Crop production simulation and analysis of climate scenarios based on the APSIM model for the long term run of the western Loess Plateau

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Introduction

The APSIM model is an effective tool for making decisions on agricultural management. The model can simulate the biophysical process in farming systems, particularly economic and ecological features of the systems under climatic risk (Keating *et al.* 1998). The APSIM model has previously been used in the Loess Plateau (Tan, 2007; Chen *et al.* 2008). Based on climate data from the Loess Plateau from 1961-2010, we simulated three commonly grown crops, wheat, maize and lucerne. Additionally, by applying three climate change scenarios, we attempted to determine the production risk in the future, and gain an understanding of the impact of climate change on crop yield in the western Loess Plateau.

Methods

This paper looks into the simulated production of three crop species (winter wheat, maize and lucerne) based on climate data between 1961-2011. We then simulated potential climate variability, using the following scenarios: (1) historical climate; (2) a 1°C increase in daily mean temperature; (3) a 10% increase in yearly rainfall; and (4) a 1°C increase in daily mean temperature and a 10% increase in yearly rainfall. The model was programmed to calculate grain yield, biomass yield, growth season rainfall and related coefficient between yield and growth season rainfall for the 3 crops.

Results

Results of the modelling for crop yield under the four weather data sets indicated that an increase of 1°C will result in a reduction in crop yield of 2.5%, 6.5% and 8.0% for winter wheat, maize and lucerne, respectively (Table 1). An increase in rainfall of 10% per year will increase crop yields for winter wheat, maize and lucerne by 7.5%, 12.4% and 14.4% per year, respectively (Table 1). An increase in temperature combined with an increase in rainfall resulted in winter wheat yields increasing by 4.3% of the historical scenario, with maize (a 5.8% increase) and lucerne (a 5.5% increase) indicating that all crops would benefit from this climate change scenario. The greater predicted production for the temperature and precipitation increase scenario, while not as great as under a rainfall increase alone, does indicate that the production risk has a greater link to rainfall.

The crops yield x probability (Fig. 1), indicate that winter wheat yield had the narrowest range of yield fluctuation, with maize and lucerne showing greater fluctuations. Over all years for the four scenarios, only maize shows a probability of no harvest (3.5%). Lucerne has an 80% probability of a harvest of 6000 kg/ha except under the 1°C increase scenario where lucerne has an 80% probability of only a 5500 kg/ha yield (Fig. 1). All crops, when rainfall alone is increased, have higher yield potentials than the no rainfall increase scenario, illuminating the impact of increased rainfall on potential productivity.

Linear regression analysis was undertaken to determine relationships between growth season rainfall and crop yield (Table 2). The coefficient between yield and growth season rainfall of the three crops was 0.57 (winter wheat), 0.16 (maize) and 0.26 (Lucerne) (Table 2). So to a certain extent, yield of winter wheat had a linear relation with growth season rainfall and thus more growth season rainfall results in a greater yield and if rainfall is not enough, yield will be reduced. However, linear relations between yield in maize and lucerne and growth season rainfall were less well correlated (Table 2). For instance, in 1973 the growth season rainfall of

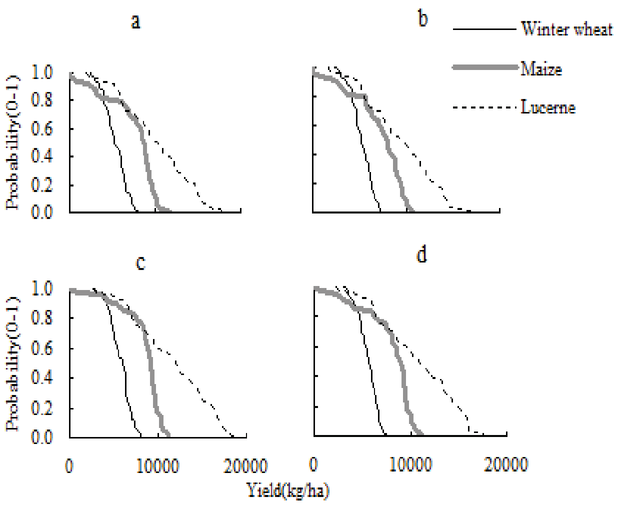

Figure 1. Probability of yield for 3 crops a) historical climate; b) 1°C increase in daily mean temperature; c) 10% increase in yearly rainfall; d) 1°C increase in daily mean temperature and a 10% increase in yearly rainfall.

Table 1. The yield of 3 crops in every scenarios.

Scenario	Winter wheat yield (kg/ha)	Maize yield (kg/ha)	Lucerne yield (kg/ha)
Historical	5342	7463	10159
Increase 1°C	5210	6980	9346
10% increase in annual rainfall	5742	8389	11623
Increase 1°C and 10% increase in annual rainfall	5573	7896	10721

Table 2. Regression analysis between growth season rainfall and yield.

Crop	Linear regression equation	R^2
Winter wheat	y = 8.5x + 3241	0.57
Maize	y = 3.6x + 6236	0.16
Lucerne	y = 9.5x + 6175	0.26

maize was 574 mm, but in the predicted yield of maize was 0 kg/ha, Our explanation is: In 1973, although there was a normal rainfall event for growth season, only 43 mm of rainfall occurred in July, which was the critic period for maize flowering, as a result, maize had no grain harvest, only biomass production available.

In 1961 and 1962, the growth season rainfall was 521 and 381 mm, and in these years, lucerne yield was 15949 kg/ha and 9979 kg/ha, respectively. For the years that maize yielded over 5000 kg/ha, growth season rainfall was between 300 - 500 mm, indicating that moderate soil moisture, can result in an increased probability of a good yield. The years that lucerne yield was over 10000 kg/ha, growth season rainfall was between 320 - 768 mm, whereas for those years that yield was less than 10000 kg/ha, growth season rainfall was between 260 - 760 mm. At the experimental region, the long term annual rainfall ranged from 320 to 810 mm, the model simulation output sensitively captured lower rainfall below 320 mm limiting lucerne production. Unlike winter wheat and maize, lucerne did not present a relationship between yield and rainfall, suggesting that the yield of this forage crop is subject to greater influence from other climate factors, and has a large root system for extracting soil water from deep soil layers.

Conclusion

If all other conditions remain unchanged, the temperature and rainfall changes are the major determining factors that cause changes in crop yields. However, different crops will respond (in terms of yield) in a variety of ways due to changes in temperature and rainfall of varying magnitudes, and changes in the different years of production are not same. When rainfall increased, simulated crop yields increased, however when the temperature was also increased by 1ºC, all crops demonstrated little difference in simulated production. While higher temperatures may adversely affect yield of these crops, climate trends for the Loess Plateau show both higher temperatures and rainfall, therefore, due to the higher rainfall, crop production prediction indicate that productivity will be greater than in previous years.

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