Effect of elevated CO_2 concentration on net photosynthetic rate and dry matter production of spring wheat in the Tibet plateau

Shigeto Fujimura[1], Pei-Li Shi[2], Kazuto Iwama[1], Xian-Zhou Zhang[2], Junichi Yamaguchi[1], Yun-Fen Liu[2], O. Shuhou[1] and Zhi-Ming Zhong[2]

[1]Crop Science Laboratory, Department of Botany and Agronomy, Hokkaido University, Sapporo, 060-8589, Japan, www.agr.hokudai.ac.jp/botagr/sakumotsu/ Email fps1f99@res.agr.hokudai.ac.jp, iwama@res.agr.hokudai.ac.jp, yama@chem.agr.hokudai.ac.jp , wang@env.agr.hokudai.ac.jp
[2]Institute of Geography Science and Natural Resources Research, Chinese Academy of Sciences, Beijing, 100101,China, shipl@igsnrr.ac.cn, zhangxianzhou@hotmail.com, Liuyunfen@btamail.net.cn

Abstract

Lhasa on Tibet plateau, China is located about 3700 m altitude and has lower CO2 and O2 partial pressure, lower night air temperature and high radiation compared with low altitude area on the same latitude. Because of this specific growth condition, it is anticipated that the responses to increased [CO2] might be different from those in low altitude area. To clarify the effect of increased [CO2] on crop production in this area may give useful information for estimating future crop production not only in this region but also in the world.

Media summary

Elevated CO_2 concentration increased net photosynthetic rate and dry matter production before heading but not after heading and decreased yield because of early leaf senescence.

Key Words

leaf senescence, nitrogen deficit, SPAD value, temperature, yield

Introduction

CO_2 concentration ([CO_2]) of the atmosphere increased from 290 μmol/mol to 360 μmol/mol for the last 100 years (Friedli et al. 1986; Keeling et al. 1995) and this [CO_2] increase coupled with the increase of air temperature is likely to continue this century (Schimel et al. 1994; Kttenberg et al. 1995). Many investigations have been made to clarify the effect of elevated [CO_2] on crop production (Amthor 2001; Okada et al. 2001; Schapendonk et al. 2000; Kang et al. 2002). In general, it is reported that elevated [CO_2] increases the dry matter production during the vegetative growth stage (Mitchell et al. 1999; Wall et al. 2000) and yield (Amthor 2001) in wheat. Moot et al. (1996) and Batts et al. (1998), however, reported that high temperature shortens the growth period and decreases the yield.

Lhasa on Tibet plateau, China is located about 3700 m altitude and has lower CO2 and O2 partial pressure, lower night air temperature and high radiation compared with low altitude area on the same latitude. Because of this specific growth condition, it is anticipated that the responses to increased [CO2] might be different from those in low altitude area. To clarify the effect of increased [CO2] on crop production in this area may give useful information for estimating future crop production not only in this region but also in the world.

Methods

Carbon dioxide treatment

12 open top chambers (3 m in the length and the width, 2 m in the height) were installed before seeding in the experimental field of Lhasa Agroecosystem Research Station, Chinese Academy of Sciences (Lhasa, China, 29^{o}41' N, 3688 m above sea level). The [CO_2] treatment of two levels of atmospheric [CO_2]

(ambient and more elevated) arranged in a randomized complete block design with six replicates. Carbon dioxide was supplied from the gas firing equipment (CG-253S2G, Nepon Co., Ltd.) and injected into the blower 13 hours/day (0500-1800 in true solar time). The blower supplied 1800 m^3/h air (approximately 2500μmol CO_2/mol) to 6 elevated chambers through plastic pipes, which were placed above the canopy. In the ambient chambers, air was not blown and narrow plastic films were set above the canopy to provide shading similar to that of the elevated chambers. [CO_2], air temperature and relative humidity in both treatments were measured seven times during growth using portable open gas-exchange system (LI-6400, LI-COR, Lincoln, USA). The crop emerged on 15 May 2001 (DAE0) and the [CO_2] treatment was applied from DAE4 (19 May) until the day before harvesting (2 October, DAE140).

Cultural practices

Spring wheat (*Triticum aestivum* L. cv.'3u-90' cultivated in the Tibet plateau) was sown in the chambers on 3 May 2001 in rows spaced 0.25 m apart at a rate of 550 seeds per m^2. N, P_2O_5 and K_2O were applied at seeding at a rate of 40, 18 and 11 kg/ha, respectively, and at heading stage at a rate of 35, 6 and 4 kg/ha, respectively. Sheep manure was also applied at seeding at a rate of 10 t/ha.

Measurements

Net photosynthetic rate and stomatal conductance of uppermost fully expanded leaf on major tiller were measured ten times during growth using LI-6400. The photosynthetic photon flux during measurements was maintained at 1600 μE/m^2/s and the leaf temperature was controlled at 20.9 ±1.2 ^oC (average±standard deviation, n=6) and 24.9 ±0.05 ^oC (n=14) before and after DAE35, respectively. The chlorophyll concentration of upper three leaves on major tiller was measured every week from heading stage until leaf senescence using portable chlorophyll meter (SPAD-502, Minolta Camera Co., Ltd., Japan). These measurements were conducted in three plots for each treatment.

Plants in each 0.3 m^2 in all plots were cut above the ground at heading stage. Samples were divided into leaf blades, leaf sheaths and culms, senescence leaf blades and panicle, and then dry weights were measured. On 3 October, plants in each 1 m^2 in all plots were cut above the ground to measure seed dry weight and yield components.

Results

[CO_2] was about 380 μmol/mol in ambient plots and 580 μmol/mol in elevated plots (Table 1). Air temperature was 0.9 ^oC higher in elevated plots than in ambient plots.

Table 1. CO_2 concentration ([CO_2]), air temperature and relative humidity at the top of the canopy. Measurements were conducted at 0800 on 22 May, 25 May, 30 May, 3 Jun. and 21 Sep., and at 1600 on 21 Jul. and 31 Aug. The number in parenthesis is standard deviation (n=7).

Plot	[CO_2] (μmol/mol)	Air temperature (^oC)	Relative humidity (%)
Ambient	378 (13)	24.3 (3.9)	36.0 (12)
Elevated	579 (59)	25.2 (4.6)	35.0 (13)

Net photosynthetic rate was higher in elevated plots than in ambient plots until DAE75, but the difference became small after DAE75 (Figure 1). Stomatal conductance (g_s) was slightly lower in elevated plots than in ambient plots during growth.

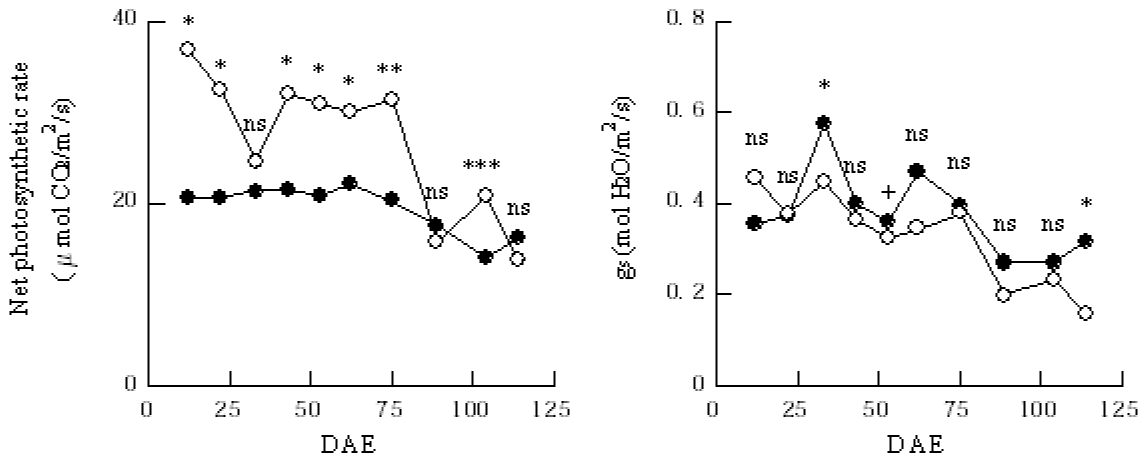

Figure 1. Net photosynthetic rate and stomatal conductance (g_s) in ambient plots (filled circles) and in elevated plots (open circles). *, **, *, † and ns for $p<0.001$, $p<0.01$, $p<0.05$, $p<0.1$, and not significant, respectively.**

Panicle number and total dry weight above ground at heading stage was larger in elevated plots than in ambient plots, but not significant ($p \geq 0.1$), (Table 2). Panicle dry weight was larger in elevated plots than in ambient plots at 10% level.

Table 2. Panicle number and dry weight at heading stage. The number in parenthesis is standard error (n=6).

		Dry weight (g/m^2)				
Plot	Panicle number (/m^2)	Leaf blade	Leaf sheath and culm	Panicle	Senescence leaf blade	Total
Ambient	599 (42)	271 (23)	836 (72)	178 (27)	117 (15)	1401 (110)
Elevated	637 (47)	256 (24)	845 (83)	228 (25)	143 (13)	1472 (126)

Though chlorophyll contents (SPAD value) of upper three leaves were the same in both treatments at heading stage, SPAD value started to decrease earlier in elevated plots than in ambient plots (Figure 2). This suggested the nitrogen deficit in elevated plots and/or higher air temperature in elevated plots might accelerate the leaf senescence.

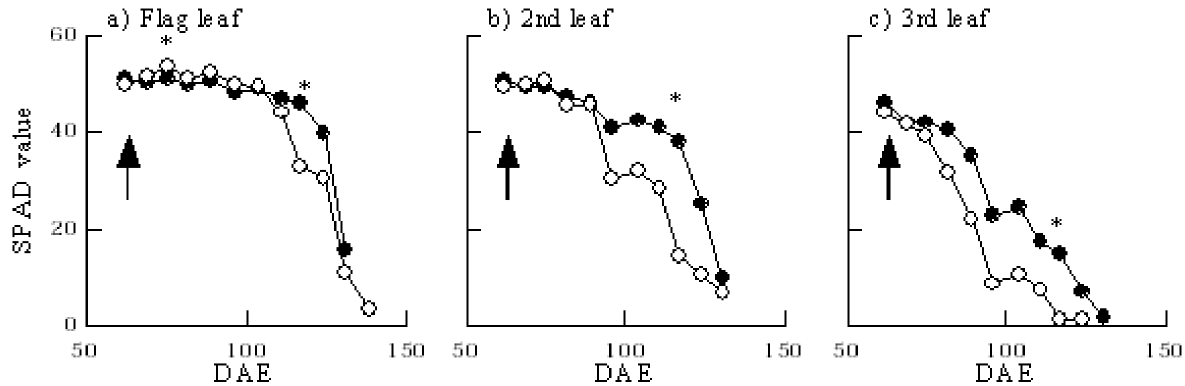

Figure 2. Chlorophyll contents (SPAD value) in ambient plots (filled circles) and in elevated plots (open circles) after heading stage. a) Flag leaf, b) 2nd leaf from flag leaf and c) 3rd leaf from flag leaf. Arrows indicate the heading stage. * and no mark for $p<0.05$ and not significant, respectively.

Yield was smaller at 10% level in elevated plots than in ambient plots, although there was no significant difference between treatments in yield components (Table 3).

Table 3. Yield components. Thousand-grain weight and yield were calculated as 12.5% water content. The number in parenthesis is standard error (n=6).

Plot	Panicle number ($/m^2$)	Grain number per panicle	Grain number (thousand/m^2)	Thousand grain weight (g)	Yield (g/m^2)
Ambient	594 (39)	27.8 (1.5)	16.8 (1.9)	41.9 (1.6)	702 (81)
Elevated	589 (18)	26.9 (2.1)	15.9 (1.4)	38.1 (2.2)	610 (70)

Conclusion

Since the net photosynthetic rate was higher in elevated plots than in ambient plots, the dry matter production during vegetative growth stage was slightly higher in elevated plots. However, because the leaf senescence occurred earlier in elevated plots, the difference in the net photosynthetic rate between treatments became small after DAE75. Higher air temperature and/or nitrogen deficit in elevated plots might be responsible for this early leaf senescence. As a result, the dry matter production after heading stage was smaller in elevated plots. This resulted in lower yield in elevated plots than in ambient plots.

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