Future elevated carbon dioxide levels largely overcome the impact of hotter and drier conditions on wheat growth in the Victorian Wimmera

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Abstract

Under future climatic conditions, will CO_2 fertilisation, lower growing season rainfall and high temperature increase the incidence of hay-off in rain-fed wheat crops? Hay-off is caused by a combination of early rapid growth, usually due to high nitrogen supply, under moderate water supply conditions, which deplete the stem soluble carbohydrate reserves, and limited water supply during grain fill, thus limiting translocation to grain. As a result hay-off produces crops with pinched kernels and low harvest indices. To test impact of future climate on wheat growth at Horsham, Victoria, we used crop simulation modelling. We validated a wheat simulation against experimental data from the Horsham Free Air Carbon-dioxide Enrichment (FACE) experiment where wheat (*cv*. Yipti) was sown under factorial combinations of two times of sowing (TOS) (optimal and late), two water regimes (rain-fed and supplement irrigation) and two nitrogen fertiliser levels at sowing (0 and 50 kg N/ha) for both ambient (386 ppm) and elevated (550 ppm) CO_2 conditions. For optimal sowing time (TOS1 4 Jun 2008) and pooled N and water treatments, elevated CO_2 produced on average 35% higher yield (3.6 v 4.8 t/ha). Irrespective of N and water treatment, wheat biomass accumulation did not stall during the growing season and HI of wheat was comparable (ambient CO_2: 0.32 v elevated CO_2: 0.33). In contrast, wheat crops that were sown late (6 Aug 2008) showed severe yield penalty compared with TOS1 crops (1.9 v 4.2 t/ha). Additionally, elevated CO_2 produced crops with low HI compared with wheat that was grown under ambient CO_2 (0.29 v 0.33). Simulations indicate that despite the hotter and drier climatic conditions anticipated for 2050 within the Victorian Wimmera, it appears that the CO_2 fertilisation effect on optimally sown wheat at Horsham, under elevated CO_2 will compensate the increasing water deficits expected with no evidence of additional hay-off. In contrast, for later sown wheat crops (5-Aug) climate in 2050 is likely to reduce crop harvest indices by about 12%, linked with increasing incidence of hay-off.

Key words

Simulation models, hay-off, FACE, climate change

Introduction

Within the cropping regions of south-eastern Australia it is anticipated that future climatic conditions of reduced growing season rainfall and increased temperature will have variable effect on crop growth depending on agro-ecological region in Victoria (O'Leary et al. 2010). The interactive effect of CO_2 fertilisation across rainfall/temperature gradients needs to be resolved to help better refine management options to growers. Despite the potential benefits of elevated CO_2 such as increased WUE of plants (Kimball 2003), these benefits may be outweighed by greater frequency and severity of drought (Xu et al. 2007). These conditions may increase the disparity between luxurious pre-anthesis crop growth and poor grain-fill conditions. Historically, crops that have early vigour and large biomass, induced by nitrogen application, have low water soluble carbohydrate (WSC) reserves and are at risk of hay-off particularly if post-anthesis rainfall is low (van Herwaarden et al. 1998). Similar to nitrogen in promoting early crop growth, will CO_2 fertilization due to increasing greenhouse gases increase the risks of crop hay-off, particularly under the expected drier Spring conditions which coincide with crop grain-fill. This paper reports on simulated wheat growth under current and anticipated 2050 climatic conditions and overlays the influences of elevated CO_2 and hotter drier climatic conditions expected by 2050. Current ambient CO_2 concentration (386 ppm) is compared with elevated CO_2 concentration (550 ppm) in accordance with A1Fi scenario. Rainfall and temperature data is projected for 2050 using method described by Weeks et al. (2010). Simulations were validated against data from a Free Air Carbon dioxide Enrichment (FACE) experiment located at Horsham, Victoria, Australia (Mollah et al. 2009). Finally, crop simulation modelling will be used to estimate the net effect of expected future CO_2, temperature and rainfall conditions on crop growth and hay-off in the Victorian Wimmera.

Methods

Crop simulation model, APSIM-Wheat (Version 7) (Keating et al. 2003) was used to examine the impact of elevated CO_2 and altered climatic conditions, according to the IPCC (2001; 2007) extreme climate change scenario, A1Fi for 2050 on wheat growth in the Victorian Wimmera and also assessed for evidence of increased hay-off under future climatic conditions. Model validations was based on 2008 results form the Free Air Carbon dioxide Enrichment (FACE) experiment located at Horsham, Victoria, Australia (Mollah et al. 2009). For setting daily climate sequencing, method B after Weeks et al. (2010) was applied to climate data from the Polkemmet (station: 079023) between 1935 and 2002. Briefly method B determines the impact of climate at a single point in time (ie 2050) based on the outputs from CSIRO's global atmosphere model (CCAM-Mark3). This method provides a run of weather data that has equivalent number of years and stochastic patterns as the historical data and avoids the confounding effects of natural variation across years. Within APSIM, wheat (*cv*. Yipti) was sown on 04-Jun and 05-Aug for TOS1 and TOS2 respectively at 215 plants/m^2. Starting soil mineral N (309 kgN/ha – TOS1 and 332 kgN/ha – TOS2) and soil water (103 mm – TOS1 and 124 mm – TOS2) was reset annually at sowing. Surface organic matter was set at 2000 kg/ha C:N ratio of 80.

Results and Discussion

Model performance

We tested the APSIM-Wheat model against observed 2008 data from the AGFACE experiment based in Horsham, Victoria. This provided the capacity to test model performance under elevated CO_2 (550 ppm to represent the year 2050 under the A1Fi scenario). The FACE experiment comprised two atmospheric CO_2 levels (ambient 386 and elevated 550 ppm), two times of sowing (4 June and 5 August, 2008), two rates of applied nitrogen (0 and 50 kg N/ha at mid tillering) under two water supply regimes (irrigation and rainfed). Daily weather data was obtained from the experimental site and supplemented with climate data from the Polkemmet weather station (079023). For 2008 data, results used for validation were means for CO_2 level, TOS and water regime combinations (pooled across nitrogen level due to no treatment response). Satisfactory agreement was obtained between observed and predicted wheat growth at anthesis (Fig 1*a*) and yield (Fig 1*b*). The model tended to under predict growth and yield under elevated CO_2 when the climate control parameter was set to 550 ppm CO_2 in APSIM. This disparity may be due to intra-ring variation in CO_2 concentration within the FACE experiment, where crops were exposed to higher levels of CO_2 than anticipated (Mollah et al. 2009). Overall root mean squared error for biomass at anthesis was 1122 kg/ha and yield was 578 kg/ha.

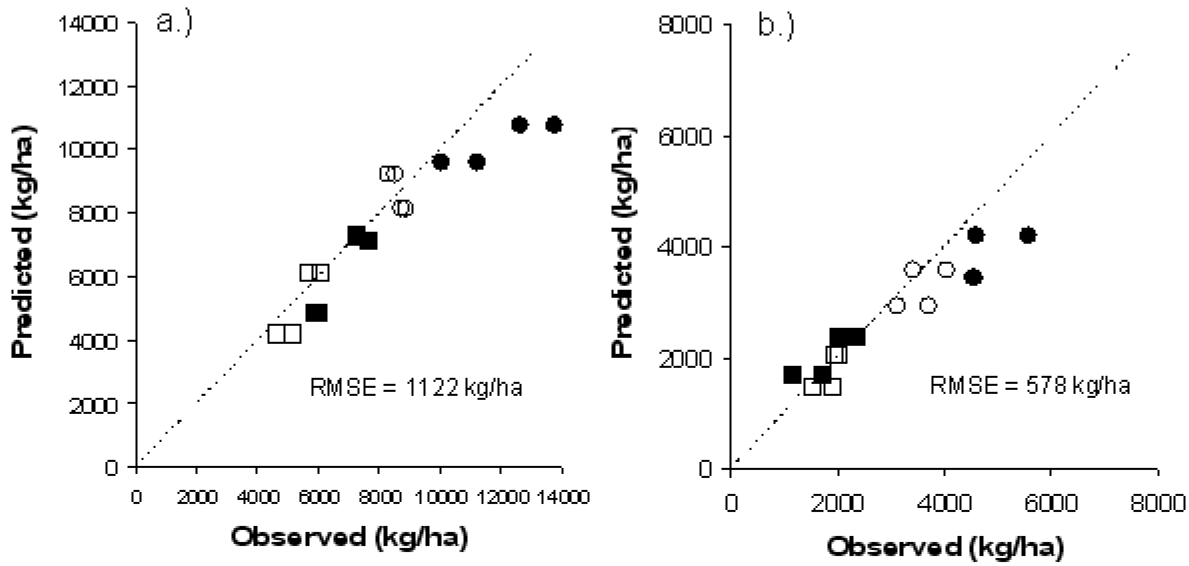

Figure 1. Comparison of simulated wheat biomass at anthesis (a) and grain yield (b) and observed data from the 2008 Australian AGFACE experiment, Horsham, Victoria. Ambient CO_2, TOS1 (○), elevated CO_2, TOS1 (●), ambient CO_2, TOS2 (□) and elevated CO_2, TOS2 (■) environments. Dashed line is the 1:1 relationship.

Model application

We used an additive approach of stacking the effects of elevated CO_2 and the IPCC (2001; 2007) extreme climate change scenario (A1Fi) on historic climate data and current ambient CO_2 levels using 68 years of data representing that scenario at 2050 for Horsham. This allowed the specific and additive effects of elevated CO_2 and temperature/rainfall on crop growth to be observed. Generally FACE experiments provide good estimation of the CO_2 fertilization effect, however, less adequately deals with the potential future effects of increasing temperature and decreasing rainfall. The current AGFACE experiment on rain-fed crops at Horsham attempted to test the effect of increased temperature by delaying the time of sowing (TOS2).

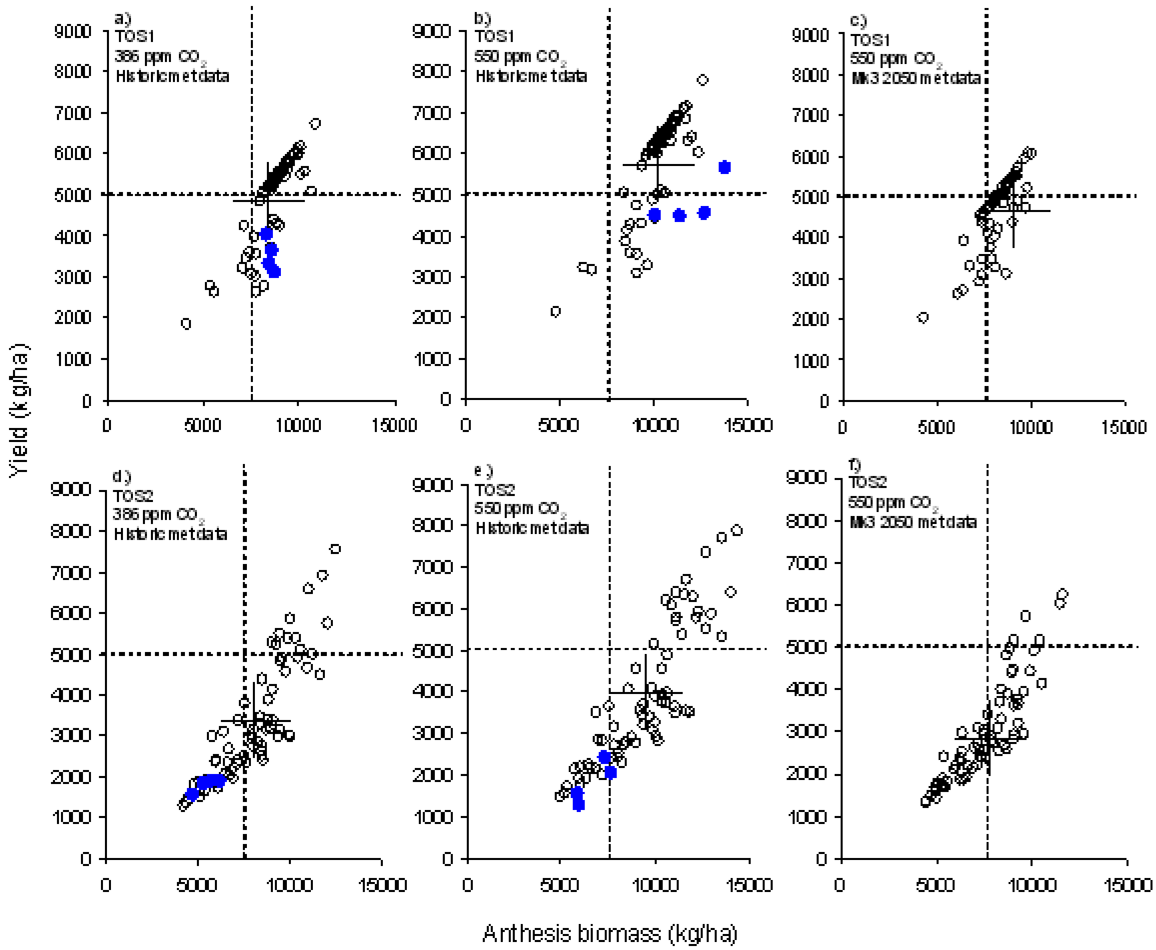

Figure 2. Main and combined effects of elevated CO_2 and IPCC climate scenario A1Fi for 2050 on wheat (*cv.* Yipti) growth (yield and biomass at anthesis (kg/ha). Two times of sowing (TOS) in line with the Horsham-AGFACE, are compared. TOS1; 04-Jun, TOS2; 05-Aug. Solid crosses show mean response of anthesis biomass and yield. Large solid (blue) circles are observed FACE data for 2008.

Simulated wheat growth under ambient CO_2 and historic weather patterns (1935 – 2002) averaged 8.7 t/ha of biomass to anthesis and yielded 5.0 t/ha (Fig 2 *a*). Simulated response to elevated CO_2 was on average a 16% increase in biomass at anthesis (10.2 t/ha) and yield (5.8 t/ha) (Fig 2 *b*), which is linked to a scaling factor operating within model. When the IPCC climate scenario A1Fi for 2050 was overlayed, (Fig 2 *c*) wheat growth to anthesis and yield was 6% less compared with crop grown under ambient CO_2 and historic weather patterns. Within the validation, the model was under-estimating growth of wheat under elevated CO_2 for optimal sowing time; therefore the model estimates may be conservative. Further validation will be conducted when additional years of the FACE experimental data are available to assess if this pattern of under predicting is consistent. Harvest indices of crops were maintained for TOS1 scenarios (Fig 3 *a*) and would suggest that crops sown at the current optimal time are unlikely to be exposed to increased risk of reduced harvest indices or hay-off. Overall the impact of wheat to increasingly drier and hotter climatic condition expected in 2050 is largely compensated by the fertilization effect of higher ambient CO_2 in Horsham, Victoria. For late sown wheat (05- Aug) growth to anthesis followed the same pattern to those crops that were optimally sown (TOS1) across the 3 scenarios (Fig 2 *d,e,f*). In contrast the yield reduction of TOS2 crops was proportionally greater than TOS1 crops when the climate scenario A1Fi for 2050 was applied. Correspondingly the HI of TOS2 crops under future climatic conditions were lower, particularly for crops which were historically above HI:0.35 (Fig 3 *b*). Delaying the time of sowing (TOS2), which provided a means to measure the impact of increased temperature on wheat yield, had greater impact than simulated temperature increases. This may be due to the confounding effect of day length for experimental TOS2 wheat crops. Irrespective the link between increasing temperature and the premature ripening of wheat and/or hay-off may be reduced by management such as using longer season wheat cultivars (O'Leary et al. 2010).

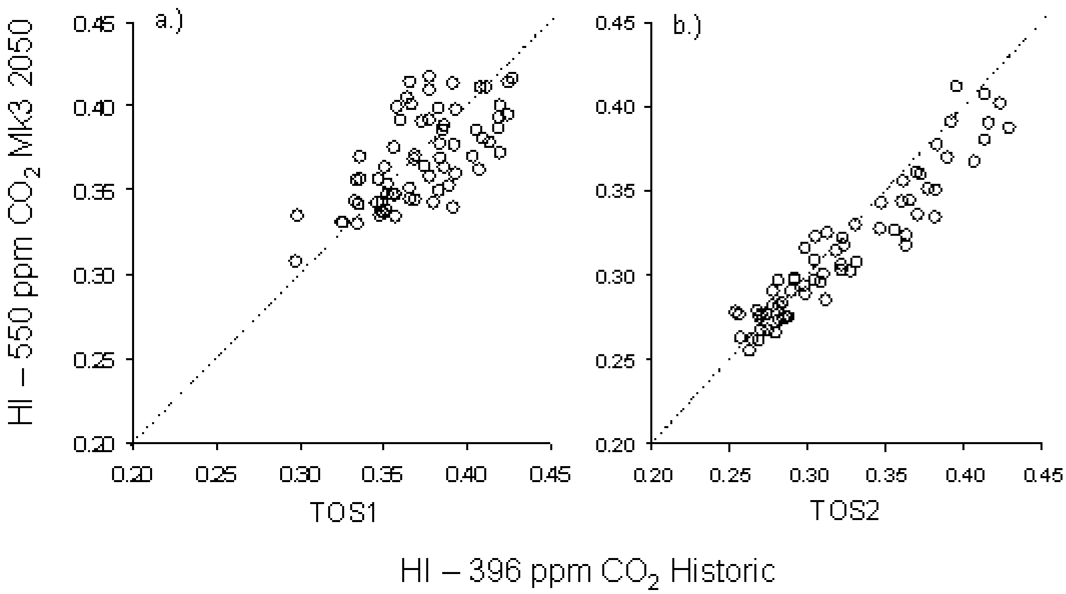

Figure 3. Comparison of harvest indices (HI) of simulated wheat growth between historic and 2050 climate scenarios for two times of sowing: (*a*)TOS1; 04-Jun, (*b*)TOS2; 05-Aug.

Conclusions

Despite the hotter and drier climatic conditions anticipated under the A1Fi climate change scenario for 2050 within the Victorian Wimmera, it appears that the CO_2 fertilisation effect on wheat crops at Horsham, under elevated CO_2 will compensate the increasing water deficits expected. For optimal sown wheat at 4 Jun, there was no evidence of decreasing harvest indices or increasing hay-off for wheat crops in 2050. However, for later sown wheat crops (5-Aug), climate in 2050 is likely to reduce crop harvest indices by about 12%, and increase likelihood of hay-off.

Acknowledgements

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References

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

IPCC (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Eds S Solomon, D Qin, M

Manning, Z Chen, M Marquis, K Averyt, M Tignor and H Miller. Cambridge University Press, UK. http://www.ipcc.ch/ipccreports/ar4-wg1.htm.

Keating BA, Carberry PS, Hammer GL, Probert ME and Robertson MJ (2003). An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18, 267–288. doi: 10.1016/S1161-0301(02)00108-9.

Kimball BA (2003). Response of plants to elevated atmospheric CO2. Indian Journal of Plant Physiology (Special Issue) 18-24.

Mollah MR, Norton RM and Huzzey J (2009). Australian Grains Free Air Carbon dioxide Enrichment (AGFACE) facility: design and performance. Crop & Pasture Science 60, 697-707.

O'Leary G, Christy B, Weeks A, Beverly C, Nuttall J, Riffkin P, Fitzgerald G and Norton R (2010). Modelling the growth and gain yield response of wheat crops under Free Air Carbon Dioxide Enrichment at Horsham and throughout Victoria, Australia. In Food Security form Sustainable Agriculture. Proceedings of the 15th ASA Conference, 15-19 November 2010, Lincoln, New Zealand. Australian Society of Agronomy (http://www.agronomy.org.au). (submitted).

Weeks A, Christy B and O'Leary G (2010). Generating daily future climate scenarios for Victoria. . In Food Security form Sustainable Agriculture. Proceedings of the 15th ASA Conference, 15-19 November 2010, Lincoln, New Zealand. Australian Society of Agronomy (submitted).

Xu Z, Zhou G and Wang Y (2007). Combine effects of elevated CO_2 and soil drought on carbon and nitrogen allocation of the desert shrub Caragana intermedia. Plant and Soil. 301, 87-97.