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Analysis of carbon distribution in rice plants grown at elevated CO_2

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Introduction

The elevation of ambient CO_2 concentration raises the photosynthetic rate in a single leaf and in the canopy owing to an increase in the substrate, and also the total non-structural carbohydrate concentration in leaf blades, leaf sheaths and culms. On the other hand, grain yield has not been shown to increase as much as expected. Furthermore, the effect of elevation of ambient CO_2 concentration on the translocation of carbohydrate photosynthate has not been examined in detail. We examined the effect of elevation of ambient CO_2 concentration on the distribution and translocation of photosynthates and its contribution to grain yield by feeding $^{13}CO_2$ to rice plants.

Materials and Methods

Plant materials: Rice plants (*Oryza sativa* L. var. Akitakomachi) were grown in the paddy field under natural CO_2 (control plants) and concentration-elevated CO_2 conditions (high-CO_2 plant) by using a Free-Air CO_2 Enrichment system in 1998 and 1999 (Kim et al. 2001). The target CO_2 concentration in the system was 200 µl l^{-1} higher than that in the natural condition.

Measurement of canopy photosynthesis and respiration: Canopy photosynthesis, and respiration were measured in a closed chamber made of transparent poly-acryl, and gray poly-vinylchloride, respectively. The increase and decrease in CO_2 concentration were measured for 15 min and 5 min, respectively, with an infrared gas analysis system (SPB-H5, ADC Limited, England). Then the photosynthetic and respiration rates were calculated.

Feeding of CO_2 : $^{13}CO_2$ was fed to plants each at the vegetative, heading, early and late grain filling stages. Each plant was covered with a transparent bag made of 0.10 mm polyvinylchloride film that neither passed through nor absorbed much air or CO_2. The plants were forced to absorb CO_2 liberated from $Ba^{13}CO_3$ powder by adding 7.3 M H_3PO_4 in the bag. The bag was sealed by water in the paddy field and each plant was exposed to $^{13}CO_2$ in the bag for 90 min.

Table 1. The distribution of fed ^{13}C to each organ (1998) (%)

Feeding day	Sampling day	Organ	Plants	
			High-CO_2	Control
Jul. 25 (vegetative)	Aug.18 (after heading)	Ears	1.2	2.5
		Leaf blades	19.9	22.7
		Stems	37.1	38.1
		Whole plant	58.1	63.3
	Oct.5 (harvesting)	Ears	8.0	6.0
		Leaf blades	13.4	19.1
		Stems	36.3	29.1
		Whole plant	57.7	54.3
Aug.9 (heading)	Aug.18 (after heading)	Ears	22.5	20.2
		Leaf blades	6.8	7.0
		Stems	40.6	43.3
		Whole plant	69.9	70.4
	Oct.5 (harvesting)	Ears	32.6	33.8
		Leaf blades	3.2	4.4
		Stems	25.9	25.0
		Whole plant	61.7	63.1
Aug.25 (early grain filling)	Oct.5 (harvesting)	Ears	71.4	66.2
		Leaf blades	1.0	1.5
		Stems	0.6	1.3
		Whole plant	73.1	69.0
Sep.9 (late grain filling)	Oct.5 (harvesting)	Ears	79.5	66.8
		Leaf blades	2.5	3.3
		Stems	4.1	3.7
		Whole plant	86.0	73.8

The amount of total fed ^{13}C was regarded as 100%. Stem includes leaf sheath and culm. Values represent the means ± SE of three replications.

Results and Discussion

About 70% and 60% of the ^{13}C fed at the vegetative stage remained in the plants at 3 weeks after feeding and after heading, respectively, and the high-CO_2 plants had a smaller amount of ^{13}C than the control (Table 1,2). On the other hand, ^{13}C fed at the grain filling stage remained at the time of harvest in larger amounts in the high-CO_2 plants than in the control plants, which indicated that the high-CO_2 plants wasted less fixed carbon. We measured the canopy respiration to examine the consumption of fixed carbon. The respiration rate in high-CO_2 plants was 29% higher than that in the control plants at the vegetative stage (Jul.25), but similar to that in the control at the grain filling stage (Aug.21) (Table 3). Therefore, the ratio of carbon wasted by respiration to carbon fixed by photosynthesis was smaller in high-CO_2 plants.

The control plants distributed ^{13}C fixed at the heading stage to the leaf blades and stems

Table 2. The distribution of fed ^{13}C to each organ (1999)

(%)

Feeding day	Sampling day	Organ	Plants	
			High-CO_2	Control
Jun. 20 (vegetative)	Jul.10 (vegetative)	Leaf blades	37.3	41.9
		Stems	21.2	21.6
		Roots	9.7	10.9
		Whole plant	68.3	74.4
Jul.25 (heading)	Jul.25	Ears	19.4	10.5
		Leaf blades	47.7	50.7
		Stems	32.7	38.6
		Roots	0.2	0.2
		Whole plant	100.0	100.0
	Jul.27 (2days after feeding)	Ears	34.7	14.7
		Leaf blades	16.7	25.3
		Stems	42.0	46.3
		Roots	0.3	0.5
		Whole plant	93.9	87.9
	Aug.21 (grain filling)	Ears	35.6	19.2
		Leaf blades	9.6	19.0
		Stems	34.0	38.2
		Roots	0.9	0.8
		Whole plant	80.1	77.2
Aug.23	Aug.23	Ears	34.3	29.4

(grain filling)		Leaf blades	46.2	51.8
		Stems	19.3	18.7
		Roots	0.1	0.1
		Whole plant	100.0	100.0
	Aug.25 (2days after feeding)	Ears	80.7	77.1
		Leaf blades	9.4	10.0
		Stems	6.3	4.6
		Roots	0.1	0.1
		Whole plant	96.5	91.7
	Sep.17 (Harvesting)	Ears	89.5	80.6
		Leaf blades	2.5	2.6
		Stems	2.2	1.6
		Roots	0.1	0.1
		Whole plant	94.3	84.9

The amount of fed ^{13}C incorporated initially into a whole plant was regarded as 100%.

Stem

includes leaf sheath and culm. Values represent the means of four replications

in a larger amount than the high-CO_2 plants did. On the other hand, ^{13}C was transferred to ears more rapidly in the high-CO_2 plants than in the control plants (Table 2). The same tendency was observed in the other experiment in an air-controlled chamber. Furthermore, ^{13}C fixed at the grain filling stage was distributed to the ear in a larger amount in the high-CO_2 plants than in the control plants, indicating that the photosynthate in the high-CO_2 plants contributed to grain yield more effectively than in the control plants. We suppose that elevation of CO_2 would promote transport of photosynthate to the sink.

Canopy photosynthesis under high intensity light (1800–2000μmol/m^2/s) was accelerated (30-60%) and the amount of ^{13}C distributed to the ear was increased by an elevation of CO_2 (Table 3). However, the grain yield in the high CO_2 plants was only about 15% higher than that in the control plants (Kim et al. 2001). Photosynthesis under a low intensity light (700-900 μmol/m^2/s) was of no advantage to carbon storage in the high CO_2 plants. (In the high CO_2 plants, 275 mg and in the control plants, 355 mg CO_2 hill^{-1} h^{-1}.) This suggests that the total carbon assimilation per day might not be as high as that expected from the canopy photosynthesis under high intensity light. Therefore, grain yield might not be increased drastically by elevation of CO_2 concentration. The degree of increase in grain yield by elevated CO_2 concentration might vary either with the light condition or weather.

Table 3. Canopy photosynthesis and respiration in 1999. ($mgCO_2\ hill^{-1}\ h^{-1}$)

Plants	Light intensity	Photosynthesis								
		Jul. 25				Aug.21				
		CO_2 for measurement				CO_2 for measurement				
		550µl l^{-1}		350µl l^{-1}		550µl l^{-1}		350µl l^{-1}		
High-CO_2	Low	275	14	218	21					
	High	586	53	405	9	398	26	239	±	1
Control	Low	437	2	355	16					
	High	632	13	366	20	497	26	310	±	5

Plants	Respiration			
	Jul.25		Aug.21	
High-CO_2	121	7	77	13
Control	94	5	71	8

Values represent the means ± SE of three replications. Low-intensity light, and high-intensity light;

Photosynthetic rates were measured at the irradiances of 700-900, and 1800-2000 µmol m^{-2} sec^{-1} PFD, respectively.

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Reference

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