The impacts of climate change on seasonal crop irrigation requirement of wheat in China

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Abstract
Irrigation is by far the largest water user in China. Seasonal crop irrigation requirement (SCIR) of individual crops may greatly be affected by global climate change, but little research has been done in this area for the entire China with high spatial resolution. In this study, a spatial explicit GIS-based Environmental Policy Integrated Climate (GEPIC) model was used to study the impacts of climate change on SCIR of wheat with spatial resolution of 30 arc-minutes. We conclude that climate change (A2 scenario) will lead to much higher SCIR of wheat for China as a whole. This will impose higher pressure on China's irrigation water supply. Effective adoption and mitigation measures have to be taken in the future to mitigate the adverse effects of climate change on SCIR of wheat.

Keywords: GEPIC, climate scenarios, irrigation

1. Introduction

Water is a key driver of agricultural production in China. In the past four decades, annual cereal production increased 3.8-fold from 110 million tones in 1961 to 410 million tones in 2004 (FAO 2006). This increase is closely related to the expansion of irrigated area, which almost doubled from around 30 million ha in 1961 to 54 million ha in 2000 (FAO 2006). In China, irrigated land accounts for 40% of the total arable land, and it produces 75% of China's total food grain (Jin and Young 2001). Irrigation is a necessary input to a high crop yield. For instance, on average, the yield of wheat in irrigated land was over 70% higher than that in rainfed land in the North China Plain, the breadbasket of China (Liu et al. 2007a).

Growing population requires more irrigation to further increase food production. However, the increasing water scarcity and the competition from other sectors have put agricultural water use under great pressure (Yang and Zehnder 2001) (Liu et al. 2007c). There has been a reallocation of irrigation water to the industrial and domestic sectors and a compromise of environmental water needs (Yang and Zehnder 2001). The challenge of irrigation water supply may be influenced by global climate change, although the impact of climate change on irrigation water demand is still not well studied. So far, there have been considerable research attempting to model the effects of climate change on China's cropping systems (e.g. Liu et al. (2004); Thomson et al.(2006); Yang et al.(2007); Tao et al.(2008)). While a number of studies focus on the effects on crop yield and production, a much smaller body of work has investigated implications for crop irrigation requirement (CIR). Here, CIR is defined as the amount of water, in addition to rainfall, that must be applied to meet a crop's water requirement without significant reduction in yield.

This study presents the results of CIR of wheat under current and future climate scenarios with a spatial resolution of 30 arc-minutes (around 50 km × 50 km in each grid cell nearby the equator) in China. Wheat is selected due to its importance in China and its high dependence on irrigation (Liu et al. 2007a). Wheat is the second largest crop after rice in terms of harvest area and production (FAO 2006). Wheat is a crop consuming large amount of irrigation water in China. In the North China Plain, wheat uses over 70% of the total irrigation water (Li et al. 2005).

2. Materials and methods

2.1. The GEPIC model

The GEPIC model is a GIS-based Environmental Policy Integrated Climate (EPIC) model designed to simulate the spatial and temporal dynamics of the major processes of the soil-crop-atmosphere-management systems (Liu et al. 2007b) (Liu et al. 2007a). GEPIC uses a daily time step to calculate all processes. The soil water balance in the root zone during crop growing period is expressed as:

$$\frac{dS_u}{dt} = P_n + I - Q - R - (E_t + E_s) \qquad (1)$$

where S_u is the available soil moisture in the root zone (mm); P_n is the effective precipitation (mm day^{-1}); I is the irrigation depth (mm day^{-1}); Q is the surface runoff (mm day^{-1}); R is the recharge to the groundwater (mm day^{-1}); E_t is the crop transpiration (mm day^{-1}), E_s is soil evaporation (mm day^{-1}), and t is time (day). All these variables are calculated with a daily time step.

CIR is calculated as the irrigation depth when sufficient water is available at any time. For irrigated agriculture, flexible automatic irrigation is set to calculate daily CIR with the following assumptions: 1). the model schedules an irrigation event when biomass production in one day is smaller than its potential; 2). the water amount applied in each irrigation event aims at bringing soil moisture content to field capacity. According to these assumptions, soil moisture remains at the field capacity level in all days, and there are no changes in soil moisture over time. Since there is no water and nutrient stress, evaporation and transpiration can always reach their maximum. Daily CIR can be calculated as follows:

$$\mathrm{CIR} = \mathrm{PET} - (P_n - Q - R) \qquad (2)$$

Where CIR is crop irrigation requirement (mm day^{-1}); PET is potential evapotranspiraiton (mm day^{-1}).

In the GEPIC model, PET is calculated with a Hargreaves method (Hargreaves and Samani 1985). Runoff is estimated by using a modification of the Soil Conservation Service (SCS) curve number technique (SCS 1971). Recharge occurs when soil moisture is higher than field capacity, and it is equal to the difference between the soil moisture and the field capacity.

The sum of the daily crop irrigation requirement in growing season is the seasonal crop irrigation requirement (SCIR).

2.2. Data

Historical monthly data on maximum temperature, minimum temperature, precipitation and wet days between 1991 and 2000 are obtained from the Climate Research Unit of the University of East Anglia (CRU TS2.1) with a spatial resolution of 30 arc-minute (Mitchell and Jones 2005a). Since daily data are needed, a MOnthly to DAily WEather Converter (MODAWEC) model is used to generate the daily weather data (Liu et al. 2008). The future monthly climate data on maximum temperature, minimum temperature, precipitation and wet days between 2091 and 2100 are obtained with the same resolution from the Tyndall Centre for Climate Change Research of the University of East Anglia (TYN SC 2.0) (Mitchell and Jones 2005b). For the TYN SC 2.0 dataset, runs of the HadCM3 model (Gordon et al. 2000) (Pope et al. 2000) for the A2 scenarios are used. A2 scenario is used because this scenario has the most serious climate change and it is also included in the latest IPCC assessment. The future daily climate data are generated with the MODAWEC model.

Soil parameters of soil depth, percent sand and silt, bulk density, pH, organic carbon content are obtained from Batjes (2006). Soil parameters are available for 5 soil layers (0-20, 20-40, 40-60, 60-80, 80-100 cm). The spatial distribution of wheat is simulated with a spatial allocation model with a cross-entropy approach for the year 2000 (You and Wood 2006). This model makes plausible allocations of crop production in each county in China into individual pixels through judicious interpretation of all accessible evidence such as production statistics, farming systems, satellite image, crop biophysical suitability, crop price, local market access and prior knowledge (You and Wood 2006).

3. Results

3.1. Present conditions

The national map indicating the simulated SCIR of wheat is shown in Fig. 1. The map shows a clear distinction between the eastern and southern regions of China where SCIR is low (<50 mm/yr) and the western and northern regions where SCIR may exceed 150 mm/yr. In northwestern China, high evaporation and low precipitation make irrigation high for wheat production. For instance, in

Xinjiang province, annual average precipitation is as low as 145 mm/yr (Shi and Lu 2001). Wheat production has to heavily rely on irrigation. SCIR is overwhelmingly higher than 250 mm/yr with some areas even exceeding 450 mm/yr. In Southern part of China, SCIR of wheat is generally under 100 mm/yr. Two major reasons among others explain the low values of SCIR. First, precipitation in the South is generally very high and it can provide large amounts of water for crop. Second, the climate conditions in the South are not as suitable as those in the North for wheat production. This means that even with sufficient water available, wheat cannot achieve a very high yield. As a general rule a lower wheat yield needs less water in the process of evapotranspiration, resulting in lower SCIR. The provincial average of SCIR is summarized in Table 1. The highest provincial SCIR is in Xinjiang province (>300 mm/yr), while the lowest provincial SCIR is in Tibet where irrigated wheat is minor in terms of irrigated area.

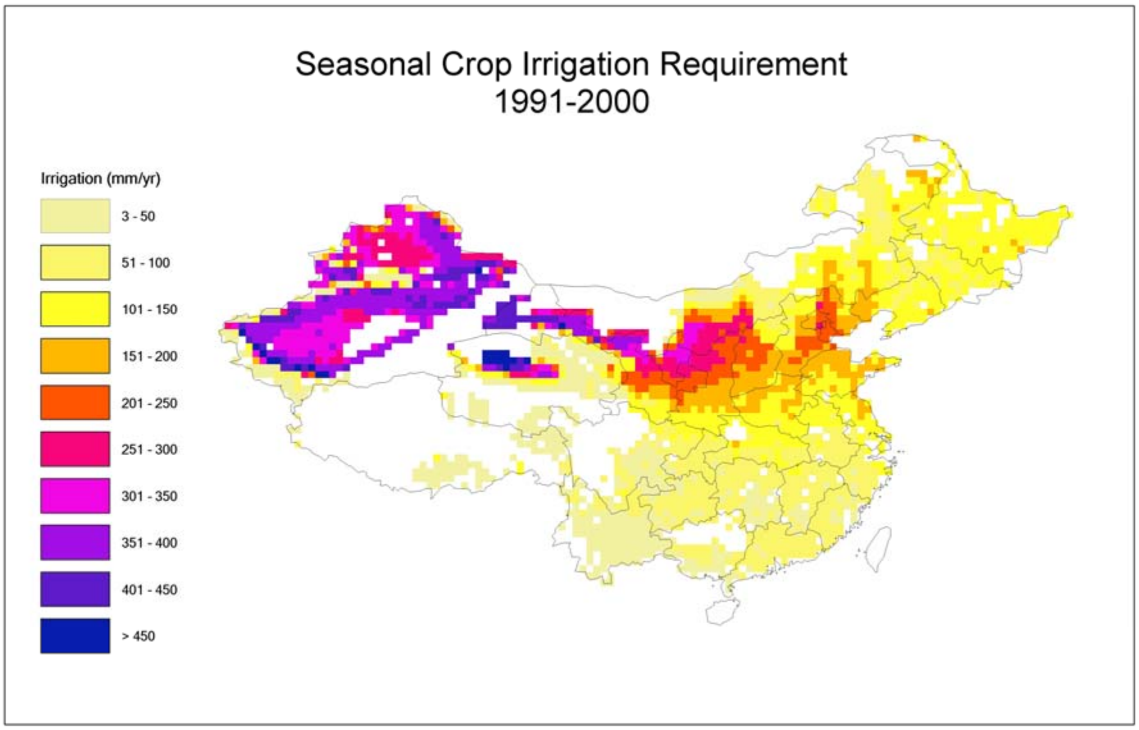

Fig 1. Seasonal crop irrigation requirement for wheat (1991-2000 average)

3.2. Future conditions

Under the A2 scenario, SCIR has low values in the Southeastern coastal areas while it has high values in the Northwestern inland areas (Fig. 2). This pattern is similar to that under current climate conditions. In spite of the similar trend, the changes of SCIR are heterogeneous in different regions. Compared to the SCIR values under current climate conditions, one notable decrease will occur in Ningxia, Northern part of Shaaxi and Shanxi, Southern part of Neimenggu, and Northern and Eastern part of Gansu. In these regions, SCIR will significantly decreases from over 250 mm/yr under current climate conditions to mostly under

200 mm/yr. Regions with significant increase is located in the Southwestern part of China (e.g. Tibet and Yunnan). SCIR under current climate conditions is dominantly under 50 mm/yr, but it will increase to over 100 mm/yr under the A2 scenario. The change of SCIR in each grid cell is demonstrated in Fig. 3. As a general trend, wheat will have lower SCIR values in the North and higher SCIR values in the South.

Table 1. Seasonal crop irrigation requirement under current and future climate conditions in different provinces

Province	SCIR2000: average SCIR between 1991 and 2000 (mm/yr)	SCIR2030: average SCIR between 2021 and 2030 under A2 scenario (mm/yr)	Change=(SCIR2030-SCIR2000) /SCIR2000 *100 (%)
Beijing	235	204	-13
Tianjin	225	214	-5
Hebei	192	156	-19
Shanxi	164	181	10
Neimenggu	162	183	13
Liaoning	127	188	49
Jilin	105	179	71
Heilongjiang	114	186	62
Shanghai	150	172	15
Jiangsu	124	169	37
Zhejiang	112	163	45
Anhui	95	136	43
Fujian	60	120	100
Jiangxi	76	125	63
Shandong	157	175	11
Henan	142	158	11
Hubei	102	175	71
Hunan	61	171	180
Guangdong	62	99	59
Guangxi	47	175	275
Chongqing	56	166	196
Sichuan	43	188	334
Guizhou	59	169	187
Yunnan	22	175	688
Tibet	13	327	2354
Shaaxi	174	188	8
Gansu	259	222	-14
Qinghai	102	233	129
Ningxia	280	182	-35
Xinjiang	309	318	3

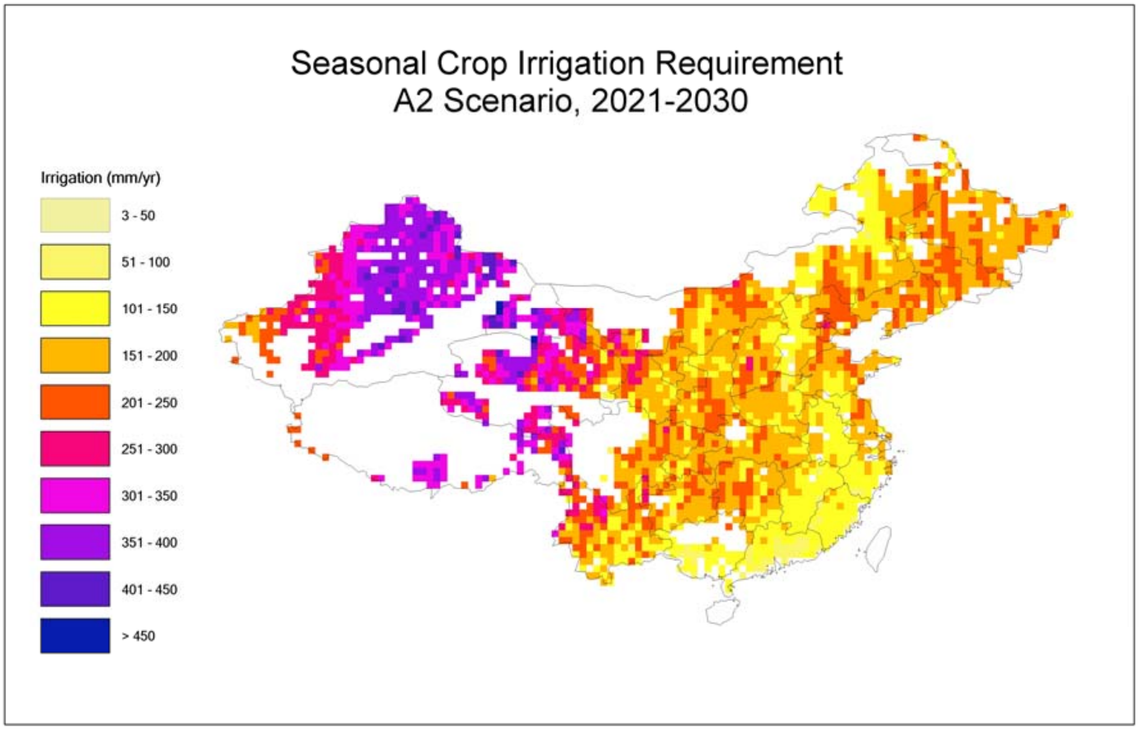

Fig 2. Seasonal crop irrigation requirement for wheat (A2 scenario, 2021-2020 average)

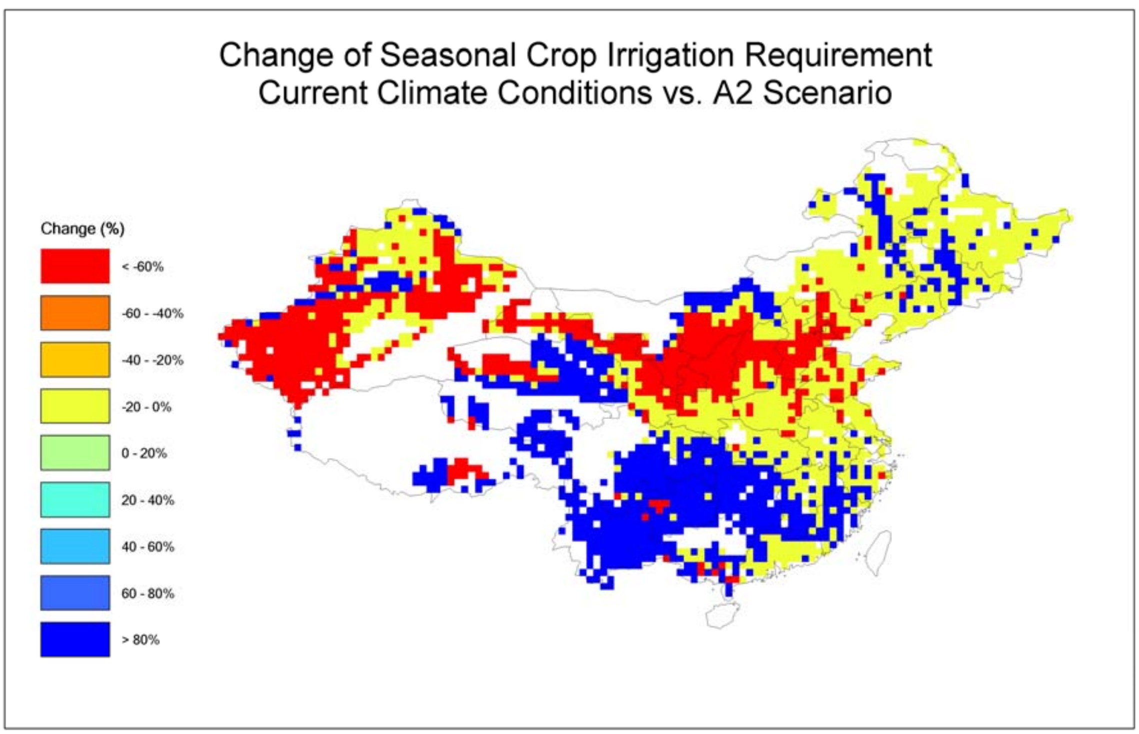

Fig 3. Change of seasonal crop irrigation requirement for wheat

The provincial average change of SCIR is summarized in Table 1. In over 80% of the provinces, SCIR will increase under A2 climate conditions. Tibet stands out as a province with the largest change of SCIR. Tibet is characterized by high mountains and low temperature. Current temperature is not suitable for the production of wheat in most areas. In this case, water is not a determining factor that influence crop yield. Even under irrigated conditions, yield is low, and wheat does not need much irrigation. However, the global warming will bring large amounts of farm suitable for wheat production there. The potential yield of wheat is significantly increased, resulting in a much higher SCIR. It can be seen that Tibet will become a province with the highest SCIR under A2 scenario, although it has the lowest SCIR under current climate conditions.

North China Plain accounts for about 50% of current wheat production. There have been many discussions on decreasing irrigation water for wheat in this area because wheat is the largest water consumer and it uses over 70% of the regional blue water. The results show that in this region, Beijing, Tianjin and Hebei will have lower SCIR, while Henan, Shandong, Jiangsu and Anhui will have higher SCIR. As a whole, North China Plain will have about 10% higher SCIR.

For China as a whole, SCIR under the A2 scenario will be as high as 240% of the current SCIR. Climate change may like impose a higher pressure on the future irrigation water supply.

4. Conclusion

In this paper, seasonal crop irrigation requirement (SCIR) of wheat is studied for China with a spatial resolution of 30 arc-minutes with a GIS-based Environmental Policy Integrated Climate (GEPIC) model. The results show that China will have much higher SCIR under the A2 scenario, indicating that global climate change will further impose pressure on China’s future irrigation water supply. China will have to formulate appropriate water and food policies to fight against the adverse effects of climate change on irrigation requirement.

We acknowledge that the A2 scenario cannot represent the future climate conditions considering large uncertainties. Using more climate scenarios is a necessity to further improve this study. Another limitation of the study is the assumption that land use for wheat will remain unchanged in the future. This assumption is clearly not correct; however, the future harvest area of wheat still remains scarcely studied in literature. Without better information of future land use change, the study cannot be significantly improved.

References:

Batjes, N. H., 2006. ISRIC-WISE derived soil properties on a 5 by 5 arc-minutes global grid. International Soil Reference and Information Centre (ISRIC), Wageningen, the Netherlands.

FAO, 2006. FAOSTAT: FAO statistical databases. In. Food and Agriculture Organization of the United Nations, Rome.

Gordon, C., Cooper, C., Senior, C. A., Banks, H., Gregory, J. M., Johns, T. C., Mitchell, J. F. B., Wood, R. A., 2000. The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. Climate Dynamics 16 (2-3) 147-168.

Hargreaves, G. H., Samani, Z. A., 1985. Reference crop evapotranspiration from temperature. Applied Engineering in Agriculture 1 96-99.

Jin, L., Young, W., 2001. Water use in agriculture in China: importance, challenges, and implications for policy. Water Policy 3 (3) 215.

Li, J., Inanaga, S., Li, Z., Eneji, A. E., 2005. Optimizing irrigation scheduling for winter wheat in the North China Plain. Agricultural Water Management 76 8-23.

Liu, H., Li, X., Fischer, G., Sun, L., 2004. Study on the impacts of climate change on China's agriculture. Climatic Change 65 (1-2) 125.

Liu, J., Wiberg, D., Zehnder, A. J. B., Yang, H., 2007a. Modelling the role of irrigation in winter wheat yield, crop water productivity, and production in China. Irrigation Science 26 (1) 21-33.

Liu, J., Williams, J. R., Wang, X., Yang, H., 2008. Using MODAWEC to generate daily weather data for the EPIC model. Agricultural & Forest Meteorology Submitted.

Liu, J., Williams, J. R., Zehnder, A. J. B., Yang, H., 2007b. GEPIC - modelling wheat yield and crop water productivity with high resolution on a global scale. Agricultural Systems 94 (2) 478-493.

Liu, J., Zehnder, A. J. B., Yang, H., 2007c. Historical trends in China's virtual water trade. Water International 32 (1) 78-90.

Mitchell, T. D., Jones, P. D., 2005a. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. International Journal of Climatology 25 (6) 693.

Mitchell, T. D., Jones, P. D., 2005b. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. International Journal of Climatology 25 (6) 693-712.

Pope, V. D., Gallani, M. L., Rowntree, P. R., Stratton, R. A., 2000. The impact of new physical parametrizations in the Hadley Centre climate model: HadAM3. Climate Dynamics 16 (2-3) 123-146.

SCS, 1971. Hydrology, National Engineering Handbook. USDA-Soil Conservation Services, Washington, DC.

Shi, Y., Lu, L., 2001. China agricultural water demand and water-saving and efficient agriculture. In, China Sustainable Water Resources Strategy Research Report Series Volume 4. China WaterPower Press: Beijing, China.

Tao, F., Hayashi, Y., Zhang, Z., Sakamoto, T., Yokozawa, M., 2008. Global warming, rice production, and water use in China: Developing a probabilistic assessment. Agricultural and Forest Meteorology 148 (1) 94.

Thomson, A. M., Izaurralde, R. C., Rosenberg, N. J., He, X., 2006. Climate change impacts on agriculture and soil carbon sequestration potential in the Huang-Hai Plain of China. Agriculture, Ecosystems & Environment 114 (2-4) 195.

Yang, H., Zehnder, A. J. B., 2001. China's Regional Water Scarcity and Implications for Grain Supply and Trade. Environment and Planning A 33 79-95.

Yang, X., Lin, E., Ma, S., Ju, H., Guo, L., Xiong, W., Li, Y., Xu, Y., 2007. Adaptation of agriculture to warming in Northeast China. Climatic Change 84 (1) 45.

You, L., Wood, S., 2006. An entropy approach to spatial disaggregation of agricultural production. Agricultural Systems 90 (1-3) 329-347.