China's Food Security and Water, Fertilizer, Pesticide, and GHG Saving through Crop Redistribution

Authors and affiliations

Wei Xie[1,*], Anfeng Zhu[1,2], Zhengtao Zhang[3], Tariq Ali[4], Kyle Frankel Davis[5,6], Feng Wu[7]

[1] China Center for Agricultural Policy, School of Advanced Agricultural Sciences, Peking University, No. 5 Yiheyuan Road, Haidian District, Beijing 100871, People's Republic of China

[2] School of Economics and Management, North China University of Technology, No. 5 Jinyuanzhuang Road, Shijingshan District, Beijing 100144, People's Republic of China

[3] Beijing Normal University, No. 19 Xinjiekou Road, Haidian District, Beijing 100875, People's Republic of China[4] School of Economics and Management, Jiangxi Agricultural University, Nanchang 330045, People's Republic of China

[4] School of Economics and Management, Jiangxi Agricultural University, Nanchang 330045, People's Republic of China

[5] Department of Geography and Spatial Sciences, University of Delaware, Newark, DE 19716, United States of America

[6] Department of Plant and Soil Sciences, University of Delaware, Newark, DE 19716, United States of America

[7] University of the Chinese Academy of Sciences, No. 19 Zhongguancundong Road, Haidian District,Beijing 100049, People's Republic of China

∗ Author to whom any correspondence should be addressed.

Abstract

In an age of climate change and resource scarcity, long-term high-intensity water, fertilizer and pesticide use leads to serious environmental pollution, which seriously threatens China's food security. It is a huge challenge to provide adequate food for the increasing population while ensuring agriculture's sustainability. We use a large-scale linear programming model based on big data of agricultural production provided by the SPAM database to study the impacts of cropping redistribution on water (blue and green water), fertilizer (nitrogen, phosphorus, kalium, and compound fertilizer), pesticide, and GHG emission saving in China. Then we build a GTAP model to stimulate effects of cropping redistribution on crops' prices and incomes.

We find that China's blue and green water will be saved by 24.3% and 17.5%, respectively, while ensuring China's food security, guaranteeing farmers' incomes, and limiting the expansion of arable land. Meanwhile, the requirement of fertilizer (nitrogen, 19.8%; phosphate, 26.6%; kalium, 9.8%; compound fertilizer, 15.6%) and pesticide (12.3%) will be decreased synchronously. And this number in specific regions are more dramatic, the nitrogen fertilizer used in Shaanxi will be saved by 46.9%, which will effectively alleviate soil eutrophication there. Accompanied with

resource demand reducing, GHG will be decreased by 12.3%, making a remarkable contribution to climate change mitigation.

We concluded that there is a large space for saving agricultural resource and emission in China, and cropping redistribution is an effective measure to solve this problem without changing the initial endowment of resources. In terms of policy implications, we argue that more attention should be paid to crop redistribution when designing global solutions for ameliorating resource scarcity. It provides a feasible solution with broad implications for seeking sustainable agricultural development around the world.

Introduction

The production of crops increased dramatically in the past 40 years in China, feeding 22% of the world's population with only 7% of the global arable land. However, China's resource utilization efficiency in agriculture is exceedingly lower than the global average, the cropping system has been overburdened by long-term high-intensive inputs of water, chemical fertilizers and pesticides, which leads to the formation of groundwater funnel in North China and soil eutrophication, accompanied with a large scale of greenhouse gas (GHG) emission. Against this background, cropping redistribution is an effective way to take advantages of resource endowments, for reducing agricultural resources consumption and building a sustainable cropping system in China.

A large body of literature has analyzed the influence of redistributing cropping production on resources saving and environment protecting. Compared with existing studies, our contributions are as follows: (1) taking advantages of agricultural big data. We divide the whole country into 72439 grids by 0.5°*0.5° (less than 10 km^2) and build a large-scale liner programming model, which improves the accuracy of model and provides more room for cropping redistribution, compared with redistributing in county level which are usually used in existing studies. (2) Building and applying crop rotations. We build 730 crop rotations and use rotations to substitute rotations but not simply change one crop to another. Assuming a grid which is suitable for wheat (growing from Jan. to May.) and maize (growing from July to Nov.), existing studies only consider weather substitute wheat to rice or not, while the crop rotation that planting wheat and rice in one year is allowed in our study, which is more suitable for current cropping system with high multiple crop index.(3) Building a Pareto set of cropping redistribution strategies. There are multiple demands in current cropping system, such as saving water use, reducing fertilizer inputs, etc. Eight indicators are simultaneously considered in our study, which includes blue water (BW), green water (GW), pesticide (PEST), GHG, nitrogen (N), phosphorus (P), kalium (K), and compound (C) fertilizer. We build an optimal model to find a Pareto set of cropping redistribution strategies. It will greatly improve the decision-making space of policy makers. Due to space constraints, this paper mainly focuses on the results simultaneously saves water, fertilizer and pesticide.

Results

The distribution of crops changes significantly after optimization. Compared with the current cropping system, the proportion of wheat production to national total in Northwest and North decreased by 9% and 3%, respectively, while the Yangtze river region increased by 14%. The main soybean production area is transferred from Northeast (-24%) and Northwest (-3%) to Southwest (+11%), North (+8%) and Yangtze river region (+7%). North (+56%) replaces

Yangtze (-42%) and Southwest (-23%) as the main production area of Rapeseed. Sugar Beet is transferred from Northwest (-20%), North (-6%) and South (-3%) to Northeast region (30%). And sugar cane is shifted from southwest (-20%) to north (14%) and south (5%). At the same time, the distribution of rice, maize and cotton are all changed in different degrees.

Table1 spatial productivity distribution changes. The top and middle part of this table represents the proportion of crops production to national total in specific regions in current and optimized cropping system, respectively. The bottom part demonstrates the changes between current and optimized cropping system.

		Wheat	Rice	Maize	Soybean	Rapeseed	Groundnut	Cotton	Sugar Beet	Sugar Cane
Current	Yangtze	14%	51%	4%	13%	55%	20%	28%	0%	3%
	North	63%	6%	29%	15%	4%	52%	40%	6%	0%
	Northeast	1%	11%	34%	53%	1%	9%	0%	26%	0%
	Northwest	15%	1%	22%	8%	8%	3%	31%	62%	0%
	Tibet	0%	0%	0%	0%	1%	0%	0%	0%	0%
	South	0%	9%	0%	2%	0%	7%	0%	3%	16%
	Southwest	6%	21%	11%	10%	30%	8%	1%	2%	81%
	Total	100%	100%	100%	100%	100%	100%	100%	100%	100%
Optimized	Yangtze	28%	46%	6%	20%	13%	18%	28%	0%	3%
	North	60%	9%	28%	23%	61%	50%	38%	0%	14%
	Northeast	2%	13%	35%	29%	9%	15%	1%	56%	0%
	Northwest	6%	2%	22%	5%	9%	9%	30%	42%	0%
	Tibet	1%	0%	0%	0%	1%	0%	0%	0%	0%
	South	0%	9%	0%	3%	0%	3%	0%	1%	21%
	Southwest	3%	21%	8%	21%	7%	4%	3%	1%	61%
	Total	100%	100%	100%	100%	100%	100%	100%	100%	100%
Change	Yangtze	14%	-4%	3%	7%	-42%	-2%	0%	0%	1%
	North	-3%	3%	-1%	8%	56%	-2%	-2%	-6%	14%
	Northeast	1%	1%	1%	-24%	8%	6%	0%	30%	0%
	Northwest	-9%	1%	1%	-3%	1%	7%	0%	-20%	0%
	Tibet	0%	0%	0%	0%	0%	0%	0%	0%	0%
	South	0%	0%	0%	1%	0%	-4%	0%	-3%	5%
	Southwest	-3%	0%	-3%	11%	-23%	-4%	2%	-1%	-20%
	Total	0%	0%	0%	0%	0%	0%	0%	0%	0%

Cropping redistribution is an effective measure to reduce the requirements of resources and environmental pollution. We find that changing the distribution of crops reduces the consumptive use of both blue water (-24.3%) and green water (-17.5%). As shown in Fig.2, the change of each crop's planting area lead to the reduction of blue water requirement, with a total reduction of 24.3% compared with current cropping system. Among them, redistributing wheat, rice and maize makes a significant effort to reducing blue water requirement, which resulted in the total blue water demand decreased by 13.0%, 6.3% and 3.2%, respectively. Meanwhile, the rearrangement of maize, soybean and rapeseed saves 7.0%, -3.2% and -3.4% of total green water demand, respectively, while cotton use more water than that in current cropping system, which led to an increase of 0.4 percentage in agricultural green water consumption. The requirement of nitrogen, phosphorus, kalium, compound fertilizers and pesticide are reduced by 19.8%, 26.6%, 9.8%, 15.6% and 12.3% respectively. The regional change of maize production was the main reason for the decrease in the consumption of chemical fertilizer and pesticide, which reduces nitrogen fertilizer, phosphorus fertilizer, potassium fertilizer, compound fertilizer and pesticide requirement by 8.2%, 5.7%, 1.9%, 6.6% and 3.3%, accounting for 41.4%, 21.4%, 19.1%, 42.4% and 27.1% of the total reduction, respectively. This resource saving was also accompanied with GHG emission decreasing (11.3%), which mainly caused by redistributing rice (-4.0%), soybean (2.3%) and maize (-2.0%).

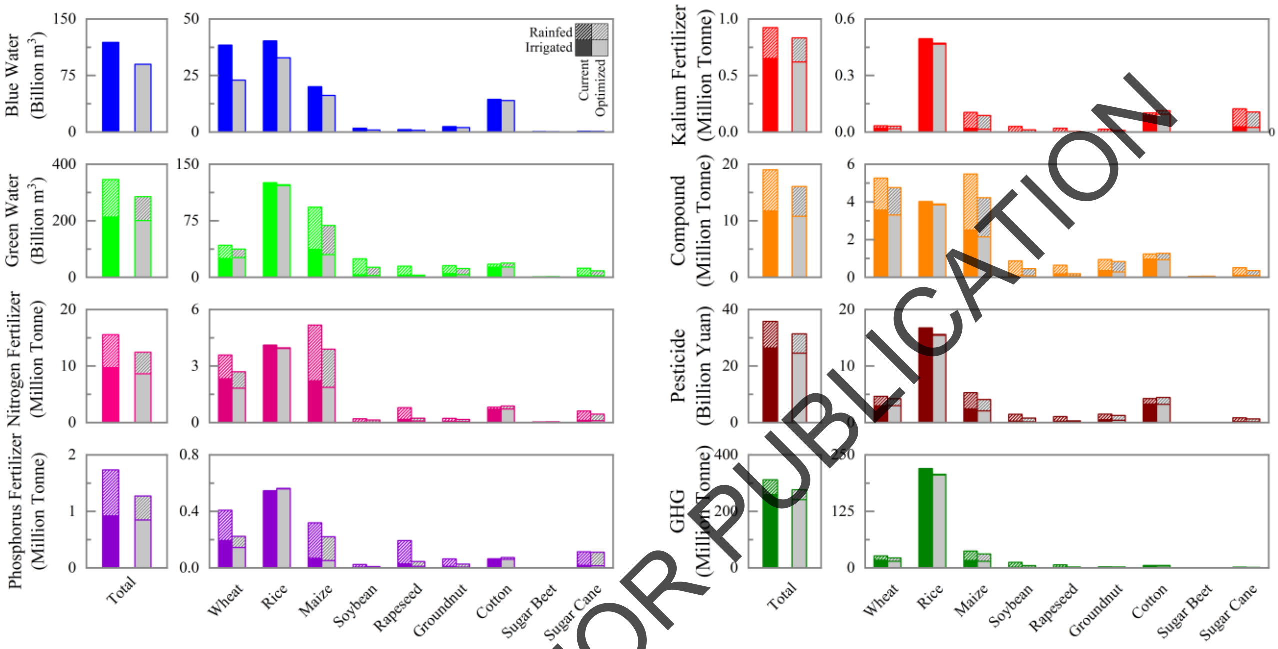

Fig.1 Changes of water, fertilizer, pesticide and GHG in specific crops due to crop redistribution.

Cropping redistribution is a perfect way to mitigate resource and environment stress, especially in the areas where resources and environment are scarce. As shown in Fig.2, redistributing crops saves agricultural blue water demand in different degrees across the country. In North China, where water resources are excessively consumed, the long-term overuse of water resources has led to the formation of groundwater funnel. After the optimization of agricultural layout, the demand for blue water in this region is significantly reduced by 9.3 billion m^3, accounting for 24% of the current total blue water consumption. At the same time, the demand for blue water in Xinjiang province, which is far away from the coastline, decreases significantly, making a significant contribution to alleviating the water resource pressure in western China. The green water requirement in inland China (Northwest, Southwest and Northeast) reduces in a large scale, while there is an increase in South China, but it leads to a slight impact to this region because it is close to the coastline. Besides, rice redistribution has resulted in a significant reduction in pesticide demand and GHG emissions in South China, which will effectively alleviate the eutrophication of water bodies in this region.

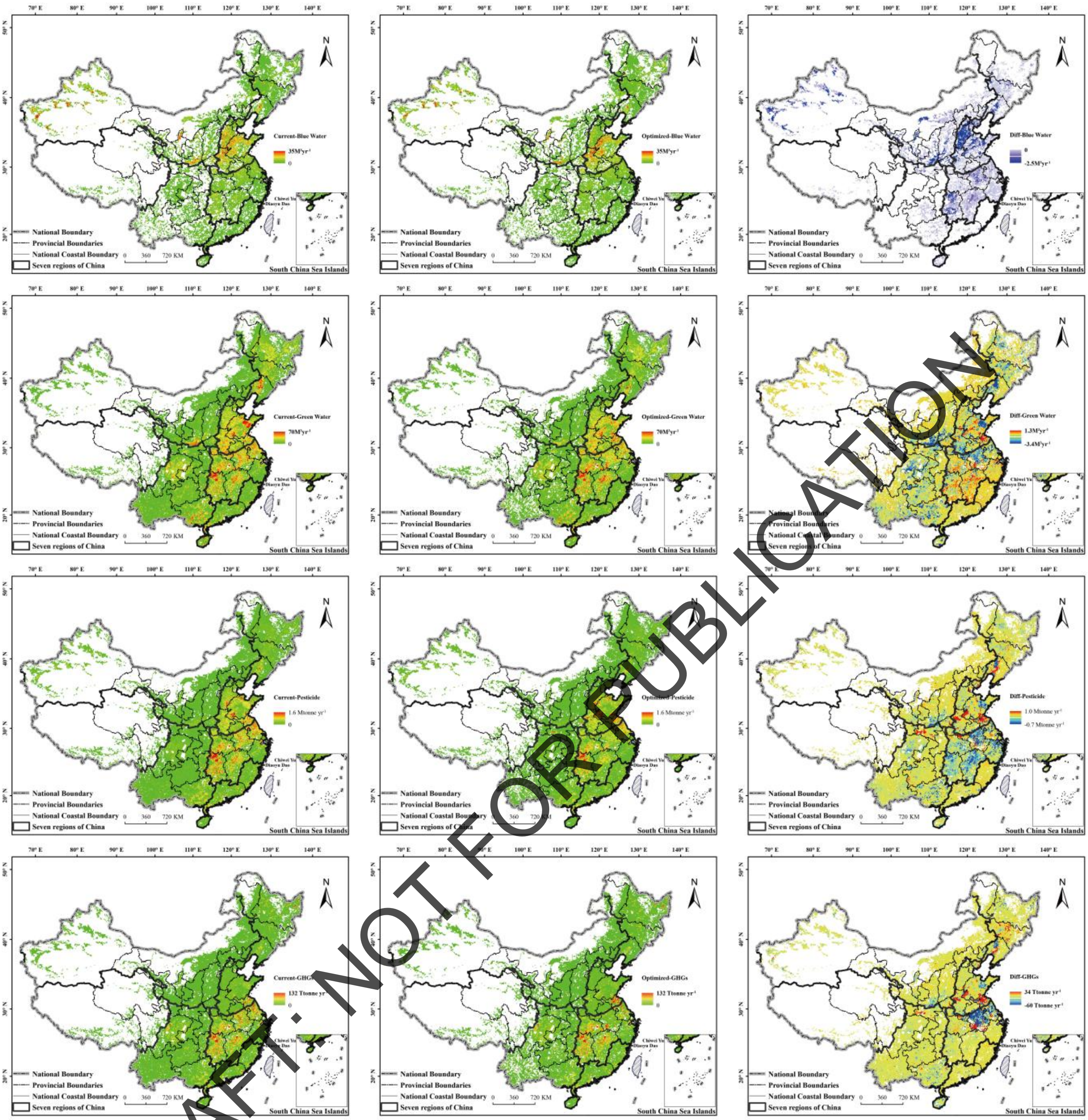

Fig. 2 Water, fertilizer, pesticide and GHG emission decreasing by redistributing crops across currently cultivated lands. Maps in the left-hand column show the current distribution of resources consumption and GHG emission. Maps in the middle column show the results of crops redistribution. And maps in right-hand column show the differences of resources use and emission between current and the optimized cropping system; a higher value indicates a greater change.

The redistribution of crops saves chemical fertilizers simultaneously, especially in the lands with high levels of eutrophication. As shown in Fig. S1, the soil nitrogen content in the middle and south of Southwest China is much higher than that in other regions, and nitrogen fertilizer demand in these regions reduces remarkably by cropping redistribution (Fig.3). Similarly, the demand of phosphorus fertilizer in southern Guizhou province and kalium fertilizer in eastern Inner Mongolia decreased, which is conducive to improving the local soil environment.

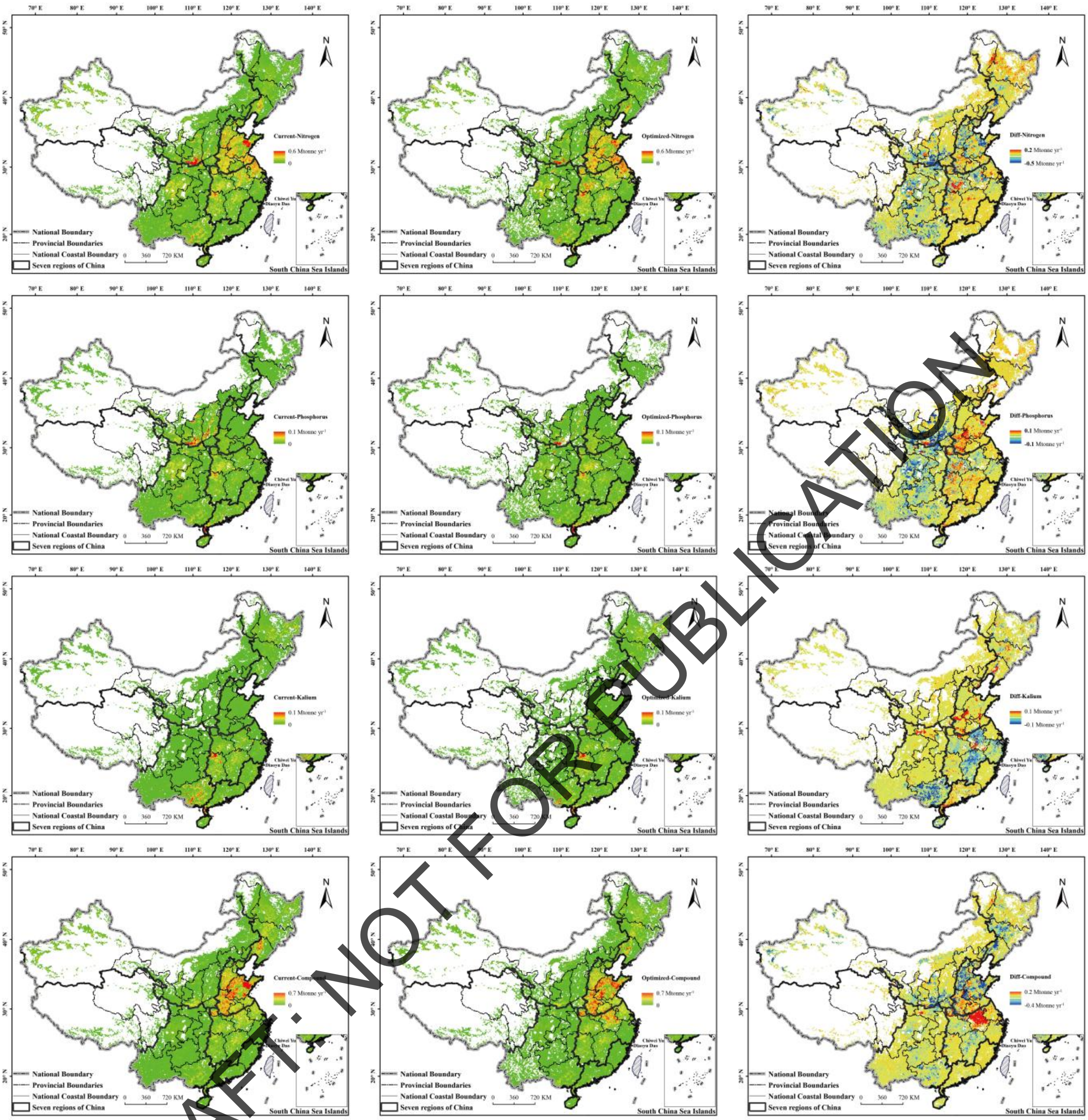

Fig. 3 Fertilizer saving by redistributing crops across currently cultivated lands.

We built eight single-objective optimization models, to minimize water (blue and green water), fertilizer (nitrogen, phosphorus, kalium and compound fertilizer), pesticide demand and GHG emission, respectively. These results represent the maximum potential savings for each resource or emission. As shown in Fig.4, blue water and green water can be reduced by 24.3% and 24.6% without constrains of other resources and environment. Compared with current cropping system, the nitrogen, phosphorus, kalium and compound fertilizer can be reduced by 24.2%, 47.4%, 33.7% and 23.7%, respectively. Meanwhile, pesticide demand and GHG emissions can be reduced by 8.4% and 11.3%, respectively, at national level.

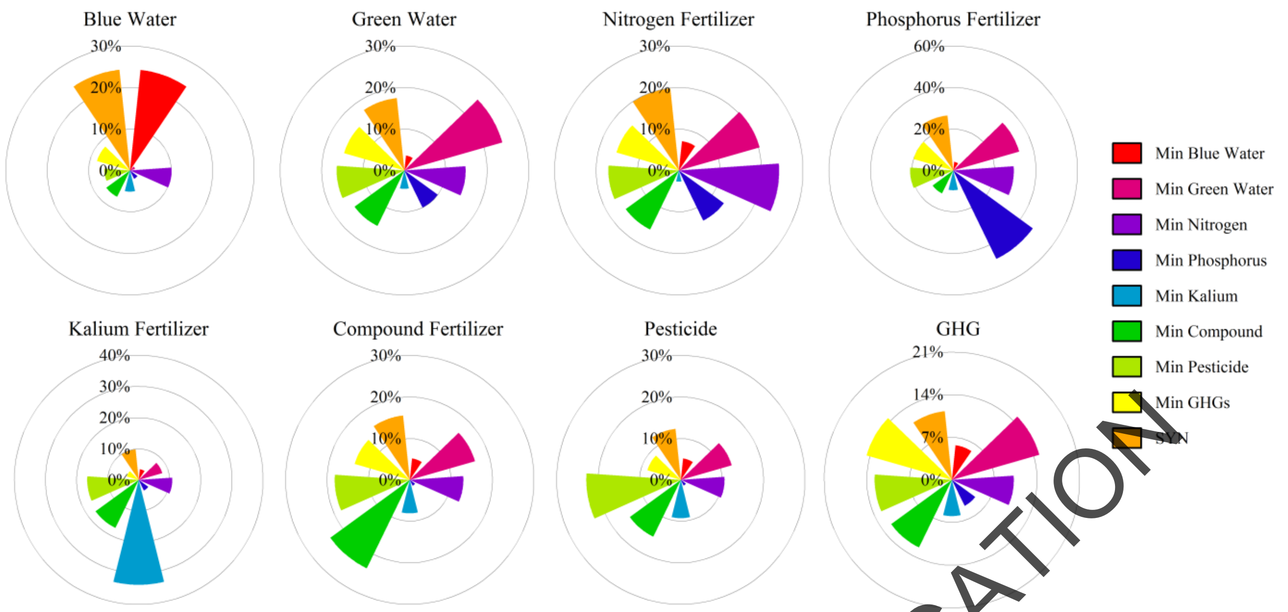

Fig. 4 Outcomes of optimizations for water, fertilizer, pesticide and GHG. Each color corresponds to 1 of 8 optimization scenarios.

Reference

To be updated.

Supplementary information

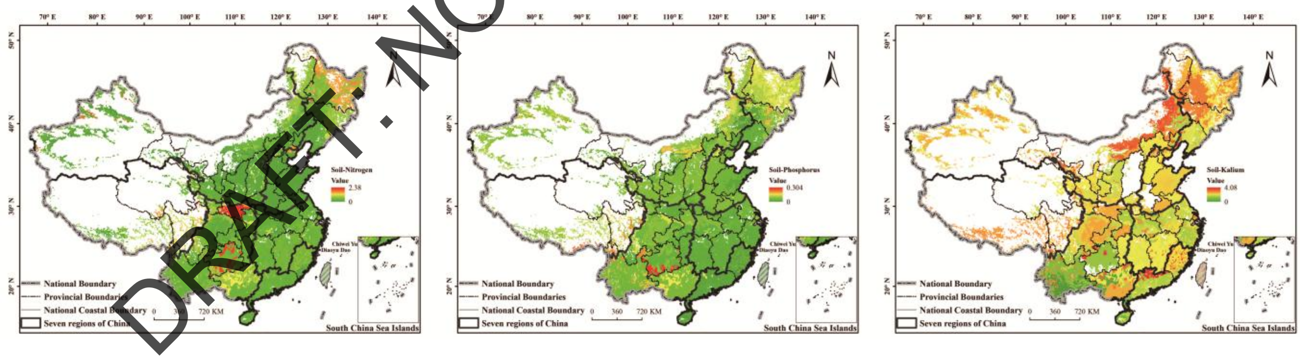

Fig. S1 Spatial distribution of the amount of nitrogen, phosphorus and kalium in the soil.