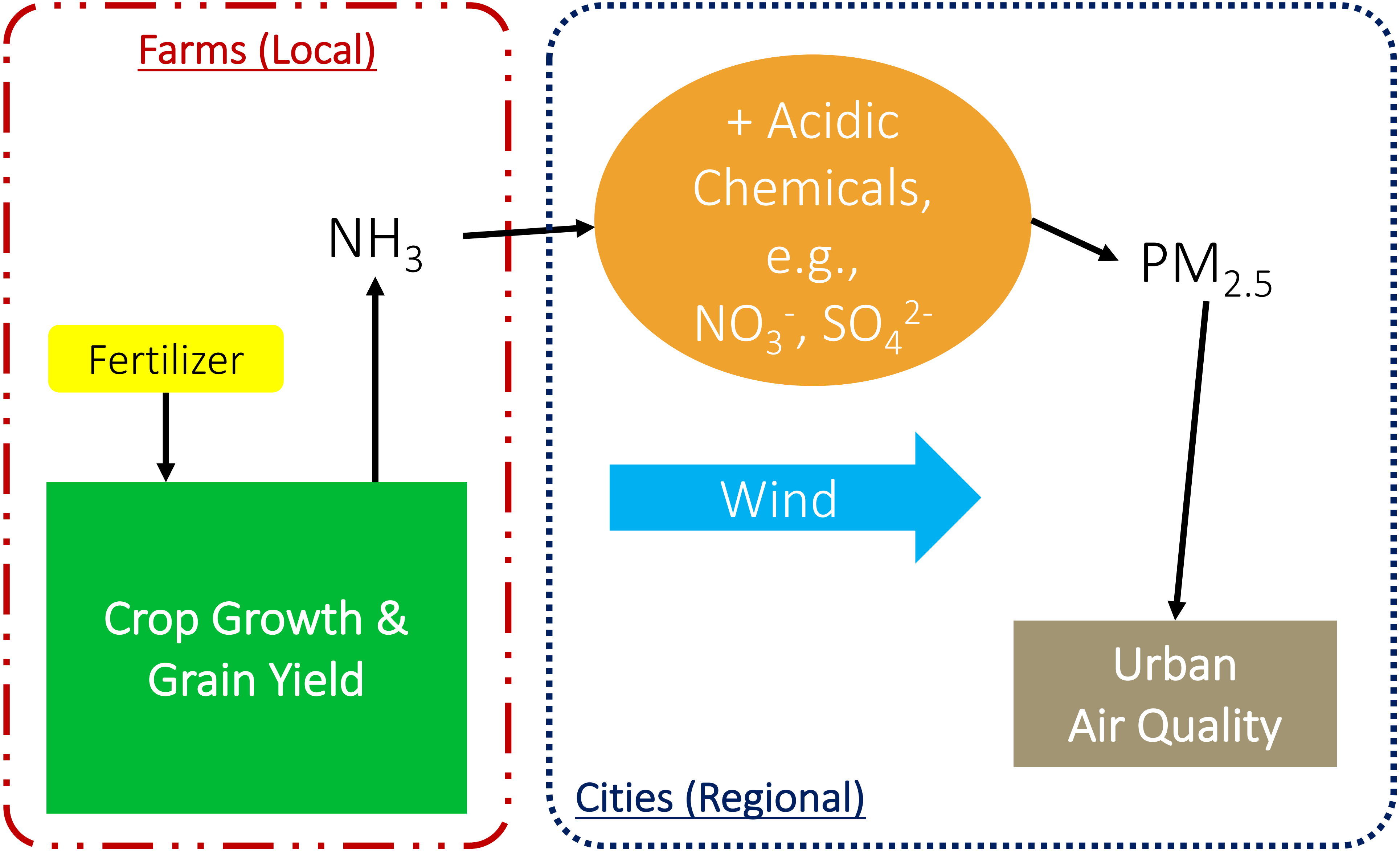


Figure 4. Summary of health damage costs by nitrogen emission among different subsystems and functional groups across China in 2008. Arrow colors: black = nitrogen fluxes to water bodies; green = N_2O; gray = nitrogen deposition; orange = NH_3; red = NO_x. The colors of the backgrounds represent different functional groups: blue = life-supporter; green = processor; red = consumer; gray = remover. Units of the damage costs are billions of US dollars. Urban greenland was reassigned to the consumer group owing to its close relationship with the human and pet subsystem as well as its nonproduct supply services.

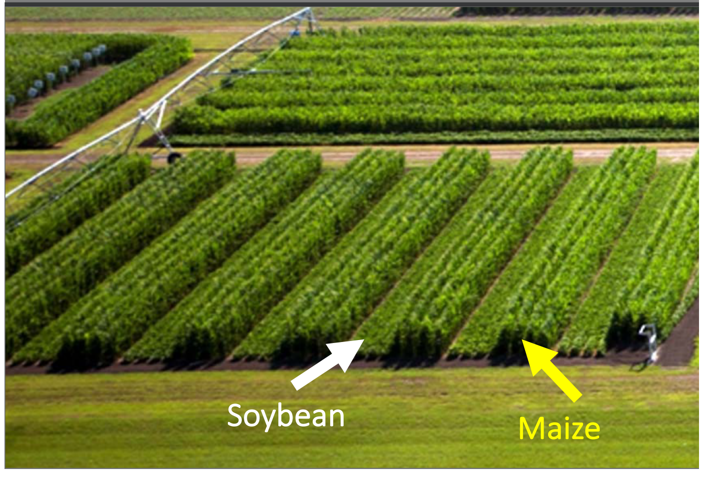
Rising food production driven by fast population growth could be a bigger threat to air quality

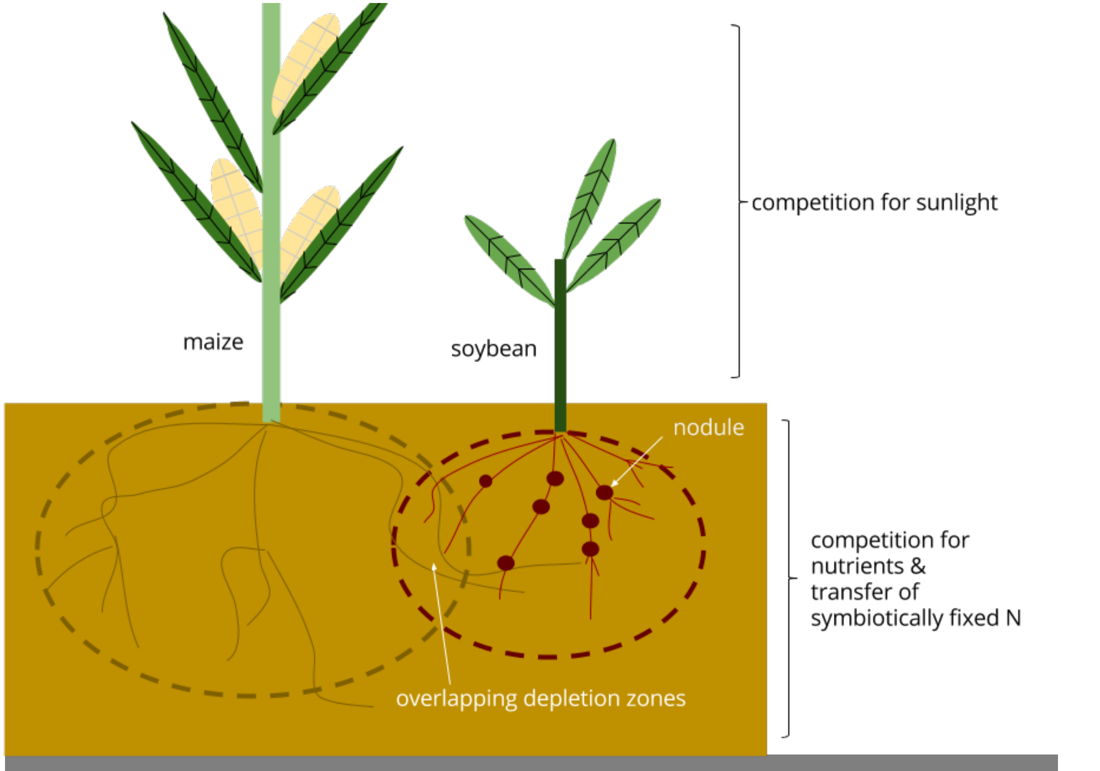


Maize-soybean intercropping is capable of generating the same amount of crop production with 30% less fertilizer, and 26% less NH_3

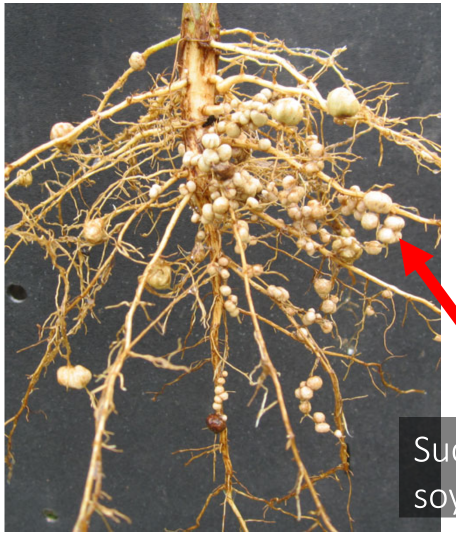
Yong et al. (2014)

Maize is first planted in the field. After a month, soybean is seeded in between maize strips.





They are placed close enough to allow belowground competition

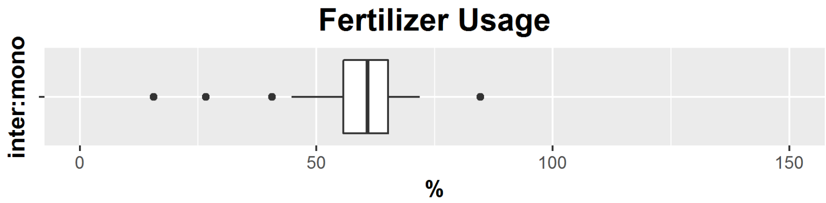


Nitrogen fixing nodules

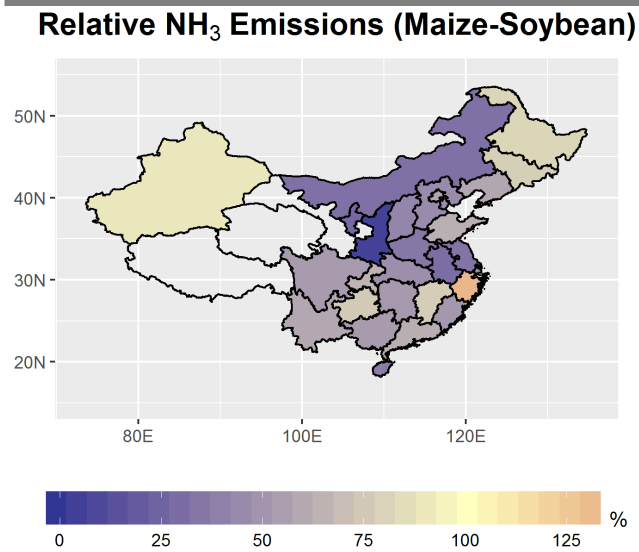
Such competition triggers and enhances soybean to fix more atmospheric N to the soil

Nation-wide adoption of intercropping could bring China both environmental and economic benefits

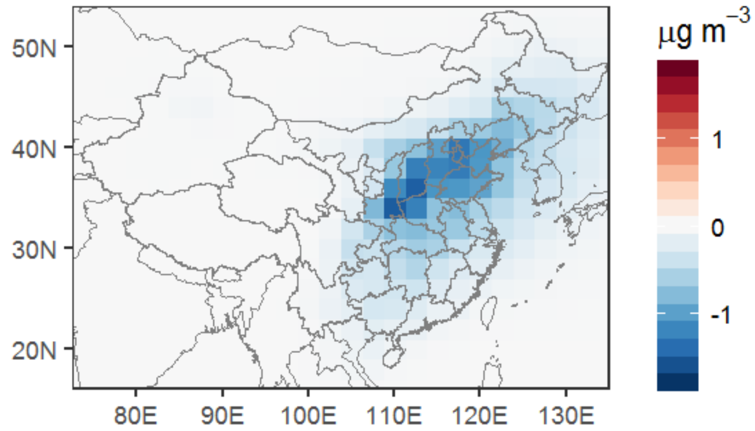
On average, maize production could be maintained with 42% less fertilizers



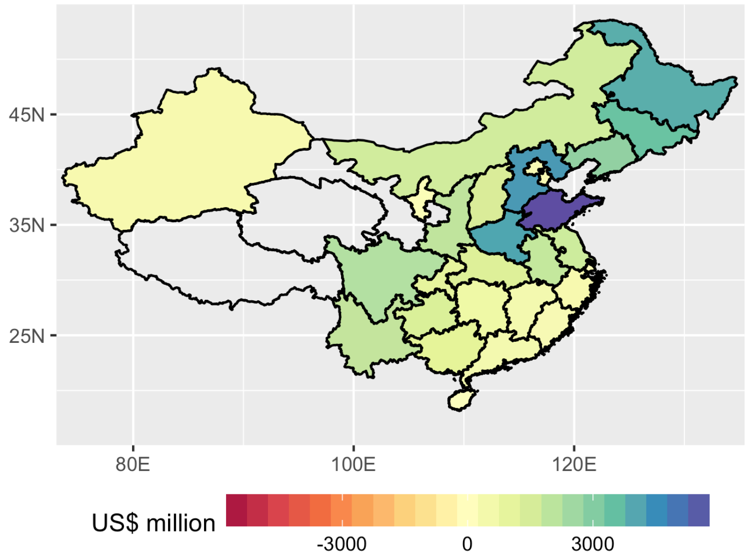
NH$_3$ emission could be lowered by 45%



Downwind PM$_{2.5}$ could be reduced by up to 2.1% (1.5 μg m^{-3})



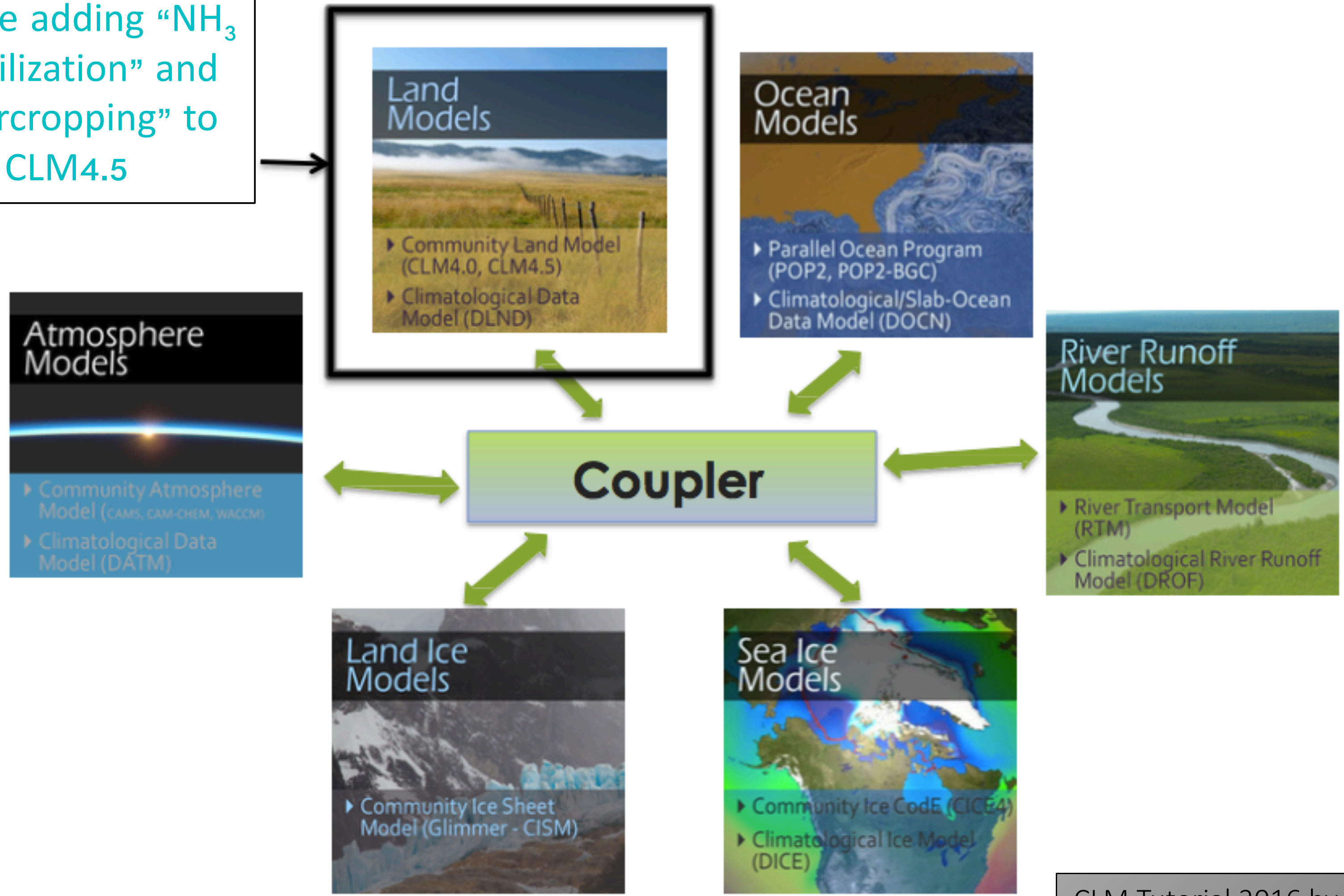
Net profit could increase US$45b (+85%) nationwide, including US$1.5b saved health cost



Fung et al. (in prep.)

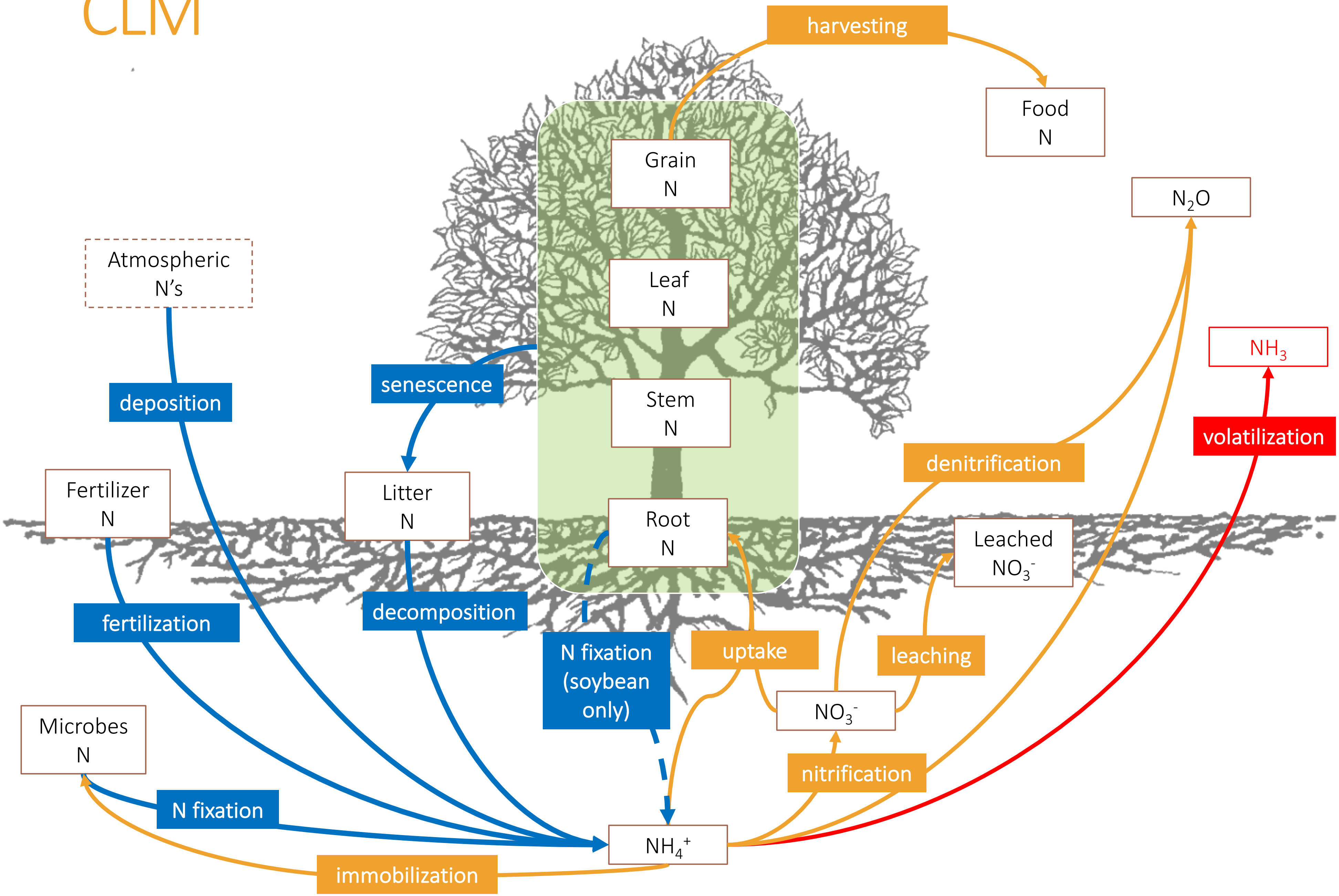
Crop growth is highly coupled with climate and the environment

We are adding "NH_3 volatilization" and "intercropping" to CLM4.5



CLM Tutorial 2016 by Lombardozzi

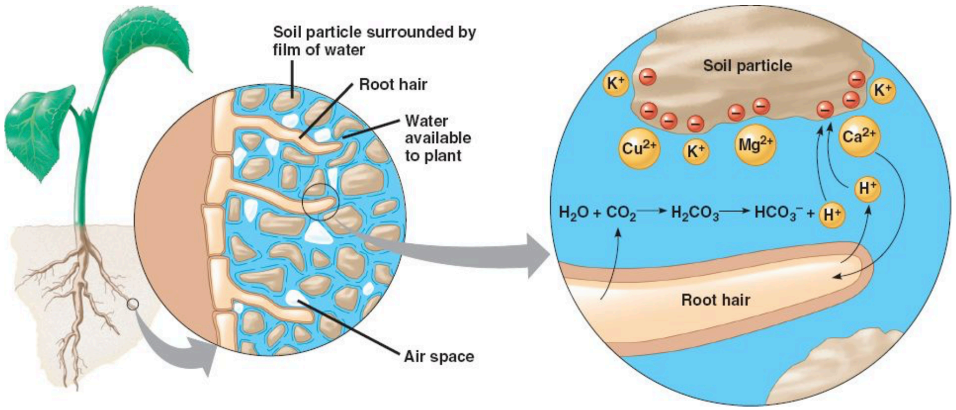
A missing pathway in the nitrogen cycle of CLM



We borrow the multi-stage NH_3 volatilization scheme for CLM from DNDC (Li et al., 2012)

NH_4^+ (soil) → NH_4^+ (non-ads) → NH_3 (aq) → NH_3 (g)

Campbell et al. (2008)



Equilibrium between [NH_4^+ (non-abs)] and [NH_3 (aq)]:

rate constants of hydrolysis

soil temperature (°C)

$$\begin{cases} K_w = 10^{0.08946+(0.03605)T_{soil}} \times 10^{-15}\ (\mathrm{mol^2\ L^{-2}}) \\ K_a = (1.416 + (0.01357)T_{soil}) \times 10^{-5}\ (\mathrm{mol\ L^{-1}}) \\ [\mathrm{H^+}] = 10^{-\mathrm{pH}} \\ [\mathrm{OH^-}] = K_w/[\mathrm{H^+}] \\ \left[\mathrm{NH_{3\,(aq)}}\right] = \left[\mathrm{NH_4^+}_{\,(non-ads)}\right][\mathrm{OH^-}]/\mathrm{K_a} \end{cases}$$

rate constants of dissociation

DNDCv9.5 uses an empirical equation for adsorption of NH_4^+:

clay fraction

$$f_{\mathrm{ads}} = 0.99(7.2733 f_{\mathrm{clay}}^3 - 11.22 f_{\mathrm{clay}}^2 + 5.7198 f_{\mathrm{clay}} + 0.0263)$$

The non-adsorbed [NH_4^+] is given by:

$$\left[NH_4^+{}_{(\mathrm{non-ads})}\right] = \left[NH_4^+{}_{(\mathrm{soil})}\right](1 - f_{\mathrm{ads}})$$

Volatilization rate of [NH_3 (aq)] from a soil layer in one time-step is found by:

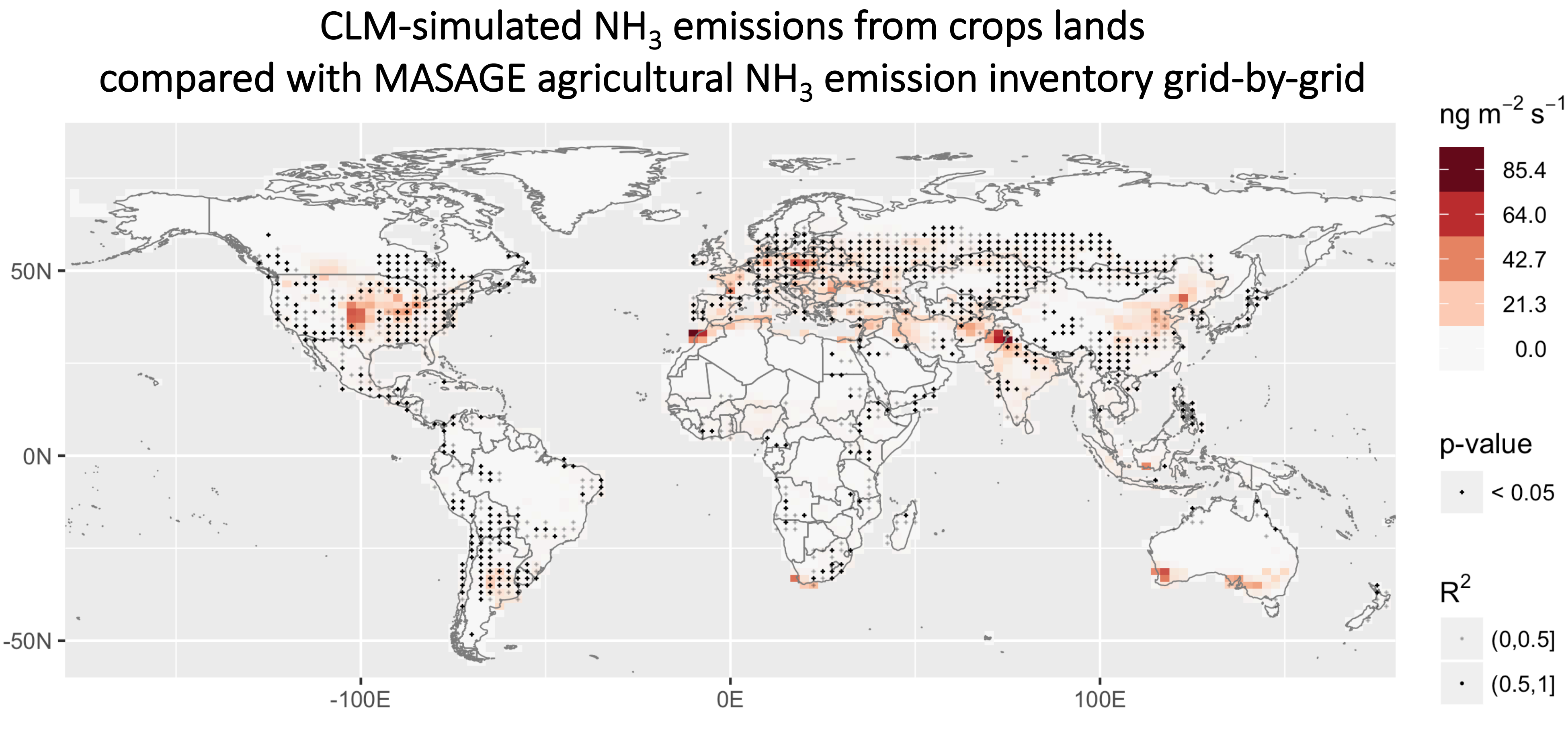
soil layer index

$$\frac{d[\mathrm{NH_{3\,(g)}}]}{dt} = [\mathrm{NH_{3\,(aq)}}]\left(\frac{1.5s}{1+s}\right)\left(\frac{T_{\mathrm{soil}}}{50 + T_{\mathrm{soil}}}\right)\left(\frac{q_{\max} - q}{q_{\max}}\right)\left(\frac{1}{\Delta t}\right)$$

wind speed (m s^{-1})

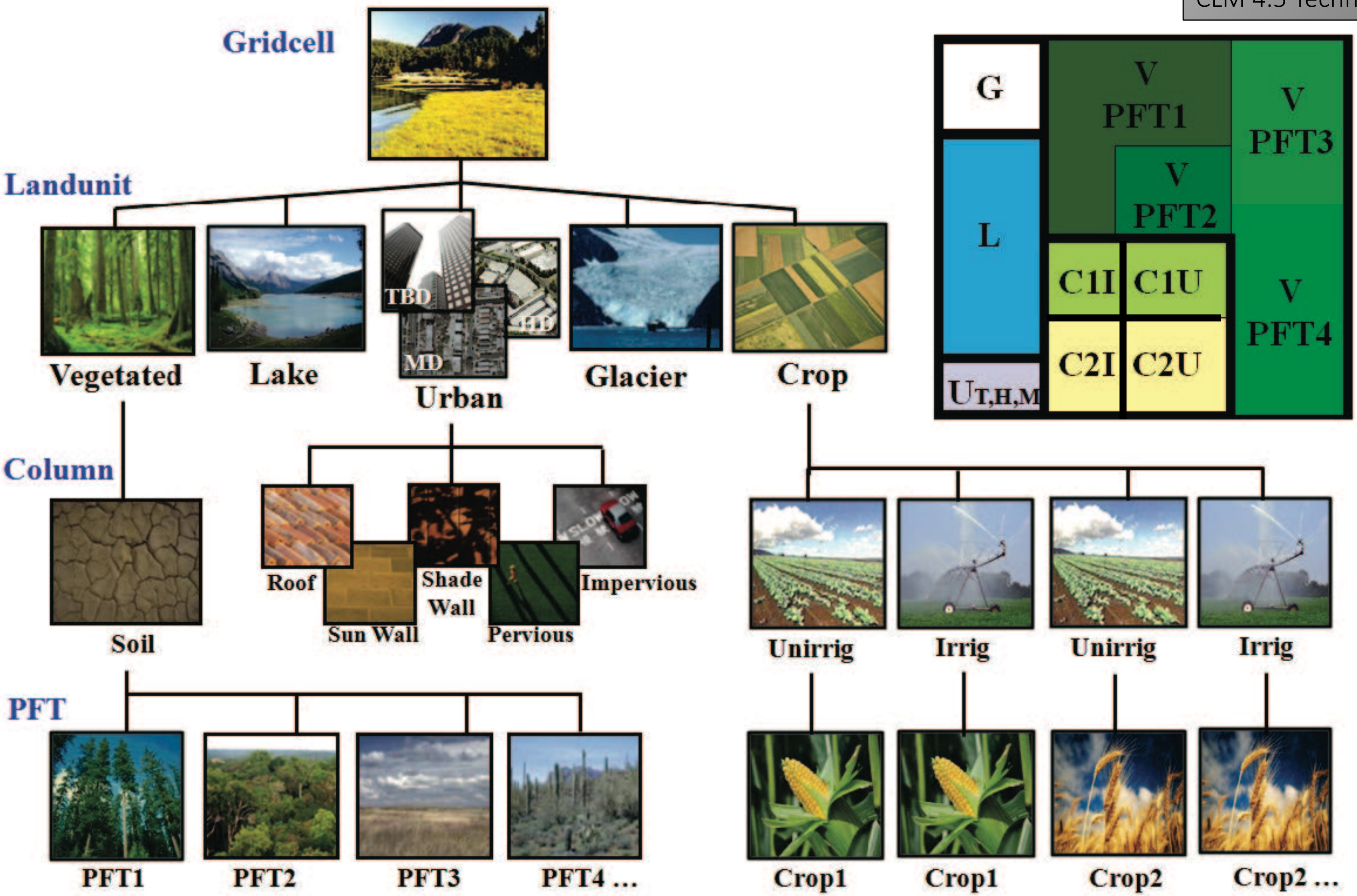
CLM time-step size (s)

CLM-simulated monthly-averaged NH_3 emission agrees well with MASAGE over most high emission regions



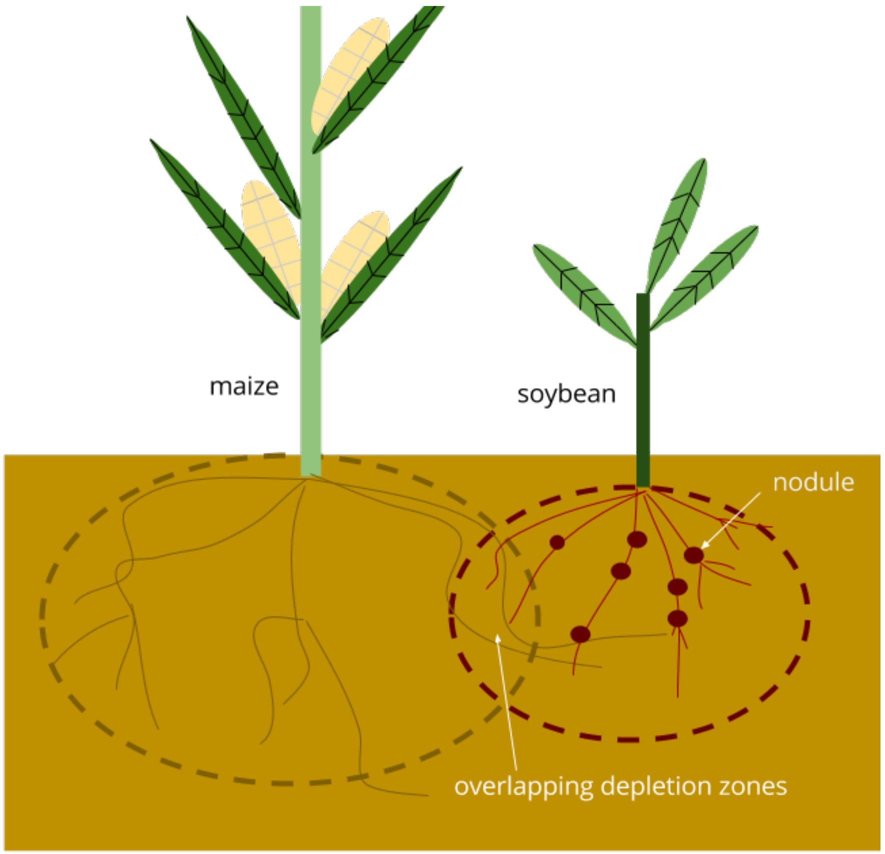
Fung et al. (in prep.)

CLM 4.5 Technical Note



To allow intercropped crops to compete for nutrients, soil N deployed for plant growth is now transferrable among intercropped soil columns

A new variable added to quantify belowground crop-crop competition under intercropping



Fung et al. (in prep.)

1. Assuming surface area of a crop’s root is proportional to its mass, a crop’s competition factor (CF) is then defined as:

$$CF_{crop} = \frac{\text{total root surface area a crop}}{\text{total root surface area of both crops}}$$

$$\approx \frac{\text{mass}_{\text{root,crop}} \cdot \text{weighting}_{\text{crop}}}{\sum_{\text{system}} \text{mass}_{\text{root,crop}} \cdot \text{weighting}_{\text{crop}}}$$

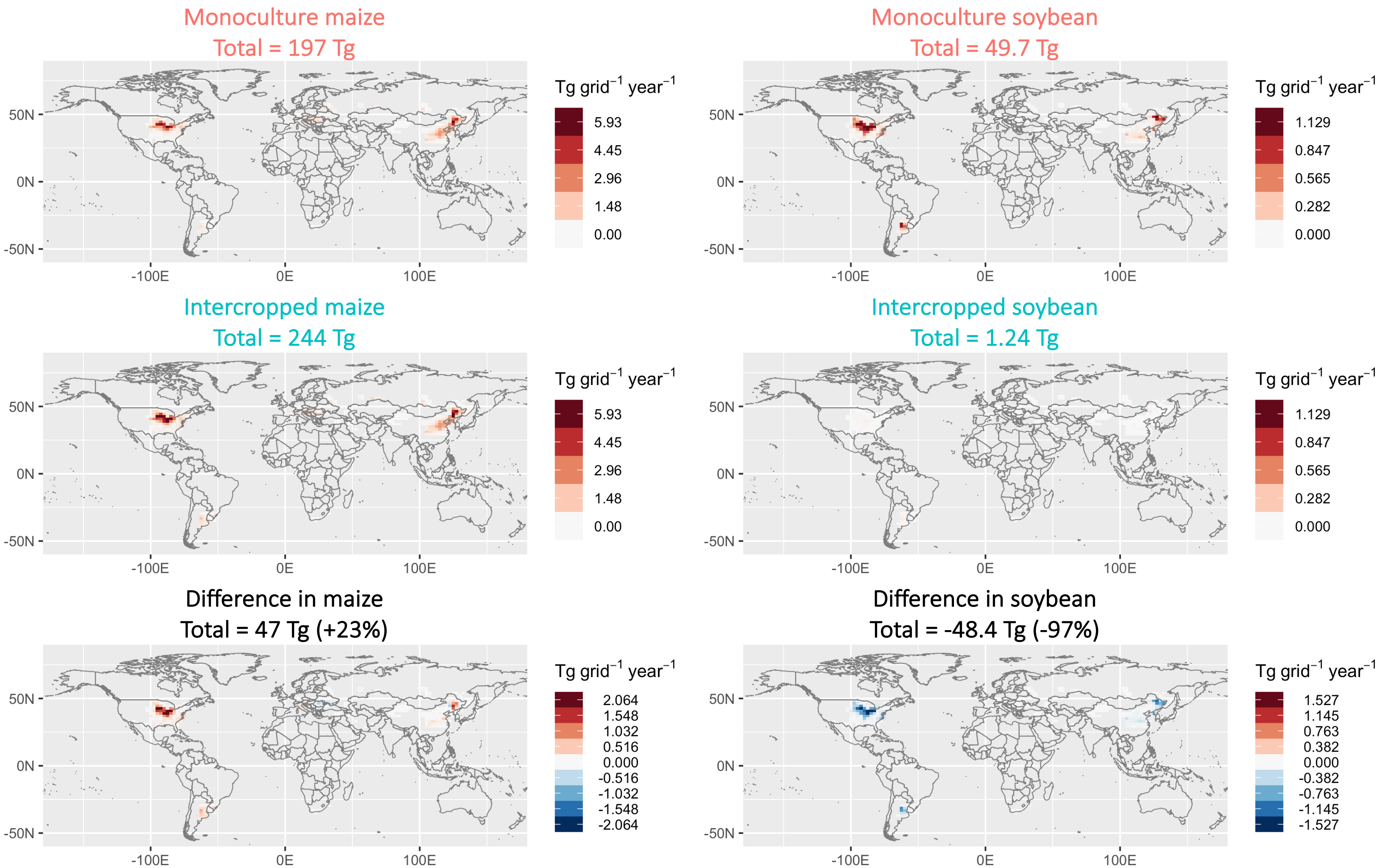
2. The amount of soil N a crop can take up is co-limited by its demand and accessible soil N:

$$N_{\text{uptake,crop}}$$

$$= \min\left(N_{\text{demand,crop}}, CF_{\text{crop}} \cdot \sum_{\text{system}} N_{\text{deployed,crop}}\right)$$

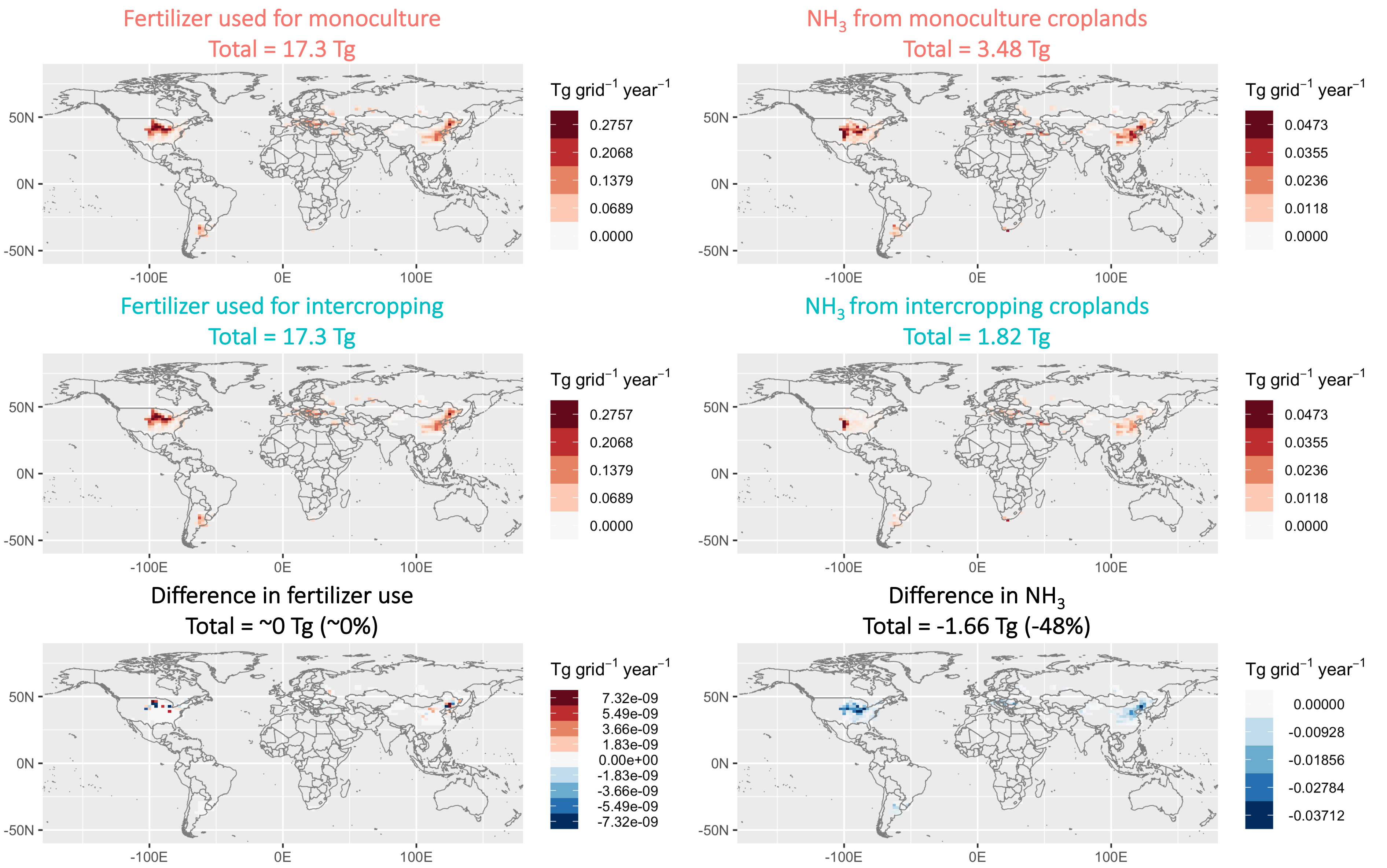
Assuming all croplands cultivating both maize and soybean are now converted to intercropping

Fung et al. (in prep.)

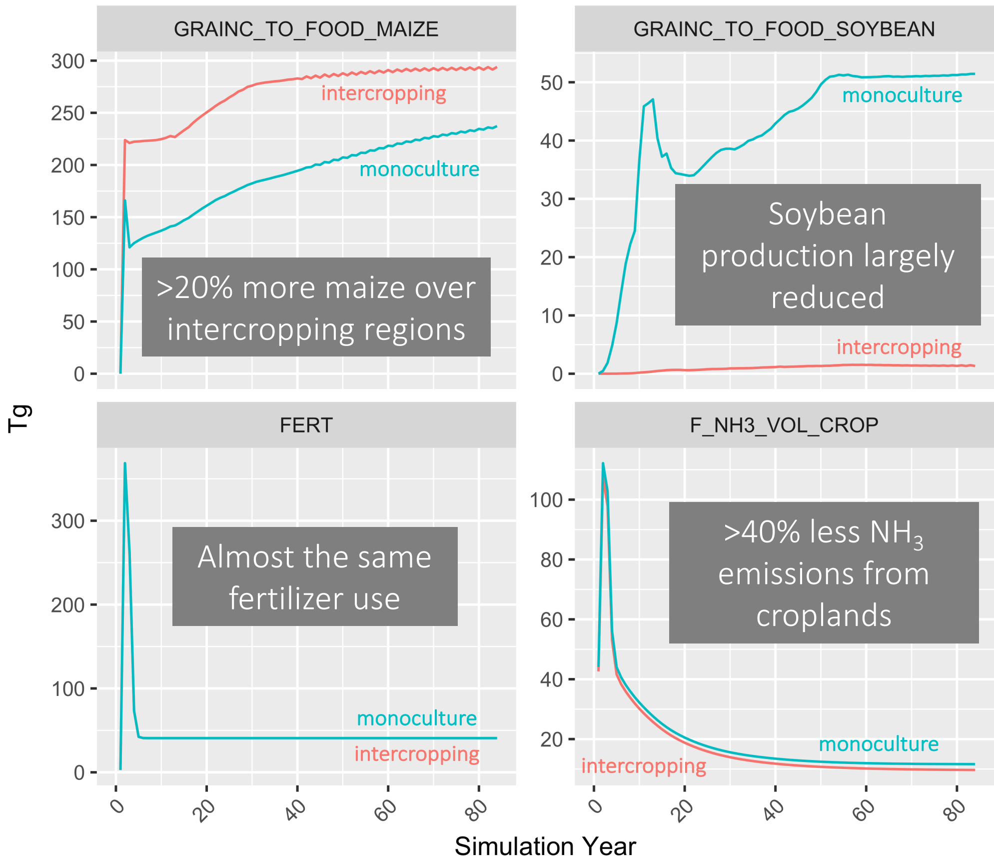


The same amount of fertilizer is applied; NH_3 emissions is reduced by >40%

Fung et al. (in prep.)



Our preliminary results show that intercropping can secure global food production and reduce air pollution



Fung et al. (in prep.)

- Future work:
  - Revising soybean fixation algorithm
  - Adding spatial variability on fertilizer use
  - Examining other intercropping pairs
  - Adding N_2O & NO_x emissions and NO_3 leaching
  - Coupling NH_3, N_2O & NO_x emissions with CAM
  - Investigating interrelationship between intercropping, the environment, and climate

Thank You!

Please don't hesitate to contact me at kamingfung@link.cuhk.edu.hk