Effect of elevated carbon dioxide on straw decomposition and soil respiration under wheat in Australia

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Abstract
This research investigates the effect of elevated [CO_2] and irrigation on straw decomposition and soil respiration in wheat field under ambient (380 μmol/mol) and elevated (550 μmol/mol) [CO_2] at the Free-Air Carbon dioxide Enrichment (FACE) experiment in a wheat field in Victoria, Australia. Pure cotton cloth, wheat straw and pea straw were decomposed using litter-bag method for 140 days. The percentage mass remaining was the highest for cotton cloth (90%), followed by wheat (73%) and pea (50%). Total C content of wheat and pea straw and total N content of pea straw were reduced only under elevated [CO_2] and irrigated conditions. Increase in C/N ratio was observed for wheat only under elevated [CO_2] and rainfed conditions. Soil CO_2 emissions were increased by elevated [CO_2] only under irrigation.

Key Words
Free air carbon dioxide enrichment, decomposition, straw C/N ratio, irrigation, soil respiration.

Introduction
The atmospheric carbon dioxide concentration ([CO_2]) has been increasing from 280 ppm in 1800 to the current value of around 380 ppm, and is expected to reach 700 ppm by the end of 21st century (Houghton *et al.* 2001). Elevated [CO_2] alters not only crop growth, but also crop tissue quality. In particular, change in tissue carbon (C)/nitrogen (N) ratio was well documented and C/N ratio was generally enhanced under high [CO_2] (Kimball *et al.* 2002). As a result, straw decomposition was reduced (Gorissen 1996; Torbert *et al.* 2000). However, a higher straw decomposition was observed under elevated [CO_2] (Hagedorn and Machwitz 2007) which is possibly related to enhanced fungal population (Jones *et al.* 1998) and microbial activity (Lipson *et al.* 2005) under high [CO_2]. While many decomposition experiments included the straw of same species but treated with different [CO_2], using straw of same quality gives a fair comparison of soil microbial activity with respect to straw decomposition. For instance, the rates of C loss from ^{13}C-labelled wheat roots per unit root dry weight were not significantly different under ambient and elevated [CO_2]. This was associated with a similar root C/N ratio of wheat grown under the two CO_2 treatments (Van Vuuren *et al.* 2000). Soil CO_2 flux reflects is another indicator of soil microbial activity. CO_2 emissions were mostly stimulated under elevated [CO_2], which was attributed to enhanced microbial and root respiration (Zak *et al.* 2000; Kou *et al.* 2007). However, the interaction between elevated [CO_2] and irrigation on straw decomposition and soil respiration needs further research. The present study was conducted on a wheat field in Victoria, Australia using Free-Air Carbon dioxide Enrichment (FACE) facility. The objectives are to investigate (i) the interaction of elevated [CO_2], irrigation and straw type on decomposition rate and straw C/N ratio; and (ii) the interaction between elevated [CO_2] and irrigation on soil respiration.

Methods
Experimental site
The study site is located in an experimental wheat farm on vertosol in Horsham, Victoria, Australia (36°45'S, 142°07'E), with an average rainfall and maximum temperature of 316 mm and 17.5°C during wheat growing season. The present experiment was conducted from late July to December in 2008.

Carbon dioxide elevation
The elevation of atmospheric [CO_2] was achieved from FACE system, consisting of 16 12 m diameter experimental areas, eight elevated and eight ambient. The two target CO_2 concentrations were 380 (ambient) and 550 μmol/mol (elevated). The design and performance of this FACE system was detailed in Mollah *et al.* (2009). Carbon dioxide exposure commenced at sowing time and terminated at the physiological maturity of wheat crop.

Irrigation
Each experimental area was split into two halves receiving different irrigation regimes. Rainfed (I0) and irrigated (I+) treatments were achieved using irrigation to give decile 5 and decile 7 rainfall conditions, respectively.

Litter-bag experiment
Three straw types were included, *viz*. pure cotton cloth, wheat straw and pea straw, representing respectively straw type of high, medium and low C/N ratios. Pure cotton cloth (100% C) was used as to indicate the presence of N in residue is the prerequisite of microbial decomposition. Wheat straw and pea straw grown under ambient [CO_2] were collected from a farm near the study site. Cotton cloth and the two straw were washed, oven-dried at 60°C and cut into pieces of around 0.3-0.5 m long. Three grams of each straw type were put into polyester bag of 0.1 m by 0.15 m, with 1 mm mesh size. Five bags of each straw type were buried to 0.5 m depth, and one of these five bags was collected at 30, 60, 90, 120 and 140 days. The straw remaining in the bag was washed with tap water to remove the dirt adhered, dried at 60°C for 48 h and weighed to give the percentage mass remaining.

Gas sampling and flux determination
The location of microplots of this experiment was different from the litter-bag experiment, but within the corresponding experimental area. Gas samples for CO_2 analysis were taken from microplots from closed flux chamber (0.15 m height by 0.16 m diameter) on 24 September, 7 & 30 October, 18 November and 10 December between 1300 and 1500 h of the day. One chamber was inserted a day before the first measurement to a soil depth of 70 mm, and remained *in situ* throughout the experimental period. Neither wheat crop nor straw was included inside the chamber. Fluxes measured from this experiment reflected soil respiration (including root and microbial activities). On each sampling day, the chamber was closed for 0.5 h prior to the first gas sampling. Five gas samples were then collected from the chambers at 7 minute intervals (chambers remained closed) using a gas tight syringe through a rubber bung. Gas of 15 mL was transferred into evacuated glass vials and transported to the laboratory for analysis by gas chromatography equipped with TCD. Flux rate of CO_2 was calculated from the linear change in gas concentrations in the chamber.

Chemical analysis
The dried straw was ground into very fine powder for the analysis of total C and total N by CHN Analyzer.

Statistical analysis
All data were analysed using the MINITAB 14 statistical package using a factorial model analysis of variance with main effects as [CO_2], irrigation, straw type and sampling time for litter-bag experiment, and [CO_2], irrigation and sampling time for CO_2 flux experiment.

Results
Percentage mass remaining
The percentage mass remaining decreased with time for cotton cloth, wheat straw and pea straw for all treatments (Figure 1), and averaged 90 ± 9, 73 ± 8 and 50 ± 5%, respectively, after 140 days of decomposition. Cotton cloth was hardly decomposed throughout the course of the experiment, indicating the presence of N is crucial to microbial decomposition. Decomposition rate was highest within the first three months of the study period, and levelled off thereafter (Figure 1). The higher percentage mass remaining for straw of wheat than pea was associated with the higher C/N ratio wheat straw (59.4 ± 4.2) than pea straw (27.1 ± 3.1) for microbial decomposition. There was no significant effect of elevated [CO_2] on the percentage mass remaining, regardless of straw type. Irrigation decreased the percentage mass remaining by 5% ($p < 0.001$), regardless of [CO_2] and straw type.

Total C, total N and C/N ratio
Chemical analysis of nutrient contents was not performed for cotton cloth (100% C). Total C was reduced by 5% ($p < 0.05$) by irrigation for both wheat and pea straw only under elevated [CO_2]. Total N was decreased by 19% ($p < 0.05$) under elevated [CO_2] only for pea straw under irrigated condition. The interaction among [CO_2], irrigation and straw type on C/N ratio was marginally significant ($p = 0.091$). Elevated [CO_2] increased (47%) the C/N ratio of only wheat straw under rainfed condition. This was probably attributed to the 3% increase ($p > 0.05$) in total C and 15% decrease ($p > 0.05$) in total N under the same condition.

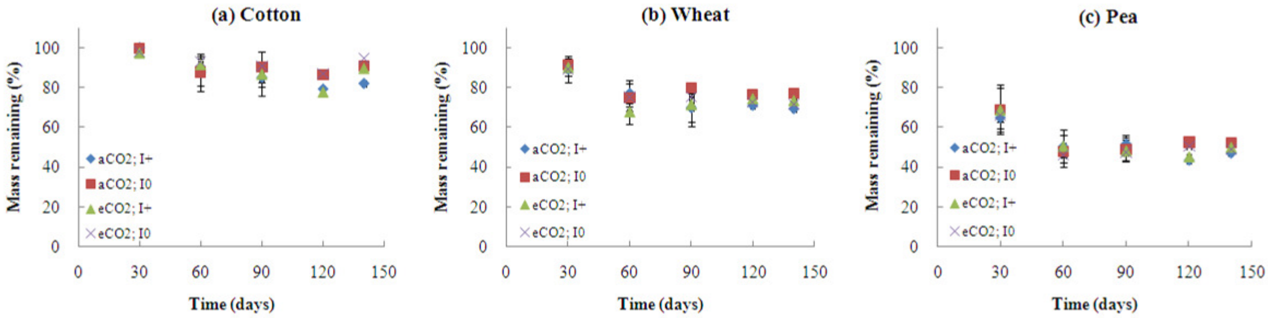

Figure 1. Percentage mass remaining at different time after decomposition of (a) cotton cloth, (b) wheat straw and (c) pea straw. Bars indicate standard deviations. aCO_2 (ambient [CO_2]); eCO_2 (elevated [CO_2]); I+ (irrigated); I0 (rainfed).

CO_2 flux

CO_2 fluxes during the experimental period were always positive. The interaction between elevated [CO_2] and irrigation was marginally significant ($p = 0.095$). Elevated [CO_2] increased CO_2 emission by 78% under irrigation (Figure 2), but not under rainfed condition.

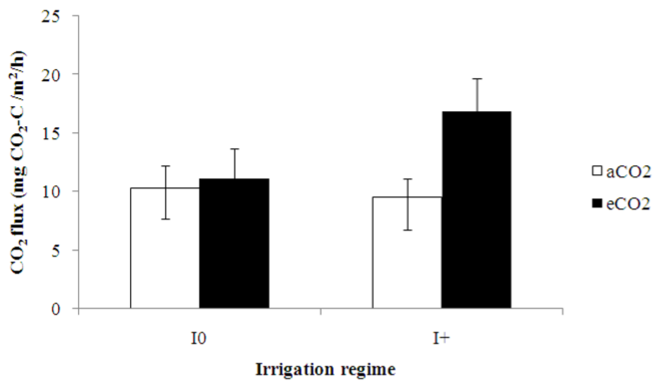

Figure 2. Effects of [CO_2] and irrigation on CO_2 flux. Bars indicate standard errors. ns, not significant; * $p < 0.05$. aCO_2 (ambient [CO_2]); eCO_2 (elevated [CO_2]); I0 (rainfed); I+ (irrigated).

Discussion

Effect of [CO_2] and straw type on straw decomposition and straw C/N ratio

Elevated [CO_2] did not significantly affect straw decomposition for cotton cloth, wheat and pea straw. Since the straw placed under ambient and elevated [CO_2] was of the same quality, the non-significant effect indicates that microbial activity of surface soil was unlikely affected by elevated [CO_2] in short term (140 days). When considering the difference in decomposition rate of the three straw types, cotton cloth was always the lowest, followed by wheat straw and then pea straw. This reflects C/N ratio is a key factor to decomposition rate under both ambient and elevated [CO_2]. For example, the higher C/N ratio of wheat straw produced under elevated [CO_2] resulted in reduced decomposition rate in a wheat field and a fallow field (both under ambient [CO_2]) (Frederiksen *et al.* 2001), in a soil incubation experiment (Marhan *et al.* 2008) under ambient [CO_2], and in a pot experiment in open-top chambers under both ambient (370 µmol /mol) and elevated [CO_2] (700 µmol /mol) (Liao *et al.* 2002). In contrast, when the root C/N ratio of wheat grown under the two CO_2 treatments was similar, there was no significant difference in the rates of C loss from ^{13}C-labelled wheat roots per unit root dry weight under ambient and elevated [CO_2] (Van Vuuren *et al.* 2000). The above findings together suggest that CO_2-induced change in tissue quality (C/N ratio), rather than microbial activity, plays a contributory role in altering decomposition rate in short term elevation of [CO_2]. Indeed, Søe *et al.* (2004) observed no significant change in soil microbial biomass under elevated [CO_2].

Irrigation reduced the percentage mass remaining (or increased decomposition), regardless of [CO_2] and straw type, which indicates water or soil moisture is critical to microbial activity. In particular, it stimulated the C mineralization of wheat straw and C and N mineralization of pea straw under elevated [CO_2]. This highlights the importance of water in C and N cycling. Moreover, the C/N ratio of wheat straw was increased under elevated [CO_2] and rainfed conditions, which has major implication on soil N immobilization as well as progressive N limitation in semi-arid regions, if there is no additional N input (Luo *et al.* 2004).

Effect of [CO_2] and irrigation on soil CO_2 emissions

Since the stimulation of efflux was associated with increased biomass under elevated [CO_2] (Jablonski *et al.* 2002; Kimball *et al.* 2002), the marginally increased soil CO_2 efflux only under elevated [CO_2] and irrigation implies that irrigation is crucial to biomass increment under elevated [CO_2] in the study site, as well as the subsequent increase in C substrates for soil microbes (Zak *et al.* 2000; Kou *et al.* 2007). Nonetheless, the decomposition experiment indicates that there was no significant effect of elevated [CO_2] on decomposition, regardless of irrigation, and the stimulation of microbial activity in surface soil was unlikely. Therefore, the stimulation of CO_2 efflux was possibly resulted from an increase in microbial activity in subsurface soil and/or root respiration, as soil respiration comprises respiration by autotrophs and heterotrophs (Kuzyakou *et al.* 2006). This is possible as root respiration was observed to increase under high [CO_2] as a result of increased root biomass and concomitant root activity (Søe *et al.* 2004). However, sufficient amount of water is a prerequisite.

Conclusions

Straw decomposition was not significantly affected by elevated [CO_2], regardless of straw type, but irrigation increased decomposition. Change in straw quality induced by elevated [CO_2], rather than microbial activity, was proposed to result in a change in decomposition rate under elevated [CO_2]. Parallel to this, the increase in CO_2 emission under elevated [CO_2] and irrigation was possibly attributed to the stimulation of root biomass and activity. Water plays an important role in regulating decomposition and soil respiration, which are important processes of soil C cycle altering the global climate.

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