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Effects of Elevated CO_2 on Maize Growth

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ABSTRACT The effects of CO_2 enrichment on growth of maize (*Zea mays* L.) were examined. Parameters analyzed include growth characteristics, yields, photosynthetic rates, evaporation rates and photosynthesis-related characteristics under elevated CO_2. The plants were grown in growth chambers with a 12-h photoperiod and a day/night temperature of 28/21℃ at the seedling stage and 30/23℃ from the silking stage. The plants were exposed to two elevated CO_2 of 500, 700 ppm and ambient levels (350 ppm). Chalok 1 and GCB 70 germinated three days after seeding, and germination rates were faster in the elevated CO_2 than the control. Germination rates displayed significant differences among the CO_2 treatments. At the seedling stage, leaf area, top dry weight, and photosynthetic rates, and plant height indicated positive relationship with elevated CO_2 concentrations. At the 5~6 leaf stage, CO_2 concentration also indicated positive relationship with plant height, leaf area, top dry weight, and photosynthetic rates. At the silking stage, increased plant height of Chalok 1 was noted in the CO_2 treatments compared to the control. No significant differences were noted for GCB 70, in which leaf area decreased but photosynthetic rates increased progressively with CO_2 concentration. Stomatal aperture was a little bigger in the elevated CO_2 than the control. CO_2 concentration was negatively related to stomatal conductance and transpiration rates, resulting in high water use efficiency.

Keywords : atmospheric CO_2, CO_2 enrichment, maize, photosynthetic rate, stomatal conductance, evapotranspiration rate, elevated CO_2

Global warming continuously increased as the atmospheric CO_2 level increases from 315.98 ppm in 1959 up to 377.38 in 2004, showing annual increment of 1.4 ppm (Keeling C. D. and Whorf T. P., 2005). Researches on plant responses to the greenhouse gas concentration conducted in environment-controlled growth chambers reported the effects of increased photosynthetic rates, temperature and interaction (Pickering *et al.*, 1994), as well as important variations in the plant growth and yield (Baker and Allen, 1993; Allen and Boote, 2000). Under elevated CO_2, 8 out of 10 C4 plants species increased photosynthetic rates by 5~30%, and weed species in particular almost doubled (+19%) its photosynthetic stimulation (Ziska and Bunce, 1997).

Especially quite a few studies about elevated CO_2 effects on the development responses of major crops such as rice, legume and maize have been executed. Rice increased photosynthetic rates in proportion to atmospheric CO_2 concentration as well as biomass, dry root weight, number of panicles per stock, and yield (DeCosta *et al.*, 2003a, 2003b; Gesch *et al.*, 2002). Soybean also increased leaf area, photosynthetic rates, and yield in proportion to CO_2 concentration increase (Jones *et al.*, 1984; 1985a, b, c; Valle *et al.*, 1985; Campbell *et al.*, 1990; Allen *et al.*, 1990; Grashoff *et al.*, 1995). To increase soybean yield in elevated CO_2, it is important to discover the varieties that can maximize the photosynthetic efficiency (Ziska *et al.*, 2001).

Under elevated atmospheric CO_2 concentration, maize increased photosynthetic rates and biomass but decreased stomata and stomatal conductance per unit leaf area, resulting in sharp enhancement of water use efficiency (Maroco *et al.*, 1999; Leakey *et al.*, 2004). Maize cultivation did not affect bad influence from elevated atmospheric CO_2 concentration (Margrin *et al.*, 2005), and in Alberta precipitation was on the increase in 1901-2002 and therefore optimum temperature area for maize production expanded and because of extended frost-free period frost damage of the crops was greatly reduced (Shen *et al.*, 2005). Potential climate change scenario in 2040-2069 predicted that with elevated CO_2 levels expected yield from breed improvement and enhanced technology may increase 114~186% (Bootsma *et al.*, 2005).

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Thus, it needs to develop new varieties tolerant to the elevated atmospheric CO_2 levels causing climate change, and as a basic preparative step this research experimented with maize to investigate the developmental characteristics, yield, and photosynthesis-related responses like photosynthesis and transpiration rates.

MATERIALS AND METHODS

For this experiment plants were grown in the CO_2-controlled growth chambers in the phytotron of the National Institute of Crop Science (NICS) in 2006. Experimental cultivars were Chalok 1 and GCB 70 of maize. Experimental CO_2 concentrations were ambient level (350 ppm), 500 ppm, and 700 ppm. CO_2 treatment was done at the germination stage, 5-6 leaf stage, and silking stage, and lasted for 15~40 days at each stage. Growth chambers were CO_2-controlled using 99.99% pure CO_2. Chamber luminosity was 900 μmol m^{-2} s^{-1}, and inside temperature was 24℃ (max 28/min 21) during the germination and 5~6 leaf stage, and 26℃ (max 30/min 23) during the silking stage. Humidity was 70~80%, and photoperiod 12 h. For cultural practice, two varieties of maize were seeded in wagner pots (1/3000a) and immediately put into the chamber for the germination stage experiment. The rest was cultivated in an open field with covered roof. Fertilization and maintenance followed conventional pot cultivation. Investigation was performed 3 times after each growing stage treatment in an interval of 7~10 days beginning from the 7th day until the 34th day. Observed parameters were growth characteristics, photosynthetic rates and stomatal aperture. Li-6400 (USA) was used to investigate photosynthesis-related characteristics such as photosynthetic rates, transpiration rates, and stomatal conductance. Stomata were investigated under the scanning electron microscope (SEM) LEO440.

RESULTS AND DISCUSSION

Germination rates (Treated immediately after seeding)

Under elevated CO_2 germination responses of maize seeds were investigated as shown in Figure 1. Both treatment groups began to germinate 3 days after seeding: With Chalok 1, the control group germinated 37% at 3 days line after seeding, while the treatment groups did 50% (500 ppm) and 53% (700 ppm), showing 13-16% higher rates than the control. CO_2-enriched groups finished germination 2 days earlier by completing germination within 5 days from seeding, while control group 7 days. With GCB 70, the control group germinated 33% at 3 days line after seeding, while both treatment groups did 63%, showing 30% higher rates than the control. As with Chalok 1, CO_2-enriched groups finished germination two days earlier by completing it within 5 days from seeding compared to 7 days of the control. Both varieties didn't show significant differences in germination between 500 ppm and 700 ppm groups. Thus, elevated CO_2 concentration is considered to stimulate germination rates.

Developmental characteristics at seedling stage

When CO_2 was treated to maize immediately after seeding (Table 1), in the case of Chalok 1, plant height was 80 cm

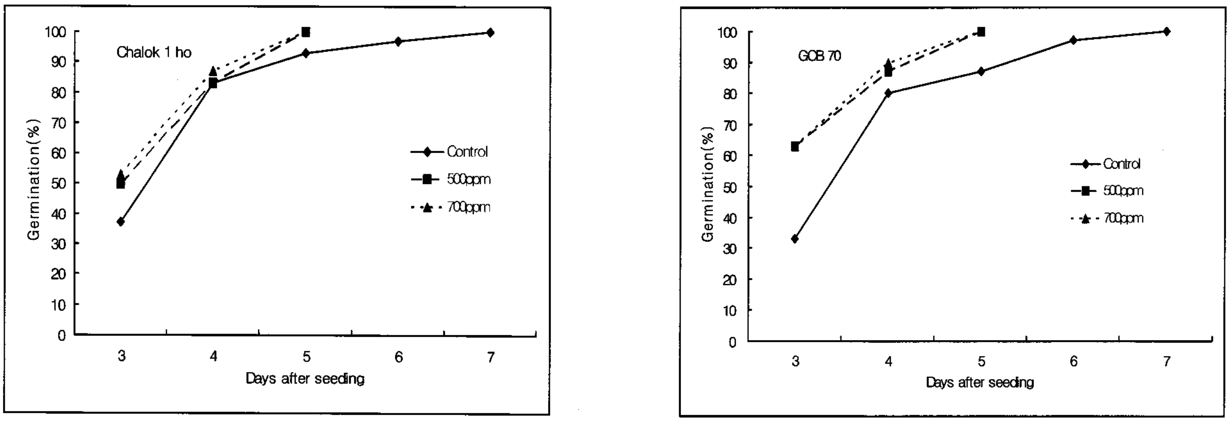


Fig. 1. Germination response of maize to CO_2 enrichment.

Table 1. Effects of CO_2 enrichment during seedling stage on the growth and photosynthetic rates of two maize varieties.

Period (days)	Cultivar	CO_2 (ppm)	Plant height (cm)	Number of leaf (No./pl.)	Leaf width (cm)	Leaf area (cm^2/pl.)	Top dry weight (g/pl.)	Photosynthetic rate†
20	Chalok 1	Control	80	5.6	1.6	282	1.1	16.8
		500	88	6.2	2.3	363	1.5	19.0
		700	96	6.4	2.4	414	1.9	22.3
	GCB70	Control	75	5.0	1.6	152	0.6	9.5
		500	81	5.4	1.7	254	1.0	17.1
		700	83	5.4	1.8	305	1.3	20.7
27	Chalok 1	Control	119	8.3	3.2	982	5.2	10.4
		500	121	8.7	3.5	1,043	6.3	18.4
		700	121	9.0	3.6	1,120	6.7	20.0
	GCB70	Control	101	7.0	2.1	660	2.1	10.5
		500	131	7.3	2.3	906	3.7	17.0
		700	135	7.0	2.8	1,219	4.3	18.0
34	Chalok 1	Control	109	9.3	3.8	1,195	5.3	7.0
		500	118	10.0	3.8	1,262	7.4	14.5
		700	156	11.3	4.1	1,604	11.0	24.3
	GCB70	Control	111	8.0	2.0	1,046	3.1	9.2
		500	149	10.3	3.9	1,544	7.8	18.1
		700	158	11.0	4.0	1,762	8.9	27.5

†Photosynthetic rate : $\mu mol\ m^{-2}\ s^{-1}$

for the control group but 88 cm (500 ppm) and 96 cm (700 ppm) for the treatment groups, showing progressively higher height with CO_2 concentration increase. Similar tendency was observed at 27 and 34 days after treatment (DAT). The plant height of GCB 70, at 20 DAT, was 75 cm for the control, and increased by 6 cm (500 ppm) and 8 cm (700 ppm) for the treatments. Investigation at 27 and 34 DAT showed still higher height than the control. For Chalok 1, the number of leaf at 20 DAT was 5.6 leaves for the control, and 6.2 (500 ppm) and 6.4 (700 ppm) for the treatments, showing positive relationship with the CO_2 concentration. The investigation results at 27 and 34 DAT were likewise increased. For GCB 70 at 20 DAT, 5.0 leaves for the control, and 5.4 for both treatment groups, showing a little increment than the control. They didn't show significant differences at 27 DAT, but at 34 DAT the control group had 8 leaves while the treatment groups had 10.3 (500 ppm) and 11.0 (700 ppm), showing 2.3~3.0 increment. Leaf width also increased for both varieties in the treatment groups compared to the control. As number of leaf and leaf width increased, leaf area increased as well for both Chalok 1 and GCB 7: Chalok 1 was 282 cm^2 for the control at 20 DAT, while 363 (500 ppm) and 414 (700 ppm) cm^2 for the treatments. At 27 and 34 DAT, increment was observed in the CO_2 treatment groups. GCB 70 likewise showed increased leaf area in the CO_2 enriched groups. Photosynthetic rates for Chalok 1 at 20 DAT were 16.8 in the control, and 19.0 (500 ppm), 22.3 (700 ppm) in the treatments, while for GCB 70, 9.5 in the control, and 17.1 (500 ppm), 20.7 (700 ppm) in the treatments, showing positive relationship with CO_2 concentration for both varieties. At 27 and 34 DAT same tendency was observed. Thus, maize increased plant height, leaf width and leaf area in proportion to CO_2 concentration, resulting in top dry weight increase, and photosynthetic rates tended to increase as well.

Samarakoon *et al.* (1996) grew maize in wet and dry soil condition under the CO_2 concentration of 362 ppm and 717 ppm and noted that under CO_2 enrichment maize in wet soil condition was significantly affected in top dry weight and plant height, while maize in dry soil condition showed increase in leaf area of 35%, top dry weight of 50%, and internode length of young plant body of 170%. During the growth period (60 days beginning from the seeding) of 10 C4 plants species, at higher levels (69 Pa) of CO_2 than ambient levels (38 Pa), 8 species increased photosynthetic rates by 5~30%, and weed species in particular almost doubled (+19%) its photosynthetic stimulation compared to crop species (+10%) (Ziska and Bunce, 1997).

The plant height development relative to CO_2 concentration beginning from germination is shown in Figure 2. For Chalok 1, the longer the treatment period, the higher the plant height in the treatment groups (both 500 and 700 ppm) compared to the control. There were no differences between 500 ppm and 700 ppm groups until 15 days from germination, but after that higher height was noted in 700 ppm. For GCB 70 as well beginning from germination, the longer the treatment period, the higher the plant height in the 500 and 700 ppm groups compared to the control. There were no differences between the 500 and 700 ppm groups, but tendency of higher height was noted in the 500 ppm group. Thus, CO_2 concentration increase stimulated plant height development.

5~6 leaf stage treatment (CO_2 treatment 35 days after seeding)

CO_2 was treated to maize plants during 5-6 leaf stage (Table 2) and at 7 DAT plant height of Chalok 1 was 107 cm in the control, and 111 (500 ppm), 114 cm (700 ppm) in

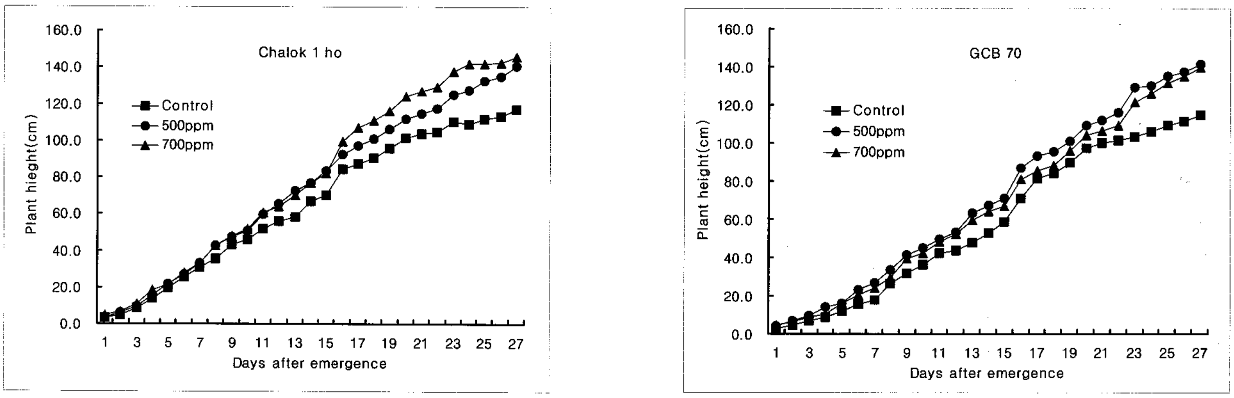


Fig. 2. Effects of CO_2 enrichment on plant height of two maize varieties at seedling stage.

Table 2. Effects of CO_2 enrichment during 5~6 leaves stage on the growth and photosynthetic rate of two maize varieties.

Period (days)	Cultivar	CO_2 (ppm)	Plant height (cm)	Number of leaf (No./pl.)	Leaf width (cm)	Leaf area (cm^2/pl.)	Top dry weight (g/pl.)	Photosynthetic rate†
7	Chalok 1	Control	107	7.3	5.0	1,043	5.5	9.7
		500	111	7.6	5.0	1,181	6.2	11.9
		700	114	7.7	5.1	1,220	6.5	10.8
	GCB70	Control	98	6.7	4.2	834	3.9	12.7
		500	103	7.7	4.3	925	4.9	12.0
		700	107	7.7	4.3	948	5.7	16.1
14	Chalok 1	Control	150	10	5.9	1,877	12.8	7.3
		500	158	10.3	6.0	1,965	14.4	9.1
		700	165	10.3	6.0	2,043	15.3	18.4
	GCB70	Control	133	9.3	5.0	1,490	9.1	6.0
		500	141	9.3	5.2	1,639	11.1	7.9
		700	145	10.3	5.3	1,905	12.3	11.5
21	Chalok 1	Control	185	11.3	7.0	2,608	27.5	9.7
		500	187	11.7	7.2	2,741	27.9	21.5
		700	189	11.7	7.3	2,824	29.4	23.0
	GCB70	Control	168	9.7	6.3	2,007	18.6	8.7
		500	185	10.0	6.4	2,025	23.2	8.1
		700	193	10.3	6.4	2,226	23.6	18.1

†Photosynthetic rate : $\mu mol\ m^{-2}\ s^{-1}$

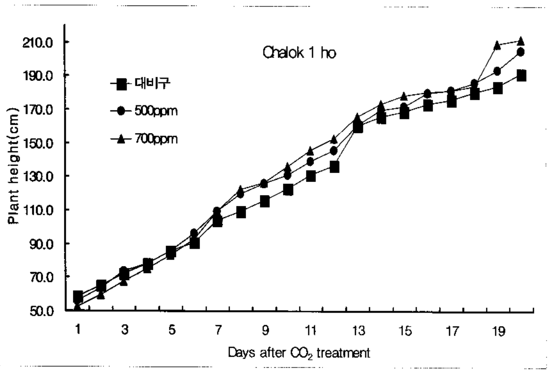
the treatments, showing positive relationship, and at 14 and 21 DAT the same tendency was noted. The plant height of GCB 70 was 98 cm in the control, and increased by 5 (500 ppm) and 9 (700 ppm) in the treatments, and at 14 and 21 DAT the same tendency was noted. The number of leaf of Chalok 1 at 7 DAT was 7.3 in the control and 7.6 (500 ppm) and 7.7 (700 ppm) in the treatments. The number of leaf increased in proportion to CO_2 concentration, but no significant differences between the 500 and 700 ppm groups. The measurements at 14 and 21 DAT also showed increase. The number of leaf of GCB 70 at 7 DAT was 6.7 in the control, and 7.7 for both treatments, showing a little increase compared to the control but no differences between the 500 and 700 ppm groups. The measurements at 14 and 21 DAT were not different. In leaf width two varieties of maize didn't show significant differences between the control and the treatments. However increased number of leaf contributed to the increase of leaf area in the treatment groups (both 500 and 700 ppm) compared to the control for both varieties. At 7 DAT leaf area of Chalok 1 was 1,043 cm^2 in the control, and 1,181 (500 ppm) and 1,220 (700 ppm) in the treatments, showing increased leaf area compared to the control, and at 14 and 21 DAT increase was noted in both treatment groups. GCB 70 also showed increased leaf area in the treatment groups. Photosynthetic rates of Chalok 1 at 7 DAT was 9.7 in the control and 11.9 (500 ppm) and 10.8 (700 ppm) in the treatments, showing increase compared to the control but slight decrease in the 700 ppm group. Photosynthetic rates of GCB 70 was 12.7 in the control and 12.0 (500 ppm) and 16.1 (700 ppm) in the treatments, showing those of the 500 ppm group lower than the control, but those of 700 ppm group higher than the control. At 14 and 21 DAT photosynthetic rates of GCB 70 showed increasing tendency in the treatment groups compared to the control. Thus, as the CO_2 concentration increased, the 5-6 leaf stage indicated top dry weight increase resulting from the increase of plant height, leaf width, and leaf area, as well as photosynthetic rates.

Leakey *et al.* (2004) grew maize in SoyFACE under ambient (354 ppm) and elevated (549 ppm) CO_2, and found out that under elevated CO_2, photosynthetic CO_2 uptake rates could be increased up to 41%, but during the rainfall season there were no differences between the plants. They also reported that during the whole cultivation period elevated CO_2 around the leaves increased photosynthetic rates an average of 10%.

Plant height development relative to CO_2 concentration observed after CO_2 treatment is shown in Figure 3. Both Chalok 1 and GCB 70 showed increased plant height in proportion to the length of CO_2 treatment period in the two treatment groups compared to the control, but no significant differences between the 500 ppm and 700 ppm groups.

Silking stage treatment (CO_2 treatment 60 days after seeding)

CO_2 was treated at the silking stage (Table 3) and plant height of Chalok 1 at 8 DAT was 170cm in the control, and 174 (500 ppm) and 172 (700 ppm) in the treatments, showing no significant difference relative to CO_2 concentration, and same inclination was noted at 15 DAT. The plant height of GCB 70 at 8 DAT was 168 cm in the control and 169 (500 ppm) and 173 (700 ppm) in the treatments,



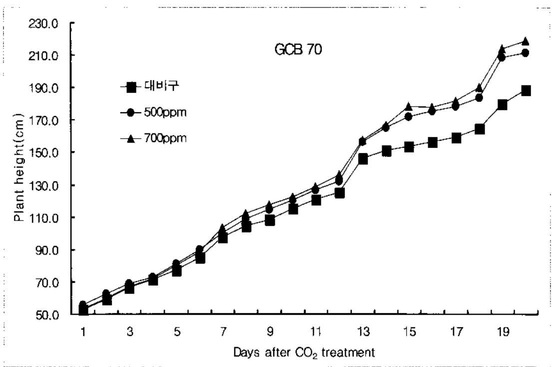


Fig. 3. Effects of CO_2 enrichment on plant height of two maize varieties at 5~6 leaves stage.

Table 3. Effects of CO_2 enrichment during silking stage on the growth and photosynthetic rates of two maize varieties.

Period (days)	Cultivar	CO_2 (ppm)	Plant height (cm)	Number of leaf (No./pl.)	Leaf width (cm)	Leaf area (cm^2/pl.)	Top dry weight (g/pl.)	Number of seed (No./pl.)	Photosynthetic rate†
8	Chalok 1	Control	170	11.0	8.3	3,273	38.7	0	18.9
		500	174	12.0	7.3	2,792	35.5	1.0	23.1
		700	172	11.7	7.1	2,507	35.5	1.0	27.0
	GCB 70	Control	168	10.0	8.2	2,603	32.4	0	5.2
		500	169	9.7	7.9	2,422	29.0	0	6.8
		700	173	10.0	8.0	2,431	33.1	0	27.7
15	Chalok 1	Control	174	12.7	5.2	2,954	36.3	1.3	11.5
		500	189	12.0	6.0	2,730	37.3	1.7	16.4
		700	187	11.7	5.8	2,596	36.1	1.7	18.8
	GCB 70	Control	196	11.3	7.0	3,282	41.2	0.7	3.6
		500	196	11.0	6.7	2,535	45.8	0.7	14.7
		700	194	11.3	6.6	2,504	45.4	1.3	21.4

†Photosynthetic rate : μmol m-2 s-1

showing no significant difference, and at 15 DAT still no significant differences were noted compared to the control. These investigation results suggest that as vegetative growth is converted into reproductive growth, increased CO_2 concentration doesn't seem to affect the development of plant height. The number of leaf of Chalok 1 at 8 DAT was 11.0 in the control, and 12.0 (500 ppm) and 11.7 (700 ppm) in the treatments, showing positive relationship with the CO_2 concentration, but at 15 DAT no significant differences were observed. The number of leaf of GCB 70 at 8 DAT was 10.0 in the control, and 9.7 (500 ppm) and 10.0 (700 ppm) in the treatments, showing no significant differences from the control, and at 15 DAT still no significant differences were observed. Leaf width showed no significant differences between the control and both treatment groups in both varieties. However, leaf area decreased in the treatment groups of Chalok 1 and GCB 70 compared to the control: Chalok 1 at 8 DAT was 3,273 cm^2 in the control, and 2,792 (500) and 2,507 (700 ppm) in the treatments, showing decrease compared to the control, and at 15 DAT leaf area decreased in both treatment groups. GCB 70 likewise showed decreased leaf area in the CO_2 enriched groups. These results are considered to be caused by withering of bottom leaves as corn grains mature, and development seems to be stimulated in the CO_2 elevated groups compared to the control. Grain formation was faster in the CO_2 enriched groups than the control, and faster in Chalok 1 than in GCB 70. Photosynthetic rates at 8 DAT was, for Chalok 1, 18.9 in the control, and 23.1 (500) and 27.0 (700) in the treatments, and for GCB 70, 5.2 in the control, and 6.8 (500) and 22.7 (700) in the treatments, showing positive relationship between the CO_2 concentration and photosynthetic rates for both varieties. Thus, as maize moves from the vegetative growth period to the reproductive growth period, CO_2 concentration seems to stimulate development, and thus stimulate grain formation, too.

Figure 4 shows the plant height development relative to the CO_2 concentration since the CO_2 treatment time at silking stage. Chalok 1 showed more growth in height in the CO_2 treatment groups than in the control, but GCB 70 showed less growth in the 700 ppm group.

It appears that Chalok 1, already having entered the reproductive growth period during the silking stage, developed plant height consistently without significant differences between the treatment groups, whereas GCB 70 accelerated its growth in response to CO_2 increase and thus the 700 ppm treatment group entered the reproductive growth period earlier than the 500 ppm group and decreased plant height compared to the control.

Climate change affected maize yield to increase up to 18% in 1970-99 compared to 1950-70 and therefore climate change didn't affect yield drop of maize cultivation (Margrin *et al.*, 2005). Shen *et al.* (2005) analyzed long-term trend (1901-2002) of climate change and in Alberta the rainfall in May-August increased 14% in 2002 compared to 1901, thus annual

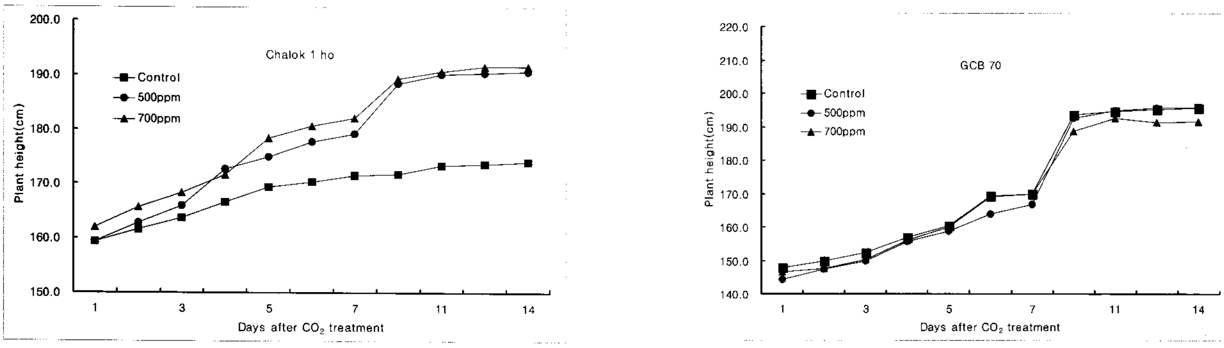


Fig. 4. Effects of CO_2 enrichment on plant height of two maize varieties at silking stage.

precipitation showed increasing tendency similar to maize yields, and maize cultivation area extended to the north about 200~300 km during 1973-2002 compared to 1913-1932, and 50~100 km compared to 1943-1972. They also mentioned that the increase of frost-free period could contribute to the decrease of frost damage, and northward extension of the maize growth area also expanded the growth area of other crops. General Circulation Model (GCM) experimentation for 2040-2069 predicted that with elevated CO_2 condition together with breed improvement and enhanced technology maize yield could increase up to 114~186% (Bootsma *et al.*, 2005).

Stomatal aperture relative to CO_2 concentration

Stomatal apertures were investigated at 34 DAT and the results are shown in Figure 5. Both Chalok 1 and GCB 70 increased stomatal size with the CO_2 concentration increase and surrounding epidermal cells transformed their shapes.

Maize plants grown under elevated CO_2 (1100 ppm) had 10% less stomata per unit leaf area than those under ambient level (350 ppm) (Maroco *et al.*, 1999). Investigation of the stomata of plant specimens collected during the past century revealed that increased CO_2 concentration with time passage had correlation with stomatal density (Woodward, 1987), and resulted in improved water use efficiency (Woodward, 1993).

Thus, the increase of ambient CO_2 concentration is considered to affect the stomata of maize plants, and the impact of ambient CO_2 elevation needs to be further examined.

The correlation of photosynthetic rates, stomatal conductance and transpiration rates

When photosynthetic rates increase, stomatal conductance increases, too, but the increase ratio of stomatal conductance relative to photosynthetic rate increase appeared lower in the

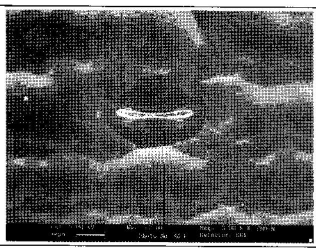
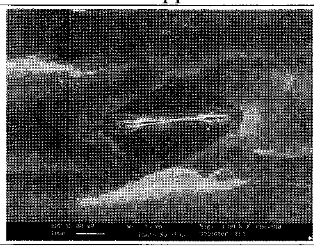
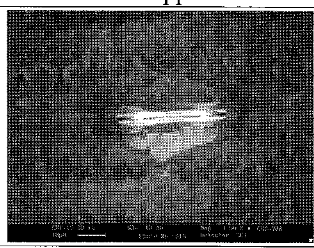
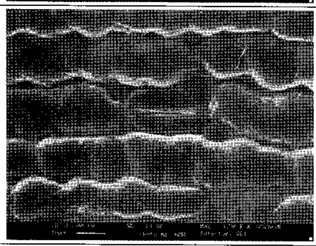
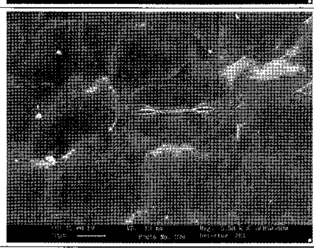
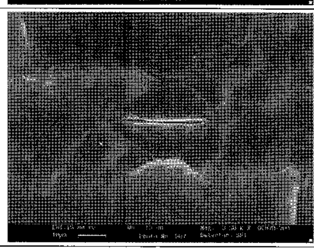
Cultivar	Control	500 ppm	700 ppm
Chalok 1			
GCB 70			

Fig. 5. Changes of stomata according to the concentration of CO_2 at early growth stage in the 2 maize varieties.

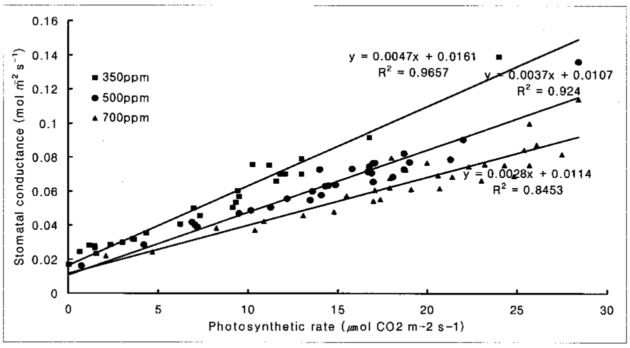


Fig. 6. Changes in photosynthetic rates and stomatal conductance according to the CO_2 concentration.

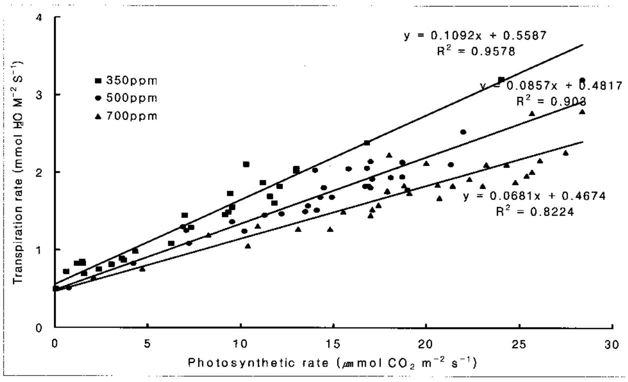


Fig. 7. Changes in photosynthetic rates and transpiration rates according to the CO_2 concentration.

high CO_2 treatment group than the low one (Fig. 6). Most plants transpire less per unit leaf area when atmospheric CO_2 increases, and thus stomatal conductance decreases but leaf area index increases. Maize plants grown under elevated CO_2 decreased stomatal conductance up to 71%, and thus increased water use efficiency by 225% (Marco *et al.*, 1999). Stomatal conductance of maize decreased 23% under elevated CO_2 compared to the ambient level, and transpiration rates decreased too (Leakey *et al.*, 2004). When CO_2 concentration doubled, generally stomatal conductance decreased by 40% and water usage by crops in chambers or experimental field dropped to below 10%, and in the aspect of actual change of evapotranspiration, crop energy balance was controlled by stomatal conductance, leaf area index, crop structure, and climate elements (Allen. 1996).

Transpiration rates, as with stomatal conductance, increased with the photosynthetic rate increase, and transpiration rate increase accompanied by increased photosynthetic rates was more significant in the low CO_2 treatment group than the high one (Fig. 7). Samarakoon *et al.* (1996) treated CO_2 to maize plants in wet soil and dry soil condition in the level of 362 ppm and 717 ppm, and in the wet soil condition transpiration rates decreased by an average of 29% in the 717 ppm group, and water use decreased by 25%, while water use efficiency increased on the whole because water usage decreased in elevated CO_2. In the dry soil condition the 717 ppm group showed reduced water use by 30% and increased soil moisture content compared to the atmospheric CO_2 treatment group.

Leakey *et al.* (2004) mentioned that the lower stomatal conductance and transpiration observed in elevated CO_2 condition would prevent the spreading of moisture stress, and the obstruction to leaf CO_2 accumulation in ambient CO_2. Rice showed the same tendency (Kim *et al.*, 2005), and Widodo *et al.* (2003) observed that during the entire growth period of rice under the CO_2 concentration of 350 ppm and 700 ppm, drought damage was more drastically noted in the nature growth groups than in the CO_2 treated groups, and in elevated CO_2 drought-resistant period was longer and recovery was faster. Also in legume, plants grown in elevated CO_2 showed more increase of water use efficiency by increased photosynthesis than by decreased respiration (Allen *et al.*, 1985; Kim *et al.*, 2006). When CO_2 concentration increased, water use efficiency also increased not much by the decreased water loss by partial closure of stomata but more by increased photosynthesis (Allen 1996).

In conclusion, as the atmospheric CO_2 concentration keeps increasing, maize will increase photosynthetic rates and plant body production rates alongside water use efficiency caused by decreased water loss from transpiration.

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