Intraspecific variation of growth and yield response of wheat to elevated CO_2 in Australian Grains Free Air Carbon dioxide Enrichment (AGFACE)

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Abstract

We evaluated eight wheat (*Triticum, aestivum* L.) cultivars, Janz, Yitpi (high tillering), Silverstar, H45 (synchronous tillering), Drysdale, Gladius, Hartog, and Zebu (medium tillering) under different conditions in the Australian Grains Free Air Carbon dioxide Enrichment (AGFACE) facility. The interacting effects of carbon dioxide (ambient aCO_2 ~380 ppm, elevated eCO_2 ~550 ppm), water supply (RainFed, irrigated) and higher temperatures during grain filling on plant growth, grain yield and yield components were investigated. Overall, above ground total plant dry mass (DM) increased by 25% at eCO_2. The responsiveness to eCO_2 was varied during plant development, on an average 25, 19 and 31% ($P \leq 0.05$) at tillering (DC30), anthesis (DC65) and maturity (DC90), respectively. Large interspecific variation in growth and yield response to elevated CO_2 were observed, cultivar Zebu showed the highest grain yield stimulation eCO2 . Across all the treatments, grain yield was increased by 30% at eCO_2. Increase in grain yield at eCO_2 was partly due to an increase in tiller number at maturity (16%), single grain weight (9%) and kernels per spike (6%) by eCO_2.

Key Words

Climate change, dry matter partitioning, plant growth, tillering

Introduction

Atmospheric carbon dioxide (CO_2) concentration has increased from 300 ?mol mol^{-1} before the industrial revolution to 387 ?mol mol^{-1} by the end of 2009 and is projected to increase to 550 ?mol mol^{-1} by the middle of this century (IPCC, 2007). Changes in atmospheric CO_2 at the global level will have a moderate or stronger effect on regional climate parameters such as temperature, prevalence of frequency of drought and rainfall pattern (IPCC, 2007). For example, in southern Australia, rainfall will decline by 50–100 mm and annual mean surface temperatures will rise by 1–2^{o}C by 2050 (Moise and Hudson 2008).

Large variations in growth and yield response to eCO_2 exist between species (Poorter 1993; Ziska 2008; Shimono et al. 2009). Very little?attention has been given to understand how plants respond to eCO_2 within the same species (intraspecific), particularly in?conjunction with other environmental parameters. Understanding of the growth and physiological basis?of such responses are essential?to select cultivars best suited to the future climate.??These findings are valuable for plant breeders in selecting lines for breeding agromomically important crop species.

This paper reports results of the 2009 FACE (Free Air CO_2 Enrichment) growth data on the physiologically diverse wheat germplasm response to eCO_2, temperature and drought under field conditions.

Materials and methods

FACE Experiment

The Australian Grains FACE (AGFACE) site is located in Horsham, Victoria. AGFACE was designed to simulate atmospheric carbon dioxide levels in the year 2050 (550 ppm) to investigate the interaction of CO_2, water and temperature on wheat. The facility has 8 elevated FACE rings and 8 control (ambient) rings, with a 16 m diameter accommodating 26 plots per ring. Each plot is 4 m long and 1.7 m wide. A description of the experimental design and equipment performance is given in Mollah et al. (2009). The AGFACE experiment was carried out for 3 years from 2007, 2008 and 2009 of which the 2009 results are addressed in this paper.

Experimental treatment

The main aim of the experiment is to investigate the interacting effects of carbon dioxide (ambient aCO_2 ~380 ?mol mol^{-1}, eCO_2 ~550 ?mol CO_2 mol^{-1}) with variations in water supply (by irrigation), temperature during grain filling (by altering sowing time), nitrogen (by fertilizer addition) and cultivars (having different traits) on crop growth, grain yield and yield components. In 2009, Yipti, Janz (high tillering), Zebu, Drysdale, Gladius and Hartog (moderate-tillering cultivars) and Silverstar and H45 (free-tillering cultivars) were grown in May/early June as TOS1 and late July/early August as TOS2. The two watering regimes were designed to provide an average (~290 mm) and above average (~350 mm) growing season (May to November) rainfall for the region. The agronomic practices of the experiment are described Mollah et al. (2009).

Growth and growth analysis

Destructive plant samplings were carried out at three physiological stages, namely tillering (DC30), anthesis (DC65) and grain maturity (DC90). Plant number, tiller number and spikes numbers were counted. The leaf blades were cut from sheaths and the leaf area was determined by a digital image analyser (Delta-T, Cambridge, UK). All of the fractions were dried at 80?C for 48 h before determining their DM. Total grain yield and 1000 grain weight was measured.

Statistical analysis

Results were analysed using ReML mixed models where some data was missing, or by a split plot ANOVA for balanced data sets. Mean separations were carried out using the Duncan Multiple Range Test at $P \leq 0.05$ to show main treatment differences using SAS (SAS user Guide 2008).

Results and discussion

On an average across all the treatments, above ground total plant DM was increased by 31% at reproductive maturity under eCO_2 (Figure 1, Table 1). However, responsiveness to eCO_2 was varied during plant development, on an average by 25, 19 and 31% ($P \leq 0.05$) at tillering (DC30), anthesis (DC65) and maturity (DC90), respectively (Table 1). The highest growth response to eCO_2 was observed at reproductive maturity (Figure 1, Table 1). TOS and IRRI had no effect on any of the growth parameters at tillering (Table 1). At anthesis, total aboveground DM was significantly increased at TOS 1. At grain maturity, all growth parameters except fertile spike numbers were significantly reduced at the RainFed condition (Table 1). In addition, a delay in sowing (TOS 2) significantly reduced the growth and yield component response. Further, supplementary water had no effect on biomass at maturity but showed a significant interaction between CO_2 and TOS.

There were variations in growth response to eCO_2 among the cultivars tested though no significant interaction between genotype and CO_2 was observed (Table 1, Figure 1). Among the cultivars tested, Zebu showed the highest response to eCO_2 and its total aboveground biomass significantly increased at eCO_2 but responsiveness largely varied during plant development by 54, 27 and 60%, at tillering, anthesis and grain maturity, respectively (Table 1). Increase in tiller number at eCO_2 is suggested to be the key factor for plant growth at eCO_2 (Seneweera et al. 2000).

Table 1. Main treatment effects of carbon dioxide (CO_2), time of sowing (TOS) and water supply (IRRI) on plant growth, growth analysis, grain yield and yield components of wheat. Values are the means across all other treatments. Treatment mean values with alphabets (a or b) indicate whether the means are statistically different at (p<0.05).

Growth stage	Growth parameter	Main Treatment Effects					
		CO_2 Concentration		TOS		IRRI	
		eCO_2	aCO_2	TOS 1	TOS 2	IRRI	RainFed
Tillering	Above ground biomass (g m^{-2})	99.8[a]	79.3[b]	90.2[a]	89.0[a]	87.4[a]	91.8[a]
	Tiller number (m^{-2})	547[a]	479[b]	490[b]	535[a]	521[a]	504[a]
	Tiller number per plant	4.2[a]	3.7[b]	4.0[a]	3.9[a]	4.0[a]	3.9[a]
Anthesis	Above ground biomass (g m^{-2})	653[a]	548[b]	763[a]	447[b]	599[a]	602[a]
	Tiller number (m^{-2})	420[a]	474[b]	454[a]	440[b]	448[a]	446[a]
	Tiller number per plant	4.2[a]	3.7[b]	4.4[a]	3.6[b]	4.0[a]	4.0[a]
	Spike number (m^{-2})	420[a]	366[b]	413[a]	373[b]	393[a]	394[a]
Maturity	Grain yield (g m^{-2})	327[a]	251[b]	413[a]	171[b]	316[a]	262[b]
	Above ground biomass (g m^{-2})	721[a]	549[b]	854[a]	425[b]	678[a]	592[b]
	Spike number (m^{-2})	405[a]	349[b]	399[a]	355[b]	391[a]	362[b]
	Fertile spikes per plant	3.9[a]	3.6[b]	4.3[a]	3.2[b]	3.8[a]	3.7[a]
	Harvest index	0.34[a]	0.32[a]	0.33[a]	0.31[b]	0.33[a]	0.31[b]

Kernels per spike	33^a	31^a	44^a	21^b	34^a	30^b

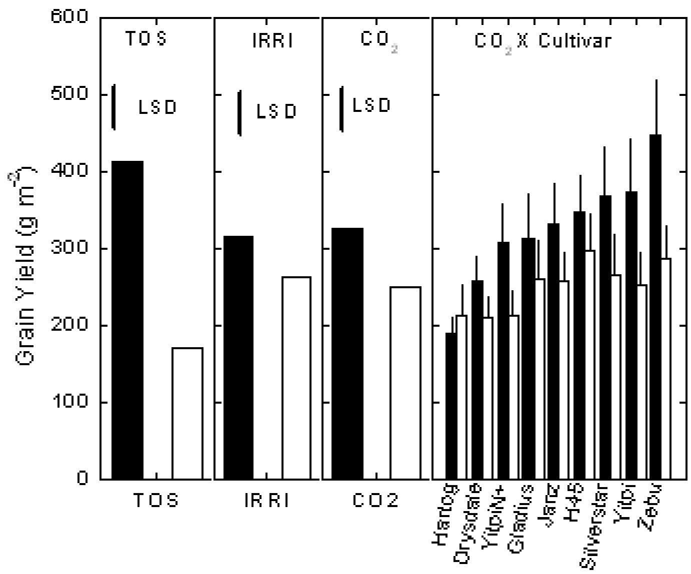

Figure 2. Grain yield for 8 spring wheat cultivars were grown under aCO_2 (clear bars) and eCO_2 (solid bars). First three panels of the graph indicate the main response across all the treatment, TOS, IRRI and CO_2. Error bars are S.E. for each cultivar.

Overall, grain yield increased by 30% at eCO_2 but the harvest index was not significantly changed between CO_2 treatments (Table 1). Increased grain yield at eCO_2 was partly due to increases in tiller number at maturity (16%), single grain weight (9%) and kernels per spike (6%) at eCO_2. Among the yield components, spikelet density was the major contributor for an increased grain yield at eCO_2 (Table 1). Contribution of increase spikes density on yield enhancement under eCO_2 has been reported in rice Kim *et al.,* (2001).

Physiological traits which are linked to the observed differences in intraspecific variations in biomass and yield response to eCO_2 are still not well understood. Modern medium tillering wheat cultivars like Zebu, Drysdale and Gladius respond well to eCO_2 by allocating more carbon to the tillers at early stages of plant development which then leads to strong tillers at maturity. In contrast, high tillering cultivars respond well to eCO_2 during vegetative development, but their survival rates are limited after anthesis possibly because they have limited carbon to support the later part of the reproductive development possibly leading to early tiller death as other environmental factors come to play, for example – high temperature and drought. Our data suggests that modern cultivars having moderate tillering capacity have greater potential to respond to eCO_2. In addition, our results suggest a capacity for plasticity among wheat germplasm that could be utilised for selection in the breeding of new wheat varieties to increase their adaptability to rising atmospheric CO_2.

Conclusion

Large growth stimulation to eCO_2 was observed but the responsiveness varied during plant development. The highest growth stimulation was observed at reproductive maturity. Modern wheat cultivars having moderate tillering capacity respond well to eCO_2. Increase in grain yield at eCO_2 is partly due to increased tiller number, single kernel weight and grain number per spike.

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