An agro-economic model to analyse climate change impacts on farmers' income

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Abstract

The increasing interests in climate change heighten the need for an agro-economic model to analyse climate change impacts on farmers' incomes. Many researchers have turned to crop yield response models to estimate farmers' yield and income loss. A classic method used by economists to establish yield response models is to build up the statistic relationship between historical yield changes and climate change through regression models. However, without comprehensive experimental data from each region such as crop yields response to CO_2 concentration, these crop-yield response models may provide misleading predications. An alternative approach is the use of crop biophysical simulation models.

Based one biophysical model Agricultural production systems simulator (APSIM), we develope an agro-economic model, WATER-BIOMASS DYNAMI, to simulate the change of crop yields and farmers' income affected by varied climate change scenarios and other economic factors. We used the WATER-BIOMASS DYNAMIC model to analyse the agricultural economic impacts of four climate change scenarios in the Australian Wagga Wagga wheat production area.

Keywords: APSIM; Climate change; agricultural economics; wheat

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1 Introduction

Quantification and simulation of climate change's impact on crop yields can and help in understanding to what extent climate risk can be managed through management strategies. Many economists use statistic models such as regression models to predict crop yield changes under varied climate change scenarios.

Chang (2002) estimates the potential impact of climate change on Taiwan's agricultural production by using multiple regression models. Qureshi et al. (2007) use an adaption of the Food and Agriculture Organization (FAO) crop-water yield functions to predict crop yield changes under varied climate change scenarios. However, Chang (2002) and Qureshi's study do not consider the fertilizer impacts of higher CO_2 on crops.

Plant systems are influenced by many environmental and management factors such as rainfall, temperature, soil and fertilizer management. Many of these factors have contrary impacts on crop yields. For instance, more CO_2 in the atmosphere may boost crop productivity. In contrast, crop yield may be damaged by higher temperatures, particularly if combined with water shortages. Without comprehensive experimental data from each region, a statistical crop yield response model may provide misleading predictions in crop yields. This limits the implication of a statistical crop yield response models in predicting crop yields under climate change.

Agricultural production systems simulator (APSIM) is a biophysical model developed to simulate biophysical processes in farming systems, particularly in relation to the economic and ecological outcomes of management practices faced with climate risk.

With the APSIM ability to simulate of the crop and soil biophysical process under climate change scenarios, researchers have done enormous work in investigating climate change impacts on crops. Reyenga et al. (1999) developed a wheat module, I_WHEAT, from the APSIM cropping system model that investigated the impacts of changes in atmospheric CO_2 concentrations on wheat crops by modifying radiation use efficiency, transpiration efficiency, specific leaf area and critical nitrogen concentrations.

Reyenga et al. (2001) studied the effects of the combination of atmospheric CO_2, climate change and crop adaptation strategies on wheat production in the Burnett region of Australian Queensland. Later, Reyenga studied another region in South Australia. The effects of several global change scenarios were studied, including: (1) historical climate and CO_2 levels, (2) historic climate with elevated CO_2 (700 ppm), (3) warmer climate (+2.4°C) +700 ppm CO_2, (4) drier climate (-15% summer, -20% winter rainfall) +2.4°C +700 ppm CO_2, (5) wetter climate (+10% summer rainfall) +2.4°C +700 ppm CO_2 and (6) most likely climate changes (+1.8°C, -8% annual rainfall) +700 ppm CO_2. Reyenga concluded that increases in CO_2 levels over the current climate record have resulted in small but significant increases in simulated yields

Luo et al.(2005) undertook a similar study in South Australia using more climate change scenarios. They claim that they refined and improved climate change scenarios to quantify the possible impacts of future climate change on South Australian wheat yield with probability attached. Her study used the APSIM-Wheat module and information drawn from the Special Report on Emission Scenarios (SRES) and nine climate models for 2080. A wheat yield response surface was constructed within 80 climate change scenarios. The most likely wheat yield changes were defined under a combination of changes in regional rainfall, regional temperature and atmospheric CO_2 concentration.

Van et al. (2003) investigated the climate change impacts on wheat productivity and deep drainage in Western Australia. They claim that climate change is not only likely to affect productivity, but also deep drainage and dryland salinity. They consider that the impact can vary in direction such that both 'win–win' and 'lose–win' outcomes may occur, depending on the relative change in precipitation.

APSIM has been listed as a primary investigating tool in climate change by UNFCCC (2002). However APSIM have not provided a user friendly tool for defining the climate change scenarios and economic functions to estimate farmers' income and crop failure risk. This study will fill this gap and provide a climate change scenario design tool for APSIM.

We believe that a modern agro-economic model to analyse climate change impacts on farmer incomes and agricultural economics should include:

1. A user friendly function to specify the climate change scenarios.
2. Use crop biophysical models to simulate crop yield changes
3. Estimate climate change economic impacts (farmer income changes and crop failure risk).

To address these issues, based on APSIM, we developed an agro-economic model (WATER-BIOMASS DYNAMIC) to simulate the economic impacts of climate change in the wheat industry affected by varied climate change scenarios. We used the WATER-BIOMASS DYNAMIC model to analyse the economic impacts of four climate change scenarios in the Australian Wagga Wagga wheat production area.

2 Traditional crop yield functions and their failure

A classic method used by economists to establish yield response models is to build up the statistic relationship between historical yield changes and climate change through regression models. However, without comprehensive experimental data from each region such as crop yields response to CO_2 concentration, these crop-yield response models may provide misleading predications. In Figure 1, based on weather data in Wagga Wagga from 1970 to 2001, we use APSIM to simulate CO_2 concentration increase from 350 ppm to 550 ppm and 750 ppm and how wheat crop yields respond to it. Because we do not have similar historical data, traditional regression models can not reflect how crop yields respond to CO_2 concentration.

This demonstrates crop biophysical simulation models can performance better as biophysical models can consider the impacts of CO_2 concentration. In WATER-BIOMASS DYNAMIC we use a biophysical APSIM to simulate how crop yields respond to climate change.

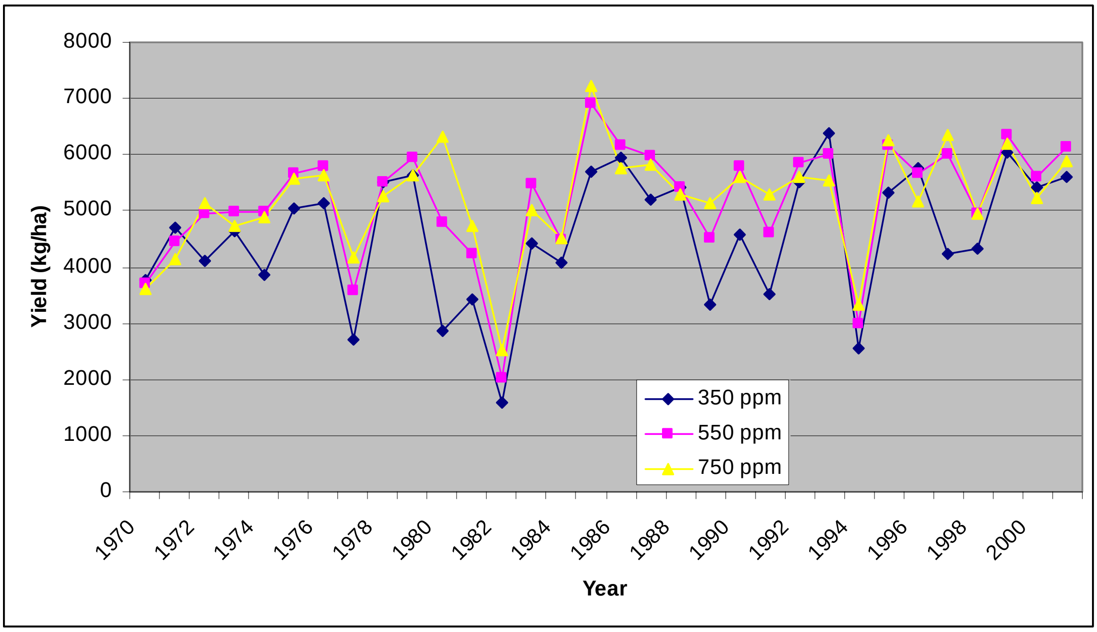

Figure 1 crop yields response to CO_2 concentration

4 Economic model in WATER-BIOMASS DYNAMIC

The WATER-BIOMASS DYNAMIC provides an economic tool to estimate farmers' income changes by climate and other economic factors. One advantage of this economic model is users can set up their own estimations for these economic factors such as grain price and harvest cost.

Farmers' income is expressed by gross margin (GM) and crop failure risk is expressed by crop failure rate.

For all the simulations, GM was calculated based on Hayman (2003) and Wang (2008) as:

$$GM = Y + P_Y – (N \times P_N + C_H + C_S + C_O) \qquad \text{(AU\$/ha)}$$

where Y is wheat grain yield (t/ha), P_Y is wheat grain price (AU$/t), N is the nitrogen application rate (kgN/ha), P_N is nitrogen price (=AU$/kgN), C_H is harvest cost, C_S is the cost of seed (C=AU$/ha) and C_O other cost (estimated Co=AU$/ha).

Grain price was dependent on grain protein content (G_{PN}):

$$P_Y = 140 + 0.5 \times (G_{PN} - 10)/0.1 \qquad (\$/ha)$$

Price of wheat grain at 10% protein was assumed to be AU$140/t and a sliding scale of $0.5 used for each 0.1% grain protein above and below 10%.

Wheat protein content was calculated from grain
nitrogen concentration (G_{NC}, kgN/kg grain) as:

$$G_{PN} = G_{NC} \times 100 \times 5.7 \quad (\%)$$

Harvest cost was dependent on grain yield level:

$$C_H = 25 + 13(Y - 2.5) \quad (\%)$$

It was assumed that harvest cost was $25/ha for grain yield up to 2.5t/ha and increased by $1.3/ha for each additional 0.1t of grain yield.

Parameters used for these economic factors in Simulations of Wagga Wagga region are listed as follows:

(1) Nitrogen price (P_N) is AU$1.0/kgN.

(2) The cost of seed (C_{S+}) is AU$100/ha.

(3) Other cost (C_O) is AU$10/ha

5 APSIM model

The APSIM modelling framework is made up of four components (Agricultural Production Systems Research Unit 2008):

1. A set of biophysical modules that simulate biological and physical processes in farming systems.
2. A set of management modules that allow the user to specify the intended management rules that characterise the scenario being simulated and control the simulation.
3. Various modules to facilitate data input and output to and from the simulation.
4. A simulation engine that drives the simulation process and facilitates communication between the independent modules.

APSIM simulation procedures:

1. Set up the soil file.
2. Set up the climate file.
3. Set up the crop file.
4. Set up the crop mange and report file.
5. Simulate and report the results.

APSIM can easily simulate crop yields under the current weather condition. However it does not provide the economic function to estimate the farmers' income and any user friendly tools to define climate change tools, such as temperature increased by 1 degree or rainfall will decrease by 20 percent. WATER-BIOMASS DYNAMIC can allow users to specify the more complex climate change scenarios and simulate plant biomass processes in wheat under these climate change scenarios using APSIM modules. Finally the economic tool in WATER-BIOMASS DYNAMIC will estimate the farmers' income changes and climate change risk.

6 Design of WATER-BIOMASS DYNAMIC model

6.1 WATER-BIOMASS DYNAMIC framework

The WATER-BIOMASS DYNAMIC simulation procedure is:

1. Users use the climate change scenario tool to design varied climate change scenarios.
2. APSIM simulates the crop yield responses to the climate change scenarios.
3. Based on the crop yield from APSIM, the economic tool estimates farmers' income and risk.
4. The WATER-BIOMASS DYNAMIC reports the results.

6.2 Climate change scenario tool

The WATER-BIOMASS DYNAMIC provides a user friendly tool to help users design complex climate change scenarios. Figure 2 shows the interface of WATER-BIOMASS DYNAMIC. Uses can design the climate change scenarios in the (set up and run) form by clicking the (simulation setup and run) menu (see Figure 3). On this climate change tool, users can specify the daily maximum or minimum temperature, daily rainfall changes and CO_2 changes.

Figure 2 WATER-BIOMASS DYNAMIC main interface

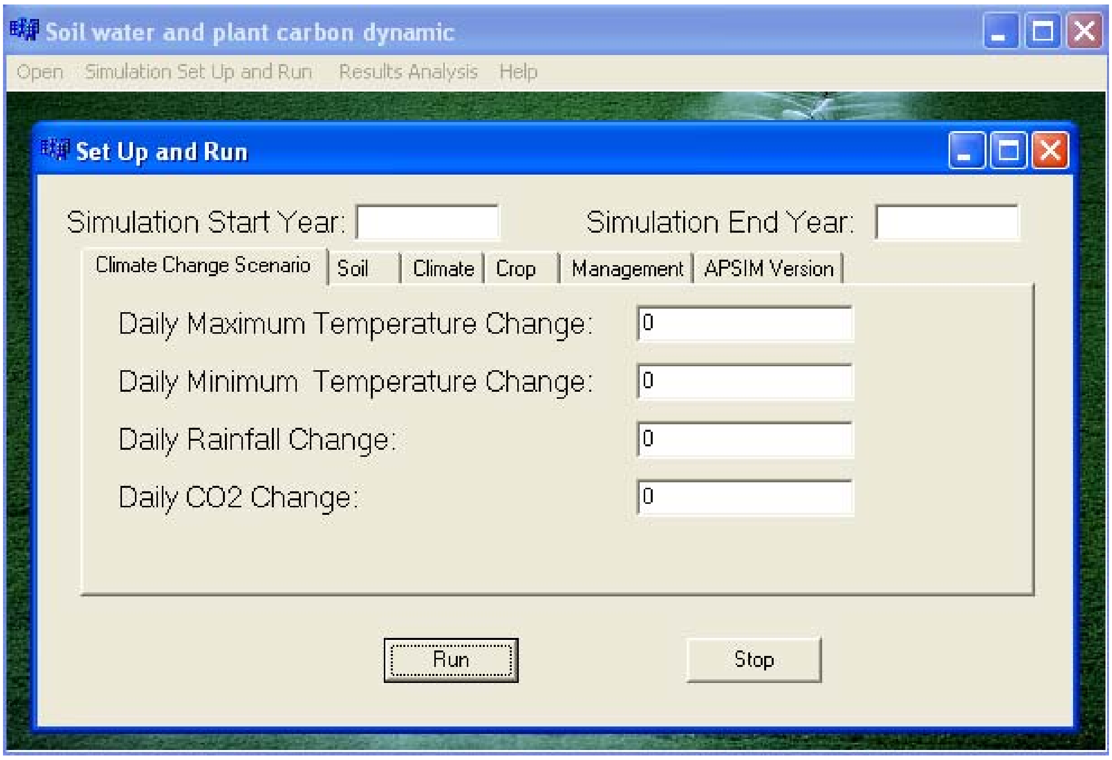

Figure 3 set up and run form (mainly for climate change scenarios design)

6.3 APSIM parameters

To simulate the crop yields, we need to specify the simulation parameters for APSIM in Figure 3:

(1) Start and end year of the simulation

(2) Soil type

(3) Climate data

(4) Crop data

(5) Management rules (Fertilizer management)

(6) APSIM version

7 WATER-BIOMASS DYNAMIC simulations on the Australian Wagga Wagga wheat production

We use the WATER-BIOMASS DYNAMIC to simulate the climate change impacts in the Australian Wagga Wagga wheat production. The simulation Parameters are:

7.1. Simulation parameters

Climate change scenarios (these scenarios are basic estimations to show the climate change differences):

1. Baseline scenario: historical climate and CO_2 levels,
2. Low Climate Change Scenario: temperature rising by 1°C, rainfall decreasing by 6% and CO_2 levels reaching 550 ppm
3. Medium Climate Change Scenario: temperature rising by 2 ° C, rainfall decreasing by 10% and CO_2 levels reaching 550 ppm
4. Severe Climate Change Scenario: temperature rising by 2 ° C, rainfall decreasing by 18% and CO_2 levels reaching 750 ppm

Soil type: CP402 from NSW, Australian

Climate data: Wagga Wagga, NSW, Australian

Simulation time: 30 years

Fertilizer management: 150 fertilizer kg/ha,

7.2. Simulation results

The simulated crop yield changes, GM and crop failure risk are in Table 1.

Table 1 Wagga Wagga simulation results

	Annual rainfall (mm)	Crop yield (kg/ha)	GM ($/ha)	Crop failure risk (%)
Baseline scenario	583.11	4704.47	395.69	3.33
Low Climate Change Scenario	548.13	5278.27	486.45	3.33
Medium Climate Change Scenario	524.80	3972.30	279.52	13.33
Severe Climate Change Scenario	478.15	5049.38	450.82	6.66

One interesting finding was that the worst agricultural returns for the Wagga Wagga wheat farmers was in the medium climate change scenario rather than the severe climate change scenario. This can be explained by the high CO_2 level which can boost the crop production**.**

8 Conclusions and discussions

The complex impacts of climate change in crop yields, traditional crop yield changes models have failed in the past. We propose three criteria for a modern agro-economic model to analyse climate change impacts on farmer income and agricultural economics. To address this failure, based on APSIM, this study develops an agro-economic model (WATER-BIOMASS DYNAMIC) to simulate the crop yield changes and agricultural economics in the wheat industry affected by rising temperatures, increased water deficit and elevated atmospheric CO_2.

WATER-BIOMASS DYNAMIC also provides an economic function to allow users to design economic factors such grain price and harvest costs. Then users can calculate the gross margin. This economic function transfers the change of crop yields and other economic factors to the change of farmers' income.

This study uses WATER-BIOMASS DYNAMIC to study climate change impacts in the Australian Wagga Wagga wheat industry under varied climate change scenarios. One interesting finding is the worst agricultural returns for the Wagga Wagga wheat farmers is in the medium climate change scenario rather than the severe climate change scenario.

The climate change scenarios used in this study are basic estimations to show the climate change differences and do not reflect the real future. In the future we need to use more accurate climate change scenarios from other models.

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