Estimation of agricultural ammonia emission under sustainable farming practices by improving terrestrial nitrogen cycle modeling

Ka Ming Fung[1] (kamingfung@link.cuhk.edu.hk), Amos P. K. Tai[1,2], Taiwen Yong[3], Xiaoming Liu[4], Hon-ming Lam[2,5], Eri Saikawa[6] and Maria Val Martin[7]

[1]Earth System Science Programme and Graduate Division of Earth and Atmospheric Sciences, The Chinese University of Hong Kong, Hong Kong
[2]State Key Laboratory of Agrobiotechnology, The Chinese University of Hong Kong, Hong Kong
[3]College of Agronomy Sichuan Agricultural University, Sichuan, China [4]Shehong Agricultural Technology Station, Sichuan, China
[5]School of Life Sciences, The Chinese University of Hong Kong, Hong Kong
[6]Department of Environmental Sciences, Emory University, Georgia, USA
[7]Leverhulme Centre for Climate Change Mitigation, Department of Animal & Plant Sciences, University of Sheffield, Sheffield, UK

1. Summary

This study evaluates the performance of large-scale intercropping of maize-soybean as a sustainable farming practice. We employ a multi-model approach a newly added scheme for mimicking belowground crop-crop interactions to simulate a scenario of nationwide adoption of maize-soybean intercropping in China. Validated with field observations, we show that intercropping can improve total maize and soybean production with less fertilizer requirement and lower ammonia emission. We also conduct a cost-benefit analysis to illustrate the environmental and economic benefits.

2. Food Production, Public Health & Intercropping

The Food and Agriculture Organization (FAO) projects that the fast-gowning population and their more meat-inclined diet would double the worldwide food demand by 2050. Yet, agriculture is the source of 95% of ammonia (NH_3) emission in China, promoting the formation of fine particulate matter ($PM_{2.5}$) in nearby regions. Without proper control, intensifying food production could lead to a severe public health issue.

Intercropping, as a sustainable farming method, is practiced to various extents worldwide. Cultivating multiple crops in the same field with overlapping planting periods, it enables mutualistic effects of legumes and non-legume plants, enhances nitrogen use efficiency and land use efficiency, and reduces reactive nitrogen emissions to the atmosphere.

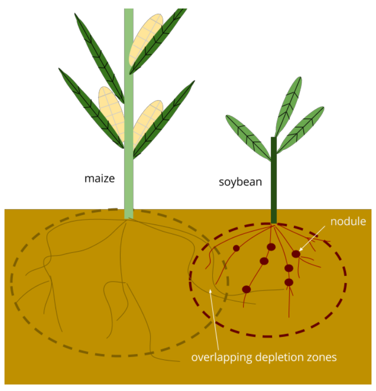

Fig.1 A schematic to illustrate intercropping of maize and soybean.

3. Modeling Intercropping in DNDC

DeNitrification-DeComposition (DNDC) (Li *et al* 1992) is a process-based model. It simulates soil biogeochemistry, plant growth and microbial activities and calculates greenhouse gas emissions from denitrification, nitrification, and fermentation etc.

We revise the plant nitrogen uptake algorithm of DNDC to capture the below-ground competition between intercropped plants:

1. Fraction of root taking up nutrients from soil:

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

2. Assuming surface area of root is proportional to its weight, competition factor is defined as:

$$CF_{crop} = \frac{\text{space occupied by crop}}{\text{space occupied by system}} \approx \frac{mass_{\text{root, crop}} \cdot f_{\text{uptake, crop}}}{\sum_{\text{system}} mass_{\text{root, crop}} \cdot f_{\text{uptake, crop}}}$$

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

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

We then replicate the field experiment conducted by Yong *et al* (2015) with the revised DNDC and find:

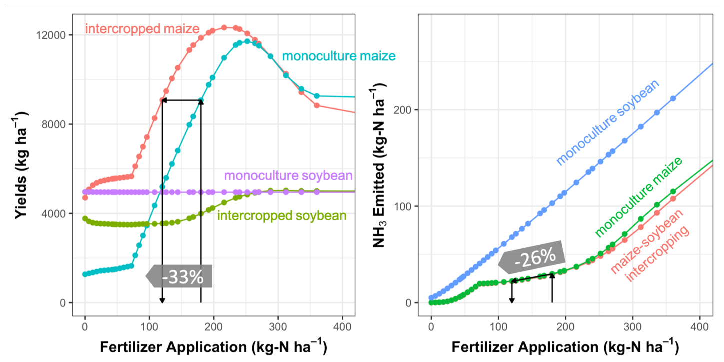

Fig.2 DNDC simulated yields and NH_3 with and without competition factor implemented. The revised DNDC captures that less fertilizer is required (-33%) for the same quantity of maize yield as monoculture due to extra nutrient supplied by soybean nitrogen fixation, which in turns lowered NH_3 volatilization by 26%.

4. Nationwide Adoption of Intercropping

Nationwide adoption of maize-soybean intercropping is simulated using the revised DNDC by assuming all cropland cultivating monoculture maize or soybean in each province of China is now adoping a maize-soybean intercropping system. Provincial representative parameters are used as model inputs, including weather conditions, soil properties, farming practices, and conventional amounts of fertilizer use.

Our results show that, while maintaining the same quantity of maize yield, national fertilizer use and NH_3 emission can be cut down to 58% and 55%, respectively.

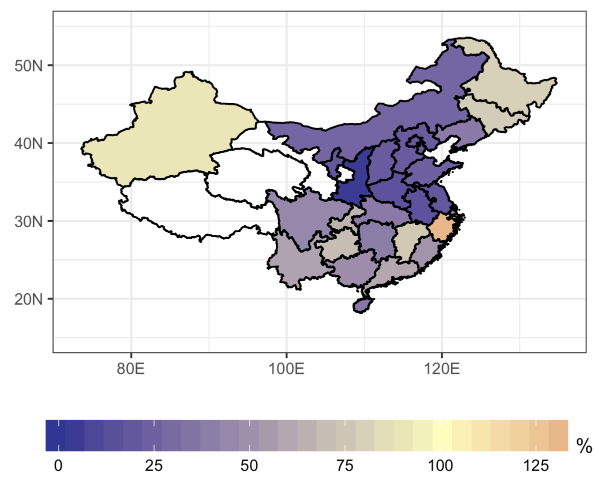

Fig.3 Ratios of DNDC-simulated NH_3 emissions of the intercropping systems to the combined amounts emitted by the corresponding monoculture systems over continental China.

5. Improvement in Air Quality

According to the simulated NH_3 reduction, we scale the MASAGE agricultural NH_3 emission inventory up/down by province and input it to a 3D global chemical transport model, GEOS-Chem. An improvement in downwind air quality is estimated with a declined inorganic $PM_{2.5}$.

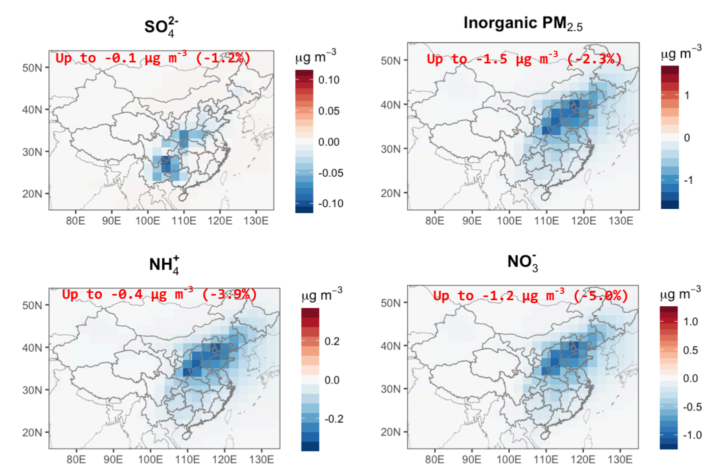

Fig.4 Changes in major composition of inorganic $PM_{2.5}$ if maize-soybean intercropping is adopted in China.

6. Environmental and Economic Benefits

A cost-benefit analysis is performed to evaluate the feasibility of promoting intercropping as a national farming standard.

Unit prices of grain yields are obtained from FAO, fertilizer and production costs are market prices while health costs associated with $PM_{2.5}$ are calculated using the population, annual mortality rate, and value of a statistical life of China, as suggested by Paulot *et al* (2014).

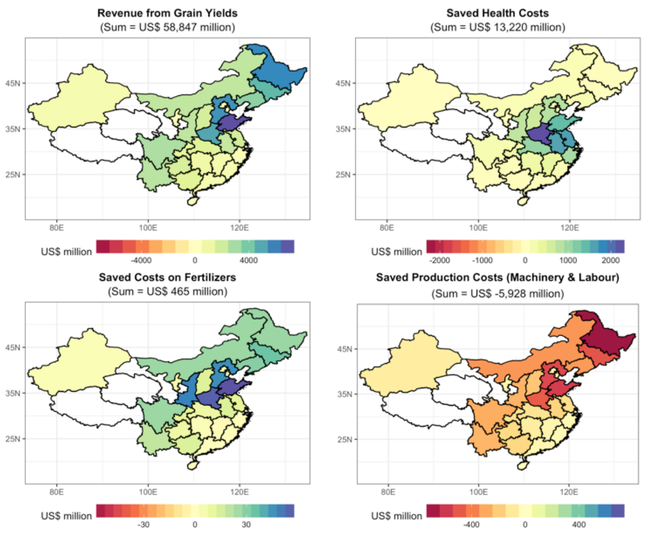

Fig.5 Maps showing the total increased revenues and savings on costs in each province after the adoption of nationwide intercropping. The summed values are aggregated over the whole China. A net gain in revenue of US\$67b (+93% compared to the current practice) is estimated.

7. Ongoing Work

We are implementing into CLM, a global land model, new parameterizations of crop competition and NH_3 volatilization to investigate the potential benefits of a global adoption of maize-soybean intercropping.

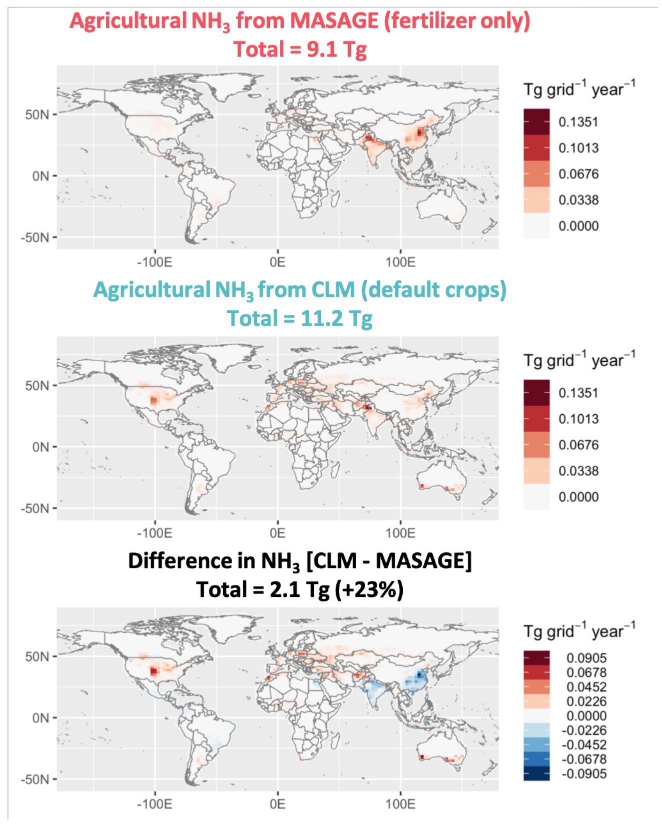

Fig.6 Maps showing the annual NH_3 emission from all croplands in CLM (middle) vs that from the MASAGE agricultural NH_3 emission inventory (top).

References

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Paulot, F. *et al* (2014). Environ. Sci. Technol., 48, 903-8.
Yong, T. *et al* (2015). J. Appl. Ecol., 25(2), 474-82.

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