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Supplementary material

Modelling reduced coastal eutrophication with increased crop yields in Chinese agriculture

Ang A. Li[A,B], *Maryna M. Strokal*[B], *Zhaohai Z. H. Bai*[A], *Carolien C. Kroeze*[B], *Lin L. Ma*[A,D] *and Fusuo F. S. Zhang*[C]

[A]Key Laboratory of Agricultural Water Resources, Center for Agricultural Resources Research, Institute of Genetic and Developmental Biology, The Chinese Academy of Sciences, 286 Huaizhong Road, Shijiazhuang 050021, Hebei, China.

[B]Water Systems and Global Change Group, Wageningen University & Research, PO Box 47, 6700 AA, Wageningen, The Netherlands.

[C]College of Resources and Environmental Sciences, China Agriculture University, Beijing 100193, China.

[D]Corresponding author. Email: malin1979@sjziam.ac.cn

Quantifying particulate forms of nutrient and dissolved silica in Global NEWS 2

Particulate forms of N and P (PN and PP) are calculated as a funtion to total suspended solids (Beusen *et al.* 2009). Beusen *et al.* (2005) describe the calculation of the particulate N and P model. Dissolved Si (Holm *et al.* 2013) is quantified based on an empirical linear relation between DSi and TSS or DIP. Beusen *et al.* (2009) describe the modelling approach of dissolved Si. TSS is calculated as a function of terrain slope, volcanic rock characters, soil bulk density, and annual precipitation (Beusen *et al.* 2009).

Summary of equations in Global NEWS 2 model

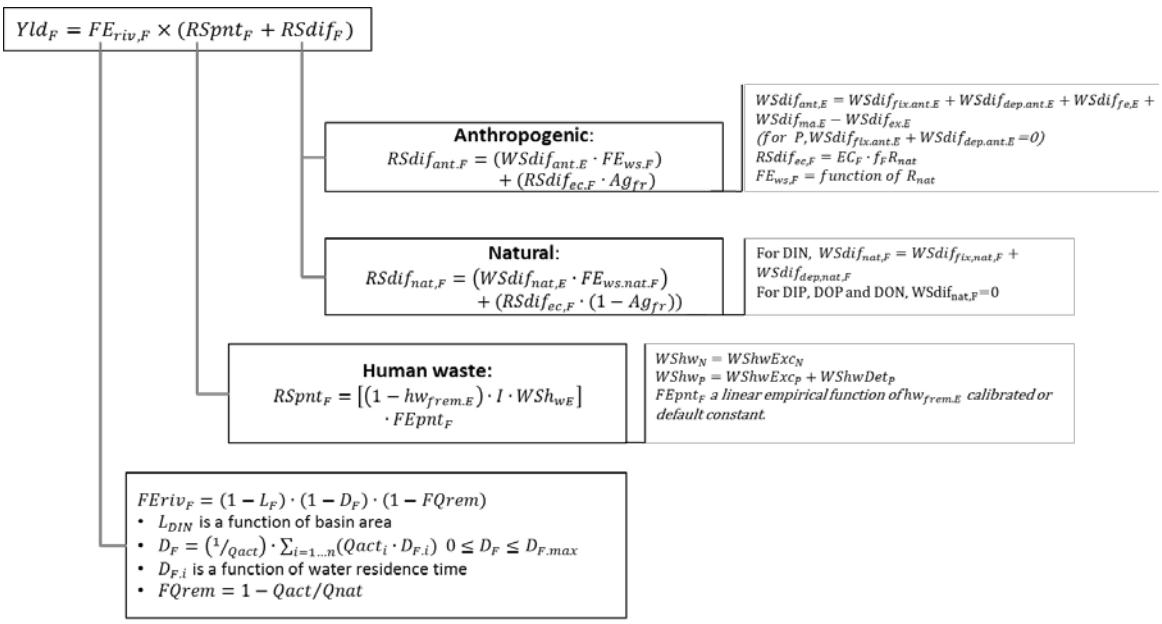

Fig. S1. Summary of Global NEWS 2 equations used to quantify annual river export of dissolved inorganic and organic nitrogen and phosphorus. Source: Global NEWS 2 (Mayorga *et al.* 2010). Abbreviations are described in Table S1.

Table S1. Description of abbreviations in Fig. S1

Abbreviation	***Unit***	***Definition***
$\mathbf{Yld_r}$	kg km^{-2} year^{-1}	total yield of river export of nutrient in the form F (F: dissolved inorganic N, dissolved organic N, dissolved inorganic P, dissolved organic P) at the river mouth
$\mathbf{RSdif_F}$	kg km^{-2} year^{-1}	total nutrient input to surface water from diffuse sources in the form F.
$\mathbf{RSdif_{ant,F}}$	kg km^{-2} year^{-1}	total nutrient input to surface water from diffuse sources in the form F on agricultural area
$\mathbf{WSdif_{ant,E}}$	kg km^{-2} year^{-1}	net nutrient element E (E: N and P) input to agricultural watersheds (kg km^{-2} year^{-1}) that include: N resulted from biological N_2-fixation ($WSdif_{fix,ant,N}$, kg km^{-2} year^{-1}), atmospheric N-deposition ($WSdif_{dep,ant,N}$, kg km^{-2} year^{-1}), synthetic fertilizers use ($WSdif_{fe,N}$, kg km^{-2} year^{-1}), excretion of animal manure ($WSdif_{ma,ant,N}$, kg km^{-2} year^{-1}) corrected by the N removal from agricultural areas through animal grazing and plant uptake ($WSdif_{ex,N}$, kg km^{-2} year^{-1}); P resulted from synthetic fertilizers use ($WSdif_{fe,P}$, kg km^{-2} year^{-1}), excretion of animal manure ($WSdif_{ma,ant,P}$, kg km^{-2} year^{-1}), corrected by the P removal from agricultural areas through animal grazing and plant uptake ($WSdif_{ex,P}$, kg km^{-2} year^{-1})
$\mathbf{EC_F}$	kg km^{-2} year^{-1}	a constant, calibrated export coefficient for DIP, DON and DOP. For DIP, this constant represents weathering of phosphorus-containing minerals, while for DON and DOP it corresponds to a net leaching or export of dissolved organic matter from land into streams
$\mathbf{FE_{ws,F}}$	0-1	nutrient export fraction from land to surface water in form F
$\mathbf{RSdif_{ec,F}}$	kg km^{-2} year^{-1}	nutrient input to surface water from weathering of minerals in the form F (for DIP), leaching of organic matters (for DON and DOP) from agriculture area
$\mathbf{Ag_{fr}}$	0-1	percentage of agriculture area to total basin area
Rnat	m year^{-1}	mean annual river runoff
$\mathbf{f_F(Rnat)}$	m year^{-1}	the modulated runoff by adjusted coefficients and empirical determination of the shape for each nutrient form
$\mathbf{RSdif_{nat,F}}$	kg km^{-2} year^{-1}	total nutrient input to surface water from diffuse sources on non-agricultural area in the form F
$\mathbf{RSpnt_F}$	kg km^{-2} year^{-1}	total nutrient input to surface water from point sources in the form F
$\mathbf{WShw_E}$	kg km^{-2} year^{-1}	the net nutrient element E production in watersheds from point sources
$\mathbf{WShwDet_P}$	kg km^{-2} year^{-1}	the net nutrient P production in watersheds from detergent usage
$\mathbf{WShwExc_E}$	kg km^{-2} year^{-1}	the net nutrient element E production in water sheds from human excretion

$hw_{frem,E}$	0-1	the fraction of nutrient E removal in sewage waste water through waste water treatment plant
I	0-1	the fraction of population connected to sewage systems
$FEpnt_F$	0-1	the fraction of nutrient in sewage effluents that can reach the river mouth as the form F
$FE_{riv,F}$	0-1	there are nutrient losses because of retention within river system, thus $FE_{riv,F}$ is the fraction of total river export of nutrient form F that can reach the coastal waters
D_F	D_F	the fraction of nutrient form F was retained in reservoirs along the river network
L_F	0-1	the fraction of nutrient form F that is retained within or/and lost (e.g. via denitrification) from the river network (only for DIN)
FQ_{rem}	0-1	the fraction of removed nutrients from the river system via water withdrawal (e.g. for irrigation). It is identical for all dissolved forms of nutrients and it is calculated based on natural (Q_{nat}, before water is consumed, under climate driven condition) and actual (Q_{act}, after water is consumed, under anthropogenic and climate conditions) water discharges

Transferring data from IAASTD to Global NEWS 2

In this study, we use the International Assessment of Agricultural Knowledge, Science, and Technology for Development (IAASTD) baseline scenario to estimate crop nutrients demand in different land use types in 2050. However, the IAASTD projection is on the provincial scale while Global NEWS 2 calculates on the basin scale. We, therefore, transformed provincial data to the basin scale as follows.

The first step is to calculate the percentage of basin areas (Hein *et al.* 2011) in each province. This step is conducted by the intersect tool in ArcGIS. Second, total fertilizer consumption is distributed over basins in a province, using the sizes of basin areas calculated in the first step (Box S1). The total fertilizer consumption for each province ($TF_{n,x}$) in different land use types is available from the IAASTD scenario. The third step is to sum up the fertilizer consumption in the different land use types in one basin ($TF_{n,m,x}$). Then the final step is to calculate the share of fertilizers applied to different land use types ($P_{n,m,x}$) in each basin.

Box S1. Description of data transferring steps from IAASTD to Global *NEWS*-2

Transferring data from IAASTD to Global *NEWS*-2

STEP 1: Calculating area percentages of land use type in each province P_m

$$P_{m,n} = \frac{A_{n,m}}{A_n}$$

STEP 2: Calculating total fertilizer consumption for each basins by land use type $Tf_{basin,m,x}$

$$TF_{m,x} = \sum TF_{n,m,x}$$

$$TF_{n,m,x} = TF_{n,x} \times P_{m,n}$$

STEP 3: Calculating share of fertilizer consumption by land use type for each basin $P_{basin,x}$

$$P_{n,m,x} = \frac{TF_{n,m,x}}{TF_{n,m}}$$

Abbreviations

$P_{m,n}$ - is the share of area that occupied by different basin in mth province (%). $A_{prov,n}$ - area (km^2) of nth province. $A_{n,m}$ – area (km^2) of m basins that covered by (nth) province.

$TF_{m,x}$ - is the total fertilizer consumption (Mg) by (x: upland crops, wetland rice, legumes, grassland) land use in m basin. $TF_{n,nm,x}$ - is the fertilizer consumption (Mg) by (x) land use in m basin that covered in (nth) province. $TF_{n,x}$ - is the total fertilizer consumption (Mg) in (nth) province.

$P_{n,m,x}$ - is the percentage of fertilizer consumed by x land use type in nth basin (%). $TF_{n,m}$ – is the total fertilizer consumption (Mg) by mth basin.

Scenarios descriptions (extended)

We use *the Global Orchestration (GO) scenario* as the baseline scenario in this study. The GO scenario is one of the Millinium Ecosystems Analysis (MA) scenarios. MA scenarios aim to project the impact of ecosystem changes on society, and to provide future trends in socio-economic development for decision makers to prevent irreversible consequences on environmental systems. These scenarios simulate future developments based on a set of coherent and interconnected assumptions on social, environmental, and economic drivers and relation between them. The GO scenario assumes a globally connected society and a reactive approach to solve environmental problems (Alcamo *et al.* 2005). Population is assumed to increase in the future. Various agriculture practices will be found to produce sufficient food for growing population. Therefore, the amount of synthetic fertilizers use is expected to increase. The water demand for hydropower and irrigation of crops will also increase. The efficiency of N and P removal during treatment in sewage systems are expected to be higher in the future. More people will be connected to sewage systems (Seitzinger *et al.* 2010).

The Improved Practice (**IP**) scenario is calculated as follows:

$$N_{IP} = N_{fer,wr} \times \left(1 - fr_{IP,wr,N}\right) + N_{fer,uc} \times \left(1 - fr_{IP,uc,N}\right) + N_{fer,leg} + N_{fer,grass} \qquad \text{Eq. (S1)}$$

$$P_{IP} = P_{fer,wr} \times \left(1 - fr_{IP,wr,P}\right) + P_{fer,uc} \times \left(1 - fr_{IP,uc,P}\right) + P_{fer,leg} + P_{fer,grass} \qquad \text{Eq. (S2)}$$

N_{IP}: synthetic fertilizer N inputs to land in the IP scenario (kg km^2 year^{-1});

P_{IP}: synthetic fertilizer P inputs to land in the IP scenario (kg km^2 year^{-1});

N_{fer}: synthetic fertilizer N use (kg km^2 year^{-1});

P_{fer}: synthetic fertilizer P use (kg km^2 year^{-1});

wr: wetland rice;

up: upland crop;

leg: legume;

grass: grassland;

fr: fraction of synthetic fertilizer N or P use reduced.

The Integrated Soil-Crop Systems Management (**ISSM**) scenario is quantified as equation S3 and S4:

$$N_{ISSM} = N_{fer,wr} \times \left(1 - fr_{ISSM,wr,N}\right) + N_{fer,uc} \times \left(1 - fr_{ISSM,uc,N}\right) + N_{leg} + N_{grass} \qquad \text{Eq. (S3)}$$

$$P_{ISSM} = P_{fer,wr} \times \left(1 - fr_{ISSM,wr,P}\right) + P_{fer,uc} \times \left(1 - fr_{ISSM,uc,P}\right) + P_{leg} + P_{grass} \qquad \text{Eq. (S4)}$$

N_{ISSM}: synthetic fertilizer N inputs to land in the ISSM scenario (kg km^2 year^{-1});

P_{ISSM}: synthetic fertilizer P inputs to land in the ISSM scenario (kg km^2 year^{-1}).

The IP with advanced manure management (**IP-MR**) scenario is quantified as equation S5 and S6:

$$N_{IP-MR} = N_{IP} - 50\% \times N_{man} \qquad \text{Eq. (S5)}$$

$$P_{IP-MR} = P_{IP} - 90\% \times P_{man} \qquad \text{Eq. (S6)}$$

$N_{IP\text{-}MR}$: synthetic fertilizer N inputs to land in the IP-MR scenario (kg km^2 year^{-1});

$P_{IP\text{-}MR}$: synthetic fertilizer P inputs to land in the IP-MR scenario (kg km^2 year^{-1});

N_{fer}: synthetic fertilizer N use (kg km^2 year^{-1});

P_{fer}: synthetic fertilizer P use (kg km^2 year^{-1});

N_{man}: animal manure N use (kg km^2 year^{-1});

P_{man}: animal manure P use (kg km^2 year^{-1}).

The ISSM with advanced manure management (**ISSM-MR**) scenario is quantified as equation S7 and S8:

$$N_{ISSM-MR} = N_{ISSM} - 50\% \times N_{man} \quad \text{Eq. (S7)}$$

$$P_{ISSM-MR} = P_{ISSM} - 90\% \times P_{man} \quad \text{Eq. (S8)}$$

$N_{ISSM\text{-}MR}$: synthetic fertilizer N inputs to land in the IP-MR scenario (kg km^2 year^{-1});

$P_{ISSM\text{-}MR}$: synthetic fertilizer P inputs to land in the IP-MR scenario ((kg km^2 year^{-1});

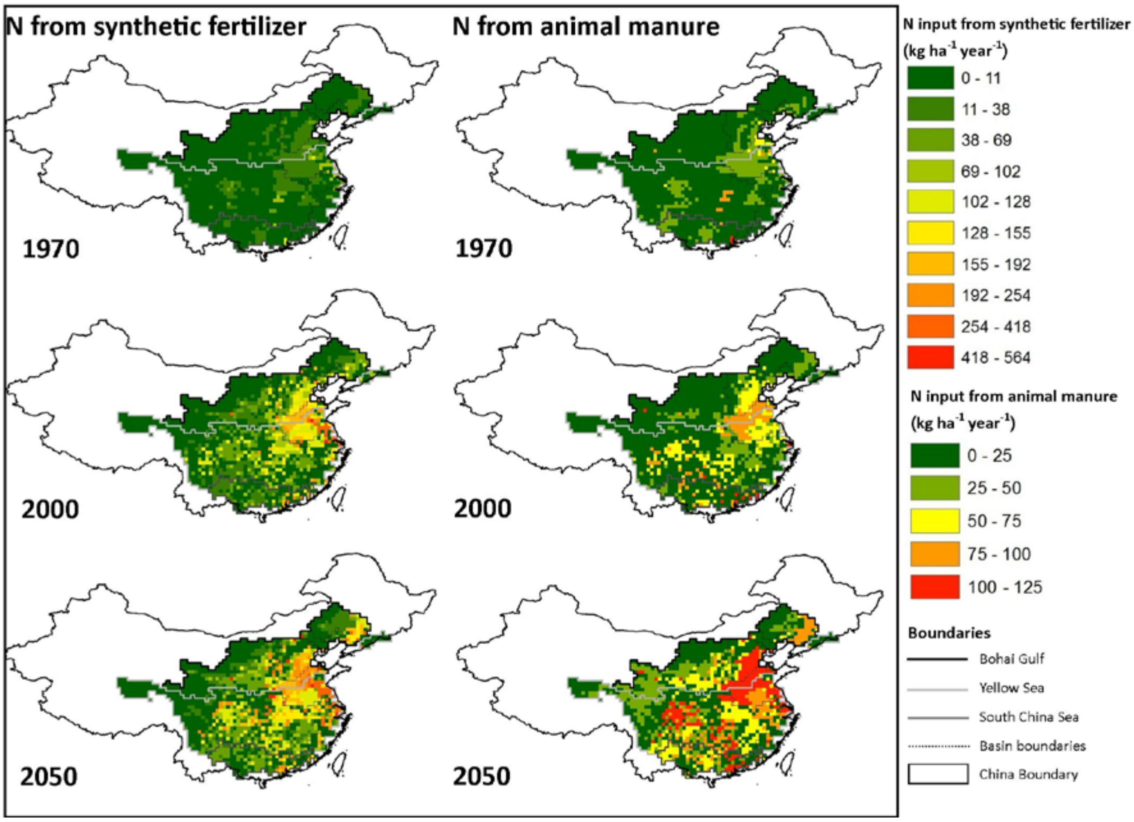

Fig. S2. Total nitrogen inputs to land from synthetic fertilizers and animal manure (kg ha^{-1} $year^{-1}$) in 1970, 2000, and 2050 for the Global Orchestration scenario. Source: Global *NEWS*-2(Mayorga *et al.* 2010) and this study.

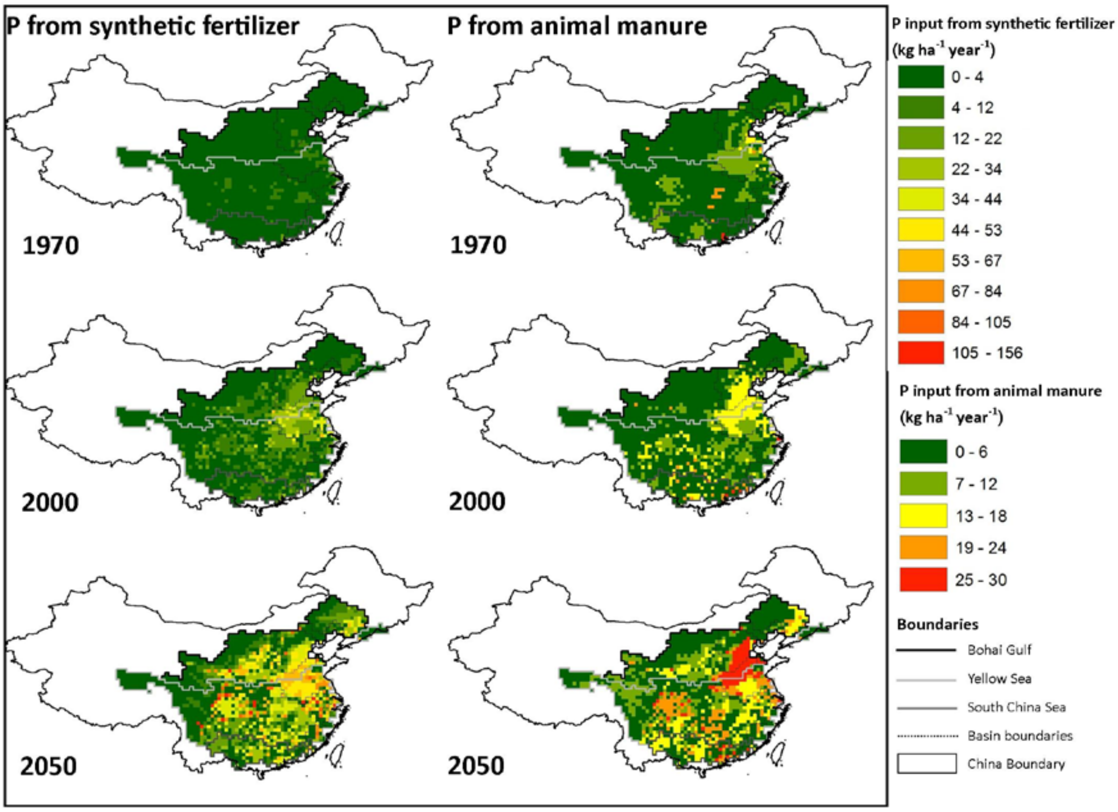

Fig. S3. As Figure S2, but for phosphorus.

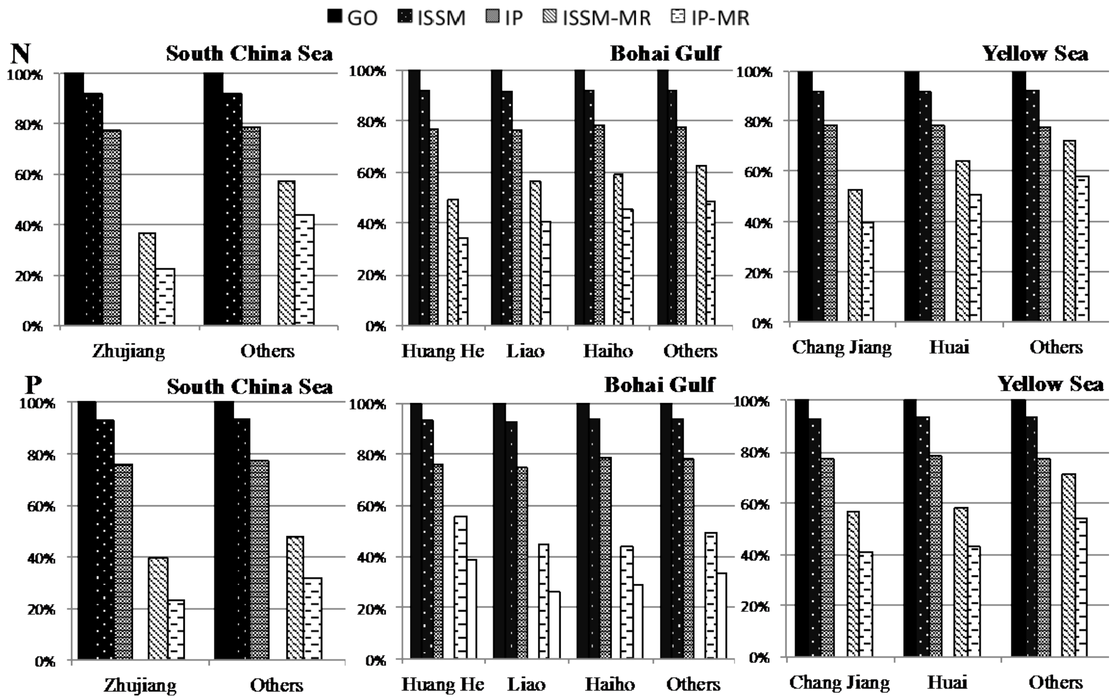

Fig. S4. Synthetic fertilizer inputs to land in "Double High Agriculture" scenarios and improved manure management scenarios as percentage of the fertilizer use in the GO scenario for 2050. Results are shown for river basins draining into three different seas, and "Double High Agriculture" scenarios and improved manure management scenarios include: IP (improved practice) scenario, IP-MR (IP scenario with improved manure management) scenario, ISSM (integrated soil-crop system) scenario, and ISSM-MR (ISSM scenario with improved manure management). Scenario description can be found in the section of Materials and Methods. Source: Global NEWS 2 (Mayorga *et al.* 2010) and IAASTD baseline scenario (Bouwman *et al.* 2013).

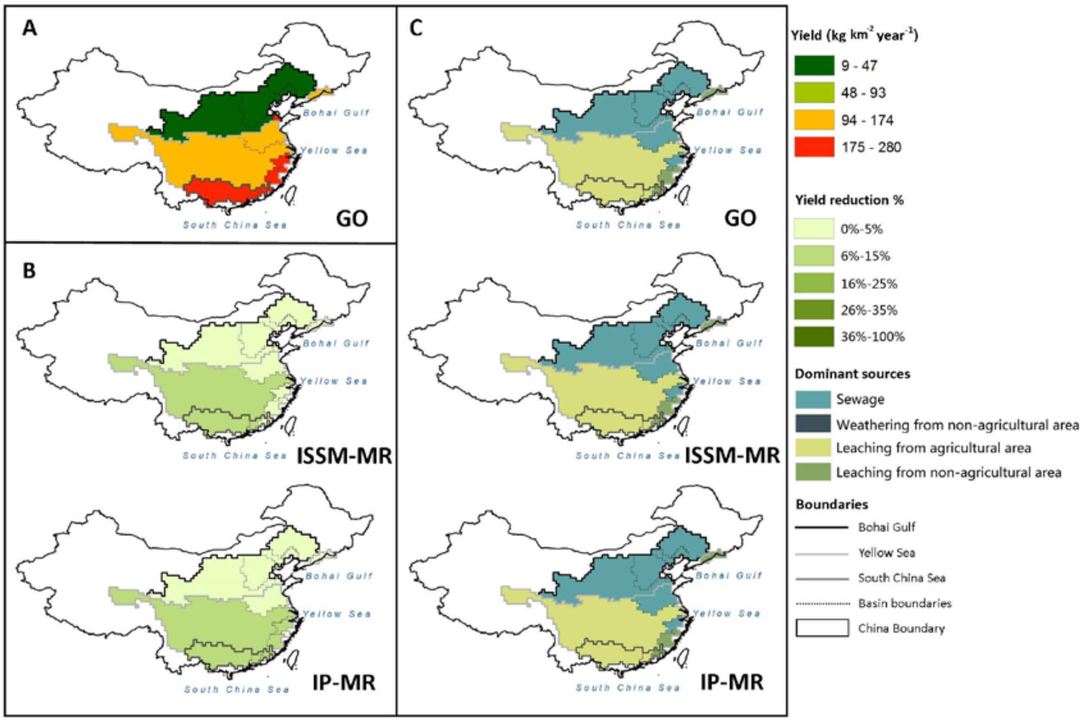

Fig. S5. A: Modelled river export of total dissolved organic nitrogen (DON) (kg km^{-2} year^{-1}) by sixteen selected rivers in 2050. B: Percentages of DON reduced by '*Double High Agricultural*' in 2050. C: Dominant source in GO, IP-MR, and ISSM-MR scenarios in 2050. Scenario description can be found in the section of Material and Methods. Source: Global *NEWS*-2(Mayorga *et al.* 2010) and IAASTD baseline scenario(Bouwman *et al.* 2013) and this study.

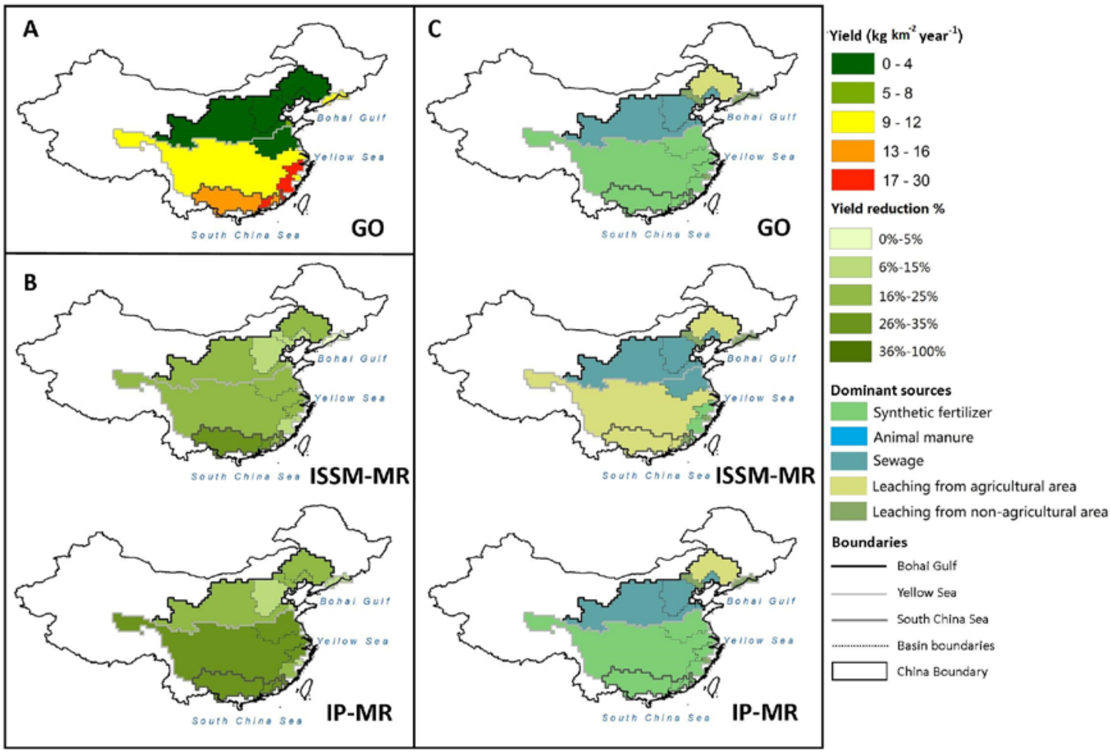

Fig. S6. As Figure S5, but for dissolved organic phosphorus (DOP).

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