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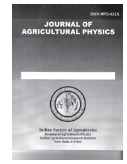

Research Article

Phosphorus Dynamics in Transplanted and Direct Seeded Rice with Varying Doses of Phosphorus under Elevated Carbon Dioxide Concentration

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ABSTRACT

The increasing atmospheric carbon dioxide (CO_2) concentration will affect growth and nutrient requirement of crops. A study was undertaken to quantify the impact of elevated CO_2 on yield, P uptake and soil P availability in transplanted and direct seeded rice (DSR). Phosphorus application at increasing doses upto100% of recommended dose resulted in higher grain weight and aboveground P uptake in both transplanted rice and direct seeded rice (DSR) crop. In elevated CO_2treatment, grain weight was higher by 11.3% and 14% in transplanted rice and DSR than ambient treatment. Partitioning of biomass to roots in DSR was more in elevated CO_2 treatment, than that of ambient treatment. Higher root growth along with moreP solubilizing enzymatic activities improved the P availability and P uptake in DSR in elevated CO_2 treatment than ambient one. Henceit can be concluded that, application of optimum P dose would be beneficial for DSR in terms of improving P availability and its uptake under future climatic condition.

Key words: Elevated CO_2, Direct seeded rice, Phosphorous uptake, Soil phosphorous availability

Introduction

The atmospheric concentration of carbon dioxide (CO_2) has increased from 280 ppm during preindustrial time to 400 ppm during 2013 due to anthropogenic activities (Dlugokencky and Pieter, 2015). The CO_2 concentration is currently increasing at the rate of 2 ppm annually (IPCC, 2014). Rise in the atmospheric concentration of CO_2 and other greenhouse gases (GHGs) is leading to global warming and climate change. The increased concentration of CO_2 may have positive or negative impacts on crop productivity. Elevated CO_2 concentration is known to increase the photosynthesis rate in different crops thereby enhancing their productivity (Ainsworth and Long, 2005; Dey *et al*., 2017; Chakrabarti *et al*., 2020). This CO_2 fertilization effect will be necessary in future to offset the anticipated harmful effects of high temperature on crop productivity to feed the ever increasing human population (Godfray *et al*., 2010). Singh *et al*. (2013) reported that the negative effect of temperature rise

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upto 3°C could be compensated by elevated CO_2 level in rice crop.

Rice (*Oryza sativa)* is an important cereal crop and worldwide it is consumed by more than 2 billion people. In India, rice is grown predominantly as transplanted rice after puddling the field. It requires large amount of water and labour. The puddled transplanted rice contributes to methane (CH_4) emission due to the prevailing anoxic conditions (Pathak *et al*., 2013). An alternative water saving method for growing rice is known as direct seeded rice (DSR). Due to its benefits in terms of water and labour saving and lower methane emission than that of transplanted rice, DSR can be considered as an alternative option of rice cultivation (Kumar and Ladha, 2011; Pathak *et al*., 2013). Globally, several researchers have studied the yield performance of DSR and reported varyingresults. Some studies have reported grain yield of more than 11.2 t ha^{-1}in DSR method of cultivation (Dong *et al*., 2005; Kato *et al*., 2009). Kumar *et al*. (2015) reported that the yield of puddled transplanted rice was 10-12% higher than that of DSR, as well as practicing DSR reduced the labour requirement by 97%. There was also a cost saving of 80% in DSR as compared to the puddled transplanted rice. The conventional method of growing transplanted rice requires approximately 2500-2600 litres of water to produce one kg rice. The water used for irrigating the transplanted rice crop is through pumping ground water which is energy intensive and leads to CO_2 emission. In order to reduce the global warming potential of rice cultivation and save water, DSR is being advocated to the farmers in irrigated rice production system.

The changing climate will also have significant effect on nutrient cycling and other soil processes linked with the soil fertility (Brevik, 2013). Plant absorbs nutrients through their root system from soil for its growth and development. The nutrient concentration in soil can vary due to climate change and plants need to adapt to the changing climate in order to fulfill their nutrient requirements. Phosphorus is one of the major nutrients affecting crop growth and productivity. Enhanced crop growth under elevated CO_2 condition is likely to increase the requirement of major nutrients like nitrogen (N) and phosphorus (P) in crops (Lagomarsino *et al*., 2008; Chakrabarti *et al*., 2020). Besides this, changes in rhizospheric activity and increased release of root exudates under elevated CO_2 concentration, might affect P mineralization (Jin *et al*., 2015), P availability and its uptake by the plants (Shen *et al*., 2011). The main problem concerning phosphorus fertilizer is its fixation in soil within a short period of time rendering more than two thirds unavailable. Therefore it is necessary to know the optimum P dose to maximize the yield of rice crop. There are reports that availability of soil phosphorus is more under submerged condition due to the change in redox potential of soil. Savant and Ellis (1964) reported that decrease in redox potential of soil after submergence increases the availability of soil phosphorus. In the current scenario when DSR is being grown by farmers for water and labour saving and lowering methane emission it is necessary to assess the availability of soil P as well as growth and productivity of transplanted and direct seeded rice under elevated CO_2 condition. Hence, the present study was aimed to assess the impact of elevated CO_2on P uptake and availability of soil P inpuddled transplanted rice and DSR crop.

Materials and Methods

Experimental details

An experiment was carried outgrowing rice during the *kharif* season (July to October) of year 2015 in ICAR-Indian Agriculture Research Institute (IARI), New Delhi (28°35′ N and 77°12′ E) India. The climate of the region is sub-tropical, semi-arid with annual rainfall of around 750 mm. The mean annual maximum and minimum temperature was 35°C and 18°C, respectively.

The experiment was conducted both inside and outside the Free Air Carbon Dioxide Enrichment (FACE) facility in Genetic H field of IARI farm with 16 treatments each with three replications. The FACE ring consisted of eight horizontal pipes through which CO_2 enriched air was released near the crop canopy (Chakrabarti *et al*., 2012).Carbon dioxide concentration inside the FACE ring was maintained at 550 ppm ± 25 ppm while ambient CO_2 concentrations outside was 400 ppm.

Rice crop (variety Pusa basmati 1509) was grown in pots of 30 cm diameter filled with 16 kg soil. The soil was collected from the top 0-15 cm layer of the research farm. It was then air-dried, sieved (0.5 mm mesh) and analyzed for various physico-chemical properties. The experimental soil was non-saline (EC 0.47 dS m^{-1}) and mildly alkaline (pH 7.8) with soil organic carbon content of 0.45%. Available N content in initial soil was 235 kg ha^{-1}, available P (0.05 *M* $NaHCO_3$ extractable) was 18 kg ha^{-1} and available K (1 *N* ammonium acetate extractable) was 180 kg ha^{-1}.Two planting methods i.e. puddled transplanted rice and direct seeded rice was followed. Transplanting of rice was carried out on last week of July while in DSR, seeds were sown on 1st week of July. For transplanted rice, the soil was puddled and 30 days old rice seedlings were transplanted as 3 seedlings per hill. For direct seeded rice, the seeds (3 in each place) were sown manually with a dibbler in a slightly moistened soil at four places in the pots. After germination, two seedlings were maintained in each pot by removing the rest two weeks after sowing. Phosphorus was applied in four different doses through single super phosphate viz. control (No P), 20 mg P kg^{-1} soil (75% of recommended dose of P), 27 mg P kg^{-1}soil (100% of recommended dose of P), 33 mg P kg^{-1}soil (125% of recommended dose of P). Nitrogen was applied through urea at the rate of 120 kg ha^{-1} while potassium was applied through murate of potash (MOP) at 40 kg ha^{-1}. Five centimeters of water level was maintained in case of transplanted rice throughout the crop growth period whereas in DSR, the soil moisture was maintained at field capacity. Weeds were removed manually as and when required during the cropping period.

Growth and yield parameters

Some rice plants were harvested at flowering stage and the harvested plants were then oven dried (65± 2°C for 72 hrs) and weight of dried root and shoot was recorded. Root: Shoot ratio was calculated by dividing dry weight of root by dry weight of shoot of the crop.After harvesting, plant samples were collected from each treatment and grain weight was recorded.

Plant P

Plant samples after harvest were dried in oven at 65± 2°C for 72 hrs, ground and analyzed for P content using vanadomolybdo yellow colour method (Jackson 1956).

Analysis of Soil Samples

At flowering stage, soil samples were collected from each pot. Each sample was divided into two parts. One portion was kept in refrigerator maintained at 4°C for estimation of enzymatic activities. Another portion was air dried under shade, processed and then sieved through 0.5 mm screen. Available phosphorus content in soil was estimated following ascorbic acid blue colour method (Watanabe and Olsen 1965). Activity of acid phosphatase and alkaline phosphatase enzymes in soil were determined using method as described by Tabatabai and Bremner (1969).

Statistical analysis

Statistical analysis of the data was done using SAS (ver. 9.3) software. The design of the experiment was factorial completely randomized design (CRD) with 16 treatments. Analysis of variance was done to test whether the differences were statistically significant.

Results and Discussion

Grain weight

Grain weight of rice increased under elevated CO_2 treatment. In transplanted rice, grain weight increased by 11.3% while in DSR, grain weight increased 14% in elevated CO_2 treatment. Increased rate of phosphorus application upto 100% of RDP caused rise in grain weight of rice crop. Grain weight of transplanted rice was significantly higher (23.4 g $hill^{-1}$) than DSR (21.3 g $hill^{-1}$) crop (Table 1). Earlier researchers also reported that both grain and biomass yield in rice increased under elevated CO_2 concentration (Raj *et al*., 2019). Kumar *et al*. (2015) reported that yield of transplanted rice was 10 to 12% higher as compared to DSR crop.

Root: Shoot ratio

Higher photosynthesis rate in elevated CO_2 treatment resulted in more biomass accumulation in both transplanted rice and DSR. But results showed that the proportionate increase in biomass was more

Table 1. Grain weight (g hill^{-1}) of transplanted rice and DSR under ambient and elevated CO_2 concentration

P Levels	Ambient CO_2		Elevated CO_2	
(mg kg^{-1} soil)	TR	DSR	TR	DSR
Control	13.6	11.3	15.6	13.1
75% RDP	23.2	21.4	26.5	24.2
100% RDP	25.8	23.3	28.1	26.6
125% RDP	25.9	23.8	28.3	26.8
Mean	22.1	19.9	24.6	22.7

LSD (p 0.05): CO_2: 1.2; Rice: 1.2; P: 1.8; CO_2 × Rice: NS; CO_2 × P: NS; Rice × P: NS; CO_2 × Rice X P: NS
(Control: No phosphorus; RDP: Recommended dose of phosphorus)

in roots than the aboveground plant part especially in DSR crop. In elevated CO_2 treatments, root: shoot ratio in DSR ranged from 0.58 to 0.60 while in ambient treatments it ranged from 0.50 to 0.58 (Fig. 1). The increase in root: shoot ratio under elevated CO_2 treatment was more in lower P doses in DSR crop. The increased aboveground crop biomass under elevated CO_2 concentration needs more amount of water and nutrients. Hence the root growth increases to a greater extent to fetch the water and nutrients for the crop. Rogers *et al*. (1994) also observed more root growth and root biomass under elevated CO_2 concentration. A study with maize crop showed that translocation of more amount of carbon led to higher relative growth rate of roots than that of shoot under elevated CO_2 condition (Whipps, 1985). A meta-analysis on the effect of CO_2 enrichment studies showed 47% increase in root biomass in C3 crops, while increase in aboveground biomass was 12% (Kimball *et al*., 2002).

Phosphorus uptake

More crop biomass under elevated CO_2 condition increased the aboveground P uptake in both transplanted rice and DSR crop. Aboveground P uptake in transplanted rice was 87.0 mg P hill^{-1} in

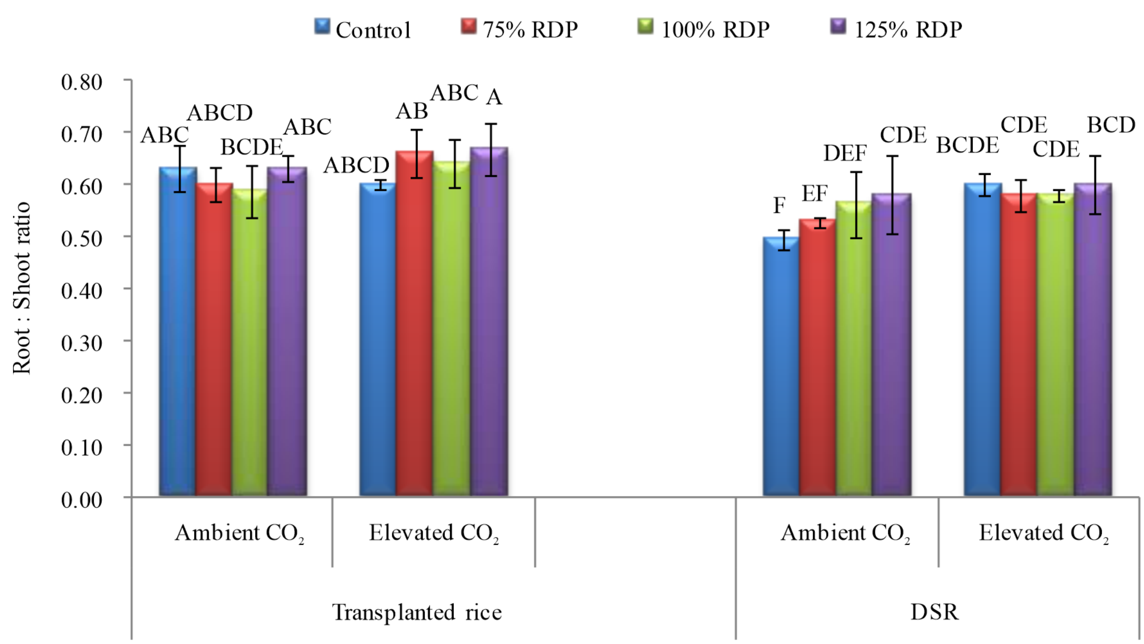

Fig. 1. Root: Shoot ratio in transplanted rice and DSR as affected by elevated CO_2 concentration. Column with different alphabet is significantly different ($p \leq 0.05$).
(Control: No phosphorus; RDP: Recommended dose of phosphorus)

Table 2. Aboveground P uptake (mg hill^{-1}) in transplanted rice and DSR under ambient and elevated CO_2 concentration

P Levels	Ambient CO_2		Elevated CO_2	
(mg kg^{-1} soil)	TR	DSR	TR	DSR
Control	45.3	34.8	50.9	39.8
75% RDP	73.7	61.3	82.8	67.8
100% RDP	82.0	67.8	87.9	77.1
125% RDP	83.6	70.1	90.4	79.0
Mean	79.8	66.4	87.0	74.6

LSD (p 0.05): CO_2: 4.2; Rice: 4.2; P: 5.9; CO_2 × Rice: NS; CO_2 × P: NS; Rice × P: NS; CO_2 × Rice × P: NS
(Control: No phosphorus; RDP: Recommended dose of phosphorus)

elevated CO_2 treatment while in ambient treatment it was 79.8 mg P hill^{-1} (Table 2). Similarly in DSR, aboveground P uptake was 74.6 mg P hill^{-1} in elevated CO_2 treatment and 66.4 mg P hill^{-1} in ambient treatment. P application at increasing doses upto 100% of RDP caused significant rise in aboveground P uptake in the crop. Earlier workers showed that requirement of nutrients like phosphorus will be more in elevated CO_2 concentration (Jin *et al*., 2012). In cowpea crop, more P uptake was observed under elevated CO_2 concentrationwhich further increased with increasing doses of phosphorus (Dey *et al*., 2019).

Soil available phosphorus

Soil available phosphorus increased significantly with P application and it was more in transplanted rice than DSR crop. In transplanted rice, soil available P at flowering stage was 12.1 mg kg^{-1}while in DSR, it was 10.7 mg kg^{-1} soil (Table 3). P availability to plants increases under submerged condition. Aoki (1941) reported that the solubility of soil P increased when rice fields were flooded. In the current study, soil available P in DSR were 11.8% and 10.5% less than transplanted rice in ambient and elevated CO_2 treatment respectively. Hence the availability of soil P improved under elevated CO_2 condition in DSR crop. This might be attributed to the fact that more root growth in elevated CO_2 treatment led to higher belowground microbial activity resulting in improved availability of P for the crop.

Enzymatic activities

At the flowering stage, activities of acid phosphatase and alkaline phosphatase enzymes were higher in elevated CO_2 treatments (Fig. 2). Higher crop growth and more crop biomass under elevated CO_2 condition resulted in higher phosphorus demand resulting in higher acid phosphatase enzyme activity. Microbial activity in the soil also improved under elevated CO_2 treatments resulting in increased activity of these two P solubilizing enzymes. In

Table 3. Available phosphorus (mg kg^{-1}) in soil in transplanted rice and DSR under ambient and elevated CO_2 concentration

P Levels	Ambient CO_2		Elevated CO_2	
(mg kg^{-1} soil)	TR	DSR	TR	DSR
Control	9.5	8.7	10.2	9.5
75% RDP	12.3	10.4	12.6	11.5
100% RDP	12.7	11.1	13.2	11.6
125% RDP	12.8	11.3	13.6	11.8
Mean	11.8	10.4	12.4	11.1

LSD (p 0.05): CO_2: NS; Rice: 0.80; P: 1.1; CO_2 × Rice: NS; CO_2 × P: NS; Rice × P: NS; CO_2 × Rice × P: NS
(Control: No phosphorus; RDP: Recommended dose of phosphorus)

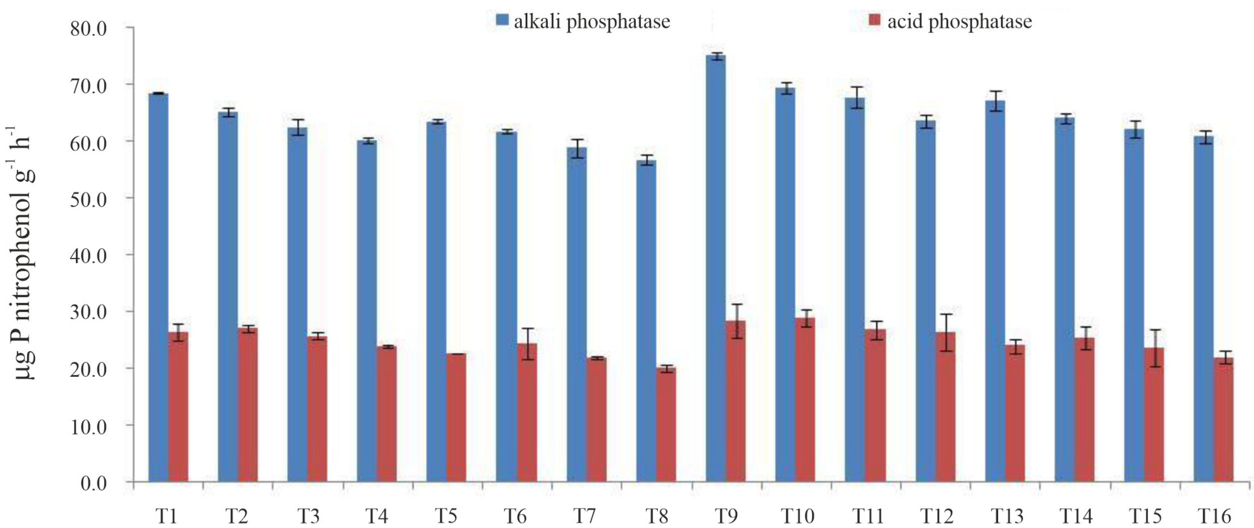

Fig. 2. Effect of elevated CO_2 and P doses on alkaline phosphatase and acid phosphatase activity (µg P nitrophenol $g^{-1}h^{-1}$) in soil. [T1: ambient CO_2, transplanted rice, control; T2: ambient CO_2, transplanted rice, 75% RDP; T3: ambient CO_2, transplanted rice, 100% RDP; T4: ambient CO_2, transplanted rice, 125% RDP; T5: ambient CO_2, DSR, control; T6: ambient CO_2, DSR, 75% RDP; T7: ambient CO_2, DSR, 100% RDP; T8: ambient CO_2, DSR, 125% RDP; T9: elevated CO_2, transplanted rice, control; T10: elevated CO_2, transplanted rice, 75% RDP; T11: elevated CO_2, transplanted rice, 100% RDP; T12: elevated CO_2, transplanted rice, 125% RDP; T13: elevated CO_2, DSR, control; T14: elevated CO_2, DSR, 75% RDP; T15: elevated CO_2, DSR, 100% RDP; T16: elevated CO_2, DSR, 125% RDP]

ambient CO_2 treatment, activity of alkaline phosphatase was highest (68.6 µg P nitrophenol g^{-1} hr^{-1}) in transplanted rice with no P application (Fig. 2). Similarly in elevated CO_2 treatment, activity of this enzyme was highest (75.1 µg P nitrophenol g^{-1} hr^{-1}) in transplanted rice with no P application. In treatments with no or lower P doses, the P demand was higher leading to more release of this enzyme. In elevated CO_2 treatment higher crop growth led to more P demand resulting in greater activity of these P solubilizing enzymes. Earlier workers also reported increased activities of these enzymes under elevated CO_2 condition in different crops (Dey *et al*., 2019; Kumar *et al*., 2011).

Correlation analysis

Multiple correlation analysis among different plant and soil parameters revealed that grain yield was significantly positively correlated with aboveground P uptake of the crop (r = 0.87). Soil available P was significantly positively correlated with aboveground P uptake (r = 0.96) and root: shoot ratio (r = 0.51) (Table 4). Elevated CO_2 level and P

Table 4. Correlation matrix of variables related to plant and soil parameters in rice crop

	Grain yield	Root:shoot ratio	Aboveground P uptake	Soil available P	Alkaline phosphatase	Acid phosphatase
Grain yield	1.00					
Root: shoot ratio	0.37	1.00				
Aboveground P uptake	0.87**	0.62*	1.00			
Soil available P	0.92**	0.51*	0.96**	1.00		
Alkaline phosphatase	-0.38	0.37	0.01	-0.17	1.00	
Acid phosphatase	-0.05	0.33	0.27	0.17	0.84**	1

* and ** Significant at 0.05 and 0.01 level respectively

application increased the root growth and soil available P causing more P uptake by the crop. An increase in root growth and soil available P resulted in higher P uptake by the rice crop.

Conclusions

Growth of both transplanted rice and DSR increased under elevated CO_2 condition. P application at increased rate upto100% of RDP caused increase in grain weight and aboveground P uptake by the crop. The proportionate increase in biomass was more in roots than the aboveground plant parts in elevated CO_2 treatment in DSR. The study illustrated that availability of soil phosphorus improved in DSR under elevated CO_2treatment. Increase in root growth and soil available P further improved P uptake. Hence application of optimum dose of P could increase the phosphorus availability and P uptake in direct seeded rice under future climatic condition.

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