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Research Article

Potential Impact of Climate Change on Rained Agriculture of Ningxia

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Abstract: Rain fed agriculture in Ningxia is one of the most vulnerable sector to climate change, as the available water and land resources are limited and most of the province's land is arid. In this study, a crop simulation model (DSSAT) was used to assess the impact of climate change scenario on rainfed maize and potato in the southern mountain areas in Ningxia. Analysis of observed crop data showed differences between cultivated and harvested areas for both crops in the study area with variations among years. Results from DSSAT model for years showed that it was able to capture the trend of yield over the years realistically well. The model predicted an average yield of maize of 5450 kg/ha, which was close to the average (5446kg/ha) yield reported by the Department of statistics of Ningxia (DOSN) and an average predicted yield of potato was 2350 kg/ha while the DOSN average was 2358 kg/ha, with higher RMSE for maize (1046kg/ha) than for potato (358kg/ha). Predictions of future yield for both crops showed that the responses of maize and potato were different under different climate changes scenarios. The reduction of rainfall by 10-20% reduced the expected yield by 7-12% for maize and 9-18% for potato, respectively. The increase in rainfall by 10-20% increased the expected yield by5-9% for maize and 10-20% for potato, respectively. The increase of air temperature by 1,2,3 and 4°C resulted in deviation from expected yield by -3.3, -0.27,+6.1 and +12.5 % for maize and -18.4, -15.7, -8 and +0.4 % for potato, respectively. These results indicated that potato would be more negatively affected by the climate changes scenarios and therefore adaptation plans should prioritize the areas cultivated with this crop.

Keywords: Climate change, DSSAT, maize, potato, potential impact

INTRODUCTION

Climate change is seen as the main threat to agricultural sector in developing countries; as vulnerability of this sector is high and adaptation measures are restricted by the limited resources of these countries (Allen *et al*., 1998, Mendelsohn and Dinar, 1999). The vulnerability of the agriculture sector to both climate change and variability is well established. The general consensus is that changes in temperature and precipitation will influence plant growth and crop yield. In many developing countries, climate change is also expected to lead to changes in farming systems and will put more pressure on the rural community to cope with these changes and to build up their adaptive capacities (Reilly and Schimmelpfenning, 1999; Liwenga, 2008; Deng, 2010).

According to the fourth assessment report of the intergovernmental panel on climate change (IPCC, 2007), the possible climate changes that had occurred or expected to occur in mid latitudes areas would be an incremental decrease in precipitation associated with increased variability and higher air temperatures. Using the UK Hadley Center's global climate model at a spatial scale of 2.5° latitude by 3.75° longitude, Yang Kan and Xu Yinlong simulated the Ningxia climate change according to 4 scenarios of greenhouse gas concentration emission for the 2100s time horizon. Results of the study showed that the temperature would continuously increase to 4~6°C by the end of the 21st century, near the increase of whole country average, corresponding to the warming trend, the precipitation would decrease by 10-15% with great inter-annual variability (Yang *et al*.,2007). In another germane study by Chen Nan and Chen Xiaoguang, results of the PRECIS showed significant decrease in summer rainfall in southern mountain areas of Ningxia (Chen *et al*., 2007).

Generally, most of the attention in Ningxia was given to the impact of climate change on the increase in temperature through the global warming caused due to greenhouse effect. According to Food and Agriculture Organization(FAO,2005), the predicted impacts of climate change were increased crop water requirements, increased competition between weed and crops, spread of pests and nematodes and increased Stalinization of soils. The combination of increased temperature and decreased rainfall would be expected to result in

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reducing yield of agricultural crops in these areas. In other agro ecological areas, crops were expected to experience a beneficial increase in productivity under moderate changes in climate (Bazzaz and Sombroek, 1996; FAO, 2005, 2007; Cruz *et al*., 2007).

In Ningxia, rainfed agriculture is likely to be the most sensitive sector to climate change. The province, located in the western of china between 35º14′N~ 39º23′N and 104º17′E~107º39′E,is predominantly arid to semi-arid and characterized by short spring and autumn, hot wet summers and cold dry winters with extreme variability in rainfall within and among years (Xue, 2009). Ningxia has three distinct ecological zones (Chen *et al*., 2005):

- **The northern Yellow River irrigation area:** Annual average rainfall is about 200mm and 1100~1200 meters above sea-level
- **The central arid areas:** The average annual precipitation between the 200~400mm and 1300~1500 meters above sea-level
- **Southern mountains areas:** More than 400mm average annual rainfall and about 2000 meters above sea-level

The most prominent impact of climate change on rained agriculture is the reduction in crop productivity that is attributed to crop efficiency in axing CO_2 through the photosynthesis process (Wolfe and Erickson, 1993; Sombroek and Gommes, 1996; Hay and Porter, 2006). In Ningxia, maize and potato are the main rainfed field crops in areas that receive more than 350 mm rainfall. Both of maize and potato are important for local farmers.

Elevated CO_2 levels in the absence of biotic or biotic stresses may increase yield due to increased photosynthesis and growth. However, at above optimum temperatures and reduced precipitation which are associated with climatic change, the beneficial effects of elevated CO_2 do not compensate the offset by negative effects of temperature on yield and yield components (Lehnherr *et al*., 1997; Hay and Porter, 2006). Therefore, investigating the impact of climate change on cereal crops is still needed to assess the levels of crop yield under the different scenarios of climate change.

This study aims to assess the vulnerability of rained agriculture in Ningxia by modeling the impacts of different scenarios of temperature and rainfall changes on crop yield of maize and potato. A previous study in Ningxia (Zhang *et al*., 2008; Hao, 2009; Wang *et al*., 2011) showed that all rained crops were adversely affected by projected temperature increase and rainfall decrease. Results, however, would not be necessarily accurate, as crop yield prediction was carried out by applying simple production functions that consider one factor at a time. Therefore, detailed studies are needed to simulate crop yield under the different climate changes scenarios. In this study, a crop simulation model (Decision Support System for Agro technology Transfer, DSSAT) was used for this purpose.

MATERIALS AND METHODS

Crop yield data of the study areas, was obtained from the Department of Statistics of Ningxia, (DOSN). The DOSN compiled crop production surveys for about 100000 holdings distributed throughout the province. All landholdings which had an area of more than 2 ha were completely enumerated. For the other holdings, the strained multistage sampling technique was adopted. Details on the survey method are available at the official website of the DOSN (http://www.nxtj.gov.cn).

Methods: Models are considered important tools that enable the understanding of process and can exploit full information's of different data sources (Fenicia *et al*., 2008). Crops simulation models are tools for research, education and outreach. They are considered holistic in nature since they combine soil, plant and climate systems together, which facilitates understanding of the role of different variables and their interaction. Recently, many researches (Popova and Kercheva, 2005; Magombeyi and Taigbenu, 2008; Twomlow *et al*., 2008; Sun *et al*., 2008; Yang *et al*., 2009) used models to assess crop yield risk and the vulnerability of agriculture with respect to climate change, in addition to developing adaptive capacities to cope with the possible vulnerability. Crop simulation models are usually preferred over production function models that test crop yield under one variable while assuming optimum conditions and inputs for crop growth.

Among the different crop models, DSSAT (Ritchie *et al*., 1986; Tsuji *et al*., 1994; Boote *et al*., 1998) model simulates the impact of different management strategies on diverse crops in diverse environments (soils and weather). The DSSAT has been widely used in China and worldwide over the last two decades because it is reasonably accurate, process-oriented, simple and requires minimum data set. The model requires daily solar radiation, maximum and minimum temperatures and precipitation. The other input parameters for the model include soil properties, crop characteristics and management practices. The DSSAT has been widely used to simulate the impact of climate change on crops world wide (Guerena *et al*., 2001; Holden and Brereton, 2003; Brassard and Singh, 2007; Kalra *et al*., 2007; Zhang *et al*., 2007). In Ningxia, the DSSAT model has been used to simulate the impact of climate change on spring wheat (Lei, 2001; Yang *et al*., 2009), but this study is the first attempt to simulate the impact of climate change on maize and potato yield using DSSAT in rainfed southern mountain areas.

RESULTS AND DISCUSSION

Analysis of the DOSN data showed variations in the total production and yield among the different years. For maize, the average cultivated area was 13931 ha while the average harvested area was 10331 ha. The average ratios of the harvested to cultivated areas for maize and potato were 74% and 67%, respectively. The coefficients of variation for harvested areas and yield were always higher for maize than for potato (Li *et al*., 2011). This could indicate the high risk associated with cultivation of maize as compared to potato. Comparing the annual rainfall with total production and yield indicated that the impact of rainfall on the average yield was more than its impact on the cultivated areas. Increased rainfall resulted in increasing the average yield and total production in southern mountain areas of Ningxia. This was obvious in year 2003 and 2005 when average yield was relatively high for maize and the year 2004 for potato. In year 2001, the total production and average yield for maize and potato were the lowest among the years. This could be explained by the low rainfall during this year, which was 70% of the average. These results would reflect the vulnerability of both crops to climatic variations. This was also indicated by the ratios of cultivated to harvested areas.

Results from the DSSAT model showed that the model was able to detect the trend of yield for the period 1999~2009. For maize, the maximum absolute difference between the DSSAT predicted grain yield and the observed one was less than 613kg/ha (12% of the DOSN average), with an average RMSE of 1305 kg/ha.

Although in some years the DSSAT over-estimated and in other years underestimated the grain yield, the model captured the trend over the years realistically well. This was a prerequisite for the crop model to estimate the impact of climate change on grain yield. For potato, similar trends were obtained between predicted yield and the yield reported by the DOSN. In most years, the absolute difference between predicted and the actual yield was less than 400 kg/ha. The average yield obtained from the model was very close to the average of the data of DOSN, with a difference of about 10 kg/ha (<0.5% of the DOSN average) and an RMSE of 1046 kg/ha.

For both crops, the predicted yield in 2001 was very close to the average yield reported by the DOSN. This could be explained by the low rainfall amounts in 2001 (70% of long-term average) which resulted in low variations in the data of DOSN. Before intercalibration of the model, the predicted yield of maize was higher than the average yield obtained from DOSN, except in year 2001. This could be explained by the variations in yield along the gradient of rainfall and climate within the southern mountain areas. Calibrating the model resulted in improving the prediction of maize yield, as the RMSE decreased to 1046 kg/ha and the mean of the simulated maize yield for the 10 years was 5450 kg/ha, which was rather close to the DOSN average of 5446 kg/ha. In the same time, as the RMSE decreased to358 kg/ha and the mean of the simulated potato yield for the 10 years was 2350 kg/ha, which was rather close to the DOSN average of 2358 kg/ha.

The use of data of DOSN to calibrate the yield of potato did not improve the modeled yield. This could be attributed to the high variations in the data of cultivated potato in areas with insufficient precipitation coincided with long periods of drought. The data of DOSN showed higher variations in cultivated and harvested areas, as well as in the total production and average yield for potato than for maize. Generally, yield of maize was more stable than that of potato; since maize was grown in areas with relatively high rainfall. The variations between DSSAT predicted yield and DOSN yield were higher for maize than for potato, with RMSE of 1046 kg/ha and 358 kg/ha for maize and potato, respectively. These variations would be expected in the modeling approach and would not limit the use of DSSAT to trace the trends of yield under future scenarios, particularly after the inter-calibration of the model.

CONCLUSION

Results presented in this study showed that rained agriculture had high vulnerability to climatic change of increased air temperature and decreased precipitation. The increased air temperature under the different future scenarios had adverse impacts on potato yield, while reduction of precipitation had negative impacts on both maize and potato. Therefore, adoption of soil water conservation to increase available water to crop could be seen as an important adaptation measure to climate change. Also, the selection of drought tolerant genotypes with shorter growing seasons than the present genotypes is another adaptation measure that should be considered to alleviate the adverse impact of climate change. Results of this study also showed that the use of DSSAT simulation model was useful in tracing the general trend of yield and its possible changes under the different climate change scenarios. The implementation of such models for other crops in different areas, after proper calibrations, should be an objective for future studies in this field. By this, critical information would be transferred to decision makers to formulate appropriate adaptation measures.

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