The effect of 'Double High Agriculture' on nitrogen losses from crop production to coastal water in China

Ang Li[1], Maryna Strokal[1], Carolien Kroeze[1,2], Zhaohai Bai[3], Lin Ma[3]

[1] Environmental Systems Analysis Group, Wageningen University, Droevendaalsesteeg 3, Wageningen, The Netherlands, 6708 PB, ang.li@wur.nl
[2] Water Systems and Global Change Group, Wageningen University, Droevendaalsesteeg 3, Wageningen, The Netherlands, 6708 PB
[3] Key Laboratory of Agricultural Water Resource, Center for Agricultural Resources Research, Institute of Genetic and Developmental Biology, Chinese Academy of Sciences, Huaizhong Road 286, Shijiazhuang, Hebei 050021, China.

Abstract
'Double High Agricultural' (DHA) is a nutrient management strategy focusing on increasing nitrogen (N) and phosphorus (P) use efficiencies, while also increasing crop yields. DHA may thus reduce losses of nutrients to the environment. We quantified the impact of DHA on N inputs to rivers and coastal seas in the year 2050. To this end, we applied the Global *NEWS* (Nutrient Export from WaterSheds) model. Two scenarios were developed based on two different agricultural practice of DHA: 1) The Integrated Soil-crop Systems Management (ISSM) scenario which assumes a 30% lower synthetic fertilizer application and 30% higher crop yields; 2) The ISSM-MR scenario, which is as ISSM, but assumes increased Manure Recycling in crop production, leading to lower synthetic fertilizer use. The results indicate that river export of dissolved inorganic N (DIN) and dissolved organic N (DON) in the ISSM scenario are about 10% lower than in the reference scenario. In ISSM-MR river export of DIN is about 30% lower than in the reference scenario.

Key Words
nutrient management, nitrogen losses, Chinese agriculture, dissolved nitrogen

Introduction
Chinese agriculture has been intensifying since the Green Revolution in 20th Century. Today, crop production is characterised by high nutrient inputs and high yields (Ma et al., 2010). For example, the average synthetic N fertilizer use in winter wheat-summer maize cropping systems increased by a factor of five during the past 30 years (Cui, Chen, & Zhang, 2010). However, the agricultural system is not very nutrient efficient, and large amounts of N are lost to the environment. As a result, N losses to rivers have developed into a severe environmental pollution problem (Ma et al., 2010). Increasing river export of nutrients resulted in harmful algae blooms in the Bohai Gulf, Yellow Seas and South China Seas (Daoji & Daler, 2004; Le et al., 2010; Liu et al., 2013). Solving this coastal eutrophication problem requires a more effective use of nutrients in crop production in China.

Recent studies introduced the so-called *'Double High Agriculture'* (DHA) management as a promising strategy for Chinese agriculture. It refers to systems with high nutrient use efficiency and high crop yield, to meet the large food demand with less negative impacts on environment (X. Chen et al., 2006; X. P. Chen et al., 2011; Cui et al., 2010). The DHA has been tested in North China Plain region with field experiments. These experiments illustrate how DHA can maintain crop yields while reducing synthetic fertilizer use by 30-60% (Ju et al., 2009). This may lead to lower N losses to aquatic systems, and thus lower the risk for coastal eutrophication. However, the impact of DHA on coastal waters has never been quantified. Therefore, the aim of this study is to quantify the impact of DHA on N losses to rivers and coastal waters in China in the future. To this end, a scenario analysis is performed using the Global *NEWS*-2 (Nutrient Export from WaterSheds) model.

Methods
Global NEWS-2 model
In this study, we modelled nutrient export by rivers to three different seas: the Bohai Gulf, Yellow Sea, and South China Sea (Figure 1) using Global *NESW-2* model. The Global *NEWS*-2 model is described in detail elsewhere (Mayorga et al., 2010; Seitzinger, Harrison, Dumont, Beusen, & Bouwman, 2005). It is a model that quantifies annual river export of nutrients from land to sea. We use it to calculate river export of dissolved inorganic N (DIN), dissolved organic N (DON), and particulate N (PN) to Chinese seas. The river network in the model is based on the Stimulated Topological Network (STN-30p) river system on a 0.5 * 0.5

degree grid. Model inputs about land use, ecosystems, and nutrient inputs to waters from different sources are from the IMAGE model (Bouwman, Beusen, & Billen, 2009; Van Drecht, Bouwman, Harrison, & Knoop, 2009).

The river export of nutrients is quantified as nutrient yields (kg per km^2 of the basin per year) or load (Mg $year^{-1}$) for the past (1970 and 2000) and future (2030 and 2050) years. For dissolved forms, nutrients are calculated based on mass-balance approach (Mayorga et al., 2010). For particulate forms, linear regression analysis on relation with suspended solids is applied (Beusen, Dekkers, Bouwman, Ludwig, & Harrison, 2005; Mayorga et al., 2010). Dissolved forms nutrients to coastal waters are from either diffuse sources or point sources after considering soil, rivers or reservoirs retention and water consumption during delivering process by rivers. Diffuse sources are classified into natural process (e.g. biological N fixation, and atmospheric N deposition) and anthropogenic activities (e.g. synthetic fertilizer and animal manure application, biological N fixation by crops, atmospheric N deposition, and leaching of organic matters from agricultural area).

Scenarios for the year 2050
We used the Global Orchestration (**GO**) scenario from Millennium Ecosystems Assessment as a reference scenario. GO assumes increasing food production for a growing population, leading to more synthetic fertilizer use and animal excretion.

We developed two DHA scenarios: The Integrated Soil-crop Systems Scenario (**ISSM**) and ISSM with increased Manure Recycling (**ISSM-MR**) (Table 1). ISSM assumes that N use efficiency in crop production is higher than in GO. The extent to which varies among crop types (X. Chen et al., 2014). To provide sufficient N, we assume that synthetic N fertilizer use equals crop demand. For ISSM-MR, we assumes that more animal manure is used to meet crop demand for N. This reduced the need for synthetic fertilizers. As a result, less synthetic N fertilizer is used in ISSM-MR than in ISSM.

Table 1. Scenario overview for 2050.

Scenarios	N Synthetic fertilizer	N Animal Manure
Global Orchestration (GO)	Increasing synthetic fertilizer use	Increasing animal manure excretion as a result of increasing animal numbers; more industrialized animal production
Integrated Soil-crop Systems Management (ISSM)	Synthetic fertilizer use does not exceed crop demand (4-14 % less N synthetic fertilizer use and 30% higher N uptake by crops than in GO).	Same as GO
ISSM with increased Manure Recycling (ISSM-MR)	Total N inputs to crop production (manure + synthetic fertilizer) do not exceed crop demand	All animal manure will be considered as source of N for crops, replacing synthetic fertilizers (assuming an N equivalent ratio of 50%); advanced manure management, such as slurry type of manure injection

Results
GO scenario (reference scenario)
Between 1970 to 2000, the total N inputs to the three seas increased substantially, in particular for DIN in the reference GO scenario. Total N export to the Bohai Gulf, increased by a factor of 2.5. This is higher than for the other two seas. The sources of N inputs to the three seas differ, and also differ over time. For Bohai Gulf, the dominant source of N is sewage. For the Yellow Sea and the South China Sea, we calculated that more than 50% of the total N is from fertilizer and manure (Figure 1: b-1, 2, 3).

DHA scenarios
In the ISSM and ISSM-MR scenarios the river export of N is lower than in the reference GO scenario for 2050. River export of total N to the South China Sea and Yellow Sea is calculated to be back at the level predicted for the year 2000. For the Bohai Gulf, the reduction is smaller (Figure 1: b-1). This can be

explained by the fact that sewage is the dominant source of N fluxes to the Bohai Gulf, which is not affected by ISSM. In the Yellow Sea and South China Sea fertilizer and manure inputs are most important, and these are considerably reduced relative to the reference. ISSM is more effective in reducing river export of DIN than of DON. Manure recycling, as assumed in the ISSM-MR scenario, reduces N inputs from fertilizer and animal manure to the three seas further.

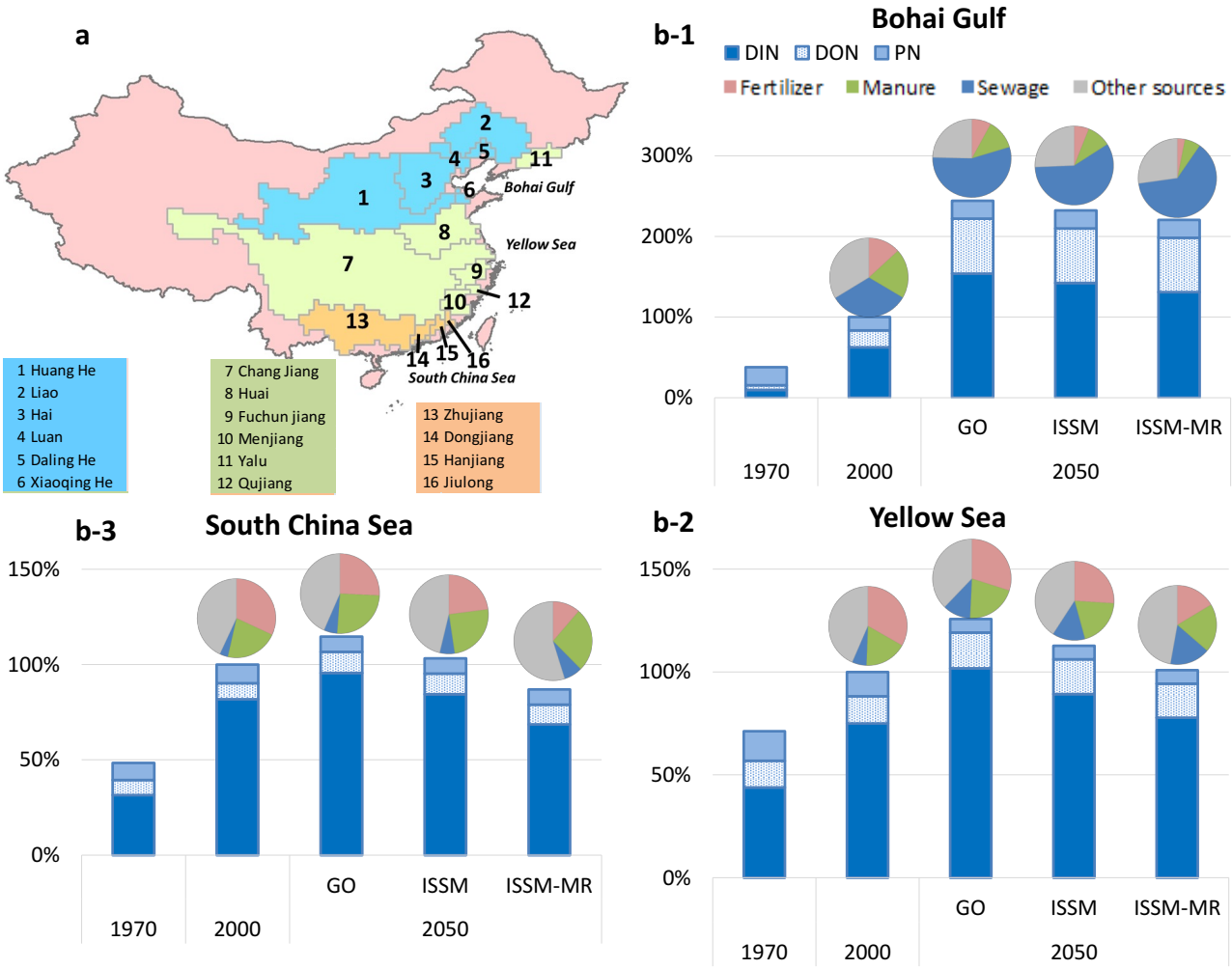

Figure 1. The spatial distribution of 16 Chinese rivers basins that drain into Bohai Gulf, Yellow Sea and South China seas (a). River export of total N and percentage of source attribution to total N in 1970, 2000, and 2050 under GO, ISSM, ISSM-MR scenarios for Bohai Gulf (b-1), Yellow Sea (b-2), and South China Sea (b-3). (scenarios description see Methods section)

Conclusion

Chinese coastal waters are polluted because of increased N export by rivers. By 2050, total N inputs to Chinese seas may be considerably higher than today. '*Double High Agriculture*' management is a promising strategy to produce food with lower N losses to the environment. It may reduce N inputs to coastal waters, particularly when combined with manure recycling. Our scenarios indicate that total N input to the Yellow Sea and South China Sea may be reduce to the levels of the year 2000. For the Bohai Gulf additional waste water management would be needed to reach such low levels.

References

Beusen, A. H. W., Dekkers, A. L. M., Bouwman, A. F., Ludwig, W., & Harrison, J. (2005). Estimation of global river transport of sediments and associated particulate C, N, and P. *Global Biogeochemical Cycles, 19*(4). doi: 10.1029/2005gb002453

Bouwman, A. F., Beusen, A. H. W., & Billen, G. (2009). Human alteration of the global nitrogen and phosphorus soil balances for the period 1970-2050. *Global Biogeochemical Cycles, 23*(4). doi: 10.1029/2009gb003576

Chen, X., Cui, Z., Fan, M., Vitousek, P., Zhao, M., Ma, W., . . . Zhang, F. (2014). Producing more grain with lower environmental costs. *Nature, 514*(7523), 486-489. doi: 10.1038/nature13609

Chen, X., Zhang, F., Römheld, V., Horlacher, D., Schulz, R., Böning-Zilkens, M., . . . Claupein, W. (2006). Synchronizing N Supply from Soil and Fertilizer and N Demand of Winter Wheat by an Improved Nmin Method. [Nutrient Cycling in Agroecosystems]. *Nutrient Cycling in Agroecosystems, 74*(2), 91-98. doi: 10.1007/s10705-005-1701-9

Chen, X. P., Cui, Z. L., Vitousek, P. M., Cassman, K. G., Matson, P. A., Bai, J. S., . . . Zhang, F. S. (2011). Integrated soil-crop system management for food security. *Proc Natl Acad Sci U S A, 108*(16), 6399-6404. doi: 10.1073/pnas.1101419108

Cui, Z., Chen, X., & Zhang, F. (2010). Current nitrogen management status and measures to improve the intensive wheat-maize system in China. *Ambio, 39*(5-6), 376-384.

Daoji, L., & Daler, D. (2004). Ocean pollution from land-based sources: East China Sea, China. *Ambio, 33*(1-2), 107-113.

Ju, X. T., Xing, G. X., Chen, X. P., Zhang, S. L., Zhang, L. J., Liu, X. J., . . . Zhang, F. S. (2009). Reducing environmental risk by improving N management in intensive Chinese agricultural systems. *Proc Natl Acad Sci U S A, 106*(9), 3041-3046. doi: 10.1073/pnas.0813417106

Le, C., Zha, Y., Li, Y., Sun, D., Lu, H., & Yin, B. (2010). Eutrophication of lake waters in China: cost, causes, and control. [Environmental Management]. *Environ Manage, 45*(4), 662-668. doi: 10.1007/s00267-010-9440-3

Liu, D. Y., Keesing, J. K., He, P. M., Wang, Z. L., Shi, Y. J., & Wang, Y. J. (2013). The world's largest macroalgal bloom in the Yellow Sea, China: Formation and implications. *Estuarine Coastal and Shelf Science, 129*, 2-10. doi: 10.1016/j.ecss.2013.05.021

Ma, L., Ma, W. Q., Velthof, G. L., Wang, F. H., Qin, W., Zhang, F. S., & Oenema, O. (2010). Modeling Nutrient Flows in the Food Chain of China. *Journal of Environment Quality, 39*(4), 1279. doi: 10.2134/jeq2009.0403

Mayorga, E., Seitzinger, S. P., Harrison, J. A., Dumont, E., Beusen, A. H. W., Bouwman, A. F., . . . Van Drecht, G. (2010). Global Nutrient Export from WaterSheds 2 (NEWS 2): Model development and implementation. *Environmental Modelling & Software, 25*(7), 837-853. doi: 10.1016/j.envsoft.2010.01.007

Seitzinger, S. P., Harrison, J. A., Dumont, E., Beusen, A. H. W., & Bouwman, A. F. (2005). Sources and delivery of carbon, nitrogen, and phosphorus to the coastal zone: An overview of Global Nutrient Export from Watersheds (NEWS) models and their application. *Global Biogeochemical Cycles, 19*(4). doi: 10.1029/2005gb002606

Van Drecht, G., Bouwman, A. F., Harrison, J., & Knoop, J. M. (2009). Global nitrogen and phosphate in urban wastewater for the period 1970 to 2050. *Global Biogeochemical Cycles, 23*(4), n/a-n/a. doi: 10.1029/2009gb003458