



Effect of Elevated CO₂ and Temperature on Phosphorus Harvest Index of Wheat (*Triticum aestivum* L.) at Various Levels of Phosphorus Fertilization

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Abstract

The possible alteration in plant growth, productivity and phosphorus (P) demand of wheat under rising atmospheric CO₂ and temperature is expected to influence the partitioning of P to different plant parts of wheat. A phytotron experiment was conducted to study the effects of elevated atmospheric CO₂ (650 μmol mol⁻¹) and elevated temperature (ambient + 3 °C) on phosphorus harvest index of wheat at various levels (control, 100% and 200% of recommended P) of P fertilization. While there was a slight increase (5.6%) in P harvest index of wheat under elevated CO₂, the reverse trend (12.7% decline) was observed under elevated temperature with no consistent effect at various levels of P fertilization. Interestingly, there was a moderate decline (7.7%) in P harvest index of wheat under combined elevation of CO₂ and temperature as compared to their ambient combination. The results suggest that temperature could be the dominant factor as compared to the atmospheric CO₂ in deciding the overall impact of projected increase in atmospheric CO₂ and temperature on P harvest index of wheat. As there is logically possible relationship between P harvest index of wheat and various physical and nutritional qualities of wheat grains such as grain Zn and Fe content and their bio-availability, grain protein content, seedling vigour, etc., the decline in wheat's P harvest index under projected levels of CO₂ and temperature in our study underscores the need of undertaking elaborate experimentations to investigate the probable effects of climate change on quality parameters associated with P harvest index of wheat.

Keywords: Climate change, Elevated CO₂, Global warming, Grain nutritional quality, Phosphorus demand, Phosphorus partitioning

Introduction

Rise in earth's surface air temperature driven by the escalating atmospheric concentrations of carbon dioxide (CO₂) is the most obvious manifestation of global climatic changes. Atmospheric CO₂ concentration has been increasing from preindustrial concentration of nearly 280 μmol mol⁻¹ to a present global average of approx. 400 μmol mol⁻¹. Currently, atmospheric CO₂ concentration which accounts for about 63% of global warming is increasing by 0.5% year⁻¹ (~2 ppm year⁻¹) and according to the projections of Intergovernmental Panel on Climate Change (IPCC), CO₂ will be reached around 550 μmol mol⁻¹ by the year 2050 and likely to be doubled by the year 2100 (Kumar and Swarup, 2012). The associated

rise in atmospheric temperature is likely to be 1.5 °C by 2015-2050 and 3 °C by 2050-2100. The possible impacts of the projected rise in these two most important factors of climate change on various aspects of crop production worldwide have become a topic of intense investigation in recent years (Kumar, 2011a; Patra *et al.*, 2012; Rakshit *et al.*, 2012; Choudhury *et al.*, 2013).

As atmospheric CO₂ is the only carbon source for plants, alterations in its concentration distinctly influence plant growth (Wrigley, 2006; Kimball *et al.*, 2002). As the current atmospheric CO₂ concentration (which is close to the K_m 'Michaelis-Menton constant, defined as the substrate concentration at which the rate of an enzymatic reaction

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is half of its maximum' of the enzyme for carbon fixation 'Rubisco' to which CO₂ acts as a substrate), is insufficient to cause photosynthetic saturation (Garcia *et al.*, 1998; Alonso *et al.*, 2008; Kumar and Swarup, 2012), current atmospheric CO₂ concentration should be considered a growth limiting nutrient for C₃ plants such as wheat and rice (Sinclair, 1992). Thus, any increase in CO₂ in atmosphere will serve as a fertilizer and will increase the rate of photosynthesis, growth and yield of C₃ crops subsequently (Long *et al.*, 2004). While increased plant growth with rising CO₂ is a complete certainty, the plant growth response to elevated temperature is region specific.

The alteration in plant growth and productivity under projected changes in climatic conditions is expected to influence the demand and critical concentrations of various plant nutrients (Sinclair, 1992; Rogers *et al.*, 1993; Campbell and Sage, 2002; Erda *et al.*, 2005; Campbell and Sage, 2006; Norisada *et al.*, 2006; Kumar and Patra, 2010; Kumar *et al.*, 2011a). Nitrogen (N) and phosphorus (P) being the two universally deficient plant nutrients logically become the most important nutrient elements in this regard. While the impacts of changes in these climatic variables on the demand and distribution of N is relatively better studied, the information on that for P are scanty (Kumar *et al.*, 2011b, Kumar *et al.*, 2012a,b). Amidst many other aspect of P nutrition of plant under changing climate, partitioning of P towards wheat grains which is reflected in P harvest index in the plant is particularly important in view of its potential importance in influencing the physical and nutritional quality of the wheat grains.

P harvest index is an important component in deciding the P content in wheat grains. On an average, approximately 75% of the total grain P remains in form of phytate-P in phytic acid, which is a major storage outline of P in wheat grains (Lott and Spitzer, 1980; Dorsch *et al.*, 2003; Steiner *et al.*, 2007; Raboy, 2009). The content of phytic acid in wheat seeds is important given its role in supplying the nutrients to emerging seedlings after germination. Conversely, the phytic acid present in wheat grains is also widely known as an anti-nutrient which reduces the bio-availability of some crucial micronutrients like Zn and Fe, potentially deteriorating the nutritional quality of wheat grains (WHO, 1996; Buerkert *et al.*, 1998; Ryan *et al.*, 2008; Kumar, 2011b). Furthermore, any changes in the partitioning of P towards wheat grains under projected increase in atmospheric CO₂ and temperature can also influence the grain concentrations of Zn and Fe by virtue of the widely recognized negative correlation of P with Fe and Zn in plant systems (Zhu *et al.*, 2001; Morgounov *et al.*, 2007; Ryan *et al.*, 2008). Given the positive correlation between P- and N-harvest indices in wheat (Calderini *et al.*, 1995), any alteration in P harvest index under future atmospheric CO₂ and temperature can also affect the N harvest index and hence, protein content of wheat grains as well.

Despite the great importance attached with the possible impacts of expected changes in P harvest index under changing climate, little information is available on how this important parameter might be influenced by the projected

rise in atmospheric CO₂ concentration and temperature particularly in the edapho-climatic conditions of India. Effects of higher doses of P fertilization (which seems unavoidable in order to meet the increased P requirement by the plants under elevated atmospheric CO₂ in future) on P harvest index of wheat also deserves to be investigated on. Keeping in view the future implications of the subject and also the huge research gap on the issue, a phytotron experiment was undertaken to investigate the impact of elevated CO₂ and temperature on phosphorus harvest index of wheat at various levels of phosphorus fertilization.

Materials and Methods

Experimental Site, Treatment Details and Crop Management

Wheat, selected as the test crop, was cultivated under controlled environment growth chambers at the National Phytotron Facility in IARI, New Delhi, where lighting conditions were artificially regulated. Wheat seeds, initially 6-7 seeds pot⁻¹, were planted in polypropylene pots with a capacity of 1.5 kg, each filled with soil (Inceptisol-Typic Haplustept) collected from surface layer (0-30 cm) of IARI research farm; only 3 plants pot⁻¹ were subsequently allowed to grow until reaching maturity. The general physico-chemical characteristics of the soil are mentioned in table 1.

Table 1: General physico-chemical properties of the experimental soil

Sl. No.	Soil properties	Values
1.	pH (1:2)	8.15
2.	Electrical conductivity (dS m ⁻¹)	0.23
3.	Texture	Sandy loam
4.	Soil type	Typic Haplustept
5.	Available N (kg ha ⁻¹)	202.6
6.	Available P (kg ha ⁻¹)	31.2
7.	Available K (kg ha ⁻¹)	220.6
8.	Total soil P (ppm)	562
9.	Organic P (ppm)	209
10.	Inorganic P (ppm)	353
11.	Soil organic carbon (%)	0.48

The research was carried out using a completely randomized design (CRD) with three factors under investigation: CO₂ concentration at two levels, temperature at two levels and phosphorus at three levels. Two levels of CO₂ concentrations, viz., (i) Ambient and (ii) Elevated (650±10 µmol mol⁻¹) were selected to represent the current atmospheric CO₂ and projected CO₂ concentration of around 2050 respectively. Two temperature levels, viz., (i) Ambient and (ii) Elevated (Ambient + 3 °C) were also chosen to represent the current surface air temperature and that of around 2050 respectively. During vegetative and grain filling period, the ambient day/night temperatures were fixed at 23/9 °C and 27/12 °C respectively; the elevated temperature during the

same period was set respectively at 26/12 °C and 30/15 °C. There were 4 combinations of CO₂ and temperature; (i) Ambient atmospheric CO₂ and ambient temperature, (ii) Ambient CO₂ and elevated (Ambient + 3 °C) temperature, (iii) Elevated CO₂ and ambient temperature and (iv) Elevated CO₂ and elevated (Ambient + 3 °C) temperature. These four different combinations were maintained in 4 separate growth chambers. In each of these four growth chambers, plants were grown with 3 levels of phosphorus application making altogether 12 treatment combinations (2 levels of CO₂ × 2 levels of temperature × 3 levels of phosphorus) with each treatment replicated thrice. Phosphorus was administered at three levels: (i) Control (no phosphorus application), (ii) 30 mg P pot⁻¹, roughly equivalent to 100% of the recommended P dose and (iii) 60 mg P pot⁻¹, roughly corresponding to 200% of the recommended P dose for wheat (Kumar and Swarup, 2012). Additionally, each pot received 200% of the endorsed doses of nitrogen (N) and potassium (K) to ensure levels sufficient for plant growth and non-limiting.

The required CO₂ and temperature levels were maintained by computer based programmed software. The light intensity inside the chambers was maintained at 600 μmol m⁻² s⁻¹ photon flux density with the help of suitable combinations of fluorescent and incandescent lamps. 12-h photoperiod and 60% relative humidity were also maintained inside the chambers. The required growth conditions were monitored two times in a day and necessary adjustments whenever needed, were made with the help of a digital control panel near the entrance of the chambers. The pots were watered every other day. A close vigil was kept at the growth responses of plants to various combinations of growth factors. Plants were harvested at maturity for the analysis of required parameters.

Plant Sampling and Measurement of Phosphorus Harvest Index

Harvested plant parts were segregated into leaf, root, stem and grains at maturity. The samples were oven dried at 70 °C and dry biomass of various plant parts were measured. Phosphorus concentration in plant samples was measured by vanadomolybdate yellow colour method and the P content was determined by multiplying it with the dry weight of respective parts of the plant. Ratio of the P content in wheat grain to the P uptake by whole plant was taken as P harvest index.

Statistical Analysis and Data Presentation

Data collected were analyzed using statistical methods described by Gomez and Gomez (1984). Three factors analysis of variance was performed using MSTATC statistical software. The DMRT coefficients were used for segregation of significant differences among the mean values. In data presentation, emphasis was placed on the primary impacts of three growth factors and interaction effects of CO₂ and temperature on P harvest index for easy comparison of the impacts of current atmospheric CO₂ and temperature with that of elevated CO₂ and temperature expected for future.

Non-significant interactions have not been presented.

Results and Discussion

As postulated at the initiation of this experiment, expected alteration in growth, yield and P demand of wheat crop under enhanced atmospheric CO₂ and temperature did influence the partitioning of P towards wheat grains as indicated by the changes in P harvest index under different levels and combinations of these two climatic factors. Rise in atmospheric CO₂ concentration over ambient caused a slight but significant increase of 5.6% (from 0.72 at ambient to 0.76 at elevated CO₂) in P harvest index of wheat (Figure 1). The result contradicts the earlier reports of Manderscheid *et al.* (1995) wherein a significant decline- and non-significant change in P harvest index of barley and wheat were reported under elevated atmospheric CO₂. This may be on account of differences in edapho-climatic conditions under which the two experiments were performed. This observation however may be ascribed to enhanced rhizodeposition of organic carbon and accelerated mineralization of organic P under elevated CO₂, possibly leading to better P availability for plant uptake and enhanced P mobilization towards grains (Jin *et al.*, 2020; Sudhalakshmi, 2021).

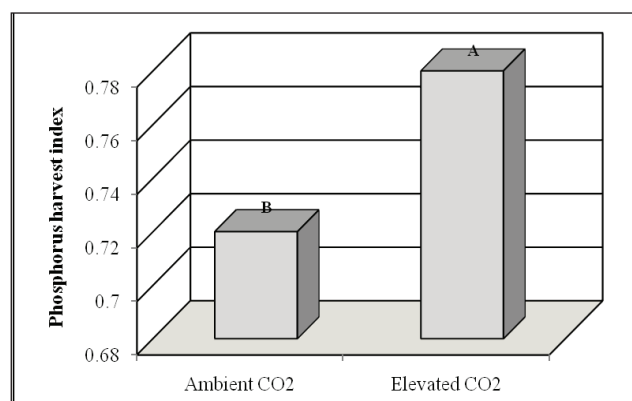


Figure 1: Effects of ambient- and elevated atmospheric CO₂ concentrations on phosphorus harvest index of wheat (values are averaged over all levels of temperature and P application)

(Bars with different upper case letters are statistically significant at $p < 0.05$)

There was a marked decline of 12.7% (from 0.79 to 0.69) in P harvest index of wheat when the plants were grown at higher temperature (ambient + 3 °C) as compared to ambient temperature (Figure 2). This particular observation again does not support the previous reports of Batten *et al.* (1986) who observed a continuous increase in P harvest index of wheat with increasing temperature. However, the temperature treatments and P fertilization regime of their experiment was largely different from the present study. They used four different temperature treatments in pre-anthesis period but provided normal temperature of 18/13 °C during grain development. In contrast, we used elevated temperature treatments throughout the plant growth up to maturity with the day/night temperature regimes in the grain filling period being set at 27/12 °C for ambient and 30/15 °C for elevated temperature treatments. The severe reduction

in grain yield owing mainly to rapid grain maturity and shortened grain filling period under elevated temperature may have caused the observed decline in P harvest index of wheat in the current experiment.

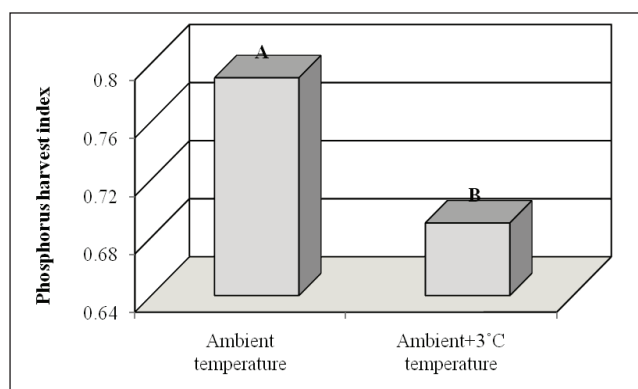


Figure 2: Effects of ambient- and elevated temperature on phosphorus harvest index of wheat (values are averaged over all levels of atmospheric CO₂ and P application) (Bars with different upper case letters are statistically significant at $p < 0.05$)

Unlike the clear trends of either increase or decrease observed under elevated CO₂ and temperature, the effect of increasing P fertilization on P harvest index of wheat was not consistent with very little variation across the P application levels (Figure 3). There was a slight increase in P harvest index of wheat at 100% P level (0.77) as compared to no P fertilization treatment (0.73) with the response remaining on par thereafter at 200% P fertilization level. However, no significant difference was observed in P harvest index of wheat at control and 200% P application level. The observed lack of consistency in the trend and very little variation in P harvest index across the P application levels can be understood in the light of earlier report by Batten *et al.* (1986) who also did not find any significant changes in P harvest index of wheat with two P application levels.

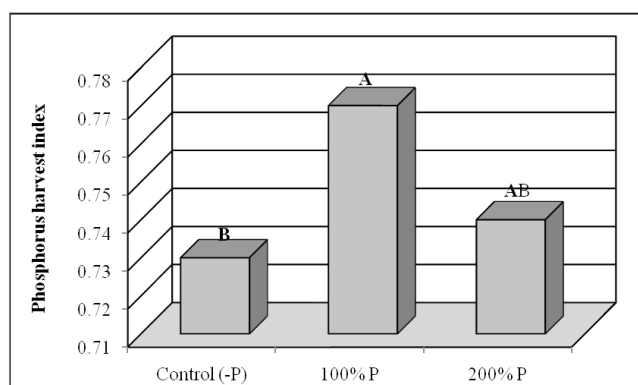


Figure 3: Effects of various levels of phosphorus fertilization on phosphorus harvest index of wheat (values are averaged over all levels of atmospheric CO₂ and temperatures) (Bars with different upper case letters are statistically significant at $p < 0.05$)

An observation of particular importance is a moderate decline in P harvest index of wheat under simultaneously elevated CO₂ and temperature as compared to their atmospheric

combination (Figure 4). The elevated temperature-induced reduction in P harvest index was also evident in interactive effects of the two factors, however the effect was more pronounced at ambient CO₂ compared to its elevated level. Consequent to the interactions of atmospheric CO₂ and temperature, there was a decline of 7.7% in P harvest index of wheat under concomitantly elevated atmospheric CO₂ and temperature (0.78) as compared to their ambient combination (0.72). The severe reduction in grain yield due mainly to hastened maturity and shortened grain filling period even under combined elevation of CO₂ and temperature can be held responsible for the observed decline in P harvest index of wheat in the current experiment. The results suggest that temperature would be the dominant factor as compared to the atmospheric CO₂ in deciding the overall impact of projected increase in atmospheric levels of CO₂ and temperature on P harvest index of wheat in future.

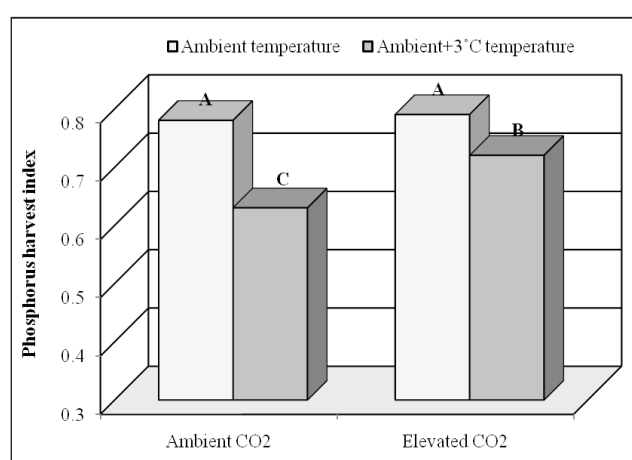


Figure 4: Interactive effects of atmospheric CO₂ and temperature on phosphorus harvest index of wheat (values are averaged over all levels of P application) (Bars with different upper case letters are statistically significant at $p < 0.05$)

The observed contradiction of our results with that of some earlier experiments conducted in edapho-climatic conditions that largely differ from the conditions in India underline the need of undertaking the region-specific experiments considering the neighbouring soil and climatic conditions for precise estimation of the possible impact of climate change on various aspects of crop production and plant nutrition. As there is a logically possible relationship between the P harvest index of wheat and various physical and nutritional qualities of wheat grains (Kumar, 2011b) (*e.g.*, grain Fe and Zn concentration and their bio-availability, protein concentration, seedling vigour, *etc.*), the observed decline in the P harvest index of wheat under projected levels of CO₂ and temperature in our study underscores the need of undertaking further elaborate experimentations to explore the possible impact of climate change on these important parameters associated with P harvest index of wheat.

Conclusion

As hypothesized, the growth of plants under increased levels of CO₂ and temperature did influence partitioning

of P towards wheat grains as indicated by the changes in P harvest index under different levels and combinations of these two climatic factors. An observation of particular importance was a moderate decline in P harvest index of wheat under concurrently elevated CO₂ and temperature *vis-a-vis* their atmospheric combination. The results suggest dominance of atmospheric temperature *vis-à-vis* CO₂ in deciding the overall impact of projected increase in CO₂ and temperature on P harvest index of wheat in future. Given the perceived links between P harvest index and various physical and nutritional qualities of wheat grains, the observed decline in the P harvest index under higher levels of CO₂ and temperature in our study necessitates further experimentations to investigate the probable effects of climate change on related nutritional qualities of wheat grains.

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