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Energy Procedia 63 (2014) 3209 – 3214
Energy Procedia

GHGT-12

Effects of CO_2 Leakage from CCS on the Physiological Characteristics of C4 Crops

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Abstract

The study of physiological impact on crops are important area of ecological impacts on CO_2 leakage on CCS. Physiological effects of CO_2 to C4 Crops were simulated with CO_2 artificial climate chamber in this paper. The main conclusions are as follows:

(1) When CO_2 concentration was less than 20000μmol/mol, net photosynthetic rate, transpiration rate and stomatal conductance of four C4 crops were increased with the increasing of CO_2 concentration. When CO_2 concentration was higher than 20000μmol/mol, the three indicators were decreased with the increasing of CO_2 concentration. The indicators of the four C4 crops were reached the maximum values at 20000 μmol/mol of CO_2 concentration and the minimum values at 80000 μmol/mol respectively. The impacts of CO_2 to corn and sorghum were greater than that of millet and broom corn millet.

(2) Intercellular CO_2 concentrations of the four C4 crops were increased with increasing of CO_2 concentration, but their growth rates were decreased gradually.

(3) With the increase of CO_2 concentration, the leaf temperature of four C4 crops showed the opposite rule with net photosynthetic rate, transpiration rate and stomatal conductance.

Peer-review under responsibility of the Organizing Committee of GHGT-12

Keywords: CCS; Risk; C4 crops; Physiological indicator.

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Peer-review under responsibility of the Organizing Committee of GHGT-12
doi:10.1016/j.egypro.2014.11.346

1. Introduction

CCS (Carbon dioxide capture and storage, CCS) is considered to be the most promising and potential technology of CO_2 emission reduction [1]. However, because of the risk of leakage in CO_2 capture, transport and storage of CCS technology, the potential environmental impacts of CCS technology has aroused widespread concern of the government and the public [2]. The high CO_2 concentration resulted from CO_2 leakage of CCS have a major impact on water environment, soil environment, growth and development of plants and animals as well as human security, will bring local and global environmental impact [3,4]. C4 plants are the results of plant evolution adapted to low concentrations of CO_2. Their reactions may be may be most sensitive to high concentrations of CO_2. Therefore, the study of the effects of high concentrations of CO_2 on C4 crop photosynthetic physiology indicators has an extremely important value for assessing the ecological effects of CCS leaks.

2. Methods and Materials

2.1. Experimental crops and soil

Four typical C4 crops were selected in this study. These crops were corn (*Zea mays* L., Ximeng on the 6th), sorghum (*Sorghum bicolor* L. Moench, Jinza on the 12th), millet (*Setaria italica* L. Beauv, Jingu on the 29th), and broom corn millet (*Panicum miliaceum* L., neiMi on the 5th). Soil was sampled from the farmland in Jingbian County, CO_2 injection test area of Shaanxi Yanchang Petroleum Co. Ltd.[5]. The soil type belongs to regosols on Loess Plateau, and was named as Huangmiantu soil. its texture is sandy loam.

2.2. Experimental methods

The occurrence of CO_2 leakage from CCS technology results in a high CO_2 concentration environment. In this experiment, a CO_2 artificial climate chamber (RXZ-500C-CO_2, Ningbo, China) was used to simulate the high CO_2 concentration environment of CO_2 leakage from CCS technology. The artificial CO_2 climate chamber's temperature ranged from 0 °C to 50 °C. The relative humidity (RH) was controlled within 30%–95%. Illumination was within 0 lux–22000 lux and multi-adjustable. The CO_2 concentration reached the maximum at 100000μmol/mol, and the target was set according to the experimental needs.

Five CO_2 concentration gradients were set, i.e. CO_2 concentration of normal atmospheric (as the control group), and 10000, 20000, 40000, and 80000μmol/mol CO_2. The experiment was repeated three times at each CO_2 concentration gradient, and the changes in physiological characteristics of each C4 crop were observed. The conditions of the artificial CO_2 climate chamber were as follows: day, 12h; temperature, 25°C; RH, 80%; and light intensity, 100%RH; and night, 12h; temperature, 20 °C; RH, 80%; and light intensity, 20% RH.

An LI-6400X photosynthesis analyzer (Nebraska, USA) was used to measure the crop physiological indicators. These physiological indicators include the net photosynthetic rate (Pn), transpiration rate (Tr), stomatal conductance (Co), intercellular CO_2 concentration (Ci), and leaf temperature (Tleaf).

2.3. Experimental procedure

The physiological experiments under five CO_2 concentration gradients were strictly performed as follows:

(1) 8 to 10 pots were prepared for each crop seeds. Experimental treated soil was placed into the pots, and the four crop seeds were planted and put into the CO_2 artificial climate chamber without passing into CO_2 firstly.

(2) Crops were allowed to grow until the appearance of several leaves (usually 10 d–12 d after planting; various crops were at the second to third leaf stage). 6 to 8 pots crops well-grown were selected for each species and passed into the required CO_2 concentration in the CO_2 artificial climate chamber.

(3) The crops were cultivated for 3 weeks (21 days) in the CO_2 artificial climate chamber and watered regularly. After 21 days, 5–10 strains were selected for every species, the indicators of net Pn, Tr, Co, Ci and Tleaf of each crop were measured multiple.

2.4. Data statistics

The physiological indicators of each crop were recorded under different CO_2 concentration gradients. The irrelevant data were excluded. The average of multiple measurements were obtained as the final reference data.

3. Results and analysis

3.1. CO_2 effects on Pn, Tr, and Co of C4 Crops

The impacts of CO_2 leakage on the Pn, Tr, and Co of the four C4 crops under normal conditions, and 10000μmol/mol, 20000μmol/mol, 40000μmol/mol, and 80000 μmol/mol CO_2 concentration were shown in Figures 1–12.

Figures 1–12 showed that the Pn, Tr, and Co of corn and sorghum were higher than those of the control group as the CO_2 concentration increased until 10000 and 20000 μmol/mol. These three indicators reached the maximum when the CO_2 concentration was 20000 μmol/mol. When the CO_2 concentration reached 20000 μmol/mol, the Pn, Tr, and Co of corn increased by 67.33%, 91.75% and 43.63% respectively, and those of sorghum increased by 51.49%, 84.39% and 77.43% respectively, compared with those of the control group. However, when the CO_2 concentration increased to 40000 and 80000 μmol/mol, the Pn, Tr, and Co of corn and sorghum were lower than those in the control group. The three indicators reached the minimum when the CO_2 concentration was 80000 μmol/mol. the Pn, Tr, and Co of corn at 80000 μmol/mol of CO_2 concentration decreased by 35.73%, 46.51% and 34. 90% respectively, and those of sorghum decreased by 22.39%, 41.51 and 35.68% respectively, compared with those of the control group.

The Pn, Tr, and Co of millet and broom corn millet were higher than those in the control group when the CO_2 concentration reached 10000, 20000, 40000 μmol/mol. The three indicators reached the maximum when the CO_2 concentration was 20000 μmol/mol. The Pn, Tr and Co of the millet increased by 57.20%, 57.33% and 71.99% respectively, and those of broom corn millet increased by 35.70%, 71.67% and 81.75% respectively compared with those of the control group. However, when the CO_2 concentration was 80000 μmol/mol, the Pn, Tr, and Co of millet and broom corn millet were lower than those in the control group, and the three indicators reached the minimum. The Pn, Tr, and Co of millet decreased by 10.47%, 6.89% and 30.85% respectively, and those of broom corn millet decreased by 16.28%, 2.85% and 28.17% respectively at 80000 μmol/mol of CO_2 concentration, compared with those of the control group.

3.2. CO_2 effects on Ci of C4 Crops

The impacts of CO_2 leakage on the Ci of the four C4 crops under normal conditions and 10000μmol/mol, 20000μmol/mol, 40000μmol/mol, and 80000 μmol/mol CO_2 are shown in Figure 13.

Figure 13 showed that the Ci of the four C4 crops were increased synchronously, but their growth rates were decreased with increasing of CO_2 concentration. The Ci of the four C4 crops reached the maximum and increased by 22.64%, 30.32%, 12.36% and 11.22% respectively when the CO_2 concentration was 80000 μmol/mol.

3.3. CO_2 effects on Tleaf of C4 Crops

The impacts of CO_2 on the Tleaf of the four C4 crops under normal conditions and 10000, 20000, 40000, and 80000 μmol/mol CO_2 are shown in Figure 14.

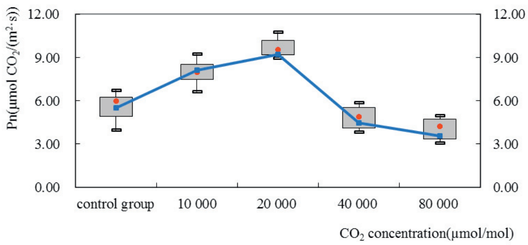

Figure 1 Net photosynthetic rate (Pn) of corn under different CO_2 concentration

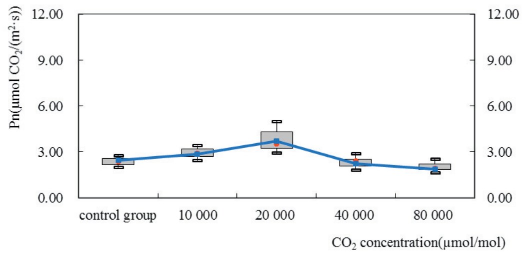

Figure 2 Net photosynthetic rate (Pn) of sorghum under different CO_2 concentration

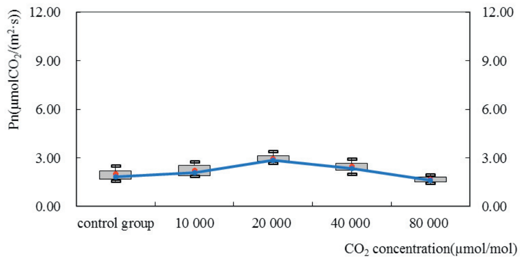

Figure 3 Net photosynthetic rate (Pn) of millet under different CO_2 concentration

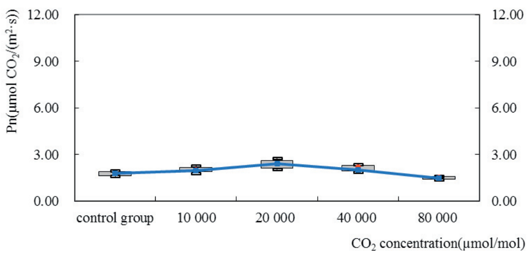

Figure 4 Net photosynthetic rate (Pn) of broom corn millet under different CO_2 concentration

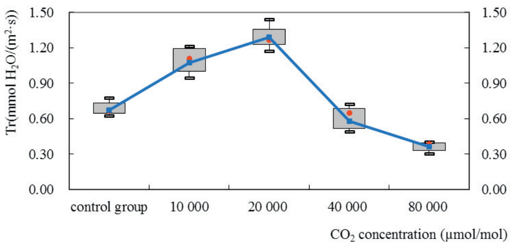

Figure 5 Transpiration rate (Tr) of corn under different CO_2 concentration

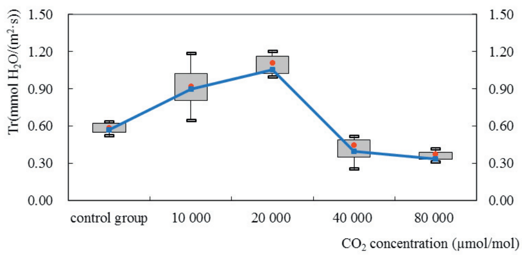

Figure 6 Transpiration rate (Tr) of sorghum under different CO_2 concentration

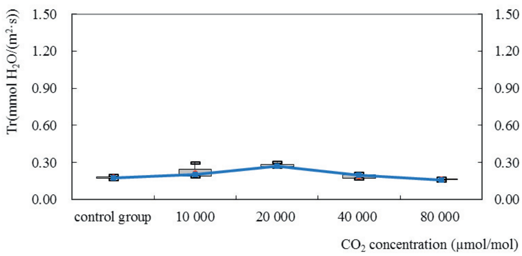

Figure 7 Transpiration rate (Tr) of millet under different CO_2 concentration

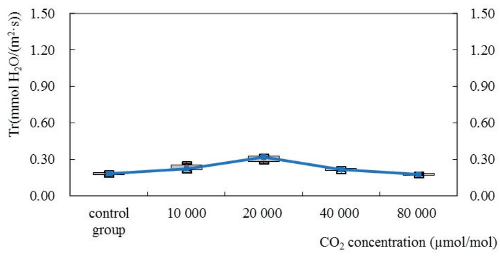

Figure 8 Transpiration rate (Tr) of broom corn millet under different CO_2 concentration

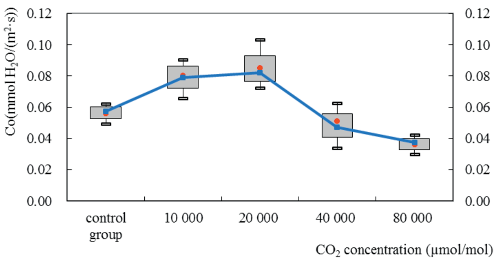

Figure 9 Stomatal conductance (Co) of corn under different CO_2 concentration

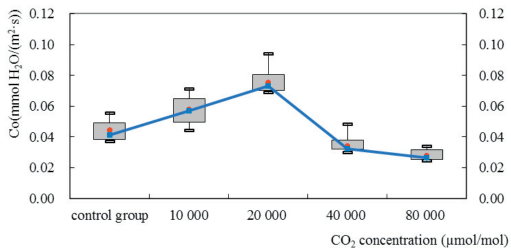

Figure 10 Stomatal conductance (Co) of sorghum under different CO_2

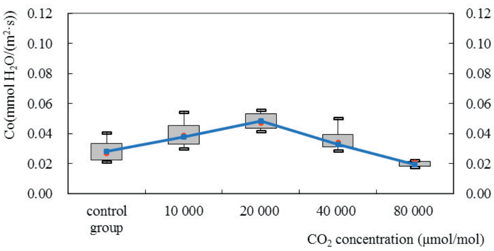

Figure 11 Stomatal conductance (Co) of millet under different CO_2 concentration

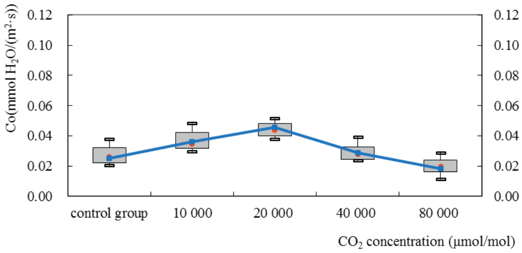

Figure 12 Stomatal conductance (Co) of broom corn millet under different CO_2 concentration

Figure 14 showed that various CO_2 concentrations simulating CO_2 leakage from CCS promoted and inhibited the Tleaf of the C4 crops, but the effect was not significantly evident. The Tleaf of corn and sorghum were lower than that in the control group when the CO_2 concentration increased to 10000 μmol/mol and 20000 μmol/mol, but they were higher than that in the control group when the CO_2 concentration reached 40000 μmol/mol and 80000 μmol/mol. The Tleaf of millet and broom corn millet were lower than that in the control group when the CO_2 concentration reached 10000, 20000, and 40000 μmol/mol, but they were higher than that in the control group when the CO_2 concentration reached 80000 μmol/mol. Moreover, the Tleaf of the four C4 crops under 20000 μmol/mol CO_2 reached the minimum value, whereas that under 80000 μmol/mol CO_2 reached the maximum value. Compared with control group, the Tleaf of corn, sorghum, millet and millet were increased by 8.32%, 7.24%, 4.19% and 4.67% at 20000μmol/mol of CO_2 concentration respectively, and those were decreased by 2.58%, 0.82%, 1.11% and 2.66% at 80000μmol/mol of CO_2 concentration respectively.

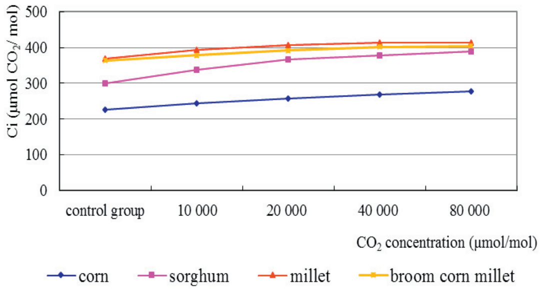

Figure 13 Intercellular CO_2 concentration of C4 crops under different CO_2 concentration

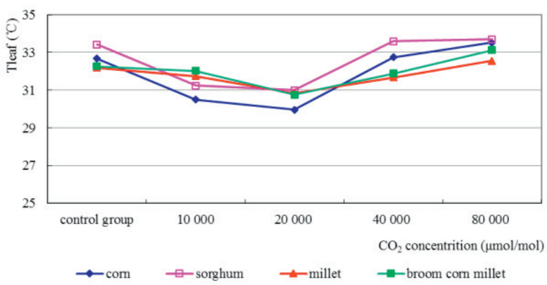

Figure 14 Leaf temperature of C4 crops under different CO_2 concentration

4. Conclusion and discussion

The Pn, Tr, and Co of the four C4 crops reached the maximum when the CO_2 concentration was 20000 μmol/mol and reached the minimum when the CO_2 concentration was 80000 μmol/mol. The impacts of the various CO_2 concentrations on the four C4 crops were different. The influence of corn and sorghum were more significant than that of millet and broom corn millet. The following reasons may explain this phenomenon. The Pn, Tr, and Co of the three indicators have a significant relationship with leaf area, and the leaf areas of corn and sorghum are significantly larger than those of millet and broom corn millet. Therefore, the responses of corn and sorghum on CO_2 concentration were more significant than that of millet and broom corn millet when the CO_2 concentration changed in the environment.

The Ci of the four C4 crops were increased synchronously, but their growth rates were decreased with increasing of CO_2 concentration. This result may be due to the increasing CO_2 concentration in the environment, which gradually filled the leaf stomata of the C4 crops by diffusion. When the CO_2 concentration reached a certain value, the Ci of the four C4 crops were gradually saturated, and thus their growth rates decreased.

With the increase of CO_2 concentration, The Tleaf of four C4 crops showed the opposite rule with Pn, Tr and Co. According to Tang's research, Tleaf was positively correlated with ambient temperature and photosynthetic rate, and was negatively correlated with transpiration rate [6]. Ambient temperature and photosynthesis were controlled in the test, so the negative correlation between Tleaf and Tr was proved again in this paper.

Acknowledgement

This work is sponsored by 863 Program Grant 2012AA050103 of Ministry of Science and Technology of China.

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