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Europe – China joint call on Sustainable Urbanisation in the Context of Economic Transformation and Climate Change:
Sustainable and Liveable Cities and Urban Areas

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UNCNET

Urban nitrogen cycles: new economy thinking to master the challenges of climate change

D4/3: Optimization of urban agriculture management to mitigate groundwater N pollution under different climate changes

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Start Date of Project: **01/04/2021** Duration: **35 + 6 months**

Organisation name of co-chairs for this deliverable: **PKU, CAS**

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Dissemination Level		
PU	Public	☒
PP	Restricted to other programme participants (including funding agencies)	☐
RE	Restricted to a group specified by the consortium (including funding agencies)	☐
CO	Confidential, only for members of the consortium (including funding agencies)	☐

1. Executive Summary

This task, D4/3, aims to optimize agriculture management to mitigate soil N losses to avoid groundwater N pollution under different climate changes. UNCNET proposed a scenario-based methodology for quantifying mitigation potential from the optimization of urban agricultural management practices (e.g., fertilization, food consumption). This methodology guided us to determine the magnitude of mitigation potential of soil N losses by adjusting fertilizer rate, type, frequency, and placement as well the food dietary and loss. Also, this task brings a paradigm shift from asking "how much of soil N losses can we mitigate?" to the more policy relevant question of "where are the best opportunities to mitigate N losses most effectively?". This task focuses on reducing N losses including N leaching and NH_3 volatilization from agricultural soils across China at 1-km spatial resolution. Therefore, the optimized agricultural management in both of urban and rural areas is beneficial for improving urban environment, such as water quality and PM2.5.

2. Objectives:

The task aims to optimize urban agriculture management to mitigate soil N losses to avoid groundwater N pollution and air pollution across China at 1-km resolution in future.

3. Activities:

Interaction with the Ministry of Agriculture of China to design mitigation scenarios.

Wulahati Adalibieke wrote codes to determine the magnitude of mitigation potential of soil N losses by choosing fertilizer rate, type, frequency, and placement as well the food dietary and loss.

4. Results:

- Optimized urban agriculture management practices and associated mitigation maps of soil N losses in China (1-km, annual).

5. Milestones achieved:

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6. Deviations and reasons:

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7. Publications:

- Zhan, X.; Adalibieke, W.; Cui, X.; Winiwarter, W.; Reis, S.; Zhang, L.; Bai, Z.; Wang, Q.; Huang, W.; Zhou, F., Improved Estimates of Ammonia Emissions from Global Croplands. *Environ Sci Technol* **2021,** *55*, (2), 1329-1338.
- Cui, X.; Zhou, F.; Ciais, P.; Davidson, E. A.; Tubiello, F. N.; Niu, X.; Ju, X.; Canadell, J. G.; Bouwman, A. F.; Jackson, R. B.; Mueller, N. D.; Zheng, X.; Kanter, D.; Tian, H.; Adalibieke, W.; Bo, Y.; Wang, Q.; Zhan, X.; Zhu, D., Global mapping of crop-specific emission factors highlights hotspots of nitrous oxide mitigation. *Nature Food*. 2021, 2, doi: 10.1038/s43016-021-00384-9

8. Meetings:

Kickoff meeting at Peking University and many UNCNET teleconferences

9. List of Documents/Annexes:

Annex: Optimization of urban agriculture management to mitigate groundwater N pollution under different climate changes.

REFERENCES

ANNEX 1

Optimization of urban agriculture management to mitigate groundwater N pollution under different climate changes

Optimization of urban agriculture management to mitigate groundwater N pollution under different climate changes

1. Scenario-based simulations

a) Land surface model

ORCHIDEE-crop model (svn version no. 2409) was used to optimize urban agriculture management to mitigate soil N losses to avoid groundwater N pollution and air pollution across China at 1-km resolution. In this work package, model improvements had been conducted for soil water dynamics, heat dynamics, and solute transport. First, surface water runoff is simulated for daily rainfall using the SCS curve number equation (Mockus, 1972). Subsequently, soil water infiltration is computed using the Green-Ampt model (Green & Ampt, 1991). The process of soil water redistribution was incorporated into the model using the Richard's equation as described by Šimůnek *et al*. (2008). The reference crop evapotranspiration ET_o is estimated using the Penman-Monteith equation (Allen et al., 1998) solved using standard grass with an assumed height of 0.12 m and a surface resistance of 70 s m^{-1}. The crop coefficient is used to calculate actual crop potential evaporation. And then, using leaf area index (LAI), separate potential crop transpiration and potential soil evaporation (Jones, 1986). Second, the simulation of one-dimensional heat transfer was taken from the HYDRUS1D model, which is described with the convection-dispersion equation (Šimůnek et al., 2008). The top and bottom boundaries are set constant boundary conditions. The temperature of the top soil layer is estimated based on the daily air temperature and leaf area index (Li et al., 1992). The bottom boundary temperature is estimated used by the method used in the DNDC model (Li et al., 1992). Third, the transport of soil $NH^+{}_4$-N and $NO^-{}_3$-N was simulated using the convection-dispersion equation (CDE), and a generalized nonlinear adsorption isotherm was used to consider the adsorption-desorption process between the liquid and solid phase as described in HYDRUS1D model (Šimůnek et al., 2008). The model assumes an equal crop absorption ratio of $NH^+{}_4$-N and $NO^-{}_3$-N. Each N transformation process was computed as a sink-source term in the CDE, and each of the processes are described detail in next two sections. The boundary conditions (Cauchy type) for the solute ($NH^+{}_4$-N and $NO^-{}_3$-N) transport equation was used to describe the solute flux at the upper or lower boundary. This CDE was solved by the general upwind difference method, and this procedure effectively avoids numerical dispersion and oscillation even under the conditions of dramatic changes in solute concentration without using dense nodes (Chen et al., 2005). Surface broadcast and deep fertilizer applications are regarded as uniformly incorporated within the top 1 cm of soil or at the prescribed application depth (usually 5–10 cm) in the soil, respectively. More details in model calibration and validation can be found in Deliverable D4.2.

b) Scenario design

To explore the future N loss mitigation potential, we performed nine scenario projections in ten-year intervals from 2020 to 2050. In the business-as-usual (BAU) scenario, we only consider current (the year

2017) policies and national plans without any further intervention. However, the crop production will increase in line with projected increases of population and gross domestic product (GDP) as projected by Zhang et al (2020). Meanwhile, climate factors, i.e. air temperature and wind speed, changed following a conservative RCP2.6 (stringent mitigation scenario, predicts the global mean temperature increases of up to 2 °C by 2100) future climate change scenario (PICIR, 2021). Scenarios OFM and OFC predict the projections based on the same assumptions as BAU, but optimize fertilizer management (OFM) and food consumption (OFC), respectively. For scenario OFM, N fertilizer rate was set according to the "N Surplus Benchmarks in China" following Zhang et al. (2019). Meanwhile, the incorporation proportion of synthetic-N fertilizers will achieve 80% for three staple food (i.e. wheat, maize and rice) according to the National Agriculture Mechanization Extension Plan (Zhang et al., 2020). For scenario OFC, the crop production will decrease by optimizing human diet structure following Zhang et al. (2020) and cut 50% of food loss and waste to achieve the Global Sustainable Development Goals (Clark et al., 2020; FAO, 2020; X. Li et al., 2021). To achieve the most ambitious mitigation target, the ALL scenario was proposed to combine all the mitigation options identified in OFM and OFC scenarios. It should be noted that for the intermediate year of scenario OFM, OFC and ALL, we assume linear adoption from 2017 until the adoption year (2050), at which point the technologies are entirely adopted (Clark et al., 2020).

c) Input data

The model is forced by multiple gridded input datasets, including a dataset describing the total synthetic-N fertilizer application rate (kg N year^{-1}) developed by Shang et al (2019), and two new datasets associating the fractions of synthetic-N forms and placement to cropland. For N forms, we obtained the crop-specific fraction of three N fertilizers, including ammonium bicarbonate, urea, other N fertilizers at province level from the Statistics of Cost and Income of Chinese Farm Produce (NDRCC, 2003, 2020). The placement of synthetic-N fertilizer largely depends on topographic condition, planting density, root depth and crop's economic value (Xi et al., 2013). Consequently, we assumed that all N fertilizers for rice paddies are applied on surface soil as mechanized incorporation is difficult (2016); and all N fertilizers for vegetables and fruits are incorporated manually due to their higher economic return and planting density. For field crops such as wheat, maize, potatoes and legumes, machines were typically employed to incorporate basal fertilizers into soil. We therefore assumed that the incorporation proportions of basal N fertilizer could be calculated as a function of the sowing area fertilized by machine divided by total sowing area (data for both from CAAMM, 2020) at province level.

Annual N in livestock manure, human excreta, and crop residues (kg N year^{-1}) returned to croplands were estimated by a Eubolism model at county-scale (Shang et al., 2019). The N amount in organic fertilizers calculated based on county-scale activity data, such as the numbers of livestock by animal, rural population, and yields by crop type from 1980 to 2017 (Shang et al., 2019). In China, farmers usually broadcast the organic fertilizers on soil surface and incorporate them in a short time accompanying with plough or rotary tillage (Beusen et al., 2008; Femke et al., 2019; Xi et al., 2013). Provincial tillage proportion, i.e. sowing areas of tillage (CAAMM, 2020) divided by the total (NDRCC, 2020), were therefore taken as the incorporation proportion of organic fertilizer following Zhan et al. (2021, details see Text S3 and Figure S3). All the dataset by crop and fertilizer were then disaggregated into grid maps at 1-km spatial resolution within each of the administrative units following the crop-specific Land-Use/cover Dataset produced for China by Liu et al. (2014). This dataset was developed based on Landsat TM\ETM+ images and field investigations at 10-year intervals.

2. Mitigation potential of soil N losses

China's crop demand is projected to increase by 140% by 2050 considering both economic development and population growth. This would require an additional sowing area of 35.4 Mha, with the total NH_3 volatilization and N leaching achieving 4.9 and 2.5 Tg N by 2050 if maintaining the 2017 management practice under increasing temperature conditions (BAU, Figs 1 and 2). Under BAU, soil emissions of NH_3 volatilization and N leaching in 2030 (5.3 and 2.2 Tg N) would exceed the peak level in 1996 and 2015 and steadily increase until 2050. Soil N loss abatement through optimizing diet composition and cutting food losses and waste (OFC) could reduce emission by 20% in 2050 compared with BAU (Figs 1a and 2a). When conducting optimal fertilizer management (OFM), N fertilizer consumption would reduce by 50.5%, inducing a subsequent N loss reduction of 63% compared with BAU in 2050. To achieve the most ambitious mitigation target, the ALL scenario combined all the mitigation options identified in OFW and OFC. The estimated total NH_3 volatilization and N leaching of the ALL scenario are 2.1 Tg N in 2050 (65% reduction relative to BAU). Under scenario ALL, China would show a quite low soil N emission intensity (0.52 g N $kcal^{-1}$ yr^{-1}) in 2050, which is closer to that of the USA (0.49 g N $kcal^{-1}$ yr^{-1}) and the EU (0.45 g N $kcal^{-1}$ yr^{-1}).

Spatially explicit information of soil N loss mitigation potential could help us to identify specific crops and hotspot areas, which may be attractive 'mitigation targets' (Figs 1 and b). We ranked gridded mitigation potentials from largest to smallest, and then added the value to the sum of its predecessors, resulting in cumulative mitigation potential up to a given point of sowing area. Soil N loss mitigation potentials were unevenly distributed across China. A half of the N loss reduction could be achieved on 26% for all crops together. Total mitigation potentials were concentrated in Huaihe and lower Yellow River Basin, which contributed about half of the total. This result implies the importance of this region on food production and highlights the benefit of focusing on a small area that could deliver large soil N loss mitigation. It should be noted that the Beijing-Tianjin-Hebei region is not the central of soil N loss mitigation, where accounts only for 8% of the total, because of relatively lower N losses in dry and cool areas.

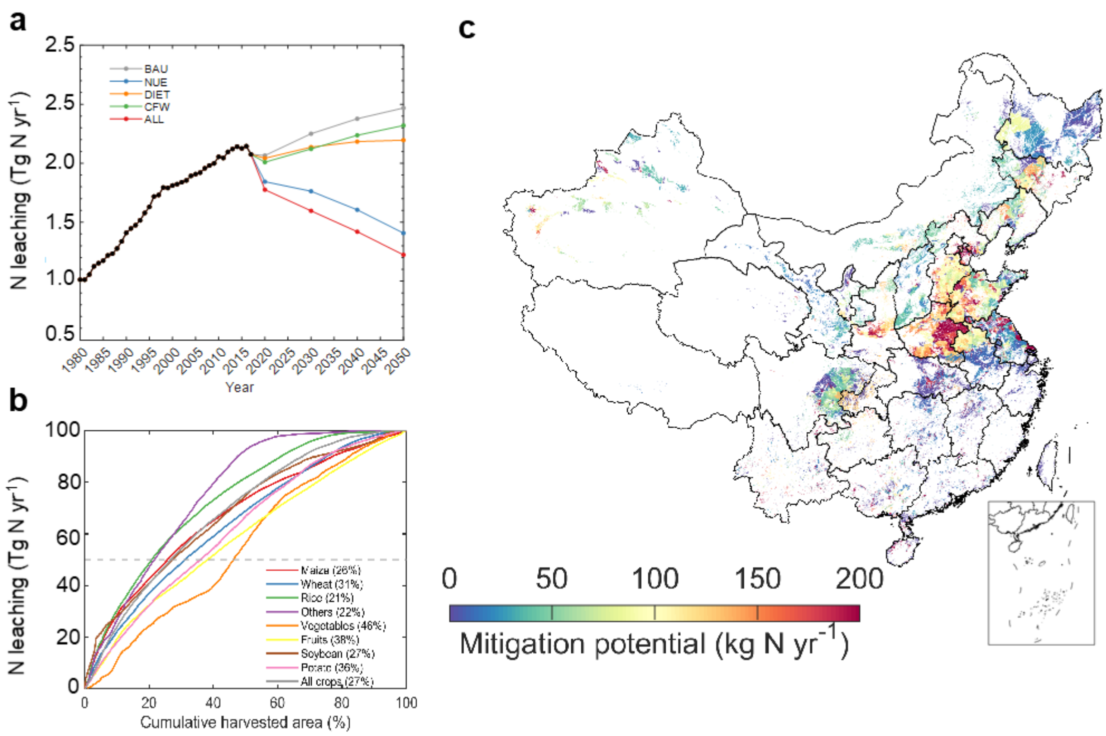

Figure 1. China's cropland N leaching mitigation potentials. (a) Future N leaching under five scenarios; (b) Spatial pattern of China's cropland N leaching under scenario BAU; (c) China's cropland N leaching mitigation potentials by crop under scenario ALL; (d) Spatial pattern of China's cropland N leaching under scenario ALL.

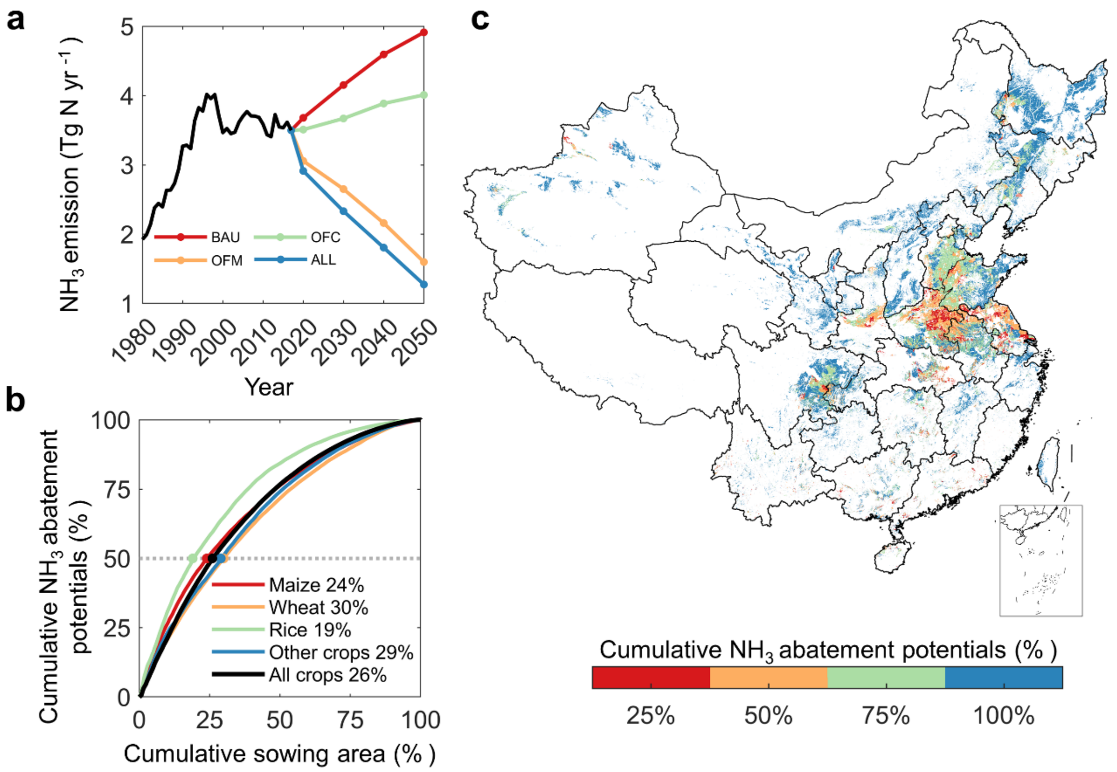

Figure 2. China's cropland-NH₃ mitigation potentials. (a) Future NH3 emission under four scenarios; (b) Spatial pattern of China's cropland-NH3 emission under scenario BAU; (c) China's cropland-NH3 mitigation potentials by crop under scenario ALL; (d) Spatial pattern of China's cropland-NH3 emission under scenario ALL.

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