Simulation of wheat grain yield under elevated CO_2 conditions in the Victorian Wimmera

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Abstract

Various contemporary crop simulation models of wheat include response to elevated atmospheric CO_2 through amendment to the fixation of carbon, by raising radiation use efficiency (RUE) and transpiration efficiency (TE) as well as reducing stomatal conductance and transpiration. Whilst the exact mechanisms in various models differ slightly, they are all very similar. The models CROPSYST and DSSAT have very similar CO_2 mechanisms whilst APSIM has an additional temperature response included, but we expect APSIM not to give any significant different response in southern Australia. We applied APSIM-Wheat and a modified version of the OLEARY AND CONNOR wheat model to the first year of the Horsham Free Air Carbon Dioxide Enrichment (FACE) experimental data. The modified OLEARY AND CONNOR wheat model was altered to account for the effects of elevated CO_2 by the methods used in CROPSYST.

Both APSIM-Wheat and OLEARY AND CONNOR wheat models simulated reasonably well wheat yield under ambient (CO_2 = 350 ppm) and elevated (550 ppm) CO_2 conditions. The Root Mean Square Errors were similar to those already published for these models (APSIM RMSE = 0.79 t/ha and OLEARY AND CONNOR RMSE = 0.36 t/ha). Whilst an overall satisfactory performance was achieved, small differences appear. Under elevated CO_2 and at the first time of sowing the OLEARY AND CONNOR model simulated a decrease in yield in the presence of high soil nitrogen whereas APSIM-Wheat decreased yield without added nitrogen fertiliser. All the other sowing time x irrigation effects were simulated quite well by the APSIM-Wheat and OLEARY AND CONNOR models, and notably the CO_2 response of the very late second time of sowing (22 August 2007) with irrigation and applied N was well captured. The differences in N response under elevated CO_2 in the first time of sowing are intriguing and warrant further investigation.

Key Words

FACE, climate change, radiation use efficiency, transpiration efficiency

Introduction

There are a numerous crop models available to study the known responses of crops to climate change. Some models, however, have not considered the effects of elevated CO_2. Many of the early attempts to study the effects of potential climate change employed models that were only responsive to elevated temperature and accelerated phenological development for our current cultivars was a common conclusion. Once the Global Climate Models began predicting the likely changes in rainfall, crop models were employed that responded to both temperature and water supply (e.g. Howden and O'Leary 1997; Howden et al; 2002; Power et al. 2004).

Now with the Inter-government Panel on Climate Change (IPCC 2001) providing future exponential projections of both temperature and atmospheric CO_2 rises, models now need the capacity to respond to elevated CO_2. Cropping systems models that have recently been employed in such analyses include the APSIM suite of models (Keating et al. 2003), the DSSAT suite of models (Hoogenboom et al. 1995; Tubiello et al. 1999), and CROPSYST suite of models (Tubiello et al. 2000; St?ckle and Nelson 2001). All these models have employed very similar CO_2 response functions via radiation use efficiency and transpiration efficiency, but APSIM has used temperature dependant CO_2 functions (Ludwig and Asseng 2006) (Figure 1).

The working research hypothesis for the Grains FACE experiment at Horsham (Norton et al. 2008) is: Increasing atmospheric CO_2 will increase crop water use efficiency and so increase overall productivity and partially alleviate the negative effects of low water availability, high temperatures and a high demand for nitrogen. The aim of this study was to test the APSIM-Wheat model and the OLEARY AND CONNOR wheat model (O'Leary and Connor 1996a;b) against the first year of the FACE experimental data. We propose future validation and application of the CROPSYST and DSSAT models with our collaborators.

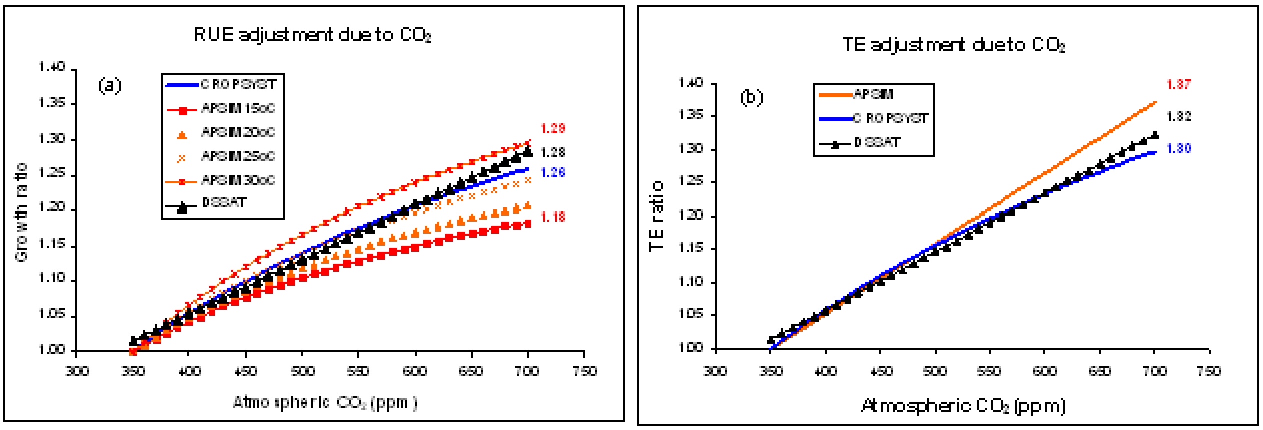

Figure 1. (a) Adjustment factors applied to radiation use efficiency (RUE) and (b) transpiration efficiency (TE) for the APSIM, CROPSYST and DSSAT models. The factors for atmospheric CO_2 of 700 ppm is noted showing very similar results. For this comparison, an aerodynamic resistance above the crop canopy of 300 s m^{-1} and canopy resistance of 36 s m^{-1} at 350 PPM CO_2 were assumed.

Methods

The OLEARY AND CONNOR model was modified to account for elevated atmospheric CO_2 by the method used in the CROPSYST model (Figure 1). This involved amending both the radiation use efficiency and transpiration efficiency.

The APSIM-Wheat (V5.3) and OLEARY AND CONNOR wheat (V6) models were validated against the first year (2007) of the FACE experimental data at Horsham. Initial soil water, bulk density, organic carbon, pH and mineral nitrogen were set in the models as measured in the FACE experiment in June 2007. The experiment comprised two atmospheric CO_2 levels (ambient 350 and elevated 550 ppm), two times of sowing (18 June and 22 August, 2007), two rates of applied nitrogen (0 and 138 kg N/ha) under two irrigation regimes (48 and 106 mm additional water applied). A rainfed treatment with zero water applied was originally proposed but local dry conditions prompted an early application of the 48 mm water to both regimes. Daily patch-point weather data was obtained from the nearby Bureau of Meteorology station (#79023 Polkemmet 36.66?S, 142.07?E) as the data from the experimental site was not available at the time of this analysis (http://www.bom.gov.au).

Results and Discussion

Both models simulated reasonably well wheat yield under ambient (CO_2 = 350 ppm) and elevated (CO_2 = 550 ppm) atmospheric conditions (Figure 2a). The Root Mean Square Errors were similar to those already published for these models (APSIM RMSE = 0.79 t/ha and OLEARY AND CONNOR RMSE = 0.36 t/ha). Whilst an overall satisfactory performance was achieved small differences appear. Figure 2b shows the comparison of the two models in simulating the response to elevated CO_2. Here, both models did not always follow the observed response. Under elevated CO_2 and the first time of sowing the OLEARY AND CONNOR model simulated a decrease in yield in the presence of high soil nitrogen whereas APSIM-Wheat decreased yield in the absence of nitrogen fertiliser (Figure 2b). All the other sowing time x irrigation effects were simulated quite well by both models, and notably the CO_2 response of the 22 August (2007) sowing with irrigation and applied N was well captured. The differences in N response under elevated CO_2 in the early sown crops are intriguing and warrant further investigation. We will first examine the measured variation among those treatments and use other models to compare response.

One problem we have in modelling experimental observations with these kind of crop models (e.g. APSIM, CROPSYST, DSSAT or OLEARY AND CONNOR) is that they typically have unexplained errors that are about three times what we can achieve in a designed field experiment (RMSE of ~0.75 t/ha compared to ~0.25 t/ha, respectively). We therefore need to be careful to not quickly dismiss a model for this reason because the models are still useful in extrapolating field response beyond the experimental site in space and time. This is particularly important when climate x soil type interactions are important in analysis of climate change across diverse landscapes.

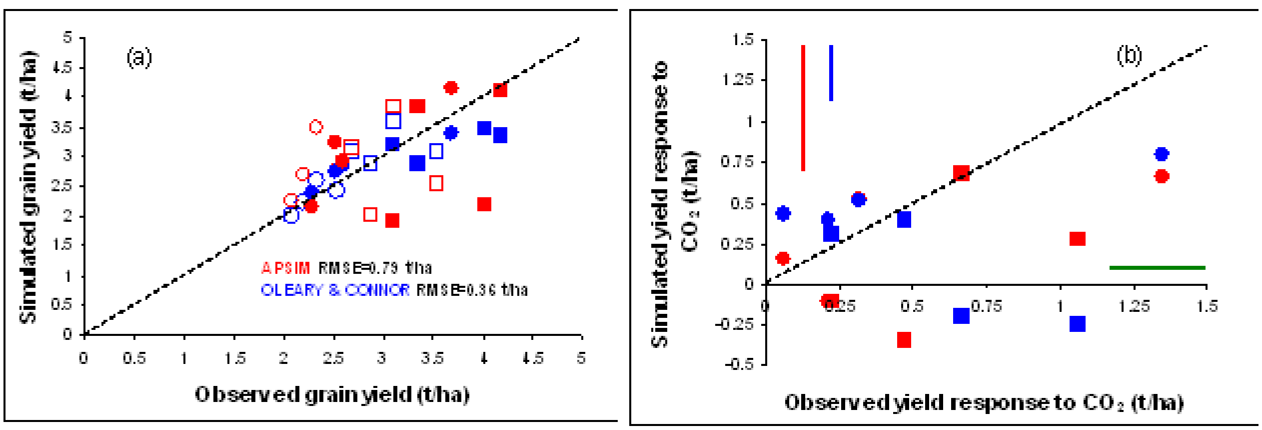

Figure 2. (a) Comparison of simulated and observed grain yield for APSIM-Wheat (red) and OLEARY AND CONNOR wheat (blue) models. The first time of sowing (18 June 2007) is represented by squares and the second time of sowing (22 August 2007) is represented by circles. Closed symbols represent elevated CO_2. (b) The comparison of the simulated and observed response to elevated CO_2 for each model. The vertical bars indicate the RMSE for each model and the horizontal bar indicates the experimental data $LSD_{0.05}$.

FACE Modelling Strategy

Because of the broader need to answer questions on the likely impacts of climate change on the agricultural productivity in regional Victoria where climate change projections differ between regions, the modelling component of the FACE experiments are relevant well beyond the FACE experimental sites. The models that are tested and revised from the experimental sites can then be used to inform policy in the regional context. This is the subject of the Victorian Climate Change Adaptation Program (VCCAP) for which results from this FACE project informs VCCAP through the validation and amendment of appropriate crop models that reflect realistic response to climate change. Consequently, our modelling has a broader objective to be applicable to regional scale questions of grain production. Our strategy comprises four components:

(1) Validation of the contemporary wheat crop models (e.g. APSIM, CROPSYST, etc…) that include submodels of CO_2, against the FACE experimental data and compare this against international FACE data.

(2) Consideration of new component submodels, including crop diseases, for better predicting the impacts of elevated CO_2. This is expected to involve new controlled environment and field experiments not at the FACE sites.

(3) Application of the above models with or without any new amendments from (1 and 2) to examine the effects of climate change (IPCC projected changes in temperature, rainfall, CO_2 and solar radiation) in Victoria. This will include an analysis of the effects of crop and agronomic adaptation that may occur during climate change.

(4) Collaboration with other national and international scientists in each of the above three components. In this, the objective is to test the current and revised models and to examine our hypothesis and questions in other localities outside Victoria. Data sets of the experimental data will be available to collaborating scientists during the course of the project who have agreed scientific and publication objectives.

Conclusions

Both OLEARY AND CONNOR and APSIM wheat models simulated reasonably well wheat yield response to elevated CO_2, but there were some contrary behaviour in each model with respect to response to elevated CO_2 under differing nitrogen regimes in the first, and more normal time of sowing (mid June).

Acknowledgements

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References

Hoogenboom G, Tsuji GY, Pickering NB, Curry RB, Jones JW, Singh U and Godwin D (1995). Chapter 3. Decision Support System to Study Climate Change impacts on crop production. In Climate Change and Agriculture: Analysis of Potential International Impacts. American Society of Agronomy Special Publication no 59. pp 51-75.

Howden SM and O'Leary GJ (1997). Evaluating options to reduce greenhouse gas emissions from an Australian temperate wheat cropping system. Environmental Modelling and Software 12, 169-176.

Howden M, Ash A, Barlow S, Booth T, Charles S, Crimp S, Gifford R, Hennessy K, Jones R, Kirschbaum M, McKeon G, Meinke H, Park S, Sutherst B, Webb L and Whetton P (2002). An overview of the adaptive capacity of the Australian agricultural sector to climate change – options, costs and benefits. Major Report commissioned by the Australian Greenhouse Office, 157 pp.

IPCC (2001). Summary for Policymakers, In: Houghton JT, Ding Y, Griggs DJ, Noguer M, Van Der Linden PJ, and Xioaosu D, (Eds), Climate Change 2001: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 944 pp.

Keating BA, Carberry PS, Hammer GL, Probert ME, Robertson MJ, Holzworth D, Huth NI, Hargreaves JNG, Meinke H, Hochman Z, McLean G, Verburg K, Snow V, Dimes JP, Silburn DM, Wang E, Brown S, Bristow KL, Asseng S, Chapman S, McCown RL, Freebairn DM and Smith CJ (2003). An overview of APSIM, a model designed for farming systems simulation. Europ. J. Agron. 18, 267-288.

Ludwig F and Asseng S (2006). Climate change impacts on wheat production in a Mediterranean environment in Western Australia. Agric. Systems, 90, 159-179.

Norton R, Mollah M, Fitzgerald G and McNeil D (2008). The Australian Grains Free Air Carbon dioxide Enrichment 9AGFACE) experiment – specifications and scope. Proceedings of the 14th Australian Agronomy Conference, Sept. 2008, Adelaide, South Australia. Ed M J Unkovich. ? Australian Society of Agronomy.

O'Leary GJ and Connor DJ (1996a). A simulation model of the wheat crop in response to water and nitrogen supply: 1. Model construction. Agricultural Systems 52, 1-29.

O'Leary GJ and Connor DJ (1996b). A simulation model of the wheat crop in response to water and nitrogen supply: 2. Model validation. Agricultural Systems 52, 31-55.

Power B, Meinke H, DeVoil P, Lennox S and Hayman P (2004). Effects of a changing climate on wheat cropping systems in northern New South Wales. Proceedings of the 4th International Crop Science Congress, Brisbane, Australia, 26 September - 1 October 2004.

St?ckle CO and Nelson R (2001). Cropping System Simulation Model User's Manual. Biological Systems Engineering Department, Washington State University. (Available at http://www.bsyse.wsu.edu/cropsyst)

Tubiello FN, Rosenzweig C, Kimball BA, Pinter Jr PJ, Wall GW, Hunsaker DJ, Lamorte RL, Garcia RL (1999). Testing CERES-Wheat with FACE data: CO_2 and water interactions. Agron. J. 91, 1856–1865.

Tubiello F, Donatelli M, Rozenweig C, St?ckle CO (2000). Effects of climate change and elevated CO_2 on cropping systems: model predictions at two Italian locations. Eur. J. Agron., 13, 179-189.