Future climate change increases canola productivity and water use efficiency in the rainfed cropping systems of Southern Australia

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Abstract

Canola is one of the major crops planted across Australia's wheatbelt. Water shortages and uneven distribution of water resources are the key limitations for Australia canola productivity. This is expected to be aggravated in the warmer and dryer future climates with higher rainfall variability, leading to a threat to Australia canola industry. However, the increase of atmospheric CO_2 concentration has the potential to increase crop yield and water use efficiency (WUE). Therefore, there is a need to conduct a comprehensive assessment by combining the impacts of the changes in future climate and atmospheric CO_2 concentrations on canola yield and WUE for providing a fundamental insight for future Australia canola industry. In this study, we tested APSIM-Canola module against the experimental data, collected in 2013-2014 and 2016 in Wagga Wagga. The tested model was then used to predict canola yield and WUE in both historical and future climatic conditions. The simulation results showed ASPIM-Canola module captured the variations of canola yield across fertilizer applications and climatic variations. Comparisons between historical and projected future climates, there is an overall tendency for a decline of cumulative rainfall in canola growing seasons and an increase of air temperature. As a consequence, the increasing temperature and decreasing rainfall leads to a clear decline of canola yield and WUE, however, this negative impact could be offset by the positive impact of increasing atmospheric CO_2 concentration on canola yield and WUE. This scenario analysis provides a foundation towards understanding changes in Australia's canola cropping systems.

Key Words: Canola, water use efficiency, climate change

Introduction

Canola (*Brassica napus* L.) increases to be a major crop in Australia Grain Industry since 1990s'. The planting area of canola increases from 150,000 ha in 1991 to 2.7 million ha in 2014 (FAO STAT, 2016). Canola has been expanding across the traditional Australia wheatbelt and is mainly grown in the high rainfall zone (annual rainfall of 450–750 mm) of southern Australia. Despite this, the average canola yield in Australia is relatively low (1.2 t ha^{-1}) comparing to the rest of the world (Zhang and Flottmann, 2016).

The climate of Australia is changing with temperature increasing by approximately 0.8°C since 1960 (Cleugh *et al.*, 2011). The recent report from CSIRO and Bureau of Meteorology (2015) indicated that annual mean temperature will increase about 1.4 - 2.7°C and 2.8 - 5.1°C in 2080 - 2099 for RCP4.5 and RCP8.5 future scenarios, respectively, with a possible decrease in spring and winter rainfall. The combined effects of increasing temperatures and changing seasonal rainfall in amounts and temporal distributions would further exacerbate the Australian grain industry. For example, research had reported that reductions in growing season rainfall have a substantial contribution to the decrease of wheat productivity (Ludwig *et al.*, 2009). However, increasing atmospheric CO_2 concentrations could enhance photosynthetic production and WUE in crops, especially if nutrients are not limiting crop growth (e. g. Faralli *et al.*, 2017). Some previous crop modelling studies show that negative effects of increased temperatures on wheat yield are partially offset by the positive effects of elevated CO_2 concentrations (e. g. Ludwig *et al.*, 2009). Comprehensive assessment of the impacts of climate change on Australia's canola industry requires the consideration of both climatic effects and the effects of CO_2 increases, and the interactions between them.

In this study, 3-year data from field experiments on phenology, biomass and yield of canola in Wagga Wagga were used to calibrate and validate the performance of the Agricultural Production Systems sIMulator (APSIM; Holzworth *et al.*, 2014). To conduct the compressive assessment, we generate the response of the transpiration efficiency to the atmospheric CO_2 concentrations by reviewing the related FACE and chamber experiments and incorporated into APSIM. The tested APSIM with the newly generated CO_2 response function was then used to investigate the impact of future climate change on water use and yield of canola in the rainfed cropping systems in the semiarid areas of Southern Australia.

Methods

Site description

Field experiments were conducted in 2013-2014 and 2016 at Wagga Wagga, NSW (35°01'45" S, 147°20'36" E; 210 m a.s.l) in a Red Kandosol (Isbell, 1996). The soil was slightly acidic with a pH of 5.1 in $CaCl_2$ and soil organic carbon content was 1.64% at the soil surface (0-0.1 m). Details of the soil properties are given in

Li *et al.* (2016) and Xing *et al.* (2017). Canola (*Brassica napus* cv. Hyola 575) was sowed in April-May each year with 25 kg N ha^{-1} of N fertilizer at sowing and 50 kg N ha^{-1} top-dressed in the branching stage. Wagga Wagga has a semi-arid continental climate with an annual average minimum/maximum temperature of 9.1/22.4^{o}C and a mean annual rainfall of 558 mm.

Brief description of APSIM-Canola module

The APSIM-Canola module is the modified versions of the generic crop model template in the APSIM framework. The capability of APSIM-Canola module to simulate phenological stages, biomass dynamics, and grain yield of canola in response to agricultural management and climatic conditions has been widely demonstrated against field measurements in the previous studies (e.g. Farre *et al.*, 2002; Robertson and Lilley, 2016). In this study, the data collected in 2013 were used to calibrate APSIM-Canola. The calibrated model was then validated using the experimental data collected in 2014 and 2016.

To investigate the impacts of future climate change on canola production without nutrient limitation condition, we generated the response of canola to the increase of atmospheric CO_2 concentration by reviewing the current studies in this area (Franzaring *et al.*, 2012; Faralli *et al.*, 2017). The newly generated function replaced the APSIM default response curve for wheat (Fig. 1).

Daily weather variables, including maximum and minimum air temperature, solar radiation, and rainfall from 1961 to 2016 for Wagga Wagga were obtained from the SILO Patched Point Dataset. RCP4.5 and RCP8.5 simulations of the 28 GCMs were downscaled using the statistical downscaling and bias-correction method of Liu and Zuo (2012).

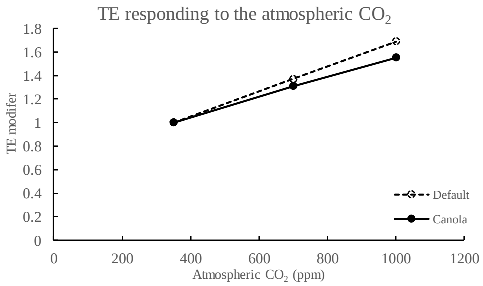

Figure 1. Relationship between factor of CO_2 for transpiration efficiency (TE) and CO_2 concentration

Results and discussion

Projected future climate change

Most of the GCMs projected rainfall in canola growing season decreases (Fig. 2a). Between 1961–2000 and 2071–2100, the ensemble-mean growing season rainfall change decreases in 7.0% for RCP4.5 and 5.3% for RCP8.5, which is close to the regional rainfall changes estimated by Wang *et al.* (2018). All GCMs agreed on a future temperature rise and, RCP8.5 had higher temperature increases than RCP4.5 (Fig.2b), which is consistent with greater greenhouse forcing of the climate system.

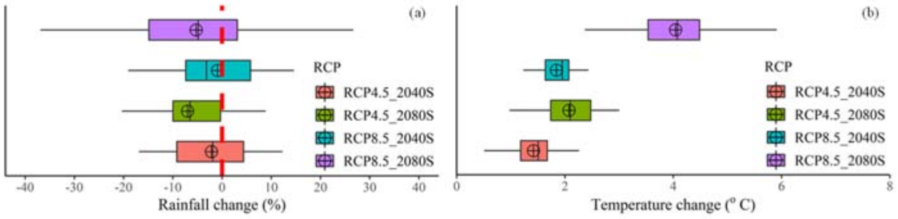

Figure. 1. Projected changes in canola growing season (April-November) (a) rainfall and (b) mean temperature from 28 CMIP5 GCMs in Wagga Wagga for RCP4.5 and RCP8.5 by 2040s (2031–2060) and 2080s (2071–2100) compared to 1961–2000, respectively. Box boundaries indicate the 25th and 75th percentiles across GCMs, whiskers below and above the box indicate the 10th and 90th percentiles. The black lines and crosshairs within each box indicate the multi-model median and mean, respectively.

APSIM Performance for simulating the growth of canola

The above-ground biomass of canola, measured in flowering and maturity stages, were simulated by APSIM-Canola with a root mean square error (RMSE) of 0.31 t ha^{-1}, (Fig. 2). APSIM-Canola could explain 79% of the variations in grain-yield of canola across N fertilizer treatments in the multiple years. The agreement indicates that APSIM was able to capture the changes of above-ground biomass and yield of canola in response to changes climatic variability and N fertilizer treatments in the study region.

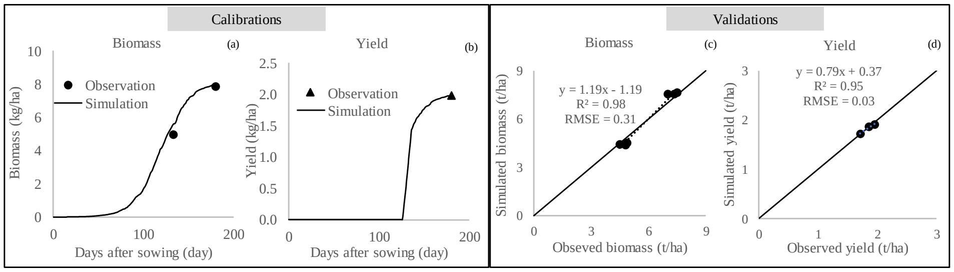

Figure. 2. Comparisons of observed and simulated above-ground biomass and yield of canola in rainfed cropping systems in Wagga Wagga, NSW, Australia.

Projected changes of canola yield and water use efficiency

Figure 3 shows the changes (%) in canola yield and WUE in the projected future climate scenarios comparing to 1961-2000. Without considering the CO_2 impacts, yields decrease 5.2% and 6.6% by the 2040s for RCP4.5 and RCP8.5, respectively, and the greater decrease occurs by the 2080s; correspondingly, WUE decreases 1.0 % and 1.1% by the 2040s under RCP4.5 and RCP8.5, and decreases 3.9% and 4.2% by 2080s, respectively (Fig. 3). However, canola yield and its WUE have a clear increase by considering the impacts of CO_2 concentrations on canola growth and water use (Fig.3). This indicates that the positive impact of the increasing atmospheric CO_2 concentration could trade off the negative impacts of increasing air temperature and decline of rainfall. Contrarily, Anwar *et al.* (2015) reported future climate will potentially decrease canola yield in their simulations. This difference is mainly because the different response curves in depicting canola water use in response to increasing CO_2 concentration were adopted in simulations. The response curve, used in this study, is from FACE and chamber experiments conducted in canola crops, whereas Anwar *et al.* (2015) used the default response curve, which is for wheat. As a comparison, Mishra *et al.* (1999) reported that the water use significantly improved by elevated CO_2 coupled with higher stomatal resistance, while Faralli *et al.* (2017) concluded from their chamber experiment that elevated CO_2 did increase water use efficiency in leaf level, but may not significantly counteract the negative effect of increasing drought intensity on canola performance. This reveals that we need further investigate and quantify the effect of elevated CO_2 concentration on canola growth. More importantly, canola variety has a clear response to elevated CO_2 concentration (Mosbæk Johannessen *et al.*, 2002). Therefore, along with the research on further quantification of the response of canola to increasing CO_2, the variety response should be emphasized, as this will exploit the future canola breeding and allow Australian canola industry to better adapt to the future climate.

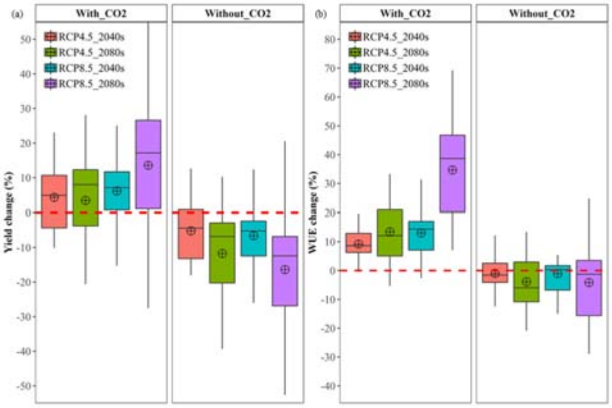

Figure. 3. Projected changes of canola yield and WUE in a rainfed cropping system. Changes are for RCP4.5 and RCP8.5 for 2040s (2031–2050) and 2080s (2071–2100) compared to 1961–2000. Box boundaries indicate the 25th and 75th percentiles across GCMs, whiskers below and above the box indicate the 10th and 90th percentiles. The black lines and black crosshairs within each box indicate the multi-model median and mean, respectively.

Conclusion

The increasing temperature and decreasing rainfall leads to a clear decline of canola yield and WUE. However, this negative impact could be offset by the positive impacts of increasing atmospheric CO_2 concentration on canola yield and WUE.

Acknowledgements

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