

Research paper

Impact of elevated CO₂ on soil phosphorus dynamics of lentil (*Lens culinaris* L. Medik) genotypes

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ABSTRACT

The rising level of carbon-di-oxide (CO₂) has an enormous impact on crop growth and physiology especially in the case of legumes. In general elevated CO₂ (e[CO₂]) has a positive impact on legumes but, to maximize the benefit crops must be supplemented with adequate levels of essential nutrients especially phosphorus (P). Therefore, a controlled experiment under OTC has been taken to understand the impact of short-term e[CO₂] on soil P-dynamics and changes in labile and non-labile soil P-pools under two contrasting genotypes of lentil namely, IPL-316 and IPL-406. Results showed soluble-P (sol-P) and di-calcium P (Ca₂-P) both increased significantly under e[CO₂] in the case of both the genotypes and results are more prominent in IPL-316. The ratio of labile: non-labile P increased under e[CO₂] by 28% and 18% for IPL-316 and IPL-406 respectively over ambient. Organic carbon and available nitrogen (N) and P also increased significantly under e[CO₂]. Short term exposure of e[CO₂] failed to show any noticeable change in bulk soil P-dynamics. Hence, short term e[CO₂] exposure can cause marked change in labile P-pools and the results are more prominent in IPL-316.

Key words: Climate change, Elevated CO₂, Lentil, Phosphorus

INTRODUCTION

Large scale urbanisation and anthropogenic activities led to exponential increase in global atmospheric carbon-di-oxide (CO₂) level and it would likely to hit 750 ppmv by end completion of 21st century (IPCC 2014). Along with its catastrophic impact on human lives, the rising level of CO₂ has profound impact on crop physiology, nutrient uptake and lastly on productivity at variable scale depending on the agro-ecology, crop species and husbandry practices (Dutta *et al.*, 2022a; McLachlan *et al.*, 2020). Therefore, assessing the impact of elevated CO₂ (e[CO₂]) on food crops under different agro-climatic and edaphic conditions is the pressing priority. Lentil (*Lens culinaris* L. Medik) is an important cool season highly nutritious, palatable, energy-rich grain legume globally grown in more than 52 countries with average productivity of 1305 kg ha⁻¹ (FAOSTAT 2022). In India lentil is grown in 1.30 m ha area with 1.58 mt production and average productivity of 1216 kg ha⁻¹ (AICRP Report 2021-22). Various reports across the globe highlighted the multifaceted impacts on crop physiology, yield and yield attributes under e[CO₂] on different grain legumes including lentil but, hardly any of the

studies focused on soil phosphorus (P)-dynamics or assessing the change in different P-fractions of soil under climate change conditions (Lamichaney *et al.*, 2021; Nasser *et al.*, 2008; Saha *et al.*, 2011). Previous study by Delahunty *et al.* (2018) reported increase in lentil biomass by 16% under with e[CO₂] (conc.: 700ppm) as compared to ambient but the study lacked information about the variations in soil P-fractions. Phosphorus (P) is the most important nutrient for legumes having multi-faceted roles in crop growth and development such as, energy conversion, root growth and translocation of photosynthates into different plant parts (Dutta *et al.*, 2022a). Therefore, attention should be given on optimal P nutrition for sustaining lentil productivity in tropical soils, particularly attention is warranted to understand the impact of e[CO₂] on soil P bioavailability and P dynamics in lentil-grown in Inceptisol.

Being a C3 crop, lentil responds positively to e[CO₂] but, at the same time it needs judicious supply of nutrients including P for sustainable growth and harnessing optimum yield potential (Dutta *et al.*, 2022b). Under P-limited situations especially in the tropical climate, high fixation can result massive yield penalties in grain legumes (Hazra *et al.*, 2018).

Understanding the soil P-dynamics, bio-available P, and organic carbon in the rhizosphere would enlighten us regarding soil P-cycling under $e[\text{CO}_2]$ conditions (Jin *et al.*, 2013). Thus, an open-top chamber-based study was conducted to investigate the effect of $e[\text{CO}_2]$ on temporal soil P dynamics during crop growing season under Inceptisol of subtropical climate (Northern India). The major objectives of this study were to determine the impact of $e[\text{CO}_2]$ on temporal dynamics of soil P pools, distribution of labile and non-labile soil P pools and available nutrients in post-harvest soil in lentil as altered with $e[\text{CO}_2]$ environment.

MATERIALS AND METHODS

An open-top chamber (OTC) experiment was conducted in the *rabi* season of 2020-21 located at ICAR-Indian Institute of Pulses Research, Kanpur (Latitude: $26^{\circ}27' \text{N}$ and Longitude: $80^{\circ}14' \text{E}$, having an elevation of 152 m of the sea level). The study site is located under sub-tropical climate with mean annual rainfall of 799 mm. Two different CO_2 concentrations [ambient (379–423 ppm) and $e[\text{CO}_2]$ (566–630 ppm)] were used as treatment to evaluate the effect of $e[\text{CO}_2]$ on soil P-dynamics. The experimental soil was low in available potassium (K) ($95\text{--}115 \text{ kg ha}^{-1}$) and medium in available N ($300\text{--}340 \text{ kg ha}^{-1}$) and P ($11\text{--}13 \text{ kg ha}^{-1}$).

The plot inside the OTCs was manually tilled and properly levelled before sowing. Two lentil genotypes (IPL-406 and IPL-316) were sown during the first fortnight of November in rows separated by 30 cm. The recommended fertilizer rate of N, P_2O_5 and K_2O at 20, 40 and 60 kg ha^{-1} was applied as basal dose at the time of plot preparation. The crop was irrigated twice at 40–45 days after sowing (DAS) and second during pod filling stage. Two hand weeding were performed at 35 and 55 DAS to keep the plots weed free. Need based plant protection measures were taken to raise a healthy crop.

From every OTC three healthy lentil plants were sampled at peak vegetative growth stage (70 days after sowing) and the rhizosphere soil was collected by scraping it from the roots using a scalpel. The soil samples were air-dried, finely grinded and passed through 2 mm sieve for laboratory analysis. Soil inorganic P (Pi)-fractions were divided into seven pools *viz.* soluble-P (Sol-P), di-calcium P ($\text{Ca}_2\text{-P}$), octa-calcium P ($\text{Ca}_8\text{-P}$), aluminium P (Al-P), iron P (Fe-P), occluded-P (Occ-P) and deca-calcium P ($\text{Ca}_{10}\text{-P}$) and analysed by procedure given by (Kuo, 1996). In brief 0.5 gram soil sample was sequentially treated with 1 M ammonium chloride

(NH_4Cl), 0.25 M sodium bicarbonate (NaHCO_3) (pH 7.5), ammonium acetate ($\text{C}_2\text{H}_7\text{NO}_2$) (pH 4.2), 0.5M ammonium fluoride (NH_4F) (pH: 8.2) and 0.1 M sodium hydroxide (NaOH), CDB (sodium citrate ($\text{Na}_3\text{C}_6\text{H}_5\text{O}_7 \cdot 2\text{H}_2\text{O}$) - sodium dithionate ($\text{Na}_2\text{S}_2\text{O}_4$)-sodium bicarbonate) and 0.25 M sulphuric acid (H_2SO_4) for extracting Sol-P, $\text{Ca}_2\text{-P}$, $\text{Ca}_8\text{-P}$, Al-P, Fe-P, Occ-P and $\text{Ca}_{10}\text{-P}$, respectively. In the final step, 10 ml of supernatant was taken in a separate 25 ml volumetric flask and P concentration was determined using phospho-molybdate method (Murphy and Riley, 1962). Student t-test ($p \leq 0.05$) was used to assess the significant difference among the treatments.

RESULTS AND DISCUSSION

Results indicated in case of IPL-316, except sol-P and $\text{Ca}_8\text{-P}$, none of the soil P-fractions showed any change under short term exposure to $e[\text{CO}_2]$. The sol-P fraction differed significantly between $e[\text{CO}_2]$ and ambient conditions ($a[\text{CO}_2]$) as in the later it increased by 18.4% as compared to former. The downturn of $\text{Ca}_8\text{-P}$ in elevated condition may be due to mobilisation of the former into labile-Pools (sol-P+ $\text{Ca}_2\text{-P}$) (Table 1). Similar results can be seen under IPL-406, where sol-P and $\text{Ca}_2\text{-P}$ increased significantly under $e[\text{CO}_2]$ condition by 11.8% and 14.7%, respectively as compared to $a[\text{CO}_2]$ with consequent reduction of $\text{Ca}_8\text{-P}$ by 23.2% under $e[\text{CO}_2]$ than $a[\text{CO}_2]$. None of Pi-fractions except aforesaid three major fractions showed any significant change under soil-plant system in short term exposure to $e[\text{CO}_2]$ (Datta *et al.*, 2022a; Jin *et al.*, 2013). Lentil as a legume can efficiently convert the non-labile P-pools into plant available labile pools via root mediated enzymes and secretion of low molecular organic acids, root proliferation in nutrient rich patches and proton (H^+) exudation which escalated manifolds under $e[\text{CO}_2]$ via translocating more photo assimilates in the roots

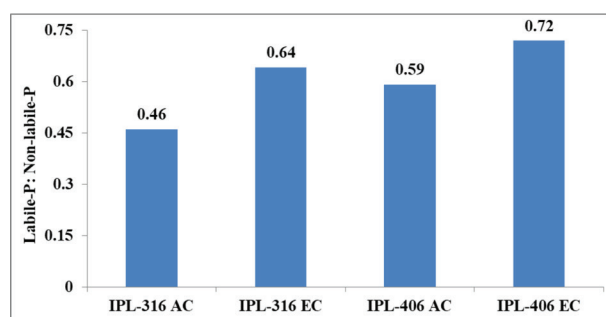


Fig 1. Proportion of labile-P: non labile P under elevated $[\text{CO}_2]$ treatment and ambient $[\text{CO}_2]$ treatment of lentil genotypes AC- ambient $[\text{CO}_2]$; EC- elevated $[\text{CO}_2]$

Table 1. Changes in rhizosphere soil phosphorus fractions, organic carbon and available nutrients under elevated [CO₂] treatment and ambient [CO₂] treatment of lentil genotypes

Geno-type	Parameter	Ambient [CO ₂]	Elevated [CO ₂]	% Δ	
IPL 316	Sol-P (ppm)	54±1.25 ^B	66.25±2.25 ^A	+18.4	
	Ca ₂ -P (ppm)	52.75±1 ^A	56.77±1.53 ^A	+7	
	Ca ₈ -P (ppm)	63.87±1.63 ^A	41.05±1.30 ^B	-35.7	
	Al-P (ppm)	42.5±0.75 ^A	38.37±1.88 ^A	-9.7	
	Fe-P (ppm)	35.37±1.13 ^A	31.5±1.50 ^A	-10.9	
	Occ-P (ppm)	22.12±1.63 ^A	21.05±1.55 ^A	-4.8	
	Ca ₁₀ -P (ppm)	64.37±1.63 ^A	60.05±2.31 ^A	-6.4	
	OC (%)	0.5±0.02 ^A	0.52±0.01 ^A	+3.8	
	Available-N (Kg ha ⁻¹)	321±3 ^B	353±3 ^A	+9	
	Available-P (Kg ha ⁻¹)	11.5±0.25 ^B	15.2±1 ^A	+24.3	
	Available-K (Kg ha ⁻¹)	186.7±4 ^A	206.62±5.02 ^A	+9.6	
	IPL 406	Sol-P (ppm)	76.62±1.12 ^B	86.87±1.37 ^A	+11.8
		Ca ₂ -P (ppm)	56.37±0.88 ^B	66.12±1.87 ^A	+14.7
Ca ₈ -P (ppm)		57.75±0.5 ^A	44.30±1.94 ^B	-23.2	
Al-P (ppm)		40.12±1.62 ^A	44.92±1.67 ^A	+10.6	
Fe-P (ppm)		33.37±0.87 ^A	44.16±2.58 ^A	+24.4	
Occ-P (ppm)		16.75±1.25 ^A	14.87±1.87 ^A	-11.6	
Ca ₁₀ -P (ppm)		74.5±3.5 ^A	64.25±2.25 ^A	-13.7	
OC (%)		0.50±0.01 ^A	0.55±0.01 ^A	+8.1	
Available-N (Kg ha ⁻¹)		334.5±2.5 ^B	350.5±1.5 ^A	+4.4	
Available-P (Kg ha ⁻¹)		11.65±0.15 ^B	15.05±0.15 ^A	+22.5	
Available-K (Kg ha ⁻¹)		180.32±1.2 ^A	169.20±2.05 ^A	-6.1	

*Values followed by different upper case letters (A-B) are significantly different between treatments at p≤0.05.

(Nie *et al.*, 2013). Both the Fe-P and Al-P decreased under e[CO₂] in case of IPL-316 but, not in case of IPL-406. The reason being increased acidification under IPL-316 than IPL-406 resulted in chelation of Fe³⁺ which caused the release of adsorbed P (Li *et al.*, 2008). The labile: non-labile P increased in case of both the genotypes while, it was 28% and 18% for IPL-316 and IPL-406, respectively (Figure 1). Variation in root morphology and physiology, association with vesicular arbuscular mycorrhizae (VAM) and divergence in plant-microbes mediated enzyme secretions might be the reasons behind genotypic difference in soil P-fractions (Cong *et al.*, 2020). Organic-C and among the available nutrients N and P increased significantly under e[CO₂] as compared to a[CO₂] (Table 1). Increased rhizodeposition with stimulated atmospheric N₂ fixation by the legumes may have resulted in increased OC (Peralta and Wander, 2008) and N, respectively

Table 2. Changes in bulk soil soil phosphorus fractions, organic carbon and available nutrients under elevated [CO₂] treatment and ambient [CO₂] treatment

Parameter	Ambient [CO ₂]	Elevated [CO ₂]	% Δ
Sol-P (ppm)	48.75±1.5 ^A	50.75±1.75 ^A	+3.9
Ca ₂ -P (ppm)	57.75±3.12 ^A	60.37±2.75 ^A	+4.3
Ca ₈ -P (ppm)	48.62±2.37 ^A	52.83±2.38 ^A	+7.9
Al-P (ppm)	31±1 ^A	39.35±1.75 ^A	+21.2
Fe-P (ppm)	37.25±1 ^A	33.13±1.13 ^A	-11.1
Occ-P (ppm)	24.37±0.875 ^A	14.25±2.25 ^A	-41.5
Ca ₁₀ -P (ppm)	62.75±1 ^A	58.38±3.38 ^A	-7
OC (%)	0.46±0.01 ^A	0.44±0.01 ^A	-4.3
Available-N (Kg ha ⁻¹)	286.5±1.5 ^A	273±2 ^A	-4.5
Available-P (Kg ha ⁻¹)	5.8±0.2 ^A	7.1±0.01 ^B	+18.3
Available-K (Kg ha ⁻¹)	240.4±5.04 ^A	213.61±7.03 ^A	-10.9

*Values followed by different upper case letters (A-B) are significantly different between treatments at p≤0.05.

(Rogers *et al.*, 2009). In case of bulk soil, except available P, none of the P-fractions and neither OC nor available nutrients in post-harvest soils (PHS) showed any of the significant response under e[CO₂].

CONCLUSION

This controlled study revealed that short term exposure to elevated CO₂ has significant impact on labile P pools and soil available phosphorus especially in case of IPL-316 however, long term studies with more number of genotypes must be undertaken to get concrete evidence with better scientific understanding.

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