Evaluating effectiveness of maize-soybean intercropping in securing food production and air quality in China using DNDC and GEOS-Chem

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Overview

- We improve the algorithm of a process-based biogeochemical model 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 ammonia-induced downwind air pollution is reduced. We also conduct a cost-benefit analysis to illustrate the environmental and economic benefits of such a large-scale sustainable farming scheme.

1. Food Production, Public Health and 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.

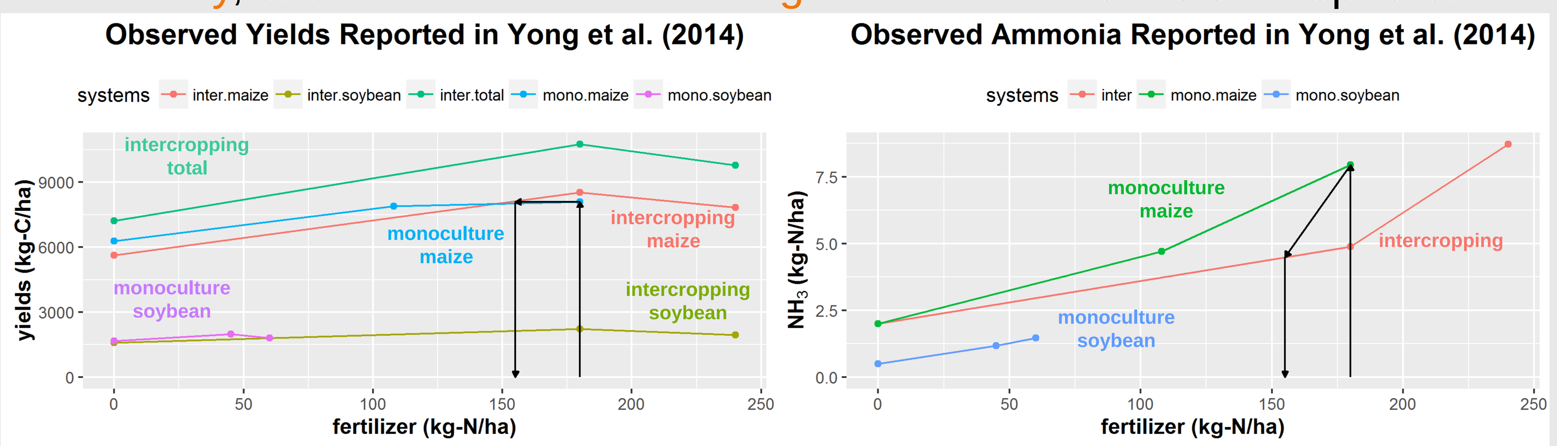

Fig.1 *Field observations of a maize-soybean intercropping system in Sichuan, China (Yong et al., 2014). Intercropping allowed maize to yield the same as its monoculture counterpart using about 30 kg-N less fertilizer. Such reduction in fertilization eliminates the NH_3 emission by more than one-third of that from maize monoculture system.*

2. Implementation of Competition Factor in DNDC

- DeNitrification-DeComposition model (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:

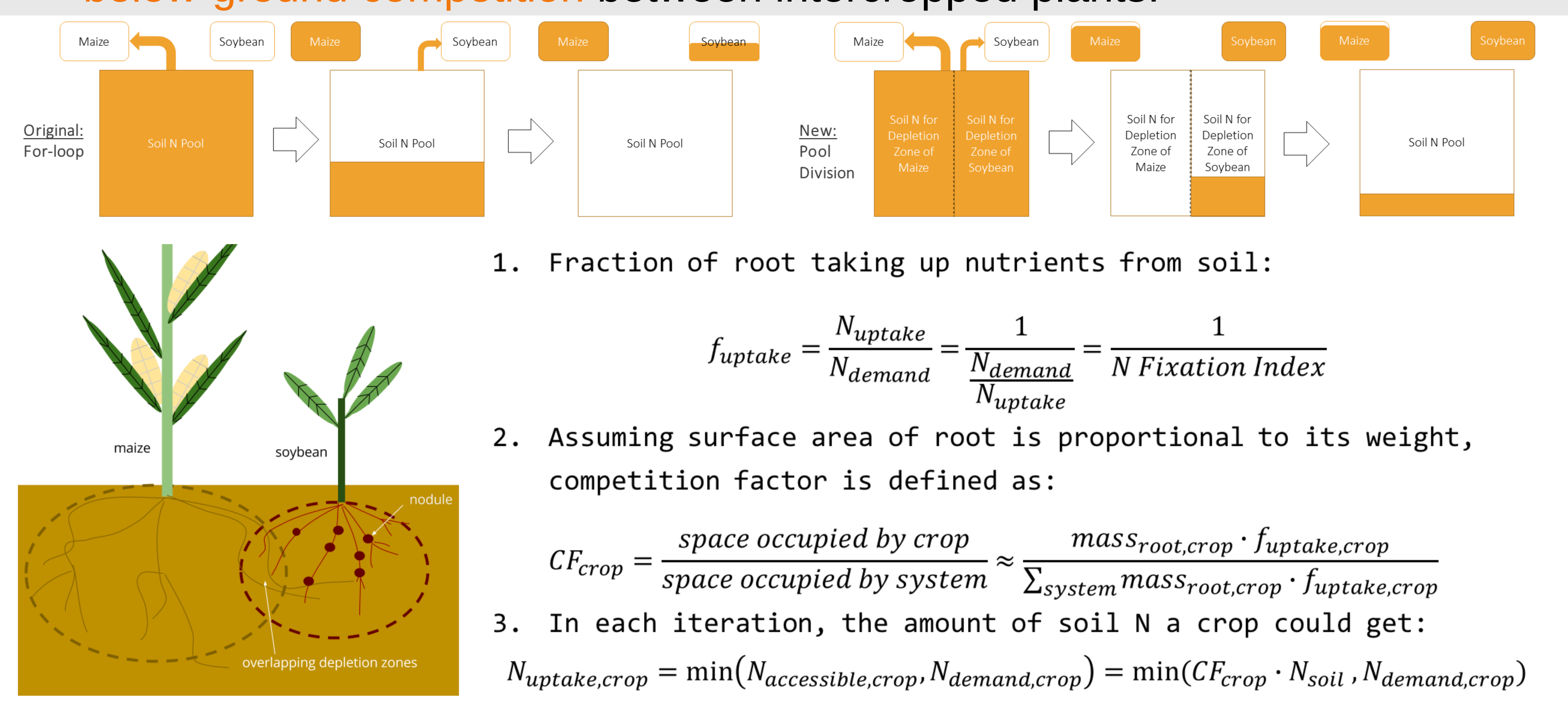

Fig.2 *Schematic diagrams and mathematical representations of crop-crop interaction illustrating the implementation of competition factor in the plant nitrogen uptake algorithm of DNDC.*

- We then reproduce the field experiment conducted by Yong et al. (2014) with the revised DNDC and find:

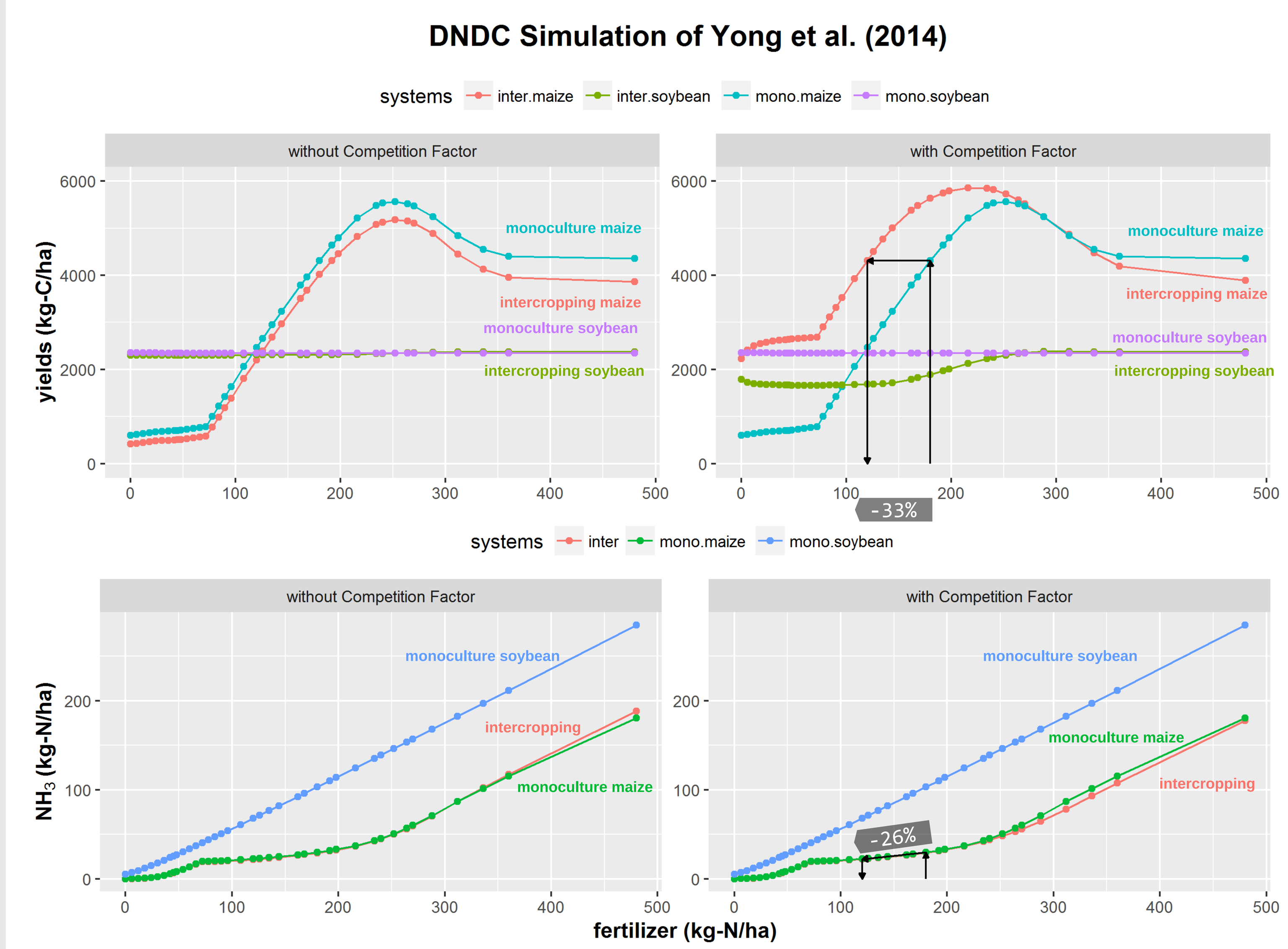

Fig.3 *DNDC simulated yields and NH_3 with and without competition factor implemented. The revised DNDC captures better yields of maize due to extra nutrient supplied by soybean nitrogen fixation. Thus, intercropping requires only 67% of conventional fertilizer usage to produce the same amount of maize with an extra batch of soybean, and reducing the corresponding NH_3 emission by 26%.*

3. 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.

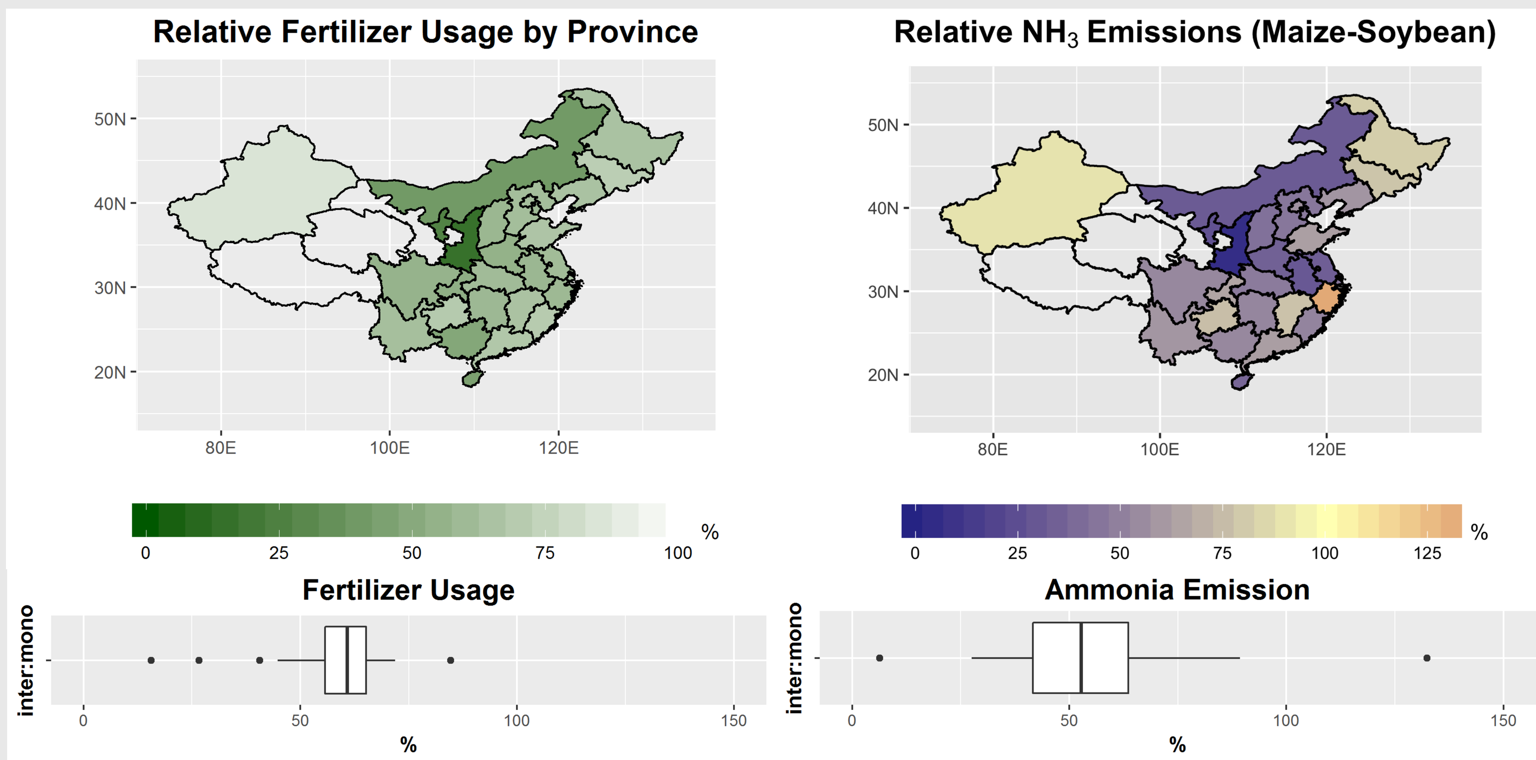

Fig.4 *DNDC simulated nationwide adoption of maize-soybean intercropping in China. The maps show relative value of fertilizer required to achieve the same yield of maize under intercropping compared to fertilizer needed under monoculture (left) and their corresponding relative reduction in NH_3 emission (right). The boxplots summarize the provincial results. It is found that the mean fertilizer requirement is dropped to 58% of conventional usage and it correspondingly cuts 45% of NH_3 emission on average. Gansu, Tibet and Xizang (blank regions on the maps), whose combined productions contribute to 1.6% of annual maize yields and 3.5% of soybean in China, are excluded from this study due to data insufficiency.*

4. Improvement of Downwind Air Quality

- According to the simulated NH_3 reduction, we scale MASAGE, an 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 $PM_{2.5}$.

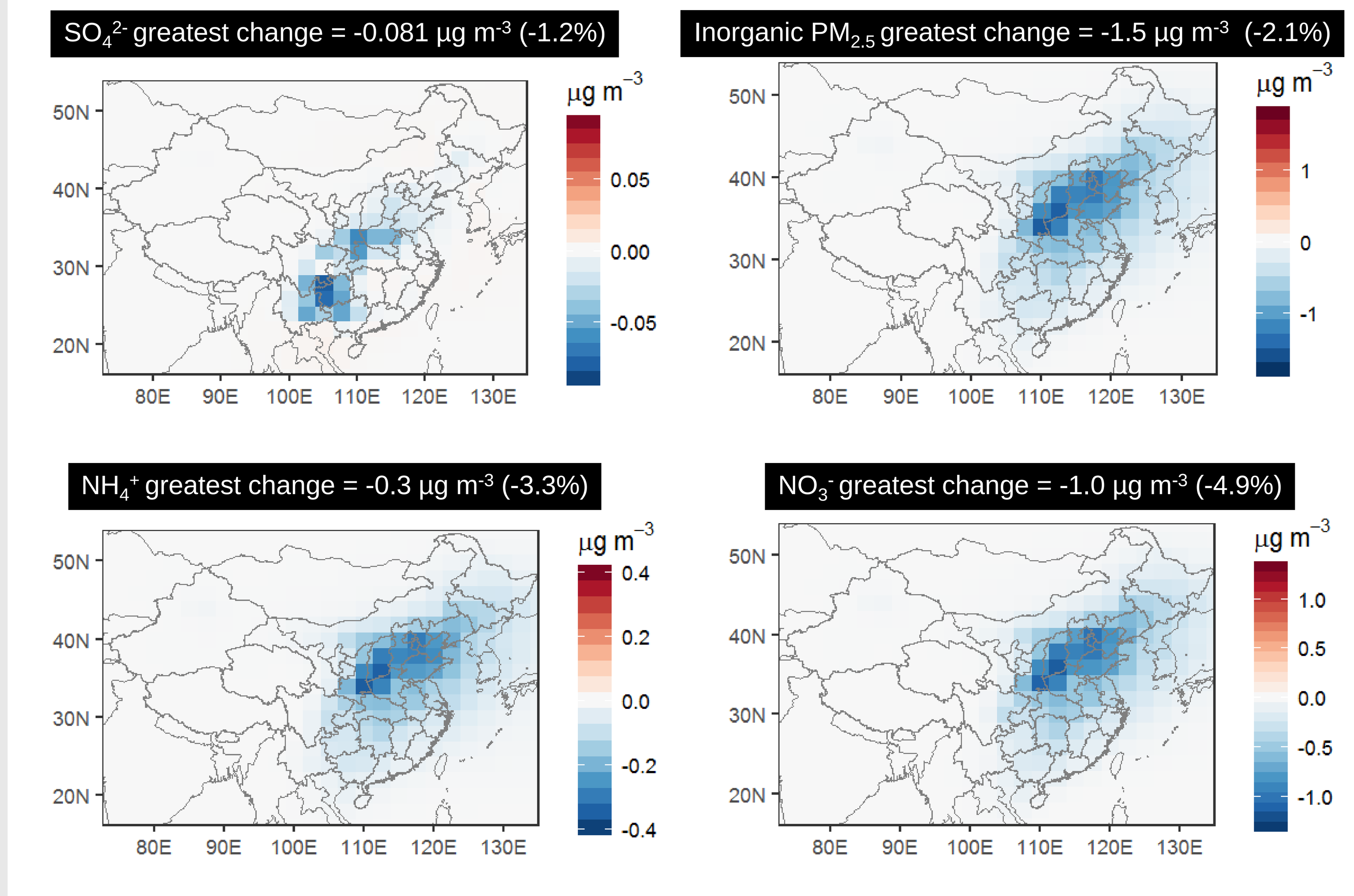

Fig.5 *Changes in simulated concentration of the major composition of inorganic $PM_{2.5}$ if maize-soybean intercropping is adopted in China. A blue grid indicates a local reduction in chemical concentration while a red one means a local rise. The percentage values indicate the greatest concentration changes relative to local mean concentrations without intercropping.*

5. 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).

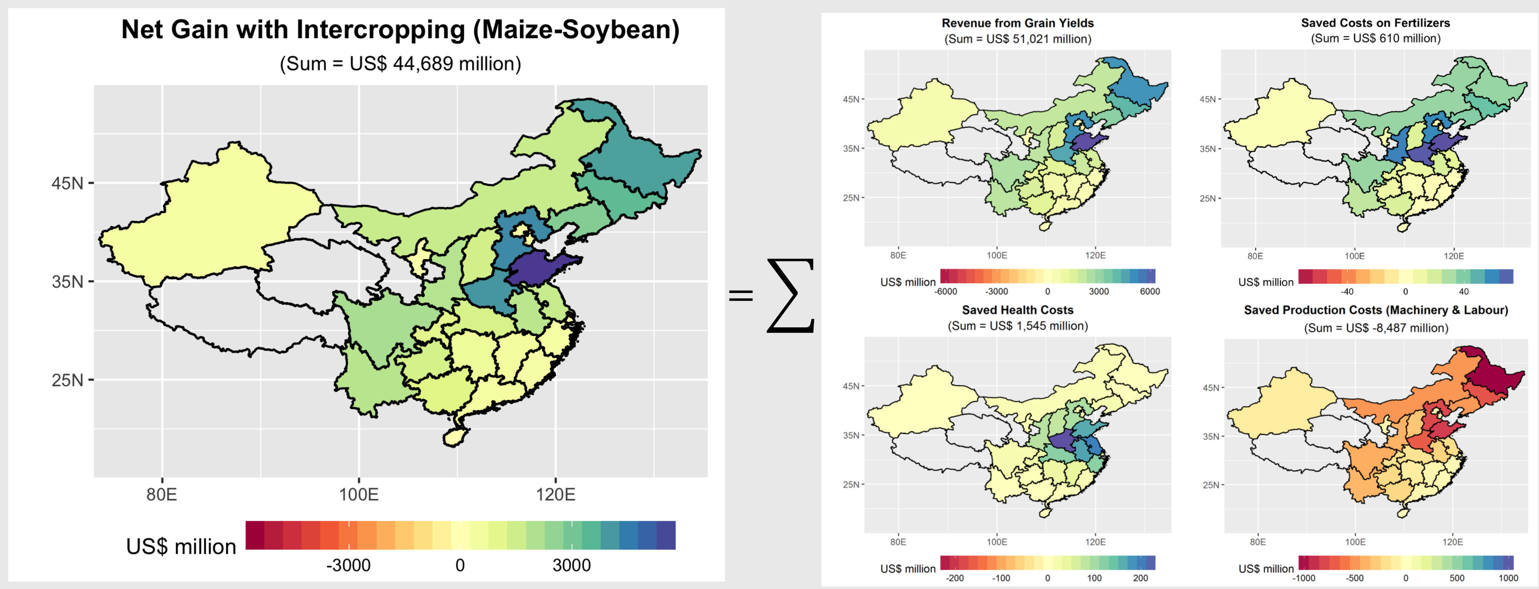

Fig.6 *Maps showing the total revenues and savings on costs in each province before and after adoption of nationwide intercropping. The summed values are aggregated over the whole China. A net gain in revenue of US\$45b (+85% compared to the current practice) is estimated, mainly from the profit of selling grain yields (US\$51b) and saving on health costs associated with $PM_{2.5}$ (US\$1.5b), despite a significant production cost increase of US\$8.5b for machinery and labour.*

References

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