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Research article

CO_2 leakage-induced vegetation decline is primarily driven by decreased soil O_2

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ABSTRACT

To assess the potential risks of carbon capture and storage (CCS), studies have focused on vegetation decline caused by leaking CO_2. Excess soil CO_2 caused by leakage can affect soil O_2 concentrations and soil pH, but how these two factors affect plant development remains poorly understood. This hinders the selection of appropriate species to mitigate potential negative consequences of CCS. Through pot experiments, we simulated CO_2 leakage to examine its effects on soil pH and soil O_2 concentrations. We subsequently assessed how maize growth responded to these changes in soil pH and O_2. Decreased soil O_2 concentrations significantly reduced maize biomass, and explained 69% of the biomass variation under CO_2 leakage conditions. In contrast, although leaked CO_2 changed soil pH significantly (from 7.32 to 6.75), it remained within the optimum soil pH range for maize growth. This suggests that soil O_2 concentration, not soil pH, influences plant growth in these conditions. Therefore, in case of potential CO_2 leakage risks, hypoxia-tolerant species should be chosen to improve plant survival, growth, and yield.

1. Introduction

Carbon capture and storage (CCS) is a technology that can reduce anthropogenic greenhouse gas emissions. CO_2 from major industrial sources is captured and subsequently injected into secure geological reservoirs for underground storage (Klusman, 2003). China has recently established over 12 CCS demonstration projects, and CCS may provide huge CO_2 storage capacities in the future (Zhang et al., 2013). However, there are risks of CCS-stored CO_2 leaking out of the storage reservoirs to the atmosphere through flawed injection wells or undetected faults (Jones et al., 2015). Before proceeding with the large-scale deployment of this technology, all potential risks should be well understood (Krüger et al., 2011).

Currently, considerable effort is being made towards understanding how stored CO_2 leakage influences plant degradation. In general, studies indicate that high soil CO_2 concentrations negatively influence plant growth and biomass (Vodnik et al., 2006; Pfanz et al., 2007; Lakkaraju et al., 2010). For example, Beaubien et al. (2008) observed no vegetation growth on a naturally occurring gas vent core in a Mediterranean pasture ecosystem. Here, soil CO_2 efflux rates exceeded 2000–3000 g m^{-2} d^{-1}, and minimum pH was 3.5. Similarly, Al-Traboulsi et al. (2012) found that where soil CO_2 was high, and soil O_2 correspondingly low, plants displayed severe chlorosis, reduced growth, and a high mortality. Moreover, a maize study showed that when soil CO_2 efflux increases from 500 to 2000 g m^{-2} d^{-1}, maize photosynthesis and dry matter significantly decreased, as well as soil pH and soil O_2 concentrations (Wu et al., 2014). This suggests that the two primary consequences of stored CO_2 leakage affecting plant development are decreased soil pH, and decreased soil O_2 concentrations. However, their relative contribution to the limitation on vegetation development is difficult to assess directly, given the considerable environmental variation among the study sites. Therefore, it is difficult to know whether hypoxia- or acid-tolerance is more important when selecting plant species that can mitigate the negative impacts of leaked CO_2.

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In this study, pot experiments that simulated various soil CO_2 efflux patterns were used to investigate: 1) how increased CO_2 leakage influences soil O_2, soil pH, maize photosynthesis, and maize biomass; 2) the correlations between the soil and maize parameters; 3) the relative contributions of soil O_2 decrease and soil acidification to the limited maize growth.

2. Methods and materials

Our experimental site in Yanqing, Beijing (40°32′N, 116°03′E, 536 m a.s.l.), was rented by our institute August to October 2011, and belongs to the agricultural company Beijing Lvfulong Agriculture Co. Ltd. The experimental plot (50 m^2) was shielded from precipitation to control water supply to the plants. For this study, maize hybrid Zhongnuo No.2, which is bred by the Chinese Academy of Agricultural Science and widely planted in Beijing, was selected. Top soil was obtained from a local farmland, and was classified as cinnamon type (depth 0–20 cm, total weight 162 kg). The soil was loaded into cultivation containers, and compacted to a thickness of 50 cm. Before the experiment, the soil had a medium loam texture with pH 7.32, a volumetric mass of 1.30 g cm^{-3}, and a volumetric water content of 22.67%.

2.1. Experimental set up

The experimental set up consisted of self-made combinations of gas chambers with soil chambers on top (Fig. 1). CO_2 was injected into the bottoms of the cultivation containers at different, manually controlled, rates. Each set up consisted of a controlled CO_2 release device, a data recording system, and a plant management system. As such, a set of simple and mutually independent farmland-based mesocosms were constructed.

2.1.1. Controlled CO_2 release

For controlled CO_2 release, the cultivation containers (50 cm in length and width, 80 cm in height) were connected to the CO_2 cylinder via a gas flow meter with a ball valve, and a gas duct with a shunt. CO_2 from the cylinder entered the gas chambers via 3 mm stainless steel gas ducts. A shim with a 0.5 cm aperture, covered with a double layer of nylon gauze, separated the soil chambers (60 cm in height) and gas chambers (20 cm in height) to enable homogeneous CO_2 release. The CO_2 inlets were installed 10 cm below the shims, under which drainage valves were additionally installed.

2.1.2. Planting and management

Maize plants were seeded on August 18, 2011. Seedlings were selected at the three-leaf stage, leaving one seedling per pot. Plants were fertilized once with urea (3 g per pot) on 14 September, and watered every 10 ± 2 d with 5 L water. CO_2 injection into the cultivation containers started on 18September, and continued until the end of the experiment in October 2011.

2.1.3. CO_2 injection scenarios

The experiment consisted of one control treatment (no added

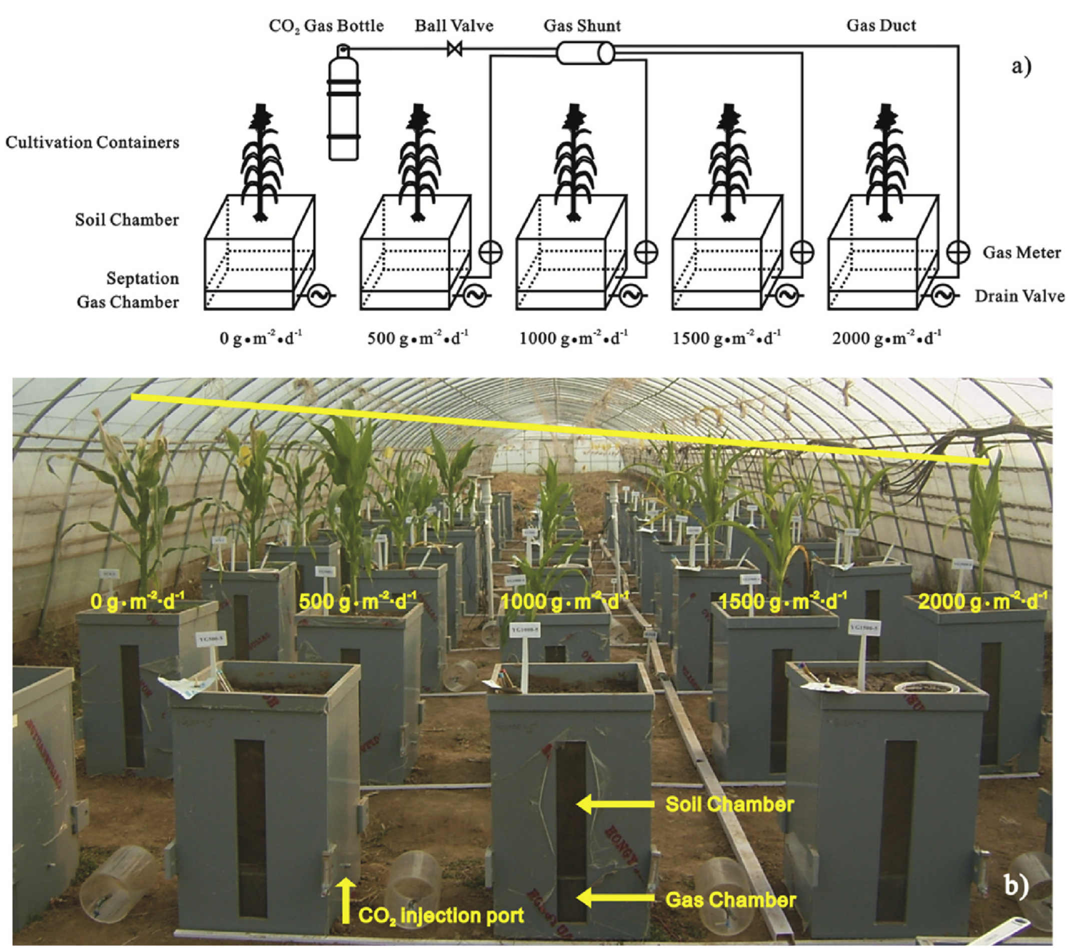

Fig. 1. (a) Diagram of experimental design and apparatus, and (b) photograph of the pot experiment platforms simulating stored CO_2 leakage. CO_2 injection rates (in g m^{-2} d^{-1}) were set to five different values. Note that crop growth from left to right went from good to poor, as indicated by the plant height (yellow line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)