Risk analysis of possible environmental change and future crop production in South Australia

Qunying Luo[1], Bill Bellotti[2], Brett Bryan [1] and Martin Williams[1]

[1]Department of Geographical and Environmental Studies, Adelaide University, South Australia, 5005, Australia
Phone: 08 8303 5645 Fax: 08 8303 4383 Email: qunying.luo@adelaide.edu.au
[2]Department of Agronomy & Farming Systems, Adelaide University, South Australia, 5371, Australia

Abstract

The potential impact of future environmental change (climate change plus pCO_2 change) on wheat production in Roseworthy, South Australia, was assessed in a view of risk by using the APSIM wheat model.

Possible future environmental change scenarios for 2080 were generated from the output of 9 climate models including GCMs (General Circulation Models) and RCMs (Regional Climate Models), historical climate records (SILO) and IPCC (Intergovernmental Panel on Climate Change) SRES (Special Report on Emission Scenarios) for Roseworthy. Plant available water capacity for a typical soil in Roseworthy was derived from the state soils database (Maschmedt, pers comm.). The APSIM (Agricultural Production System Simulator) Wheat module was run for the historical climate record (baseline) and eighty possible environmental change scenarios. A wheat crop was simulated for each year of a 100-year period under each environmental scenario. A critical economic yield was derived from current input costs, grain prices, and standard return on investment (3%) and resulted in a critical yield for Roseworthy of 1,870 kg/ha. The conditional probability of not exceeding the critical yield increased from 27% (low level risk) of years under the historical baseline to 35~50% (medium level risk) of years under the most probable environmental change scenario. This result indicates that some solid adaptation strategies should be put forward to deal with the increased risk associated with Roseworthy wheat production.

Keywords

Critical yield threshold, APSIM-Wheat module

Introduction

Environmental change impacts on agriculture have attracted considerable attention from the governments and scientists over the last decade due to the importance of agriculture to world people's subsistence and world grain trade. A large number of impact studies have been conducted worldwide. Progress has been made in the application of process oriented crop model, the adoption of the outputs of RCMs and of downscaled GCMs, the incorporation of CO_2 fertilisation effect and the inclusion of grain nitrogen content impact evaluation etc. Even with these substantial studies, there still remain many uncertainties and methodological problems, which obstacle accurate assessment of agricultural impact from environmental changes.

Uncertainties existed and propagated in every step of environmental change impact assessment from the projections of greenhouse gas emissions, the projections of global climate change, the projections of regional climate change and with all three propagating through to impact assessments. How to quantify and manage these uncertainties is becoming a crucial task. This study focused on the quantification and management of uncertainties surrounding impact assessment. Risk analysis was carried out within the uncertainty range.

APSIM-Wheat Module and Its Parameterization

The APSIM-Wheat model was used to quantitatively assess wheat production impacts in Roseworthy resulting from environmental change. APSIM stands for Agricultural Production Systems sIMulator. It is an integration of several interactive modules including Biological Modules (Crop Modules, Grazplan Module etc.), and other utility and application modules. The wheat module is one of the crop modules within the APSIM system. It simulates the growth and development of a wheat crop in a daily time-step on an area basis as a function of weather (temperature, rainfall and radiation), soil (soil water and soil nitrogen), crop genetic coefficients and crop management information. APSIM-Wheat has been validated for several locations in Australia (Wang et al., 2001)**.** Yunusa et al (2002) has tested the performance of APSIM-Wheat under South Australian conditions.

Climate data

Maximum temperature, minimum temperature, solar radiation and rainfall are identified as key climatic variables, which are explicitly dealt within the APSIM-Wheat model to be used in risk analysis. Two tiers of climate information were acquired: historical climate data and climate change information.

Historical daily climate data including maximum temperature, minimum temperature, rainfall and solar radiation covering 1889-1999 were downloaded from http://silo.roseworthy.adelaide.edu.au/silo (Anon, 2000) in APSIM format for Roseworthy. There are two functions for historical climate data. First, it was used to drive wheat model to produce baseline wheat yields and other assessment indicators. Second, it is the historical weather data that was perturbed by climate change to produce climate change scenarios which were then forwarded to wheat model to explore potential impacts of climate change on wheat production.

Downscaled outputs of 9 climate models for local climate change per degree of global warming, information about global warming scenario and atmospheric CO_2 emission scenario for 2080 were obtained from Atmospheric Research CSIRO, and used to construct environmental change scenarios by applying Monte Carlo Random Sampling techniques. The global warming range, local climate change ranges and atmospheric CO_2 concentration change ranges were sorted out and random sampled according to Luo (2003) to derive regional environmental change information. The random samples for regional temperature, regional rainfall and CO_2 change ranges were rounded, tabulated and binned. The percentage frequency of outcomes for rounded regional temperature, regional rainfall and atmospheric pCO_2 was calculated and summed from the most frequent to the least frequent. The constructed environmental change scenario contains an upper and lower limit with probability attached to each level of scenario (The shaded area in Figure 1). Five contour levels represented by different levels of grey were set based on the cumulative probability information. Each contour contains a level of cumulative probability of particular environmental change being reached. The darkest grey represents the most likely environmental change scenarios with cumulative probability ranging from 0-20%. The white stands for the least likely environmental change scenario with cumulative probability between 80-100%. The cumulative probabilities represented by other levels of grey are between the most likely and the least likely. 80 environmental change scenarios (5 rainfall levels * 4 temperature levels * 4 CO_2 levels) were chosen to drive APSIM-Wheat module to simulate grain yield change in Roseworthy.

Soil data

A large number of soil water and soil nitrogen parameters are needed to run APSIM-Wheat module such as initial soil water, volumetric drained upper limit-layered, volumetric 15 bar lower limit-layered, organic carbon, and C: N ratio of the soil etc. The soil profile data were obtained from Land Resources Unit, Primary Industry and Resources, South Australia (PIRSA).

Model setting

Two types of wheat cultivar were used in this study. One is Janz: Australian Hard Wheat (AH) with grain protein content greater than 12%. The other one is Excalibur: Australian Soft Wheat (ASW) with grain protein content within 8%-12%. Janz, is a mid-late maturity variety, while Excalibur an early maturity cultivar. Their genetic coefficients are listed in Table 1. Soil nitrogen, soil water, and residues were reset on the first of March for each year simulation run. The sowing rule was specified as follows: if cumulative rainfall within 3 days >= 20 mm between 15 of April and 15 of June, then sow Janz; if cumulative rainfall within three days >=15 mm between 15 of June and 15 of August, then sow Excalibur. Sowing density was 200 plants/m^2, at a depth of 3 cm. 40kg/ha NO_3-N was applied at planting date at a depth of 5 cm. In addition to fertilizer nitrogen, initial soil nitrate-N was set at 60 kg NO3/ha in the top 35cm of the soil profile at Roseworthy. These levels were chosen to represent a non-limiting nitrogen environment. The physiological effects of increased atmospheric CO_2 on wheat production were taken into account. Modifications have been made to the Wheat Module through changes to Radiation Use Efficiency (RUE), to Transpiration Efficiency (TE), and to Critical Nitrogen Concentration (CRC) based on experimental data (Wang et al., 2001). CO_2 levels were set to 330ppm(baseline), 527.2ppm, 634.8ppm, 687.1ppm, and 785.8ppm respectively, to explore the direct effects of CO_2 on grain yield.

Results

Risk is defined here as the conditional probability of not exceeding the critical yield. Before conducting risk analysis, the critical yield threshold should be determined first.

Table 1 Genetic coefficients for Janz and Excalibur*

Coefficient	Janz	Excalibur
p1v: sensitivity to vernalisation	1.0	1.5
p1d: sensitivity to daylength	2.0	2.0
p5: grain filling duration, ^oCd	640	703
grno: grain number per head	34.0	27.0
fillrate: rate of grain filling, mg d^{-1}	2.5	3.5
stem weight (mg)	1.65	2.4
phyllo: phllochron interval, ^oCd	95	95
sla: specific leaf area (mg cm^{-2})	185	180

* Data Source: Department of Agronomy and Farming Systems, Adelaide University

Determination of critical yield threshold

Yield is a very important economic indicator for the sustainability of crop production. The critical yield threshold for this study was determined under many assumptions and practical situations. The determination of critical yield is directly related to the profit (return) of wheat industry. The calculation for profit is involved in many factors as listed in table 2. Table 2 gives the specific value for each of these factors and calculation equations in Roseworthy with an annual rainfall of 440mm. The specification of some of these variables such as land value and machine value is annual rainfall dependent. In reality, the long term average return on agricultural land is set >=3%. Once other values determined/assumed, in order to obtain the minimum return (3%), there must be a critical yield (below which, the wheat industry is not sustainable) corresponding to this return. The critical yield for Roseworthy is 1.87 t/ha (Luo, 2003).

Table 2 Factors considered in calculating critical yield threshold

Variables	Value
Farm size (ha)	500
Grain price ($/ha)	170
Interest rate (%)	10
Labour hour (hours/ha)	1.2
Labour price ($/hr)	11
Value of machinery ($)	100,000
Rate of depreciation on machinery (%)	16
Allowance for other overheads ($)	5,000
Land value ($/ha)	2000
Long term average return on agricultural land (%)	3
Critical yield threshold (t/ha)	1.87

Risk analysis

The probability of not exceeding the critical yield has been calculated for the 81 scenarios (one baseline plus 80 environmental change scenarios) and presented in Figure 1. The reason for using conditional probability rather than probability is that the procedures to produce probabilistic scenarios involved some assumptions such as the uniform distribution of random sampled variables (Luo, 2003). Higher conditional probability means higher risk of wheat production under that environmental change scenario. Conditional probability is divided into 5 levels for the convenience of quantifying the risk degree with <20% conditional probability assigned as very low level, 20%~40% as low level, 40%~60% as medium level, 60~80% as high level, >80% as very high level.

The conditional probability of not exceeding the critical yield (1.87 t/ha) under baseline is 27% (low level) in Roseworthy. 23%~70% conditional probability occurred in the horizontal plane and the main vertical plane. 46%~70% conditional probability covered the side vertical plane. Conditional probability mainly increased under future environmental change scenarios compared with baseline probability. The conditional probability is around medium level under the most likely environmental change scenarios.

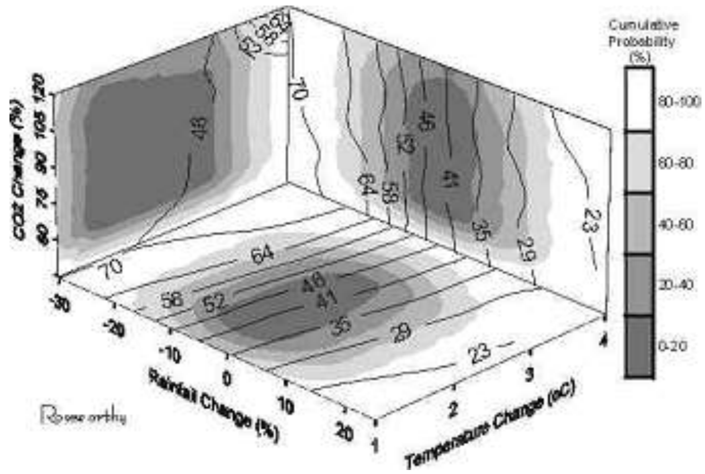

Figure 1 Conditional probability of not exceeding the critical yield (line thing) was overlaid with probabilistic environmental change scenarios (shaded area)

Discussion and Conclusions

The most likely grain yield in Roseworthy decreased ranging from 23% to 41%, which is more risky than previous studies. This difference can be attributed to the fact that different emission scenarios were adopted. IPCC (1996) IS92a-f scenarios were used in previous study, while SRES marker scenarios were used in this study. A warmer and drier climate regime was projected under the IPCC SRES scenarios, which lead to greater decrease in wheat grain yield.

The conditional probability of not exceeding the critical yield threshold increased in Roseworthy (27%) under baseline to (43%~48%) under most likely environmental change scenarios. Risk level increased one class from low level to medium level indicating less profitable in wheat production in Roseworthy under future environmental change. Effective adaptation strategies should be put forward to counteract the adverse effect of environmental change on wheat production in this area.

References

(1) Anonymous, 2000, http://silo.roseworthy.adelaide.edu.au/silo

(2) IPCC, 1996: Technical Summary, in Houghton, J. T., Meria, Filho, L. G., Callander, B. A., Harris, N., Kattnberg, A. and Maskell, K. (eds) Climate Change 1995: The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York, 9-49.

(3) Luo, Q.Y.: 2003, Assessment of the Potential Impacts of Environmental Change on South Australian Wheat Production. Adelaide University.

(4) Wang, E., Robertson, M., Oosterom., E.V. and Meinke, H.: 2001, The APSIM-Wheat Module (-Wheat), Version 2.0.

(5) Yunusa, I.A.M., Bellotti, W. D., Baldock, J. A. and Moore, A. D.: 2002, Analysis and Simulation of Cereal Yield Response to Soil Water and Nitrogen in a Rotation System. In: Proceedings of International Soil Conservation Organization Conference. Purdue University, West Lafeyette, U.S.A. May, 23-29