Supplementary Information for

Food Benefit and Climate Warming Potential of Nitrogen Fertilizer Uses in China

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Reference

Evaluation of model performance

The DLEM model has been widely used to investigate the net exchange of GHGs between terrestrial ecosystems and the atmosphere. The model performance in capturing the daily/seasonal patterns and spatial distributions of terrestrial CO_2, CH_4 and N_2O fluxes has been intensively validated in China[1, 2, 3] and North America[4, 5]. The model's capacity to simulate net C exchange and storage in response to N additions has also been validated against results from N fertilization experiments in China and meta-data analysis worldwide[2, 6]. In this study, we compared the modeled responses of crop yield, soil C sequestration, and N_2O emissions to N fertilizer application with the estimates from census, meta-data analysis of N addition experiments[7, 8, 9] in major crop types of China (Figure S1). These tests have shown that the DLEM model can capture the observed N addition effects on C dynamics and N_2O fluxes in China's cropland. First, we compared the provincial average PFP_N for major crop types in China derived from census data[8] and the DLEM model simulation (Figure S1-I), and found that both of them showed a similar decreasing trend as N fertilizer uses increased and PFP_N appeared to level off since the 1990s. It implied that excessive N fertilizer would not further stimulate crop production. Second, we also validated SOC sequestration in response to N additions against the published data from field experiments in major crop types of China shown in Lu et al.[7]. Field experiments include 11 paired data (control/N fertilized) from 4 sites for maize, 28 paired data from 13 sites for wheat-maize rotation, 24 paired data from 9 sites for wheat, and 16 paired data from 9 sites for paddy rice[7]. Modeled estimates are averaged from 50 randomly selected crop sites for each crop type across China in the year of 2008. The median fertilizer N addition rate in the field experiments is 15 g C m^{-2} yr^{-1}, ranging from 2.1 to 38.5 g C m^{-2} yr^{-1}, while the median N fertilizer input for driving the DLEM model in these randomly distributed crop sites is 18.2 g

C m^{-2} yr^{-1}, ranging from 4.4 to 45.7 g C m^{-2} yr^{-1}. It indicated that the average model estimates from 50 randomly-selected sites in each crop type was quite close to the average experimental evidence, except maize for which observations were only available from 4 sites (Figure S1-II). The standard deviation of field experiments appeared larger than that of model estimates, indicating that the ecosystem model we used is incapable of fully accounting for site-specific variations, which might be caused by missing or simplified mechanisms in our model assumptions, as well as measurement errors in the field data. Likewise, the modeled direct N_2O emission factor (EF_d, kg N_2O-N emission induced by per kg N added) was evaluated against multiple field experiments compiled by Gao et al[9]. The y axis of Figure S1-III indicates average EF_ds of 500 sites randomly selected from model estimation in different crop groups during 1990-2008; the x axis indicates average EF_ds from 261 observations in upland crops and 195 observations from paddy fields[9]. We found that the modeled EF_d average for upland crops and paddy fields was quite comparable to the observed mean values (Figure S1-III). However, the standard deviations of modeling estimates were smaller than that of observations. Model simplification, such as the difference in N_2O estimates due to fertilizer types and timing, and inherent uncertainties in site-scale EF_ds estimation derived from fertilizer treatments, measurement stage and frequency are the likely reasons responsible for the mismatch of the estimates from these two approaches.

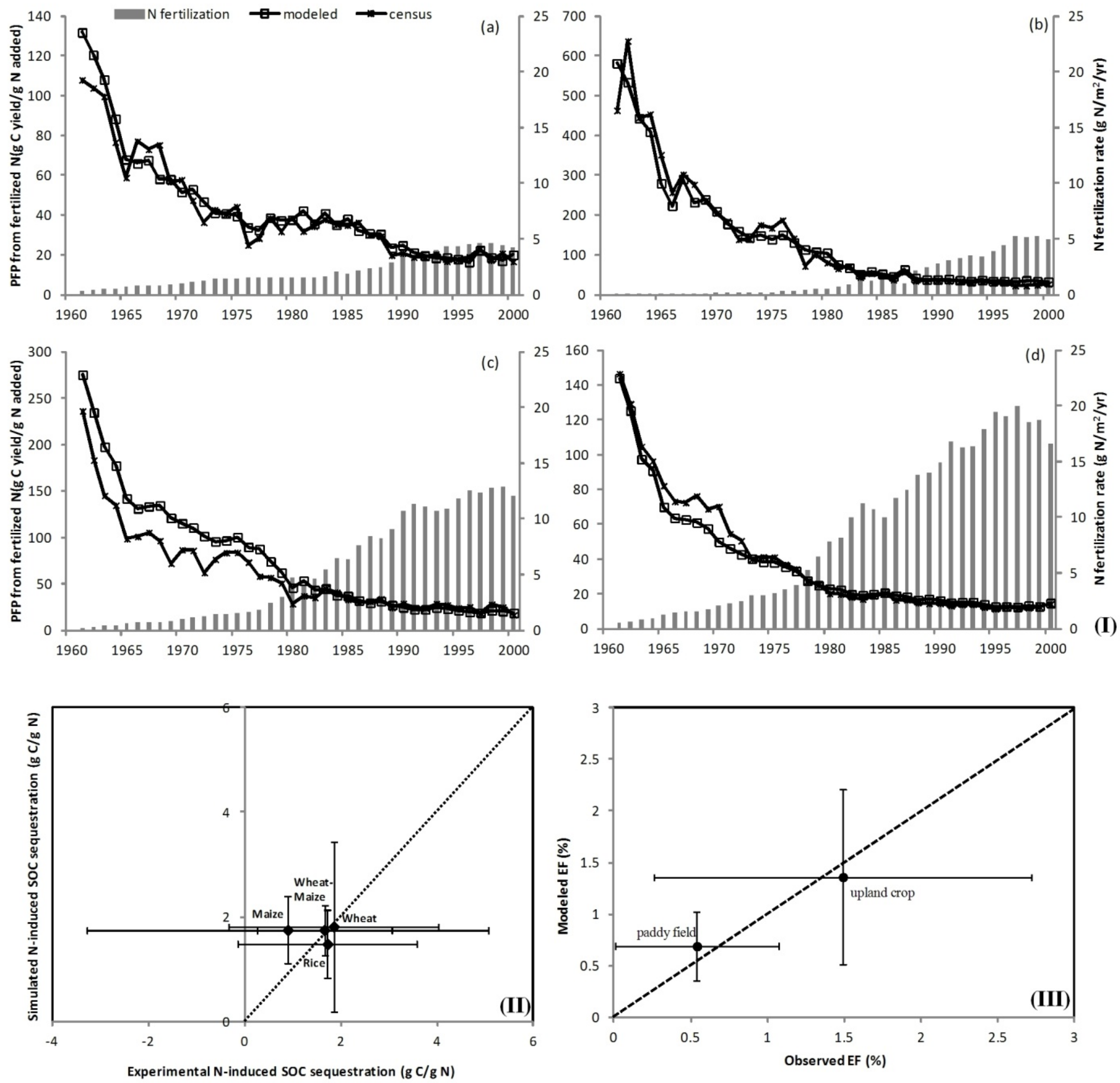

Figure S1 Comparison of the modeled and observed ecosystem response to N additions. (I) Partial factor productivity from fertilized N (PFP_N calculated as the ratio of provincial average crop yield for a specific crop type and average N fertilization rate, unit: g C yield/g N added) in soybean, Heilongjiang (a), wheat, Inner Mongolia (b), maize, Jilin (c) and rice, Jiangxi (d) derived from DLEM model simulation and census during the period 1961-2000; (II) N fertilizer-induced soil organic carbon (SOC) sequestration in China's cropland as estimated by field experiments and the DLEM simulations; (III) Direct emission factor of N_2O induced by N fertilizer application (EF_d, unit: % kg N_2O-N/kg N added) estimated by the DLEM simulation and multi-site observations in upland crops and paddy field. The horizontal and vertical error bars in figure II and III are standard deviations among sampled data from experiments and model estimates, respectively. Dashed line is 1:1 line.

Comparison between this study and others at national level

To evaluate the robustness of the DLEM-based national estimates, we compared our simulated soil C sequestration and N_2O fluxes with inventory-based and other modeled results and found our estimates are comparable to them. For example, Lu et al.[7] estimated that N fertilizer application in China's cropland resulted in a net soil C sequestration of 5.96 Tg C yr^{-1} in the top soil (0-20 cm) of three major cereal crops (rice, wheat and maize), which covered 46.6% of China's total cropland area and received less than 50% of total N fertilizer uses. When the remaining amount (>50%) of N consumed is considered, their estimate can be increased to nearly 12 Tg C yr^{-1} over the entire China. Another study[10] also made a similar conclusion that N fertilizer uses increased soil organic C by 14.7 Tg C yr^{-1} throughout 0-30 cm soil layer. These two estimates are comparable to our estimate of 15 Tg C yr^{-1} for top 20-cm soil layer in the same period. The DLEM estimate of N_2O emission due to chemical N fertilizer uses in China's cropland, 222 Gg N yr^{-1} in the 1990s, is very close to others' empirical results, 210.5 Gg N yr^{-1} resulting from chemical N fertilizer[11], and lower than estimatesof 275 Gg N yr^{-1} (ref. 12) and 228.7 Gg N yr^{-1} (ref. 9) resulting from multiple N inputs including residue return, chemical fertilizer and manure application, etc. Most of the above studies only focused one aspect of ecosystem functions altered by N addition, and adopted empirical approaches while overlooking the complex interactions among C and N cycling. Undoubtedly, we could compile the existing studies together to get a rough estimate of N fertilizer impacts on soil C storage and N_2O emissions on national scale. However, apart from C-N coupled, process-based biogeochemical modeling, it is impossible to assess the coupled responses of crop production, soil C sequestration and GHG emission to excessive N fertilizer uses in China in the spatial and temporal contexts.

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