Co-benefits of Intercropping, as a Sustainable Farming Practice, for Safeguarding Food Supply and Air Quality

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EARTH SYSTEM SCIENCE PROGRAMME

1. Summary

This study evaluates the efficacy of intercropping as a sustainable farming alternative. We employ a multi-model approach to simulate a **nationwide adoption of maize-soybean intercropping** in China. Validated with field observations, we show that intercropping can **improve total maize and soybean productions** with **less fertilizer use** and **lower ammonia emission**. We also conduct a cost-benefit analysis to quantify its **environmental** and **economic benefits**.

2. Food Production, Public Health & Intercropping

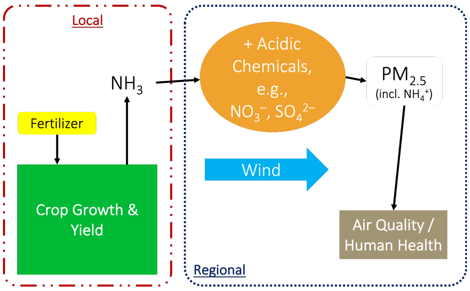

Fig.1 **Rising population** and **increased meat consumption** will nearly double global food demand by 2050, stressing farmers to produce more crop by means such as **overfertilization**. However, **agricultural ammonia (NH_3) emission** is attributable to 95% of atmospheric NH_3 and 20% of **fine particulate matter ($PM_{2.5}$)** formed. Intensified food production could hence pose a **risk to environmental health**.

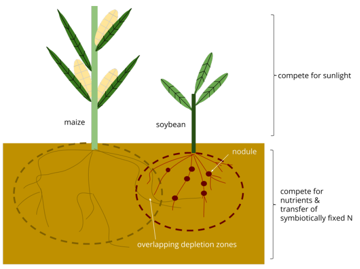

Fig.2 In contrast to monoculture, **intercropping** of maize and soybean allows **nutrient competition** and stimulates soybean to fix more atmospheric nitrogen as an extra supply of nutrient, which is also accessible by maize. This **mutualistic effect** allows the field to generate more crop yield with **fewer fertilizer inputs**, **enabling efficient nitrogen- and land-use**, as well as **reducing NH_3 emission**.

3. Modeling Intercropping with DNDC

DeNitrification-DeComposition (**DNDC**) (Li *et al.* 1992) is a process-based model that simulates **soil biogeochemistry** and **plant growth** as well as **greenhouse gas emissions**. We revise its **plant nitrogen uptake algorithm** to represent intercropping:

Fraction of root taking up nutrients from soil:

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

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

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

The amount of soil N taken up a crop is thus:

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

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

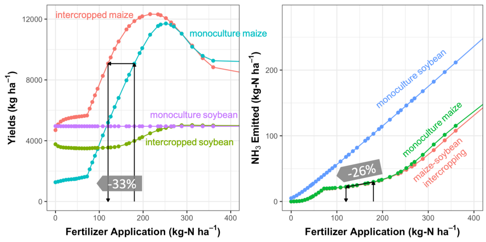

Fig.3 DNDC-simulated yields and NH_3 of a) monoculture maize; b) monoculture soybean, and; c) maize-soybean intercropping. Our simulation shows that intercropping requires **less fertilizer (–33%) to produce the same quantity of maize as monoculture** due to the extra nutrient supplied by soybean nitrogen fixation, which in turns **lowered NH_3 volatilization by 26%**. These results are consistent with field measurements.

4. Nationwide Adoption of Intercropping

We then simulate a scenario in which all cropland cultivating maize or soybean is converted into maize-soybean intercropping in each Chinese province. Provincial representative parameters, including **weather conditions**, **soil properties**, and **farming practices**, are used as model inputs.

We find that intercropping can cut down **national fertilizer use by 42%** and, hence, lower **NH_3 emission by 45%**, while maintaining the same quantity of maize yield.

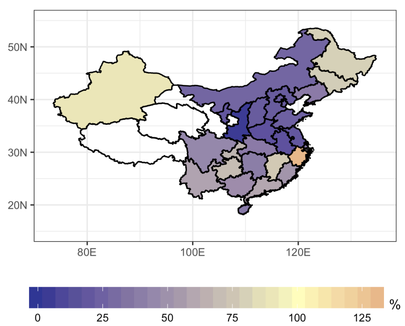

Fig.4 Relative changes in NH_3 emitted by maize-soybean intercropping compared with monoculture maize and soybean systems in Chinese provinces. Three provinces, which contribute 1.6% and 3.5% to China's production of maize and soybean, are excluded due to data insufficiency.

5. Improvement in Air Quality

Based on the simulated NH_3 reduction, we scale the **MASAGE agricultural NH_3 emission inventory** up/down by province and use it to drive a 3D global chemical transport model, **GEOS-Chem**. Downwind **inorganic $PM_{2.5}$** concentration is decreased.

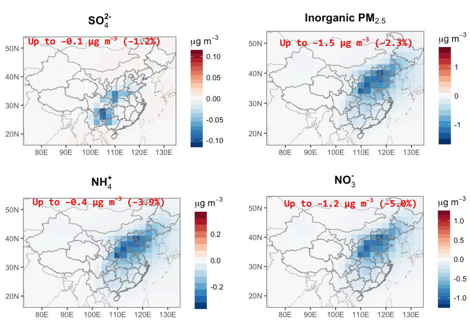

Fig.5 Changes in major inorganic $PM_{2.5}$ composition if maize-soybean intercropping is widely adopted in China.

6. Environmental and Economic Benefits

We perform a **cost-benefit analysis** to evaluate the feasibility of promoting intercropping as a national farming standard. Unit prices of **grain yields** are from FAO, **fertilizer** and **production costs** are market prices in 2006 while **health costs associated with $PM_{2.5}$** are calculated using population, annual mortality rate, and value of statistical life of China, as suggested by Paulot *et al.* (2014).

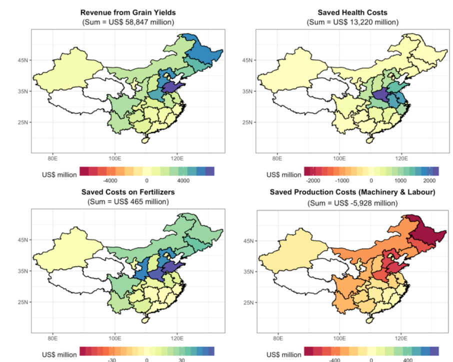

Fig.6 Net changes in revenues and costs after a nationwide conversion into intercropping. A **net national economic benefit of US$67b (+93% compared to the current practice)** is estimated.

7. On-going Works

We are implementing into **CESM**, an earth system model, new schemes to parametrize NH_3 emission and investigate the **potential feedback mechanisms** of nitrogen (N) **deposition** and **aerosol-climate interactions** within the NH_3-aerosol-climate system. These results allow us to examine the efficacy of global adoption of intercropping.

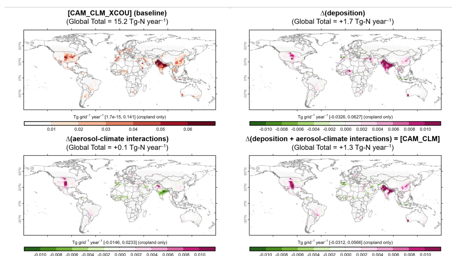

Fig.7 N deposition (+1.7 Tg-N) and aerosol-climate interactions (+0.1 Tg-N) both **promote annual NH_3 emission**, but their combined effect (+1.3 Tg-N) is non-additive.

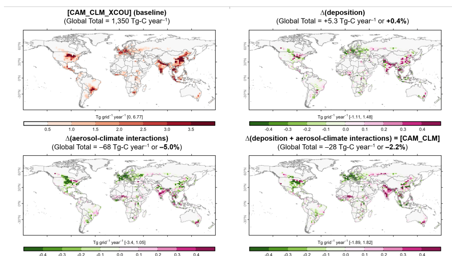

Fig.8 The combined effect of N deposition and aerosol-climate interactions **reduces global food production by 2.2%** with large variability in regional impacts.

References

Li, C. *et al.* (1992). J. Geophys. Res., 97(D9), 9759-76.
Paulot, F. *et al.* (2014). Environ. Sci. Technol., 48, 903-8.
Yong, T. *et al.* (2015). J. Appl. Ecol., 25(2), 474-82.
Fung, K. M. *et al.* (2019). Environ. Res Lett., 14, 044011.

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