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Factors responsible for diurnal and seasonal changes in the reduction of stomatal conductance in paddy rice caused by elevated CO_2

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ABSTRACT

Understanding of leaf stomatal responses to the atmospheric CO_2 concentration, [CO_2] is essential for accurate prediction of plant water use under future climates. Elevated [CO_2] generally reduces stomatal conductance (g_s), but the magnitude of the reduction in g_s varies. Limited information is available for the diurnal and seasonal changes of g_s under elevated [CO_2]. We examined the factors responsible for diurnal and seasonal changes of g_s under elevated [CO_2] with three rice cultivars grown in an open-field environment under flooded conditions for two years. Conductance of all cultivars was generally higher in the morning and at noon than in the afternoon, and was significantly decreased by elevated [CO_2] at most times of day for all cultivars by 0-63% (25 out of 38 days in two years). There were no significant interactions of [CO_2] × cultivar, [CO_2] × time of day, [CO_2] × cultivar × time of day at all measurement days excepting for one time of day. Ball, Woodrow & Berry model (1987) well explained the g_s responses in the morning and at noon over years, days, cultivars and [CO_2] conditions, but the model could not well explain the g_s responses in the afternoon especially under ambient [CO_2]. Leaf water potential was reduced in the afternoon especially under ambient [CO_2]. This suggested a need for incorporating factor of plant water status into the model for improving accuracy for simulating g_s responses under future climates.

KEYWORDS: Elevated atmospheric CO_2, Free-air CO_2 enrichment (FACE), Global change, Leaf water potential, Rice, Transpiration

OBJECTIVE

To clarify the factor responsible for g_s variation in rice, we measured diurnal and seasonal changes of g_s of three rice cultivars under fully-open air conditions under two [CO_2] for two years. Detail conditions were shown in the previous study (Shimono et al., 2009).

The variation of g_s was analyzed using the Ball, Woodrow & Berry model (Model 3 in the present study) who proposed an empirical, but robust model for simulating g_s to various environments over species, and is widely used to predict g_s:

Model 1 $$g_s = g_0 + m\frac{SLNh}{[CO_2]} \quad (1)$$

Model 2 $$g_s = g_0 + m\frac{A_{LS}h}{[CO_2]} \quad (2)$$

Model 3 $$g_s = g_0 + m\frac{Ah}{[CO_2]} \quad (3)$$

where *SLN* is the specific leaf N content (g m^{-2}), A_{LS} *and* A is the photosynthesis rate of light-saturated condition and actual light condition (μmol m^{-2} s^{-1}), respectively, h is the fractional atmospheric relative humidity (dimensionless), g_0 is the y-axis intercept, and m is the slope of the line.

RESULTS AND DISCUSSION

Under ambient [CO_2], the g_s of all cultivars in both years of 2003 and 2004 was higher during the morning (0.395 mol m^{-2} s^{-1}, all data combined) and at noon (0.391 mol m^{-2} s^{-1}) than in the afternoon (0.281 mol m^{-2} s^{-1}). Elevated [CO_2] reduced g_s of all cultivars by 0 to 63% (23 ± 2%, mean ± standard error), and the main effect of [CO_2] was mostly significant at 25 days out of 38 days (9 days out of 13 days in the morning and at noon and 7 days out of 12 days in the afternoon). The mean reductions were 20% in the morning (averaged for all data), 24% at noon, and 23% in the afternoon. The cultivar effect was not significant for all days and there was no significant interaction between [CO_2]×cultivar.

Leaf water potential in the morning was higher (less negative), and decreased to its minimum value at noon for both growth stages as g_s increased to its maximum. The reduction in leaf water potential was smaller under elevated [CO_2] than under ambient [CO_2]. With decreasing g_s, the water potential recovered after the noon.

The variations were analyzed by the three models. The correlation coefficients for both [CO_2] between estimated and observed g_s were high in the morning and at the noon ($P<0.001$), and low especially at ambient [CO_2] than elevated [CO_2] in the afternoon for all models (Table 1). Among three models, the model 3 improved the accuracy for estimation of g_s in the afternoon. These results suggested that g_s in the afternoon was determined not only by the factors of Ball, Woodrow & Berry model of photosynthesis, atmospheric humidity, [CO_2], but also other factors such as leaf water potential to estimate accurately g_s in the future climate.

Table 1. Correlation coefficent between observed stomatal conductance and estimated stomatal conductance using three models, and root mean square deviation (RMSD).

[CO_2]	Time of day	Correlation coefficient			RMSD (mol m^{-2} s^{-1})		
		Model1	Model2	Model3	Model1	Model2	Model3
Ambient	Morning	0.83 ***	0.83 ***	0.86 ***	0.15	0.08	0.11
	Noon	0.89 ***	0.89 ***	0.91 ***	0.17	0.11	0.13
	Afternoon	0.25 ns	0.27 ns	0.42 ns	0.08	0.07	0.07
Elevated	Morning	0.87 ***	0.86 ***	0.85 ***	0.09	0.06	0.08
	Noon	0.90 ***	0.89 ***	0.87 ***	0.09	0.06	0.07
	Afternoon	0.50 **	0.49 **	0.54 **	0.05	0.08	0.05

Stomatal conductance of lower surface was measured by LI-1600 on plants grown under a free-air CO_2 enrichment conditions. Model1, SLN basis model; Model2, Light-saturated photosynthesis basis Ball&Berry model; Model3, Actual photosynthesis basis Ball&Berry model. ***, $P<0.001$; **, $P<0.01$; *, $P<0.05$; ns, not significant. Light-staturated photosynthesis was estimated from regressions for each [CO_2] with SLN, and actual photosynthesis was estimated from light-saturated photosynthesis and a reduction factor which was deprived from light-photosynthesis responses.

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