China’s food security threatened by soil degradation and biofuels production

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Abstract

We present a large scale assessment of the combined effects of soil degradation and biofuels production on long-term food security in China by using a web-based land evaluation system (http://weble.ugent.be) and grid datasets. Our results predict that the relationship between food supply and demand will turn from an 18% surplus in 2005 to 3-5%, 14-18% and 22-32% deficits by 2030-2050 under the zero-degradation (0xSD), business-as-usual (BAU) and double-degradation (2xSD) scenarios, respectively, if no harvests are to be diverted to produce biofuels, while this relationship will turn from a 17% surplus in 2005 to 14-17%, 22-32% and 30-46% deficits by 2030-2050, respectively, should 10-15% of the total harvests be used for biofuels production. Technical countermeasures and policy interventions (cropland protection, agricultural investment, soil conservation, etc.) need to be enacted today in order to avoid food insecurity tomorrow.

Key Words

Food security, soil erosion, biofuels production, scenario building, land evaluation, policy options.

Introduction

The global battle to ensure food security for humanity on earth is far from won (Borlaung 2007). As the world’s most populous country and the third largest in size, China has succeeded in achieving food self-sufficiency in the past few decades. However, whether China will have the ability to produce enough food for a growing population which demands a richer diet in the twenty-first century remains a subject of debate with far-reaching impacts on the world food market (Anderson and Peng 1998). Whereas the effect of climate change on food security has received much attention recently (Lobell *et al.* 2008), much less attention has been paid to soil degradation as a major driver of global environmental change; systematic studies to link soil degradation and food security (Lal 2007) are still lacking, especially at the national scale. Moreover, as the world’s third largest bio-ethanol producer, China used some 5 Mt of maize and wheat, or 1% of its total grain harvest, to produce 1.6 Mt of ethanol in 2005. The Chinese ethanol output is expected to increase under the new national energy stratagems (Li and Chan-Halbrendt 2009). Although this biofuel boom might help mitigate climate change, it could also threaten food security (Boddiger 2007). The objectives of this paper are to (1) simulate China’s food security status by 2030 and 2050 in terms of a food security index (FSI); (2) quantify the FSI responses to soil degradation and biofuels production scenarios; and (3) formulate policy options in order to safeguard long-term food security in China.

Methods

A five-step approach has been adopted in this research. First, climatic, crop, soil, management and socio-economic data were collected, manipulated in a 5×5 km grid system and used to simulate the yields of food crops (i.e. rice, wheat, maize, sorghum, millet, soybean and potato) using a Web-based land evaluation system (WLES, http://weble.ugent.be; see Ye *et al.* 2008) which adopts a three-step, hierarchical, deterministic land evaluation model (Ye and Van Ranst 2002). Second, the simulated yields were compared to the observed yields in order to validate the simulation process. Third, the food production capacities in 2030 and 2050 were estimated based on the most-likely scenarios of population growth, urbanization rate, cropland area, cropping intensity, soil degradation and biofuels production. Fourth, a food security index (FSI) was computed following a food supply-demand equilibrium approach. Finally, the effects of soil degradation and biofuels production on FSI were quantitatively assessed, and policy options toward long-term food security in China were formulated (Figure 1).

The effect of soil degradation on crop yield was quantified in two steps. First, an overall score was computed from the extent and impact class of five common degradation types (i.e. water erosion, wind erosion, physical deterioration, fertility decline and salinisation) on crop yield (van Lynden and Oldeman 1997):

$$d = \sum_{i=1}^{5} \left(E_i \cdot I_i \right) \tag{1}$$

where d is the overall score, E_i is the extent of degradation type i, expressed as area percentage (%) within a mapping unit, and I_i is the code of the impact class (ranging from 0 for "negligible" to 4 for "extreme") of degradation type i. Second, the overall score was regrouped into 5 classes (Table 1) and each class was associated with a corresponding level of relative yield loss (Ye and Van Ranst 2009).

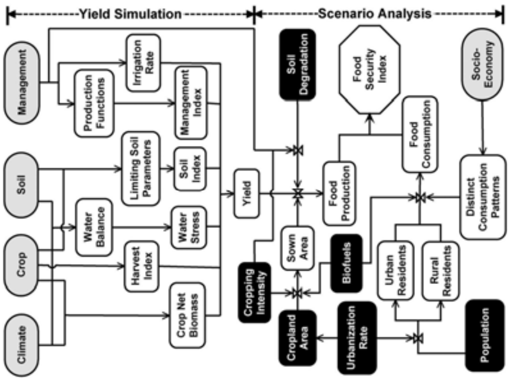

Figure 1. The research framework illustrating yield simulation and scenario analysis approaches.

Table 1. Yield effect of soil degradation expressed in relative yield loss (%).

Class of overall score d (Eq. 1)	Input level		
	High	Intermediate	Low
Negligible	0	0	10
Light	0	10	25
Moderate	10	25	50
Strong	25	50	75
Extreme	50	75	100

Table 2. The settings of the most-likely scenario for food production in China by 2030 and 2050.

Scenario	2005	2030	2050
Population (billion people)	1.31	1.46	1.44
Urbanization rate (%)	43	73	83
Cropland area (million ha)	130	113	107
Multi-cropping index (%)	120	133	147
Soil degradation (yield loss since 2005)			
Zero degradation	-	$0 \times p^{a}$	$0 \times p$
Business-as-usual	-	$1.67 \times p$	$3 \times p$
Double degradation	-	$3.33 \times p$	$6 \times p$
Biofuels production (million ton - Mt)			
Planned output	1.6	13	20
Estimated use of grain harvest	5.0	41	63

[a] p: relative yield loss (%) between 1990 and 2005 (Eq. 2).

The factor of soil degradation was incorporated into yield simulation using this equation:

$$Y_2 = \left(1 - n \cdot \frac{t_2 - t_1}{15} \cdot \frac{p}{100} \right) \cdot Y_1 \tag{2}$$

where Y_1 is the observed crop yield in year t_1, Y_2 is the average crop yield in year t_2, p is the fraction (%) of yield that is lost due to soil degradation during a 15-year period (van Lynden and Oldeman 1997) prior to year t_1, and n is a multiplicative coefficient. The product ($n \times p$) denotes the effective degradation rate during [t_1, t_2], compared to p during [t_1-15, t_2]. Under the business-as-usual (BAU) scenario, soil degradation occurred at the current intensity. The same amount of yield would be lost in the next 15 years as in the past 15 years, or $n = 1$. Under the zero-degradation scenario (0× SD), no degradation would occur ($n = 0$), whereas under the double-degradation scenario (2× SD), soil degradation would occur at twice the rate, limiting the crop yield more than at present ($n = 2$).

The relative food surplus in per capita terms was defined as the food security index (FSI):

$$FSI = \frac{(s-b)/g-d}{d} \cdot 100 \tag{3}$$

where s is the per capita supply, d is the per capita demand, b is the amount of food diverted to produce biofuels, and g is the expected food self-sufficiency level (g = 0.95).

China’s food production capacities in 2030 and 2050 were assessed under the most-likely scenarios of cropland availability, cropping intensity, and soil degradation (Table 2). The FSI values for the years 2030 and 2050 were computed, after the distinctive food consumptive patterns of the urban and rural residents were characterized, involving additional scenarios (Table 2) including population growth, urbanization rate and biofuels production (see Figure 1).

Results

Comparison between simulated and observed yields in major regions

Crop production was simulated per grid cell and the simulated yield was aggregated to compute the average yield per major region in food production. The arithmetic mean was used as the aggregation algorithm since the area of each grid cell is equal. The difference between the predicted yield in 2030/2050 and the baseline yield in 2005, or yield loss, was obtained and summarized in Table 3 for the following regions in food production: the northeast (NE), the North China Plain (NCP), the lower Yangtze River Basin (YRB), and the Sichuan Basin (SB). In 2005, these major regions contributed over 70% of the total production of food from crops sown on 60% of China’s croplands and supported 70% of China’s population. An average grain yield of 4.85 t/ha was achieved in, e.g., the NCP in 2005. If the current trend of fertility decline and salinisation is not controlled, 6-10% of this yield will likely be lost by 2030-2050. The yield decrease would be as high as 10-18% by 2030-2050, should the situation continue to deteriorate (2× SD) in the NCP.

Table 3. Simulated versus observed yields of food crops in 2005 across major regions and simulated yields in 2030 and 2050 as compared to 2005 under the business-as-usual and double-degradation scenarios.

Region	Yield in 2005			Yield in 2030				Yield in 2050			
	Observed	Simulated	Error	Under BAU		Under 2× SD		Under BAU		Under 2× SD	
	t/ha	t/ha	%	t/ha	diff [a]	t/ha	diff	t/ha	diff	t/ha	diff
NE	4.61	4.64	+0.65	4.04	-12.93	3.74	-19.40	3.84	-17.24	3.04	-34.48
NCP	4.85	4.89	+0.82	4.59	-6.13	4.39	-10.22	4.39	-10.22	3.99	-18.40
YRB	5.23	5.21	-0.38	4.81	-7.68	4.61	-11.52	4.71	-9.60	4.11	-21.11
SB	4.77	4.52	-5.24	4.02	-11.06	3.62	-19.91	3.72	-17.70	3.02	-33.19
National	4.62	4.59	-0.64	4.09	-10.89	3.79	-17.43	3.89	-15.25	3.19	-30.50

[a] Percentage (%) difference of the yield as compared to 2005.

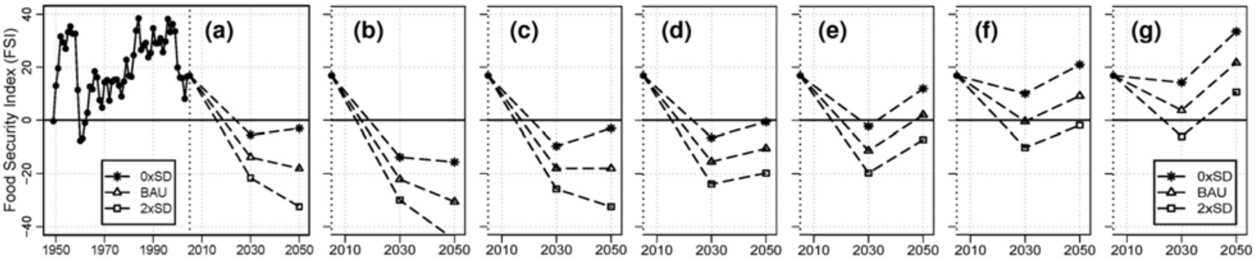

Figure 2. (a) Food security index as assessed on the basis of observed data during 1949-2005 and as predicted under the scenarios of zero degradation (0× SD), business-as-usual (BAU) and double degradation (2× SD) in 2030 and 2050. (b-c) FSI in 2030 and 2050 as affected by both soil degradation and biofuels production using first- or second-generation technologies. (b) Biofuels are derived from grain harvests. (c) Biofuels are derived from non-food crops, but 50% of such crops still compete with food crops for land in 2030. (d-e) Same as (b) and (c) but under a raised management scenario. Crop management level in middle China is raised to the same level as in east China. Crop management level in west China is raised to the level of middle China in 2030 and to the level of east China in 2050. (f-g) Same as (b) and (c) but under a high-yielding varieties scenario. Yields are steadily improved at an average rate of 0.8%/yr during 2005-2030 and 0.5%/yr during 2030-2050. Such yield improvements are only possible in areas under the high management level.

Food security index

Historical variations in China’s food security status were well captured by the FSI values (Figure 2a). The results suggest that China faces great challenges in safeguarding its food security in the long run. The FSI is predicted to drop from 17 in 2005 to -5 and -3 in 2030 and 2050, respectively, under 0× SD (Figure 2a), exhibiting the adverse effect of population growth on food security. This suggests that the present-day (2005-level) production capacity will not sustain the long-term needs of the Chinese population, even under 0× SD. Our results also show that 14-18% and 22-32% of per capita demand will not be met by 2030-2050, under BAU and 2× SD, respectively (Figure 2a). This translates into an addition of 300-500 million malnourished people by 2050 to the 2005-level of 120 million. By 2030, some 41 Mt of maize and wheat could be diverted away from human consumption to the production of 13 Mt of bio-ethanol (Table 2). This diversion alone may drag the FSI down by 9 units (from -5 to -14) under 0× SD in 2030 (Figure 2b), showing that first-generation biofuels (which depend on food crops) have a strong adverse effect on food security. There are hopes that the full-scale development of second-generation biofuels (which are derived from non-food crops, e.g. wood chips and switch grasses, and require fewer water resources) could help reduce the impact of biofuels on food security (Figure 2c). However, such a solution is at least a decade away. Even with second-generation biofuels, the competition with food crops for land and water still remains if the growing of such second-generation crops is not on e.g. the abandoned land through delicate planning (Campbell *et al.* 2008).

Conclusion

The reproduction of the spatial variations in the observed yields of food crops by the simulated yields and the close reflection of the historical variations in food security in China since 1949 by the obtained FSI values show that the proposed research framework applied well in this large-scale assessment of the effects of soil degradation and biofuels production on long-term food security status in China. One of the major predictions made by this research is that soil degradation will become the most influencing factor that threatens China's food security in the long run. The food security status will further deteriorate if more grains are to be diverted away from human consumption to produce biofuels. Our simulation results strongly suggest that the present-day production capacity will not sustain the long-term needs of a growing population which demands a richer diet under the current management level. We advise the following policy interventions and institutional reforms: (1) Non-agricultural occupation of cropland should be strictly controlled. The abandoned land resources should be reutilized for biofuels production. The impact of second-generation biofuels is largely controllable if produced on abandoned land, as illustrated by comparing Figure 2c to 2a for year 2050. (2) Agricultural investments are essential to mitigate, or even to reverse, the impact of soil degradation on food security. Significantly positive responses of the FSI values have been predicted to either a higher management scenario (Figure 2d-e) or a higher-yielding varieties scenario (Figure 2f-g). (3) Institutional changes in, e.g., the selection and extension of a locally suitable soil and water conservation techniques pool are needed to control the environmental damages caused by production intensification. Otherwise, the improvements in food security (Figure 2d-g) will not be sustainable in the long run.

References

Anderson K, Peng CK (1998) Feeding and fueling China in the 21st century. *World Dev.* **26**, 1413-1429.

Boddiger D (2007) Boosting biofuel crops could threaten food security. *The Lancet* **370**, 923-924.

Borlaung N (2007) Feeding a hungry world. *Science* **318**, 359.

Campbell JE, Lobell DB, Genova RC, Field CB (2008) The global potential of bioenergy on abandoned agriculture lands. *Environmental Science and Technology* **42**, 5791-5794.

Lal R (2007) Anthropogenic influences on world soils and implications to global food security. *Advances in Agronomy* **93**, 69-93.

Li SZ, Chan-Halbrendt C (2009) Ethanol production in the People's Republic of China: Potential and technologies. *Applied Energy* **86**, S162-S169.

Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP, Naylor RL (2008) Prioritizing climate change adaptation needs for food security in 2030. *Science* **319**, 607-610.

van Lynden GWJ, Oldeman LR (1997) The Assessment of the Status of Human-Induced Soil Degradation in South and Southeast Asia. ISRIC: Wageningen.

Ye L, Van Ranst, E (2002) Population carrying capacity and sustainable agricultural use of land resources in Caoxian County (North China). *Journal of Sustainable Agriculture* **19**, 75-94.

Ye L, Van Ranst E (2009) Production scenarios and the effect of soil degradation on long-term food security in China. *Global Environmental Change* **19**, 464-481.

Ye L, Tang H, Zhu J, Verdoodt A, Van Ranst E (2008) Spatial patterns and effects of soil organic carbon on grain productivity assessment in China. *Soil Use and Management* **24**, 80-91.