Agriculture, Ecosystems and Environment 268 (2018) 52–60

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Elevated carbon dioxide and temperature imparted intrinsic drought tolerance in aerobic rice system through enhanced exopolysaccharide production and rhizospheric activation

S.R. Padhy[a], S. Nayak[a], P.K. Dash[a], M. Das[a], K.S. Roy[b], A.K. Nayak[a], S. Neogi[c], P. Bhattacharyya[a,*]

[a] ICAR-National Rice Research Institute (NRRI), Cuttack, Odisha, India
[b] Department of Environmental Science & Engineering, Marwadi University, Rajkot, Gujarat, India
[c] University of Ahmedabad, Gujarat, India

ARTICLE INFO

Keywords:
Elevated CO_2 and temperature
Aerobic rice
Water stress
Exopolysaccharide
Labile carbon
Plant enzymes

ABSTRACT

Elevation in atmospheric carbon dioxide (CO_2) concentration and temperature coupled with moisture stress is anticipated by most of the climate change prediction models (IPCC, 2014). Climate change results in atmospheric warming that trigger water stress to rice and could influence soil health, functioning and biological activities. Therefore, it is required to quantify indicative parameters like soil-exopolysaccharides which indicates greater water holding capacity of soil and imparted drought tolerance to rice. Carbon pools and related soil enzymes are also indicative of soil health status. We designed one field study in open top chambers (OTCs) to assess the impact of elevated CO_2, temperature and deficit moisture stress on rice. There were two replicated CO_2 enrichment treatment in OTCs, namely, ambient CO_2 (394 ± 20 ppm and ambient temperature; a-CO_2) and elevated CO_2 (550 ± 20 ppm) with temperature (2 °C ± 0.3 more than ambient; e-CO_2T). Three aerobic rice (grown in saturated soil moisture condition) cultivars (CR-143-2-2, APO and CR Dhan 201) were grown in separate blocks in each OTCs with adequate nutrient level and water stress (−40 kPa). Total soil and colloidal exopolysaccharides (EPSs), soil labile carbon (C) pools, soil enzymes (dehydrogenase, Fluorescein diacetate and β-glucosidase) and plant enzymes (catalase, peroxidase and super oxide dismutase) were measured as indicators of the soil health, functioning and intrinsic drought tolerance to the system. Total soil EPS (29%), colloidal EPS (37%), microbial biomass C (30%), readily mineralizable C (29%), dehydrogenase (15%), FDA (38%), and β-glucosidase (13%) activities were significantly higher under elevated CO_2 and temperature (e-CO_2T) to that of ambient condition (a-CO_2). The total and colloidal EPS, soil labile C pools and soil enzymatic activities were found higher at panicle initiation (PI) and grain filling (GF) stage than other physiological growth stages of rice. On the other hand, plant stress enzymes like catalase, peroxidise and superoxide dismutase (SOD) were decreased under e-CO_2T by 24, 20 and 32%, respectively, as compared to a-CO_2. All these indicated e-CO_2T could impart additional intrinsic drought tolerance to tropical aerobic rice system (aerobic rice cultivars grown with adequate nutrient supply) in future climate change scenario.

1. Introduction

The present atmospheric carbon dioxide (CO_2) concentration is about 394 μmol mol^{-1}. The concentration of CO_2 is anticipated to be 550 μmol mol^{-1} by 2050 owing to its current rate of increase of 1.9 μmol mol^{-1} y^{-1} (Solomon et al., 2007; IPCC 2007, 2014). Ongoing and projected changes in atmospheric CO_2 and other greenhouse gases may result in climatic anomalies related to temperature, precipitation, sea level rise, increase of extreme weather events, etc. (Lobell and Field, 2007; IPCC. Climate Change, 2014). Climatic anomalies, specifically elevated CO_2, temperature and moisture stress have direct consequences on agricultural productivity and more so on rice. As rice is a C_3 species and generally responds favourably to increased CO_2 concentration by increasing its carbon assimilation rate. However, its productivity is affected negatively with increase in temperature and more so when coupled with deficit moisture stress condition. (Cheng et al., 2010; Roy et al., 2012).

Deficit moisture stress is one of the major problems limiting rice productivity in the tropics, semiarid and arid regions of the world. Unseasonal drought in rice is a major consequence of climate change. It

* Corresponding author at: Division of Crop Production, National Rice Research Institute, Cuttack, 753006, Odisha, India.
E-mail address: pratap162001@gmail.com (P. Bhattacharyya).

https://doi.org/10.1016/j.agee.2018.08.009
Received 16 April 2018; Received in revised form 28 June 2018; Accepted 8 August 2018

would deteriorate soil physico-chemical and biological properties which affect soil microbial activity and ultimately rice yield. Aerobic rice is one of the feasible options to address the deficit moisture stress situation of rice in tropics. It is the production system, where, rice is grown in aerobic soil condition (saturated soil moisture) like wheat and maize. However, aerobic rice in tropics is subjected to be grown under additional water stress exposed to elevated CO_2 and temperature (IPCC. Climate Change, 2014).

Additional water stress in soil could be partially overcome by increasing water holding capacity soil either through cultural practices or by microbial intervention. Water holding capacity of soil is improved by presence of exopolysaccharides (EPSs). It not only absorbs and retains moisture for longer time but at the same time improve soil aggregation which imparts intrinsic drought tolerance to system. Exopolysaccharides are high molecular weight, biodegradable polymers and biosynthesized by a wide range of bacteria (Vijayabaskar et al., 2011). Additionally, it protects the bacteria from environmental stresses (Iqbal et al., 2002). It protects bacterial cells from antibodies, bacteriophages and antimicrobial compounds. Moreover, hydrated EPS bacteria have 97% of water in polymer matrix that provides protection against desiccation (Bhaskar and Bhosle, 2005). High water retention capacity of exopolysaccharide helps in biofilm formation as well as protects soil from desiccation (Pereira et al., 2009; Di Pippo et al., 2011). Apart from this EPS also protect the soil microbes from UV radiation, enhances soil mechanical strength, antibiotic resistance and exo-enzymatic degradation activities (Pereira et al., 2009). It also plays an important role in rhizospheric carbon mobilization through water absorption/retention regulation.

Elevated CO_2, temperature and moisture stress are closely related to soil carbon pools and enzymes in rice rhizosphere (Bhattacharyya et al., 2013,2014,2016). Increasing atmospheric CO_2 could alter the labile soil carbon pools and carbon cycling in terrestrial ecosystem as well (Ainsworth and Rogers, 2007). Labile soil carbon pools including microbial biomass carbon (MBC) and readily mineralizable carbon (RMC) vary significantly under stressed environmental condition like water stress. The MBC and RMC are also identified as sensitive indicators of rhizospheric activities. Like carbon pools, soil enzyme activities are also influenced by elevated CO_2 and temperature in various rice growing stages (Bhattacharyya et al., 2013). Moreover, soil warming due to seasons and weather fluctuations could also increased enzyme activities (Sardans et al., 2008). Further, temperature alone or in combination with moisture influences the activities of soil enzymes. Soil enzymes like dehydrogenase (DHA), Fluorescein diacetate (FDA) and β-glucosidase (β-GLU) are effective ecological indicators which are quantifiable and sensitive to moisture stress, elevated CO_2 and temperature. These also indicate the rhizospheric activation and response of microbes to atmospheric / soil temperature and CO_2 change.

Based on above discussion the question arises how the elevated CO_2 and temperature along with deficit soil moisture stress affect the aerobic rice production system in tropics? Is anticipated elevated CO_2 and temperature would aggravated moisture deficit stress or provide additional tolerance to system to cope up with the situation? And how the soil health indicators like EPS, labile carbon pools and enzymatic activities behave in those anticipate climate change situation. So we hypothised that elevated CO_2 along with moisture stress could pose diverse impact on soil health and productivity of aerobic rice ecosystem. For testing the hypothesis, our objectives were, to study the performance of aerobic rice cultivars when subjected to additional moisture stress and exposed to elevated CO_2 and temperature, and to quantify rhizospheric EPS production, labile carbon pools and enzymatic activities under aerobic rice system.

2. Material and methods

2.1. Experimental site

Experimental site was at ICAR- NRRI in India, (20°25′N, 85°55′ E; 24 m s^2). It is in tropical climate with an average rainfall of 1500 mm. June to September receives around 70–80% of total precipitation. Elevated CO_2 and temperature condition was simulated under OTCs in field with two replications. The treatments (CO_2 concentration) were replicated twice in randomized block design (RBD) under corresponding OTCs (De Costa et al., 2006; Roy et al., 2012). Under each OTC the cultivars (CR 143-2-2, APO and CR Dhan 201) were grown in separate blocks (six blocks in each OTC; two blocks for each cultivar). The circular OTCs were having 4 × 3 m (diameter × height) dimension (Neogenesis Engineering Pvt Ltd, India). Ambient CO_2 (a-CO_2; 394 ± 20 μmol mol^{-1} CO_2); and chamber with elevated CO_2 and temperature (e-CO_2T; 550 ± 20 μmol mol^{-1} CO_2; 2 °C ± 0.3 higher temperature than ambient temperature) were maintained 24 × 7, throughout the crop growth period. The elevated temperature was maintained by putting infrared lamps (IR) inside the OTC. The IR lamps transfer heat to the soil and air above the surface without direct contact of a heating element on the soil (Roy et al., 2012). Two IR lamps (each of 1000 W output) in each e-CO_2T chamber was hanged 2.0 m above the soil surface. The operating wavelengths of the infrared lamps were above 1000 nm. The lamps were equipped with ceramic core coated with in coloy, a metal alloy effective in high temperature applications ensuring a consistent infrared wavelength. The on/off action of infrared lamps was controlled by power semi-conductor controllers operated by the program logic control (PLC; OTMATIC; M/s Magnetic Brains, Mumbai, Maharashtra, India).

2.2. Soil characteristics and crop-water management

The soil order was Aeric Endoaquept and the soil texture was sandy clay loam. There was non-significant variation in soil texture, bulk density, CEC and conductivity within the treatments. The soil separates varied across the treatments/samples were 24–26% clay, 20–22% silt and 53–55% of sand. The bulk density, CEC and electrical conductivity were varied between 1.41-1.43 Mg m^{-3}, 13.7–14.3 cmol (p^+) kg^{-1}, and 0.43–0.49 dS m^{-1} respectively in the soil samples. The total carbon and nitrogen content was 0.76 and 0.07%, respectively. Twenty one to twenty four days old seedlings of three aerobic rice cultivars (CR-143-2-2, APO and CR Dhan 201) were transplanted inside OTCs. Nitrogen application rate was 100 kg ha^{-1} and applied in 3 splits. The first nitrogen dose (40 kg ha^{-1}) was given at 7^{th} day of transplanting. Next two splits were (30 kg ha^{-1}) at maximum tillering and panicle initiation. Basal dose of phosphorous and potassium were applied as single super phosphate and muriate of potash at a rate of 40 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1}, respectively. Rhizospheric soils were collected with sample probe nearer to root surface (within 2–5 cm from root) with replications under each variety and OTCs and stored in a polythene bag at room temperature for EPS analysis as well as refrigerator (4 °C) for microbial and bio-chemical (MBC, RMC, soil enzymatic essay) assays. Soil moisture potential was maintained at −40 ± 3 kPa lower than the recommended for aerobic rice (−30 kPa in sandy clay loam soil) (Belder et al., 2005) up to 10 days before harvesting of crops. Soil moisture tension was maintained by regulating field irrigation scheduling. Irrigation scheduling was based on the soil moisture characteristic curves (previously done for the experimental site) considering soil moisture tension (measured by tensiometer and pressure plate) and gravimetric moisture content of soil. Periodic checking of soil moisture content / tension was done during the study period. This was done with the hypothesis that anticipated climate change would cause addition water stress (limited) under elevated CO_2 and temperature condition. Although, it is expected higher moisture stress under e-CO_2T than a-CO_2, but for comparison and limited field replication of OTCs similar