The size of free air carbon dioxide enrichment (FACE) rings affects overall system performance: An Australian experience

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Abstract

In 2007 and 2008, Australian Grains Free Air Carbon dioxide Enrichment (AGFACE) facilities were established at Horsham (36?45′07″S latitude, 142?06′52″E longitude, 127 m elevation) and Walpeup (35?07′20″S latitude, 142?00′18″E longitude, 103 m elevation) in Victoria, Australia with an aim to investigate the effects of "elevated atmospheric carbon dioxide concentration" (e[CO_2]), water supply and nitrogen fertiliser on wheat growth and development under Australian field conditions. Over the past three years a number of AGFACE rings, 4 m, 12 m and 16 m in diameter, were used to deliver CO_2 in separate experiments. In the AGFACE system the performance goal was set as having at least 80% of the ring area with a CO_2 concentration [CO_2] at or above 90% of the target concentration at the ring-centre for 80% of the time. The AGFACE performance was also assessed by determining the percentage of time that 1-min average [CO_2] was held to within ?10% of the target [CO_2] at ring-centres. Monitoring showed that whilst engineering performance criteria were met in all sized rings, variation in performance between different sized rings existed. The mid-95 percentile ranges of [CO_2] at the ring-centres were smaller for large rings, implying that larger rings maintained the target [CO_2] of 550 μmol mol^{-1} at the ring-centres better than the smaller rings. More importantly, the spatial variation of [CO_2] in the inner 80% of the rings were found to be higher in smaller rings compared with larger rings. This means that the larger rings had more areas of relatively uniform [CO_2] to conduct experiments.

Key Words

AGFACE, climate change, spatial variation.

Introduction

Annual rainfall across the wheat growing regions of Australia has been declining in recent decades. In addition, the IPCC 2007 emissions scenario A1B indicates that global atmospheric carbon dioxide (a [CO_2]) levels will increase from 386 μmol mol^{-1} to 550 μmol mol^{-1} by 2050. As a consequence, annual rainfall in the grain production regions of Australia will decline by 50–100 mm and annual mean surface temperatures will rise by 1-2?C. These changes in climate will significantly challenge grain production in Australia. Consequently, in 2007 and 2008, Australian Grains Free Air Carbon dioxide Enrichment (AGFACE) facilities were established at Horsham (36?45′07″S latitude, 142?06′52″E longitude, 127 m elevation) and Walpeup (35?07′20″S latitude, 142?00′18″E longitude, 103 m elevation) in Victoria, Australia with an aim to investigate the effects of elevated atmospheric carbon dioxide concentration (e[CO_2]), water supply and nitrogen fertiliser on wheat growth and development under Australian field conditions.

A critical component of this wheat growth data set is to ensure that the FACE system performs adequately. Over the past three years a number of 4?m (Walpeup 2008 and 2009), 12?m (Horsham 2007 and 2008) and 16?m (Horsham 2009) AGFACE rings were used in separate experiments. In the AGFACE system the performance goal was set as having at least 80% of the ring area with [CO_2] at or above 90% of the target [CO_2] at the ring-centre for 80% of the time. Also, the AGFACE performance was previously assessed by determining the percentage of time that 1-min average [CO_2] was held to within ?10% of the target [CO_2] at ring-centres (Mollah et al. 2009a). Analysis of data from 4?m and 12?m AGFACE rings indicated that the spatial variation of [CO_2] depends on ring size and the gap between ring and canopy heights but not wind speeds (Mollah et al. 2009b). Further data on spatial variation of [CO_2] was collected from a 16?m ring at Horsham using a multi-port (32 channel) Infra Red Gas Analyser

(IRGA). This paper compares the performances of three different sizes of AGFACE rings and determines the factors that affect their performance.

Methods

2008 spatial CO_2 data

In 2008, two rings for early sowing and two rings for late sowing were selected at both Walpeup (4?m rings) and Horsham (12?m rings) sites to assess the spatial distribution of [CO_2]. Twenty two locations in each of the 4?m rings and 32 locations in each of the 12?m rings were pre-determined and marked as sampling points. A portable IRGA (model EGM-4 manufactured by PP Systems) was used to measure [CO_2] at these points within each ring. Data were recorded manually and the sampling head of EGM-4 was mounted on a purpose-built frame so that the sampling head was at least 1.5?m in front of and upwind of the operator to avoid contamination from operator's breathing. A single reading was taken at each of the sampling locations at the same height as the IRGA's sampling head at ring-centre. The sampling head at ring-centre was always kept 50?mm below the ring height to ensure that [CO_2] was measured inside the blanket of CO_2 above the canopy. The measurements were repeated 7 times throughout the season with 7 different ring heights.

2009 spatial CO_2 data

A multi-port IRGA was used for automatic logging of [CO_2] from 32 different locations within a 16?m ring over a week in November 2009 for one crop height. The sampling heads of the multi-port analyser was kept 50?mm below the ring height.

Multi-port IRGA

This IRGA is the same model (SBA-4, PP Systems) which are used at each ring-centre (Mollah *et al* 2009a). It uses 16 diaphragm air pump (Schego, Germany) powered by 12 V direct current to draw air samples. Two-way valves split the inlets of 16 pumps into 32 inlets (ports). Air is drawn continuously through one of the two ports of a particular pump at a time. Any number of ports between 1 and 16 (inclusive) can be selected for use at any particular time. Also, 32 ports can be selected for use but not any number of ports between 16 and 32. For example, if 9 ports are selected, then the algorithm allows using a single port from each of the 9 pumps (pumps 1 to 9) and the loop continues until stopped. For 5 ports, 5 pumps, for 12 ports 12 pumps and so on for up to 16 ports. When 32 ports are selected, the sampling starts at port 1 on pump 1 and continues up to port 16 on pump 16. When sampling at port 16 is finished, the two way valves inside each pump automatically change their direction closing the used ports and opening the unused ones. Again sampling starts at pump 1 through its second inlet (port 17) and continues until reaches port 32 on pump 16. After sampling through port 32, two-way valves change direction again and the loop continues until stopped. The sampling, analysis and line purging takes about 10 seconds for each port, therefore it takes about 320 seconds (5.33 minutes) to complete a set of data collection from 32 different locations.

Statistical methods and contour mapping

The data collected by the multi-port analyser and IRGA's at ring-centres were categorised according to whether the CO_2 flow was on or off (CO_2 was turned off at night to save gas and if the wind speed exceeded 8 m/s in day-time) and summarised using means, medians, standard deviations and mid-95% ranges. The 1-min average [CO_2] logged from the ring centres were used to calculate the percentage of time when the ring-centres recorded [CO_2] within various ranges. To assess spatial variation of [CO_2] across the ring, the data collected from each experiment were used to develop a linear regression of the [CO_2] against distance from the source. The [CO_2] were logarithm-transformed and the terms tested in the model were the logarithm of the distance downwind from the CO_2 source to the sampling point, [CO_2] at the centre of the ring and wind speed. The *x–y* coordinates of each location within the rings from the ring-centres were estimated. The distance downwind from the CO_2 source for each sampling location was calculated (for details see Mollah *et al* 2009a).

The spatial interpolation method of Kriging (point type) employing a linear variogram model was used to draw contour maps of spatial variation of [CO_2] within each ring. The proprietary software Surfer version 7 (1999) was used.

Results

The [CO_2] measured at different locations inside AGFACE rings showed large variability at high concentrations near the CO_2 source which varied non-linearly with the distance downwind of the source (data not shown – see Mollah *et al* 2009a and Mollah *et al* 2009b for examples). This variability is also shown in the contour maps (Figs. 1 and 2). However, in large rings relatively more areas of the inner 80% ring areas (circles, Fig. 1) were close to the 550 μmol mol^{-1}, the target [CO_2] (Figs. 1 and 2). This implies that the larger rings had more areas of relatively uniform [CO_2] to conduct experiments. Also, larger rings are relatively cheap to run in terms of experimental plots that can be accommodated into it. By increasing the ring size from 12 m to 16 m we accommodated twice as many experimental plots for a 33% increase in gas use. The extra capital cost was insignificant.

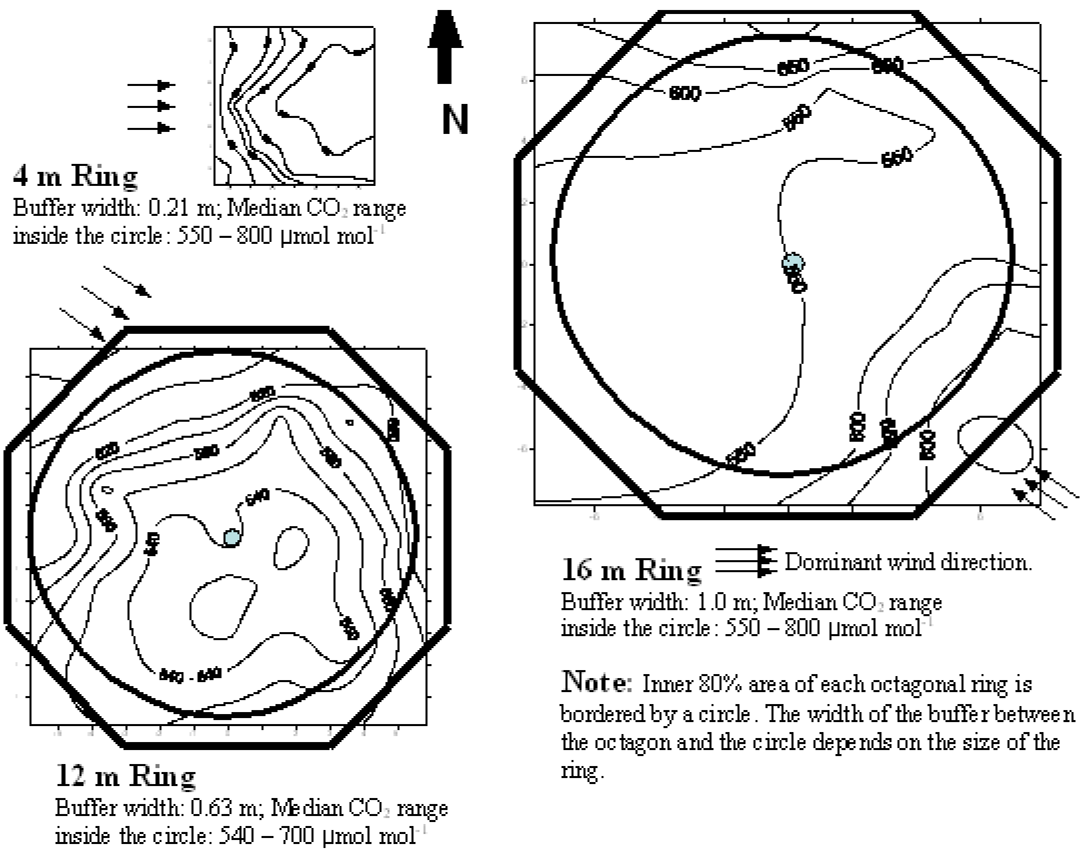

Figure 1. The distribution of median [CO_2] in three different ring sizes.

Wind speeds had no significant ($P = 0.05$) effects on the spatial variation of [CO_2] inside the AGFACE rings but at high wind speeds, certain parts of the ring may have received slightly less than the target [CO_2] (Fig. 2). Also, [CO_2] appears to be more variable (especially near the edge) inside the ring at low wind speeds (Fig. 3). The high-frequency variability in [CO_2] inside the FACE rings may be biologically significant which may be one of the limitations of the FACE system (Hendry and Miglietta 2006). This is most probably true only around the edge of the FACE rings where mean variation (in all directions) is very high as shown in our studies (Fig. 3). However, in the coming seasons the AGFACE team plans to use a 32 channel multi-port analyser to accurately measure the variation in [CO_2] inside AGFACE rings and the factors that affect it. The intent is to develop a mathematical model for FACE systems to determine the [CO_2] at any given point inside a FACE ring for accurate assessment of plant responses.

The 1-minute average [CO_2] logged at ring-centres during the period of spatial data collection showed an oscillation around the target 550 μmol mol^{-1} concentration with only a few readings (0.5% in 4 m ring, 1.0% in 12 m ring and 1.76% in 16 m ring) being the same as the target. However, all sized rings on average (over 160-day season) maintained a 549 μmol mol^{-1} concentration at ring-centres. The mid-95 percentile range and overall oscillation decreased with the increase of the ring size (Table 1). Generally, there was no significant effect of these oscillations on the spatial variation of [CO_2] measured inside each ring. The results were conclusive, despite the fact that the data for all ring sizes did not come from the same location and same season. The 4?m and 12?m rings just failed to meet ? 10% of the target protocol which can be attributed to limited number of data available for analysis. Monitoring in 2007 showed that [CO_2] at the ring-centre was maintained within ? 10% of the target across eight 12?m rings between 86 and 94% of the time (Mollah *et al* 2009a). Therefore, it is expected that analysing the data for the whole season will improve the figures for 4?m and 12?m rings but the trend shown in Table 1 will persist.

Table 1. One-minute average [CO_2] at the ring centres.

CO_2 at ring-centres (μmol mol^{-1})	**Occurrence in each ring (% time)**		
	4?m ring	**12?m ring**	**16?m ring**
>495 (90% of the target)	83	89.5	96.5
495 – 605 (? 10% of the target)	68.5	79.0	91.7
Mid-95 percentile range (μmol mol^{-1})	512 – 580	520 – 576	534 – 566

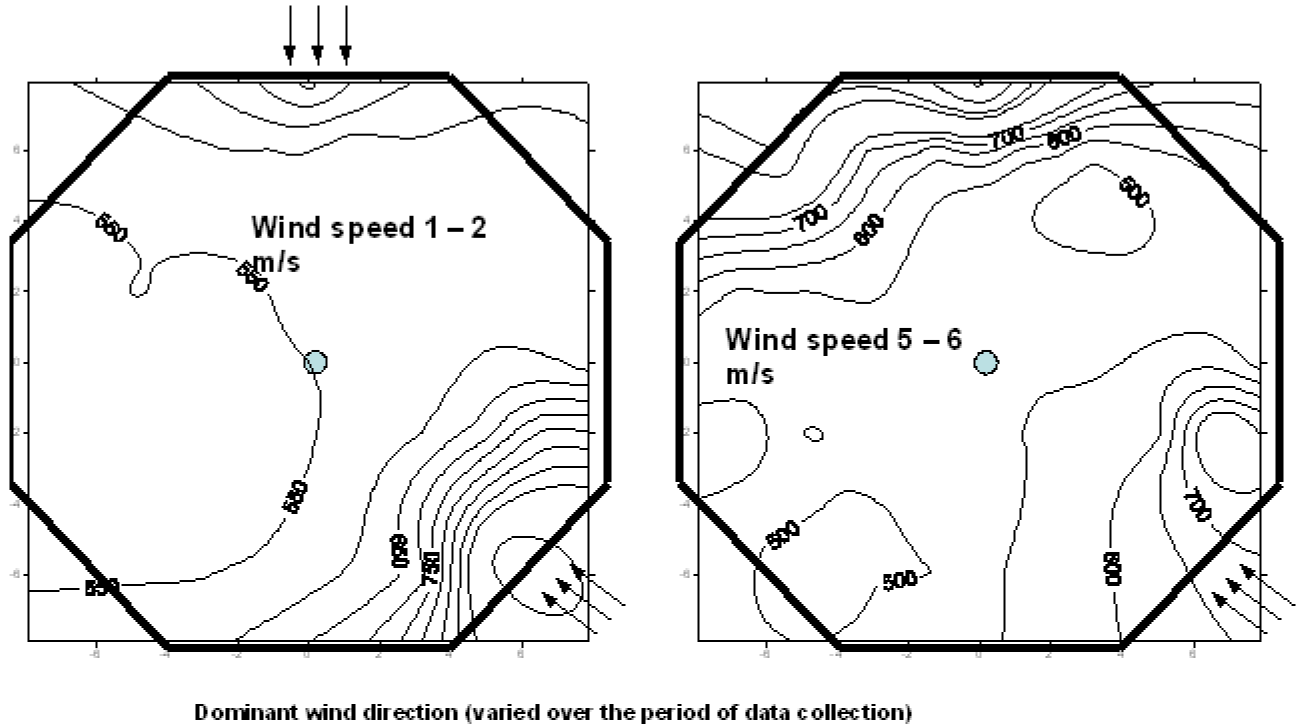

Figure 2. The distribution of median [CO_2] in 16?m ring for two categories of wind speeds.

Conclusion

Despite engineering performance criteria being met in all sized rings the larger rings maintained the target CO_2 concentration of 550 μmol mol^{-1} at the ring-centres better than the smaller rings. More importantly, the spatial variation of [CO_2] in the inner 80% of the rings were found to be higher in smaller rings compared with larger rings. This means that the larger rings had more areas of relatively uniform [CO_2] to conduct experiments. Larger rings are also more economical to run on the basis of CO_2 cost per experimental plot.

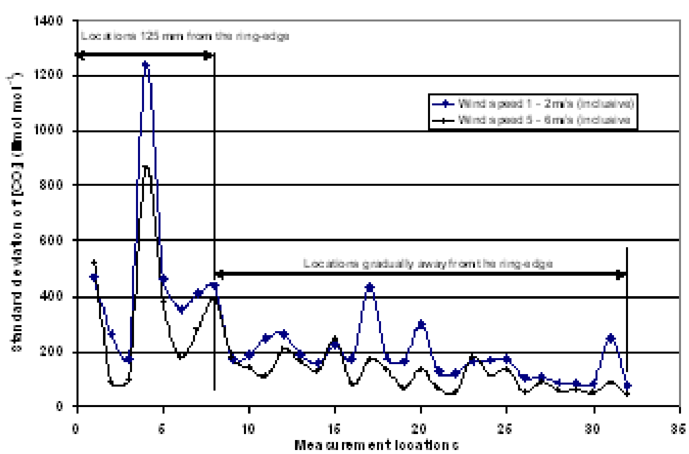

Figure 3. Mean variation in [CO_2] inside a 16?m AGFACE ring.

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