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VIEWPOINT

Comment on 'Improving ecophysiological simulation models to predict the impact of elevated CO_2 concentration on crop productivity' by X. Yin

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• *Scope* The recent publication by Yin (2013; *Annals of Botany* **112**: doi:10.1093/aob/mct016) referred to in the title above provides an excellent review of modelling approaches to predict the impact of elevated CO_2 on crop productivity, as well as on the controversy regarding whether yield responses observed in free-air CO_2 enrichment (FACE) experiments are indeed lower than those from chamber-based experiments. However, the wheat experiments in the example of fig. 1 in Yin's paper had a flaw as the control plots lacked blowers that were in the FACE plots, which warmed the FACE plots at night and hastened plant development. This Viewpoint seeks to highlight this fact, and to comment on the relative merits of FACE and enclosure experiments.

Key words: elevated CO_2, free-air CO_2 enrichment, FACE, climate change, global change, crop models, wheat.

The paper by Yin (2013) referred to in the title above provides an excellent review of modelling approaches to predict the impact of elevated CO_2 on crop productivity, as well as on the controversy regarding whether yield responses observed in free-air CO_2 enrichment (FACE) experiments are indeed lower than those from chamber-based experiments. I do not disagree with Yin's main thesis that nitrogen-based functional relationships are a robust way to simulate many growth processes.

However, as a leader of the Arizona FACE wheat project, I feel a responsibility to point out that our 1992–1993 and 1993–1994 FACE wheat experiments (Kimball *et al.*, 1995) in the example of fig. 1 by Yin (2013) had a flaw. Unfortunately, for those two cropping seasons, our control plots lacked blowers that were in the FACE plots, which warmed the FACE plots at night and hastened plant development (Pinter *et al.*, 2000). Therefore, our measured CO_2 response ratios in those two experiments must have been under-estimated, so for the models to be correct, we should expect higher response ratios from them than were measured for those two crops. The measured average wheat yield response ratio for those two seasons was 1·08 under ample water and nitrogen. In contrast, for the same ample water and nitrogen conditions, when we had proper controls (i.e. plots at ambient CO_2, but with blowers) in 1995–96 and 1996–97 our measured yield response ratios were 1·15 and 1·17, respectively (Kimball *et al.*, 2002), which are closer to what several of the models predicted (Yin, 2013, fig. 1) and higher than GECROS, Yin and van Laar's (2005) model.

The range in crop response to elevated CO_2 in FACE and, especially, in chamber-based experiments is rather large (e.g. Kimball, 2011, fig. 9), so it is unclear whether there is a distinct difference in crop responses between the two approaches. Moreover, differences in CO_2 response exist among varieties within a species. Recent reports of responses of hybrid rice to elevated CO_2 from the Chinese FACE project (Liu *et al.*, 2008; Yang *et al.*, 2009*a*, *b*) were about 1·32 or more than double the 1·12 increase observed for non-hybrid rice in prior FACE experiments. Such varietal differences also need to be addressed by the modellers, and researchers need to be searching for more high-CO_2-responsive varieties.

Even though there appears to be no consistent difference between FACE and enclosure experiments in their relative yield responses to elevated CO_2, and although fluctuating CO_2 concentrations in FACE experiments can reduce responses (e.g. Holtum and Winter, 2003; Bunce, 2012), the FACE approach still offers distinct advantages. The generally larger plot sizes enable more extensive and robust multidisciplinary experiments (e.g. Ainsworth *et al.*, 2008). Kimball *et al.* (1997) showed that plants often do not grow by the same *absolute* amounts inside open-top chambers as they do outside, even though *relative* responses to elevated CO_2 may be similar. Because a very important objective of much global change research is to obtain data suitable for validating crop growth models, therefore, a very important advantage of the FACE approach is that such data can be obtained under conditions with greater realism — for both *absolute* and *relative* responses. At the same time, however, enclosure experiments also can continue to contribute valuable data about physiological mechanisms because they enable greater control of individual environmental variables over much larger ranges than are possible in field experiments.

LITERATURE CITED

Ainsworth EA, Beier C, Calfapietra C, *et al*. 2008. Next generation of elevated $[CO_2]$ experiments with crops: a critical investment for feeding the world. *Plant, Cell and Environment* **31**: 1317–1324.

Bunce JA. 2012. Responses of cotton and wheat photosynthesis and growth to cyclic variation in carbon dioxide concentration. *Photosynthetica* **50**: 395–400.

Holtum JAM, Winter K. 2003. Photosynthetic CO_2 uptake in seedlings of two tropical tree species exposed to oscillating elevated concentrations of CO_2. *Planta* **218**: 152–158.

Kimball BA. 2011. Lessons from FACE: CO_2 effects and interactions with water, nitrogen, and temperature. In: Hillel D, Rosenzweig C. eds. *Handbook of climate change and agroecosystems: impacts, adaptation, and mitigation*. London: Imperial College Press, 87–107.

Kimball BA, Pinter PJ, Garcia RL, *et al*. 1995. Productivity and water use of wheat under free-air CO_2 enrichment. *Global Change Biology* **1**: 429–442.

Kimball BA, Pinter PJJr, Wall GW, *et al*. 1997. Comparisons of responses of vegetation to elevated carbon dioxide in free-air and open-top chamber facilities. In: Allen LH Jr, Kirkham MB, Olszyk DM, Whitman CE. eds. *Advances in carbon dioxide research*. Madison, WI: American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, 113–130.

Kimball BA, Kobayashi K, Bindi M. 2002. Responses of agricultural crops to free-air CO_2 enrichment. *Advances in Agronomy* **77**: 293–368.

Liu H, Yang L, Wang Y, *et al*. 2008. Yield formation of CO_2-enriched hybrid cultivar Shanyou 63 under fully open-air field conditions. *Field Crops Research* **108**: 93–100.

Pinter PJJr, Kimball BA, Wall GW, *et al*. 2000. Free-air CO_2 enrichment (FACE): blower effects on wheat canopy microclimate and plant development. *Agricultural and Forest Meteorology* **103**: 319–333.

Yang L, Liu H, Wang Y, *et al*. 2009*a*. Impact of elevated CO_2 concentration on inter-subspecific hybrid rice cultivar Liangyoupeijiu under fully open-air conditions. *Field Crops Research* **112**: 7–15.

Yang L, Liu H, Wang Y, *et al*. 2009*b*. Yield formation of CO_2-enriched inter-subspecific hybrid rice cultivar Liangyoupeijiu under fully open-air field condition in a warm sub-tropical climate. *Agriculture, Ecosystems and Environment* **129**: 193–200.

Yin X. 2013. Improving ecophysiological simulation models to predict the impact of elevated atmospheric CO_2 concentration on crop productivity. *Annals of Botany* **112**: doi:10.1093/aob/mct016.

Yin X, van Laar HH. 2005. *Crop systems dynamics. An ecophysiological simulation model for genotype-by-environment interactions*. Wageningen: Wageningen Academic Publishers.