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Effects of Elevated Soil Carbon dioxide (CO_2) Concentrations on Spring Wheat (*Triticum aestivum L.*) and Soil Chemical Properties in Sutton Bonington Campus of the University of Nottingham, UK

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ABSTRACT: This study examines the effects of elevated soil carbon dioxide (CO_2) concentrations on spring wheat and soil chemical properties in the Sutton Bonington Campus, of the University of Nottingham, United Kingdom using Artificial Soil Gassing and Response Detection (ASGARD) facility which controls CO_2 injection into the soil. Eight plots (each 2.5 x 2.5m) were laid out within the experimental area and used for the study and were treated with high CO_2 concentrations (area within 75cm from the point of injection), low CO_2 concentration (area farther than 75 cm from the point of CO_2 injection) and no CO_2 concentration (control) at CO_2 injection rate of 1.0l/min from a source point 60cm below the soil for eight (8) weeks. The variability of CO_2 concentrations were determined by 3D and barholing method. The wheat plant showed visible symptoms of wilting, chlorosis and poor development within 15- 21 days of gassing. Gassing at the rate of 1.0l/min resulted in reduced plant height and a 60% decrease in chlorophyll content of wheat plant exposed to high CO_2 concentrations when compared with control plots. The soil pH for the control plots at the depth of 15-30 cm was 6.31 and 6.7 after injection, showing a difference of 0.39. At the depth of 45-60 cm, the pH before injection was 5.89 while post-injection was 6.39, showing a difference of 0.5. The study showed that organic carbon at 45-60cm depth of soil ranged from 2.54% to 2.58% with a mean value of 3.26%, while carbonate content ranged from 0.73 to 0.77%. Furthermore, at 45-60cm depth of soil after injection, the mean value of K across all experimental plots was 64.16 mg/lK, available P content ranged from 15.4 to 16.9 mg/lP, N content ranged from 11.2 to 16.9 mg/lN, Ca ranged from 1000 to 1300 mg/lCa, Mg ranged from 158 to168 mg/lMg while at 15-30cm depth of soil, Na range from low to moderate (10.16–10.2 mg/l Na). There was no significant difference ($P<0.05$) or changes in mineralogical content of the soil properties studied. © JASEM

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***KEYWORDS*:** controlled injection; CO_2; soil chemical properties, soil depth

Introduction

Storing carbon dioxide (CO_2) in geologic formations has the potential to be an effective way to reduce atmospheric carbon dioxide levels (IPCC, 2005; Pierce and Sjogersten, 2009; West et al., 2009). Storage sites should be selected to minimise the potential for leakage of stored carbon dioxide to the ocean or atmosphere (West *et al.,* 2009).

The effects of high CO_2 injection in the soil, either through natural or anthropogenic means on plants and microbial communities are poorly understood (Pierce and Sjogersten, 2009). Carbon capture and storage (CCS) is an emerging technology. There is no evidence till date on the long term safety of CO_2 injected into the soil (Celia *et al.,* 2002). Carbon capture and storage involves capturing the CO_2 arising from the burning of fossil fuels, for example during electricity generation, separating it from other waste gases, and transporting it to a site where it will be stored away from the atmosphere for many centuries (Marland *et al.,* 2005). Global carbon-equivalent of CO_2 emissions in 2002 were nearly 7Gt of which UK emissions were approximately 0.15 Gt, of which power generation accounted for about 0.062 Gt (Marland *et al.,* 2005; Defra, 2006).

There are various suggestions for the long-term storage of CO_2, including deposition into the water column in the deep ocean floor and injection into geologic formations (Marland *et al.* 2005; Defra, 2006). Over pressurisation, poor engineering and pipe line failure could lead to leakage during CO_2 transportation, capture and storage (Pierce and Sjogersten, 2009). The large release of CO_2 due to over pressurisation in geologic media and slow release through faulty systems can occur (Heinrich *et al.,* 2003). However, for effective storage of CO_2 in geologic media, the techniques applied would depend on the reduction of CO_2 leakage from source of release (Pierce and Sjogersten, 2009). The captured CO_2 from a production source can be transported through pipeline, marine tanker or road tankers to the storage site. The risk of severe leaks and the impact from these leaks depends on whether the pipelines are under ground. However, if pipelines are underground, CO_2 can diffuse through the soil into the atmosphere. Slow leaks could increase CO_2 concentrations levels in soil and above plant levels (Pierce and Sjogersten, 2009). The increase in CO_2 levels, also have significant implication for the growth of vegetation and the local environment (Vodnik *et al.,* 2006). Carbon dioxide leakage into the geologic media could be limited but not prevented by safety structures and proper site selection. Slow release of CO_2 and diffusion in the atmosphere could go unnoticed (Pierce and Sjogersten, 2009; Heinrich *et al*., 2003).

Carbon dioxide has been injected into the soil for various purposes; however, its long term storage is a new concept. The first commercial CCS project was in the year 2000 in Weyburn, Canada (Markels and Barber, 2002). Looking at the long term effect, the storage of CO_2 would have on the environment, it is therefore very necessary to understand the effects of CO_2 leakage on the overlying ecological unit (Heinrich *et al*., 2003), as toxic concentration of CO_2 in the soil could lead to changes in soil properties and death of vegetation (Pierce and Sjogersten, 2009).
Various plants survive differently to anoxic or hypoxic stress and variations in the natural environment (ecosystem) have made it difficult to measure the intensity of exposure (Pierce and Sjogersten, 2009).

Spring wheat (*Triticum aestivum L.)*, a member of the *Poaceae* family has a wide range of cultivars. The popularity and large hectares of land used in the cultivation of the crop may be attributed to the survival of a broad range of its species with diverse adaptation and its numerous end-uses (Porter and Gawith, 1999). It is a staple food for about 35 percent of the world's population and; it supplies about 20 percent of the total calorie requirement of the people (Breiman and Graur, 1995; FAO, 2006). There is little research information on the growth rate and development of agricultural plants in a soil injected with CO_2. Therefore the aim of this study is to determine the effect of CO_2 injection on height and chlorophyll content of spring wheat and on soil reaction and soil properties.

MATERIALS AND METHODS

Study site location: Geology and Description of the Study Area: This study was carried out at the Artificial Soil Gassing and Response Detection (ASGARD) site, Sutton Bonington Campus, University of Nottingham, UK. The University lies between 52.8^0N and 1.2^0W of Leicestershire, and is approximately 18 km south out of central Nottingham (West, *et al.,* 2009). The site was chosen by the Asgard facilitators on the basis of reasonable uniformity of soil type down to a depth of 1m with good exposure, particularly towards the North, to give room for experimental analysis and for access to facilities (The Asgard Facility Resource Document for UKCCSC, 2007). The study area is located on flat open grassland which was formerly used for sheep grazing. The maximum temperature in January is approximately 6.9^0C and the minimum temperature is 1.2^0C, and in July, 11.4^0C and 21.3^0C respectively. The mean annual rainfall of the area is 606mm, which is distributed evenly all through the year (The University of Nottingham Sutton Bonington Metrological Site) (West *et al.,* 2009).

The geology of Asgard site is characterised by up to 1.5m of overlying mudstones of the Mercia group, sand and gravel rich terrace deposits, surrounded by sheets of lithologically variable head (Ford, 2006). A detailed geological description of the site and surrounding area has been described (Ford, 2006). The soil used for the study has a dark brown sandy top soil of approximate 0.3m thickness, a relatively persistent horizon of gravelly head of 0.15m thick, occurring at regular depth of 0.3m to 0.6 m beneath the ground surface was also observed (West *et al*., 2009)

Field study**:** Eight plots (each 2.5 x 2.5m) were laid out within the experimental area and used for the study. Carbon dioxide was injected into soil at a depth of 60cm, the CO_2 gas was released from a source which is 60 cm below the centre of each 2.5 x 2.5 m plot. Carbon dioxide was delivered to three plots within the experimental site; the injection rate for all gassed plots was a constant 1.0 l/min for a period of eight weeks. The remaining five plots were controls, without any injection of CO_2 and are distributed among the experimental plots, adjacent to gassed plots (Source: RISCS, 2010). The experimental treatments were high carbondioxide concentration (area within 75cm from the point of injection), low CO_2 concentration (area farther than 75 cm from the point of CO_2 injection, but within the plots that had CO_2 injected) and control, where no gassing/CO_2 was injected into the soil. A revised 2-D method known as Barholing was used to map CO_2 at 30 cm depth across the plots. This was used to measure the dispersion of CO_2 throughout the plots.

***Sample collection, preparation and laboratory analysis*:** Core samples of soil were collected before and after injection of CO_2 at 75 cm, close to the point of injection (high gas zone) and 225 cm away from the point of injection (low gas zone) in the gassed plot. Core samples were also collected from the control plot. Soils were taken at depths of 15-30 cm and 45-60 cm on the same date after clearing the experimental plots. The core samples collected were air-dried at room temperature 25^o C – 27^o C for a period of two to three days. The samples were crushed and sieved through a 3mm sieve and packed in a well labeled sample cups for laboratory analysis. They were analysed for the following chemical properties. Soil pH was determined using the pH meter

Total nitrogen and available phosphorus was determined by chemical extraction method, using a spectrophotometer.

Exchangeable bases (Ca, Mg, k and Na) – These were determined by chemical extraction using the Palin test method. Exchangeable bases were extracted using each extraction reagents. Calcium, Mg, K, were read through a spectrophotometer while Na was determined using the flame photometer.

Chlorophyll analysis of wheat plant was determined using the method of Legood (1993).

Determination of plant growth and development: Spring wheat was planted on the 23rd and 24th of March, 2011 at a rate of 350 seeds m^{-2} into the eight plots. Wheat seeds germinated on the 5th of April, 2011. Gas was delivered to the plots that received them on the 23rd of May 2011 at a nominal flow rate of 1 $Lmin^{-1}$ and switched off on the 15th of July, 2011.

The heights of five selected plants were measured using a meter rule in each plot. Data collected were subjected to analysis using Excel to show the temporal changes in the height of wheat plant over control, low gas and high gas zones.

RESULTS AND DISCUSSION

Effects of CO_2 injection on wheat growth and development: Visual observations: In this study, visible change in the growing wheat due to CO_2 injection was observed from 2 weeks of gassing (Plate 1). Generally, there was decrease in growth and discolouration of the leaves of wheat around the point of injection. This visible difference in plants under low gas, high gas and control is in line with results of other researchers (Pysek and Pysek 1989; Smith *et al.,* 2005). Also, Smith *et al.* (2005) observed that the stress effect on pot grown bean and barley crop due to the displacement of O_2 by CO_2, argon gas or water logging was seen to be highest between 14 and 21 days after treatment application. West *et al.,* (2009) noted that monocotyledonous plant, such as grass are more tolerant to high CO_2 concentrations than dicotyledonous species but also stated that other factors, such as nitrogen concentration, plant age and access to photosynthesis can affect plant growth.

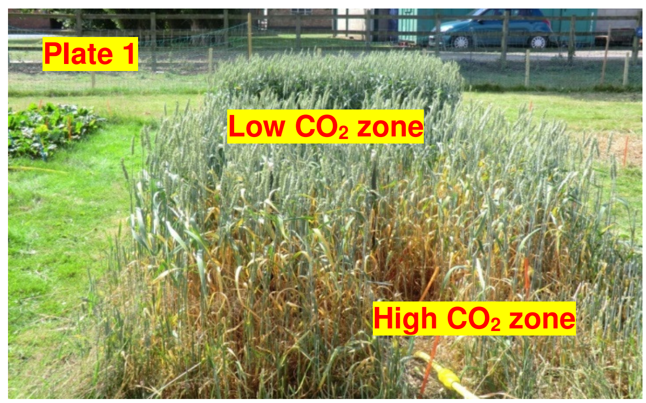


Plate 1 shows a gassed plot with areas of high and low CO_2 zones. Picture taken on 12/07/2011

***Plant height*:** Figure 1 shows the temporal change in the height of wheat. Differences between wheat height grown under control, low and high gas zones was noticed from 15 days of gassing (Figure 1). The height of wheat plant at the centre of the plot was 40 percent higher in the control plot than the gassed plot and 20 percent higher than the edge of the plot. Plants response to high CO_2 concentration was measured at three locations in Slovenia and was found to be generally shorter due to exposure to high CO_2 concentration (Pfanz *et al., 2007).* This is in line with the findings of other researchers (Smith *et al.,* 2005; Pierce and Sjogersten, 2009; West *et al.,* 2009). Plant under high gas zones were 20 to 40 percent smaller ($P<0.05$) in height and had fewer leaves than the control plants. There was no significant difference between the control plots and the low gas zones of the plot but a significant difference ($P<0.05$) was observed between control plot and the high gas zones of the gassed plots

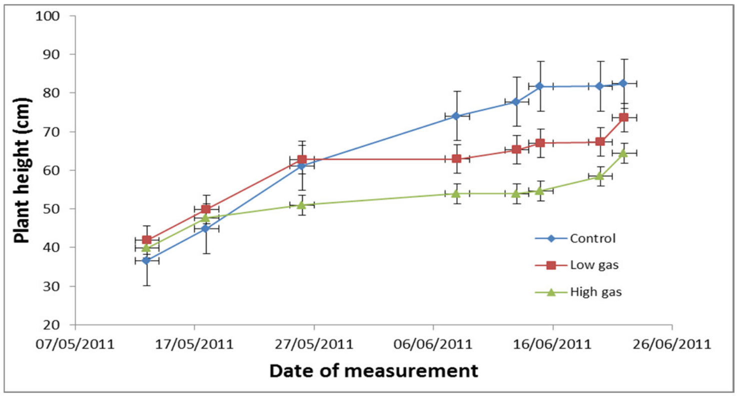


Fig 1: Showing the temporal changes of wheat from germination to full growth and development

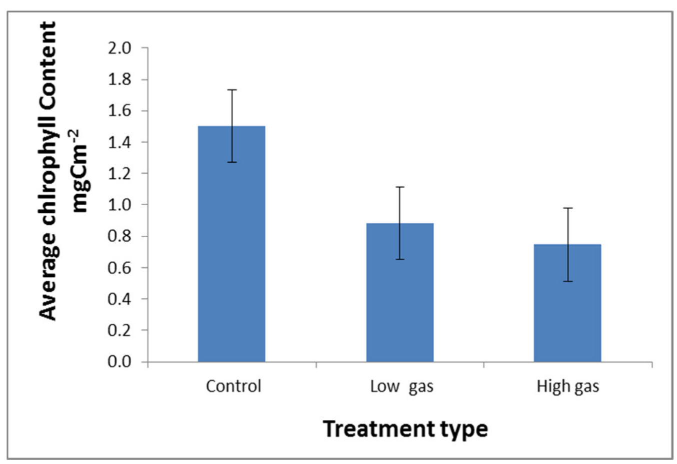
The height of wheat plant at the centre of the plot was 40 percent higher in the control plot than the gassed plot. In line with the findings of this study, it was reported that plant height measured at three locations in Slovenia showed that plants on plots under high CO_2 concentration were shorter relative to control plots with low CO_2 concentration (Vodnik *et al.,* 2006; Pierce and Sjogersten, 2009). Schollenberger (1930) carried out a study and noted that areas of leaks from gas pipelines, lead to the death of oat seedlings within 1 to 1.3 m and immature seedlings up to 4 to 5 m, beyond which no damage was visible (Smith *et al.,* 2005). Results from this study also confirmed the findings of other researchers like Hutsch (2001) who noted that different plants have different sensitivity to natural gas zones (Hutsch, 2001). It has been reported that plants grown on naturally high CO_2 levels is affected in a variety of ways (Pierce and Sjogersten, 2009).

Chlorophyll Analysis: The result of this study shows a 60% decrease in chlorophyll of wheat plant exposed to high CO_2 concentration (high gas zone, at 75 cm from point of injection) and a 40% decrease in chlorophyll of wheat plant at low gas zone (225 cm from point of injection) when compared with control plots (Table 1 and Figure 2).
The changes in the chlorophyll content for wheat plant for control, low and high gas zone of CO_2 experimental plots was expressed on an area basis calculated from.

Chlorophyll ($mgcm^{-2}$) = chlorophyll a + chlorophyll b

Table 1: Effects of treatments on Chlorophyll content (%) of wheat

Treatment	Chlorophyll
Control	1.501
Low gas	0.884
High gas zone	0.746



The percentage difference between the chlorophyll content of wheat leaves of the control, low and high gas area of the plots was calculated using excel. Researchers have also found similar findings. Smith *et*

Fig 2: Average chlorophyll content of wheat plants for control, low and high CO_2 experimental plots

al. (2002) reported that, barley plant which was grown above a leaking natural gas pipeline had a significant decrease of between 15 and 56 % in chlorophyll content. Smith *et al.,* (2005) also noted a decrease of 30% in chlorophyll in monocotyledonous plants exposed to high CO_2 concentrations. Other researchers have reported stress effects in plants due to gas leaks. The symptoms experienced in these plants included yellowing of leaves and shifts in the developmental stage (Schollenberger, 1930; Pysek and Pysek, 1989; Smith et *al*. 2002; Smith *et al.,* 2005). It is important to note that decrease in chlorophyll, especially in a canopy, occurs not only to stress caused by increase CO_2 intake but due to time and spatial distribution of the plant, especially within the canopy. Smith *et al.,* (2005) indicated a drastic decrease in chlorophyll production in oil seed rape that grew in extreme shade when compared to the control growing in open space. However the variations measured in this study are much greater, indicating severe responses to stress caused by CO_2.

Effects of treatments on soil properties: The effects of treatments on soil pH, organic carbon, carbonate, available Phosphorus and Nitrogen contents are given in Table 2.

Soil Ph*:* Prior to CO_2 injection, the soil pH for the control plots at the depth of 15-30 cm was 6.31 and 6.7 after injection, a difference of 0.39 (Table 2). At the depth of 45-60 cm, the pH before injection was 5.89 while post-injection was 6.39, a difference of 0.5. Hence, there was an increase ($P<0.05$) in pH.

According to Celia et al. (2002), the increase of the concentration of CO_2 influences soil pH which consequently influences the rate of weathering and to some extent, the availability of plant nutrients. However, some researchers indicated that soil injected with CO_2 cause only small changes in the pH of the nutrient solution (Stolwijk and Thimann, 1957; Gahrooee, 1998). Studies have also shown that there is insignificant change in the pH when a high level of CO_2 is introduced to the soil (Ravi *et al.,* 2010). Still other researchers have found a decrease in soil pH after CO_2 has been injected into the soil (Smith *et al*., 2005).

Organic carbon content*:* The soil organic carbon content of the studied area ranged from medium to high, values of 2.54% to 2.58% was observed for soil at the depth of 45-60 cm. Soils at 15-30 cm depth ranged from high to very high, values of 3.82% to 4. 68% were observed before and after CO_2 injection. The mean value for the experimental plots was 3.26%. This could be attributed to high organic matter returns and other human factors such as reduction in tillage, incorporation of plant roots and residues into the soil (Nnaji *et al.,* 2005). Other cultural practices such as the application of organic manures during agricultural production of crops can also be linked to this. There was no significant difference ($P.>0.05$) in organic matter content of the soils as regards treatment application.

Table 2: Soil pH, average amount of organic carbon, carbonate content and Phosphorus contents for control plot, high and low CO_2 zones at 15-30cm and 45-60cm depth of soil post injection.

Treatment	15-30cm soil Depth	Soil properties	45-60cm soil depth
		Soil pH	
Control	6.7		6.3
High CO_2 zone	6.7		6.1
Low CO_2 zone	6.7		6.9
		Organic carbon (%)	
Control	3.94		2.54
High CO_2 zone	3.99		2.52
Low CO_2 zone	3.86		2.59
		Carbonate content (%)	
Control	0.83		0.77
High CO_2 zone	0.81		0.76
Low CO_2 zone	0.82		0.73
		Phosphorus (P mg/l)	
Control	44.4		30.6
High CO_2 zone	47.0		46.3
Low CO_2 zone	63.3		33.3
		Nitrogen (N mg/l)	
Control	18.2		11.22
High CO_2 zone	24.4		16.97
Low CO_2 zone	22.93		15.43

***Carbonate content*:** The carbonate content of soils of the experimental plots was 0.82% at 15-30 cm depth of the soil and ranged from 0.77% to 0.82% at 45 to 60 cm depth of the soil. The high carbonate content of the soils can be attributed to the carbon held in the soil zone, primarily associated with the soil organic content. Carbon plays a significant role in the carbon phase and is therefore very important in obtaining a representation of global climate models (Stevenson *et al.,* 2005). Also, there was no significant difference (P0>0.05) in carbonate content of soils as regards treatment application. Studies carried out on high concentration of CO_2 soils have reported no difference in carbon content between the treatment and control plots (Pierce and Sjogersten, 2009).

The amount of available P in soil was high across all treatments. Values obtained ranged from 8.57 to 24.4 mg/l. The highest ($P<0.05$) soil P content was obtained in plots of low gas concentration/zone at 15-30 cm soil depth and high gas concentration/zone at 15.30 cm of soil depth.

Table 2 also shows that the amount of N across the experimental plots ranged from 18.2 to 24.4 mg/lN at 15 to 30 cm soil depth and 11.2 to 16.9 mg/l at 45 to 60 cm soil depth. However, the N content of the gassed plot tend to increase at the rate of 4.5 at the various depth of the soil. The lower N content of the control plot may suggest that soil degradation process such as volatilization or leaching was higher in the control plots. Nitrogen is highly mobile in the soil and could thus be lost due to poor soils management and conservation practices adopted by farm manager

Exchangeable bases (K, Ca, Mg and Na): The amount of exchangeable potassium in the control soil was very high (>80mg/l) at all soil depth examined with values greater than that of gassed plots (Table 3). The mean value of exchangeable K across all experimental plots was 64.16 mg/l K which is above 20 mg/l K, regarded as the critical limit of exchangeable K of soil (Onyekwere *et al.,* 2001).

Calcium content was highest in the high CO_2 zone and lowest in soil of low CO_2 zone at 15-30 cm soil depth

(Table 3). The same trend was observed at 45-6.0 cm soil depth. There was no significant difference between the control and gassed plots at 15 to 30 cm depths of the soil but there was slight reduction of Ca content at 45-60 cm depth of the soil.

Magnesium was 210 mg/l Mg and 182 mg/l Mg in the control plot at 15-30cm and 45-60 cm depths, indicating a slight decrease in Mg with depth. The amount of Mg in the gassed plot ranged from 158.3 to 178.3 mg/l Mg. Exchangeable Na ranges from low to moderate (9.4–10.2 mg/l Na). There was no significant difference ($P < 0.05$) between the gassed plot and the control plots. However, soils of the studied area was reported to be moderate to high in potassium and sodium contents; this is in line with the findings of (West *et al.,* 2009).

Table 3: Effect of CO_2 injection on soil exchangeable bases content (mg/l)

	Soil properties	
Treatment		
	15-30cm soil Depth	45-60cm soil depth
Exchangeable Potassium (k)		
Control	83	81
High CO_2 zone	53.3	60
Low CO_2 zone	61.7	68.3
Exchangeable calcium (Ca)		
Control	1450	1300
High CO_2 zone	1416.7	1083.3
Low CO_2 zone	1333.3	1000
Exchangeable Magnesium (Mg)		
Control	210	182
High CO_2 zone	168.3	158.33
Low CO_2 zone	178.3	168.33
Exchangeable sodium (Na)		
Control	10.16	
High CO_2 zone	10.2	
Low CO_2 zone	9.37	

Generally, high rainfall leaches away basic soil nutrients down the profile leaving the acidic cation (Al^{3+} and H^+) at the surface. This may influence salt content and consequently influence electrical conductivity.

Conclusion**:** From this study it was observed that injection of CO_2 into the soil at a rate of I.0l/min over 8 weeks had non-significant impact on soil chemical properties studied but has significant effect on wheat growth and development. However, the effects were more in areas with high CO_2 concentration in the soil. Some of the effects included yellowing of the leaves, reduction in plant growth, decrease in chlorophyll content and a significant decrease in above ground vegetation over time. It is recommended that further studies aimed at determining the effects of higher rates of CO_2 injection and duration period on soil and wheat growth should be carried out.

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