# Co-benefits of maize-soybean intercropping for securing air quality and global food supply


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## 1. Summary


We investigate the feasibility of adopting large-scale intercropping by implementing new schemes into a biogeochemical model (DNDC) to simulate a scenario of nationwide adoption of maize-soybean intercropping in China, validated with field results. We show that intercropping can improve total maize and soybean production with less fertilizer required and reduced ammonia-induced downwind air pollution. 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 global food demand will be doubled by 2050 because of the fast-growing population. Yet, agriculture, contributing to 95% of ammonia ($NH_3$) emission in China, promotes the formation of fine particulate matter ($PM_{2.5}$) in downwind regions. Without proper control, increasing food production could become 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.

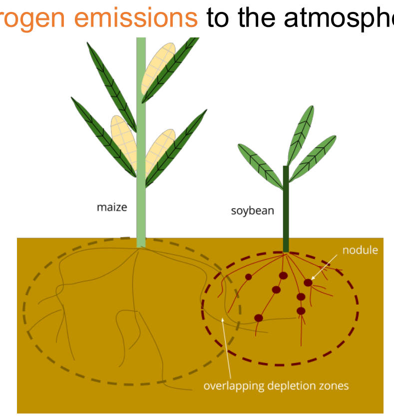


*Fig.1 A schematic to illustrate Intercropping of maize and soybean.*

## 3. Implementation of Competition Factor 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:

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

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

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

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

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

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

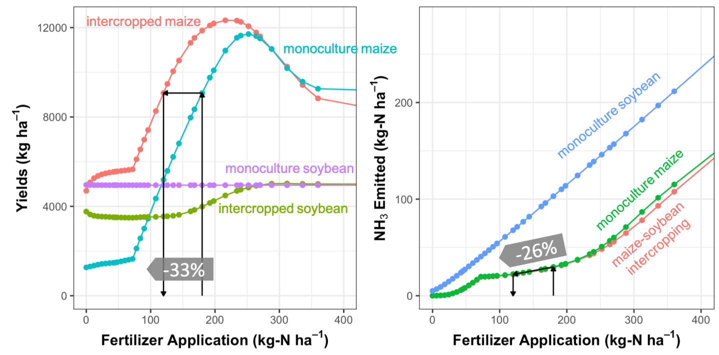


*Fig.2 DNDC simulated yields and $NH_3$ with and without competition factor implemented. The revised DNDC captures that less fertilizer is required (-33%) for the same quantity of maize yield as monoculture due to extra nutrient supplied by soybean nitrogen fixation, which in turns lowered $NH_3$ volatilization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

## 4. Nationwide Adoption of Intercropping in China

Nationwide adoption of maize-soybean intercropping is simulated using the revised DNDC in all farming areas cultivating monoculture maize or soybean in each province of China. Provincial representative parameters are used as model inputs, including climate, soil properties, farming practices, and conventional fertilizer use.

While maintaining the same quantity of maize yield, national fertilizer use and $NH_3$ emission can be cut down to 58% and 55%, respectively.

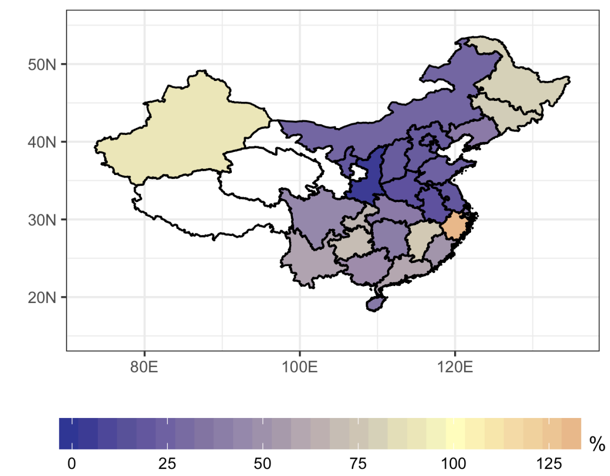


*Fig.3 Ratios of DNDC-simulated $NH_3$ emissions of the intercropping systems to the combined amounts emitted by the corresponding monoculture systems over continental China.*

## 5. Improvement of Downwind Air Quality

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

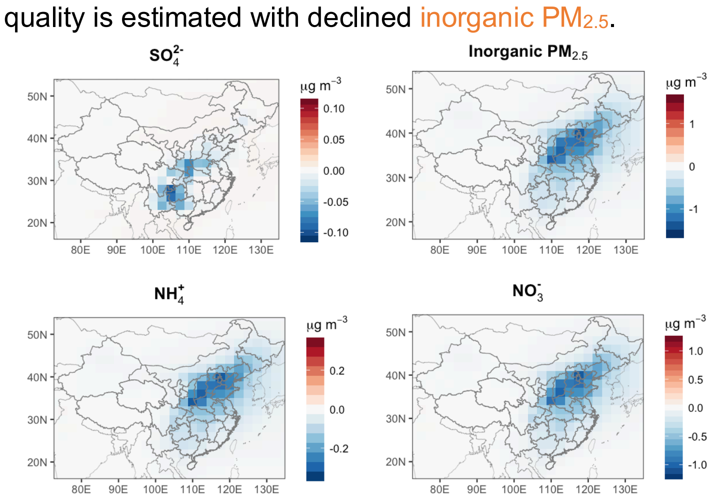


*Fig.4 Changes in major composition of inorganic $PM_{2.5}$ if maize-soybean intercropping is adopted in China.*

Largest changes:

| | | |
|---|---|---|
| Inorganic $PM_{2.5}$ | -1.5 μg $m^{-3}$ | (-2.3%) |
| $NH_4^+$ | -0.4 μg $m^{-3}$ | (-3.9%) |
| $NO_3^-$ | -1.2 μg $m^{-3}$ | (-5.0%) |
| $SO_4^{2-}$ | -0.1 μg $m^{-3}$ | (-1.2%) |

## 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* (2013).

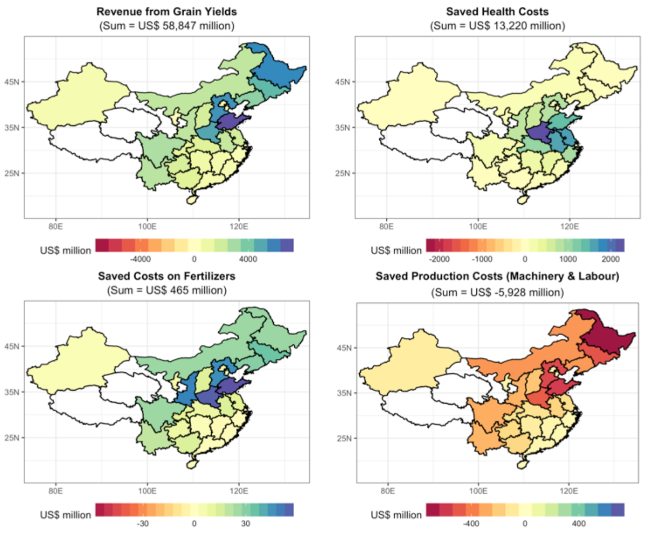


*Fig.5 Maps showing the total revenues and savings on costs in each province before and after adoption of nationwide intercropping. The summed values are aggregated over the whole China. A net gain in revenue of US$67b (+93% compared to the current practice) is estimated.*

## 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.

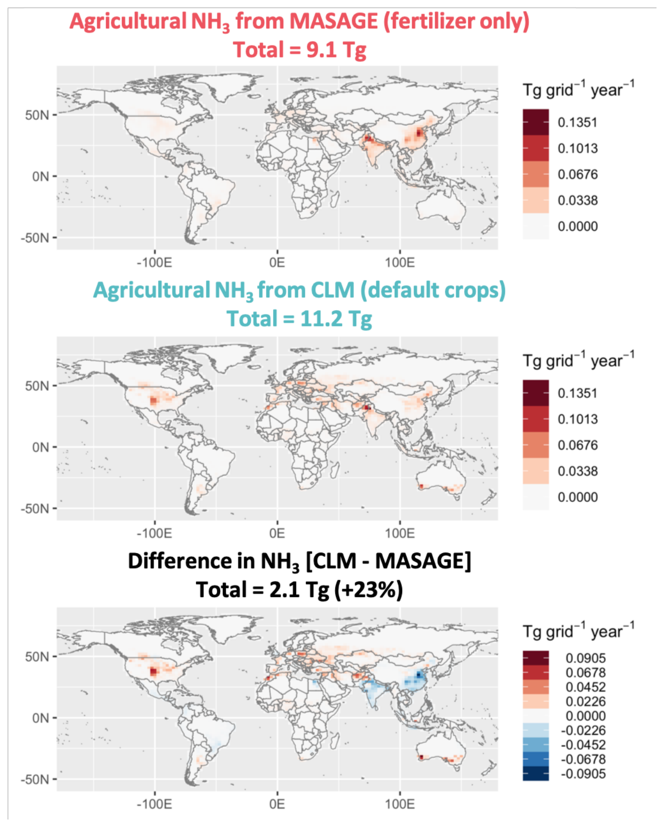


*Fig.6 Maps showing the annual $NH_3$ emission from all croplands in CLM (middle) vs that from the MASAGE agricultural $NH_3$ emission inventory (top).*

## References


Li, C. *et al* (1992). J. Geophys. Res., 97(D9), 9759-76.
Paulot, F. *et al* (2013). Environ. Sci. Technol., 48, 903-8.
Yong, T. *et al* (2015). J. Appl. Ecol., 25(2), 474-82.


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