Effects of simulation leakage of CCS on physical-chemical properties of soil

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Abstract

Because of the risk of leakage with CCS (Carbon Capture and Sequestration) projects, the near surface ecological impact is considered to be an important area on CCS. In order to research soil impact of CCS, physical-chemical properties of soil were analyzed through the simulation in CO\textsubscript{2} artificial climate chamber. The results showed as follows: Soil particle size distribution and the concentrations of heavy metal have no significant impacts with the elevated of CO\textsubscript{2} concentration. All ionic concentration except HCO\textsubscript{3}\textsuperscript{-} descended slightly at low concentration and increased obviously at high concentration with the elevating of the CO\textsubscript{2} concentration. HCO\textsubscript{3}\textsuperscript{-} and pH had no obvious variation with the change of the CO\textsubscript{2} concentration. AHN, TN, AP, TP and AK of soil had a slightly increasing with the elevating of CO\textsubscript{2} concentration. But AHN/TN, AP/TP had no significant change with the elevating CO\textsubscript{2} concentration.

1. Introduction

With the increasing emphasis on GHG abatement, it is imperative for many industry companies to take measures to cut down their CO\textsubscript{2} emissions, or capture the CO\textsubscript{2} emitted and sequester it \cite{1}. CCS is considered as one of the most effective way to control the CO\textsubscript{2} emissions \cite{2}. CCS includes three process: capturing CO\textsubscript{2} from power plants or industrial processes, transporting captured and compressed CO\textsubscript{2} (usually in pipelines), and injecting and storing it in
deep formation or deep sea. Currently, many researchers have focused on CCS technology. However, few studies were reported about the risks induced by CO₂ leakage especially the risks of ecological environment impact on high concentration of CO₂.

Soil is the basic element of ecosystem. Soil Changing can lead to changes in other elements of the ecosystem [3]. CO₂ geological storage is the most important way in currently experimental studies and project implementation. If CO₂ leaked out to the surface from stored formation, soil physical-chemical properties would be affected firstly, and other factors would be impacted as well as especially crop. Therefore, the impact research on soil properties with high concentrations of CO₂ in CCS is an important subject.

2. Materials and measurement methods

2.1. Soil samples

Soil samples were come from the pots in which 4 kinds of C₃ crops (green beans, soybeans, buckwheat and potatoes) were cultivated 30 days in CO₂ artificial climate chamber on normal atmospheric, 10000μmol/mol, 20000μmol/mol, 40000μmol/mol and 80000μmol/mol of CO₂ concentrations. The original soil cultivated C₃ crops were sampled from the farmland in Jingbian County, CO₂ injection test area of Shaanxi Yanchang Petroleum Co. Ltd.. The soil type belongs to regosols on Loess Plateau, and was named as Huangmiantu soil. Its texture is sandy loam.

In order to ensure water and fertilizer demands of the crop in the course of potted plants, the pots were watered once every 2-3 days and fertilized once a week. Fahraeus plant nutrient solution which was selected as the fertilizer and was fertilized 15ml one times [4].

2.2. Indicators and analysis methods

The soil physical-chemical properties include the indicators of soil texture, cations and anions of soil, soil fertility and soil heavy metal. According to international soil texture classification, soil particle size were classified to <0.001mm, 0.001-0.002mm, 0.002-0.005mm, 0.005-0.01mm, 0.01-0.02mm, 0.02-0.05mm, 0.05-0.1mm, 0.1-0.2mm and 0.2-0.25mm. Cations and anions of soil include K⁺, Na⁺, Ca²⁺, Mg²⁺, Cl⁻, HCO₃⁻ and SO₄²⁻. Soil fertility indicators include total N, alkali-hydrolyzable N(AHN), available P(AP) and total P(TP) and available K(AK). Soil heavy metal include total Cu (TCu), total (T Zn), total Pb (TPb), total Cr (TCr), total Cd (TCd), total As (TAs), total Ni (TNi) and total Hg (THg). Other indicators include pH, organic matter (OM) and cation exchange capacity (CEC).

Soil particle size distribution were analyzed using laser particle size analyzer (WJL-602, Shanghai, China). Soil cations and anions, cation exchange capacity(CEC), organic matter(OM), total N, alkali-hydrolyzable N, available K, available P and total P, contents of some heavy metal were detected by ICP-MS (X SERIES 2, Waltham, USA), X-ray spectrometer (Axios, Almelo, The Netherlands). Atomic Fluorescence Spectroscopy (AFS-230, Beijing, China) respectively. pH were detected using pH meter (pHS-3C, Shanghai, China).

2.3. Soil samples

A set of data on soil physical-chemical properties of each planting crop can be analyzed under different CO₂ concentration gradient. By means of excluding irrelevant data, the average values were calculated for soil samples that cultivated four kinds of C₃ crops on different CO₂ concentration.
3. Results and discussions

3.1. Soil particle size distribution

The results of soil particle size analysis showed that the percentage of clay, silt and sand changed within 6.16-6.94%, 11.93-13.75% and 79.30-82.28% respectively (Fig.1). The texture type of all soil samples were all belonged to sandy loam. The changing of CO₂ concentration had no significant impacts on soil particle size distribution [5]. CO₂ as a weak acid gas had not enough ability to affect soil particles.

3.2. Soil nutrients

The analysis results of soil nutrients showed that the concentration of N and P of soil had a slightly increasing with the elevating of CO₂ concentration in the pots of the climate chamber after 30days planting. But the concentration of available K of soil had significant changes with the elevating of CO₂ concentration.

Both alkali-hydrolyzable N and total N had a small rise in pace with CO₂ elevation. But the ratio of alkali-hydrolyzable N and total N had no significant change with the elevating CO₂ concentration (Fig.2).

Along with the increasing of CO₂ concentration, both available P and total P had a small rise. Because the available P increased more obviously than total P, the trend of available P / total P increased with the elevating CO₂ concentration (Fig.3).

When CO₂ concentration is smaller than 20000μmol/mol, the concentration of available K had no distinctive change with the control group. But when CO₂ concentration is greater than 40000μmol/mol, the concentration of available K suddenly become to two times of the control group (Fig.3). On the contrary, CEC of soil descended with the increase of CO₂ concentrations. OM of soil had not be affected by changes of CO₂ concentration (Fig.4).
N, P and K are important nutrients of crop. Alkali-hydrolyzable N, available K, and available P are mainly impacted by reduced uptake of crop at 40000μmol/mol and 80000μmol/mol. The high concentration of total N and total P can be explained by the reducing of OM decomposition rates resulted from low level of oxygen in soil air at 40000μmol/mol and 80000μmol/mol. The no significant change of AHN/TN, AP/TP and OM can be explained by the similar original matters and decomposition mechanisms.

3.3. Concentrations of cations and anions

The soil ionic concentrations of soil had different trends with the elevating of CO₂ concentration (Fig.5). All ionic concentration except HCO₃⁻ descended slightly at low concentration and increased obviously at high concentration with the elevating of the CO₂ concentration. The concentration of SO₄²⁻, Ca²⁺, Na⁺, K⁺ and Cl⁻ reached the minimum value at 10000μmol/mol of CO₂ concentration. Only Mg²⁺ reached the minimum value at 20000μmol/mol. When CO₂ concentration were greater than 20000μmol/mol, The concentration of SO₄²⁻, Ca²⁺, Na⁺ and Mg²⁺ increased more significantly than that of K⁺ and Cl⁻ with the elevating of the CO₂ concentration. HCO₃⁻ concentration and pH had no obvious variation with the change of the CO₂ concentration.

Soil ions are the most active components. Their concentrations were controlled by many balance systems, i.e. acid-base system, redox system, colloidal system, soil-plant system etc. When CO₂ of soil air is increased gradually, the concentration of CO₂ in soil solution will be synchronized rise, pH of soil solution will be reduced[5]. But because of the existing of colloidal system on base saturation and ion exchanges of soil colloid and soil solution, the base cations come from colloid surface can prevent the reducing of pH in soil solution. These are the reasons when the CO₂ concentration rose from normal concentration (380μmol/mol) to 80000μmol/mol, soil pH were only reduced 0.1unit, and the cations of Na⁺, K⁺, Ca²⁺, Mg²⁺ were risen rapidly. The minimum of Ca²⁺, Na⁺, K⁺ at 10000μmol/mol and Mg²⁺ at 20000μmol/mol were corresponded to the most vigorous growth of C₃ crops at, i.e. the cations were the most obviously absorbed by crops as nutrients at 10000μmol/mol of CO₂ concentration[6].

Among the anions of soil solution, SO₄²⁻, Cl⁻ had simulate rules with the cations that were corresponded to the situation of crop growth. But HCO₃⁻ and pH had no distinguish with the changes of CO₂ concentration. The reasons were still need further study.

3.4. Concentrations of some heavy metal

All heavy metals were not distinctly impacted with the elevating of CO₂ concentration (Fig.6). But there were different ways affected by CO₂ for different heavy metals. Compared with the control group, total Zn and total As increased slightly with the increasing of CO₂ concentration. On the contrary, total Cr and total Ni decreased slightly with the increasing of CO₂ concentration. Total Cu, total Pb, total Cd and total Hg kept balance at all CO₂ concentration. These are obviously related with that heavy metals are almost exist within soil particles.

![Fig.5. Concent of soil cations and anions under different CO₂ concentration](image1)

![Fig.6. Contents of heavy metals under different CO₂ concentration](image2)
4. Conclusion

(1) Soil particle size distribution and the concentrations of heavy metal have no significant impacts with the elevated of CO₂ concentration.

(2) All ionic concentration except HCO₃⁻ descended slightly at low concentration and increased obviously at high concentration with the elevating of the CO₂ concentration. HCO₃⁻ and pH had no obvious variation with the change of the CO₂ concentration.

(3) AHN, TN, AP, TP and AK of soil had a slightly increasing with the elevating of CO₂ concentration. But AHN/TN, AP/TP had no significant change with the elevating CO₂ concentration.

(4) Because the demand quantity of soil tested was too much, different batches of soil may exist tiny difference.

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