Modelling impacts of climate variability and change on wheat cropping across New South Wales

Submitted by

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Certificate of original authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as part of the collaborative doctoral degree and/or fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Date: 23/01/2017

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Publications arising from this thesis

Journal Publications

1. **Wang B**, Chen C, Liu DL, Asseng S, Yu Q, Yang X (2015a) Effects of climate trends and variability on wheat yield variability in eastern Australia. Climate Research 64:173-186, https://doi.org/10.3354/cr01307.

2. **Wang B**, Liu DL, Asseng S, Macadam I, Yu Q (2015b) Impact of climate change on wheat flowering time in eastern Australia. Agricultural and Forest Meteorology 209:11-21, http://dx.doi.org/10.1016/j.agrformet.2015.04.028.

3. **Wang B**, Liu DL, Macadam I, Alexander LV, Abramowitzc G, Yu Q (2016) Multi-model ensemble projections of future extreme temperature change using a statistical downscaling method in south eastern Australia. Climatic Change, 1-14, http://dx.doi.org/10.1007/s10584-016-1726-x.

4. **Wang B**, Liu DL, Asseng S, Macadam I, Yu Q (2017) Modelling wheat yield change under CO_2 increase, heat and water stress in relation to plant available water capacity in eastern Australia. (submitted).

5. **Wang B**, Liu DL, Asseng S, Macadam I, Yu Q, Yang X (2017) Spatiotemporal changes of wheat phenology, yield and water use efficiency under the CMIP5 multimodel ensemble projections in eastern Australia. Climate Research, https://doi.org/10.3354/cr01458.

Conference Proceedings

Wang B, Liu DL, Macadam I, Alexander LV, Abramowitz G, Yu Q Multi-model ensemble projections of future extreme temperature change using a statistical downscaling method in eastern Australia. MODSIM2015, Gold Coast; 11/2015.

Contents

Summary

Wheat is the most important crop in Australia in terms of the gross value of production. However, in Australia wheat yield is extremely variable from year to year among major production regions, such as New South Wales (NSW), with its agricultural system being significantly affected by water stress and ongoing climate change. To accurately quantify crop yield, and estimate greenhouse gas emissions (GHG) at specific sites and regional scales, it is essential to link spatial information of agro-resources and crop simulation model to assess crop growth in response to agricultural management and environmental variation. The outcomes of this project will enhance the capability of farmers and policy makers to adapt and manage farm outcomes in the face of climate change/variability.

For this study, I extracted the historical daily climate data (1900-2010), known as SILO patched point dataset (PPD, http://www.longpaddock.qld.gov.au/silo/ppd/index.php), for maximum and minimum temperature, rainfall, and solar radiation at 894 weather stations evenly distributed across the NSW wheat belt. Wheat yields at shire level during 1922-2000 (data in some shires were not available in some years) across the NSW wheat belt were obtained from Fitzsimmons (2001). Statistical methods were used to quantify the relationship between reported shire wheat yields and climate factors during the wheat-growing season across the NSW wheat belt in eastern Australia from 1922 to 2000. I found that wheat yields were positively correlated to rainfall and minimum temperature while negatively correlated to maximum temperature at a significant level ($p<0.05$). Growing season rainfall is usually the main direct climatic driver affecting wheat yields variation in this semi-arid area, but the indirect effects of temperature and solar radiation are also important. A detailed understanding of how historical climate variation has impacted on wheat yield can provide useful insights for the development of sustainable agricultural systems in the face of future climate change.

I used the statistical downscaling and bias-correction method developed by Liu and Zuo (2012) to generate realistic daily site-specific climate data from monthly GCM output on a coarse-resolution grid. Briefly, monthly GCM output data (solar radiation, rainfall, daily maximum and minimum temperature) from each of the selected GCMs were downscaled to the 894 observation sites using an inverse distance-weighted interpolation method. Biases were then corrected using a transfer function derived from interpolated GCM data and observed data for the sites. Daily climate data for each of 894 sites under two RCPs for 1900-2100 were generated by a modified stochastic weather generator (WGEN) with parameters derived from the bias-corrected monthly data. The results show that wheat growing season rainfall is projected to decrease under different future scenarios across the NSW

wheat belt. Future climate projected an averaged warming of 2.1 ˚C for RCP4.5 and 3.8 ˚C for RCP8.5 across this region in 2061-2100 compared to the baseline period 1961-2000.

A crop simulation model (APSIM) driven by statistical downscaling data was used to simulate wheat productivity and water use efficiency under the CMIP5 multimodel ensemble projections across the NSW wheat belt. Despite an acceleration of crop development and shortening of growth duration together with declining growing season rainfall, GCMs projected that multi-model median yields could increase by 0.4% (4704 kg/ha) for RCP4.5 and 7.3% (5027 kg/ha) for RCP8.5 by 2061-2100. These results show that drier area would benefit more from elevated CO_2 than wetter area in the NSW wheat belt. Without the increase in CO_2 concentration simulated wheat yield decrease rapidly under RCP4.5 by 2061-2100 and much more so under RCP8.5 compared to the present. The simulated evapotranspiration (ET) decreased by 11.9% (282 mm) for RCP4.5 and 18.8% (260 mm) for RCP8.5 over the whole wheat belt. Increasing yields combined with decreasing ET resulted in simulated water use efficiency increasing by 11.4% (15.4 kg ha^{-1} mm^{-1}) for RCP4.5 and 29.3% (17.8 kg ha^{-1} mm^{-1}) for RCP8.5. Wheat production in water-limited, low yielding environments appears to be less negative impacted or in some cases even positively affected under future climate change and elevated CO_2, compared to other growing environments in the world.

Agro-ecosystems have high spatial heterogeneity and temporal variation of productivity, arising from the spatial and temporal variability of climate, soil texture/water, and management practices. Furthermore, the projected yield increase in the future could be overestimated because the crop model generally does not sufficiently account for yield reduction due to diseases, pests and weeds. I did not explicitly consider certain aspects such as efficient management practices, breeding new crop cultivars, which will obviously have a significant impact on wheat yield in the future. Therefore, these current simulated results would provide a baseline for future adaptive strategies such as incorporating new traits into new cultivars in new management systems not currently available.