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Response of potato to elevated CO_2 under short days: Growth, physiological parameters and tuber yield

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ABSTRACT

An experiment was conducted at ICAR-Central Potato Research Station, Jalandhar during 2014-15 to study the effect of elevated CO_2 concentration (600 ppm) on the physiological parameters, growth and yield of potato under short day conditions. Effects on plant growth and yield was positive with increased stem height (7.5%), stem numbers (18.9%), leaf area (19.4% at 70 DAP), photosynthesis (21% at 40 DAP) and total biomass product (14%). Tuber yield increased by 28% under CO_2 enrichment. Although harvest index did not change, specific leaf area (-2.6%) and stomatal conductance (-19 %) decreased under CO_2 enrichment. The increase in biomass and tuber yield may be due to enhanced leaf area coupled with increased rate of photosynthesis.

Key words: CO_2 enrichment, OTC, photosynthesis, stomatal conductance.

INTRODUCTION

Global climate has never been static. Since 1880, the Earth's temperature has increased at a rate of 0.09 degree per decade, which has increased to 0.29 degree per decade over the past 30 years mainly due to anthropogenic activity which has increased emission of GHGs like CO_2, methane etc. At present concentration of CO_2 in the atmosphere has touched 400 ppm, which is likely to increase to 421-936 ppm by the end of the century which could result in a temperature rise between 1 to 3.7ºC (IPCC, 7).

A general positive effect of CO_2 enrichment on growth and productivity of plants has been reported with C_3 plants responding more favorably to increase in CO_2 concentration compared to C_4 plants (Kimball, 9). Potato is a C_3 plant and has very large sink organs coupled with apoplastic mechanism for phloem loading (Riesmeier *et al.*, 13). Both these factors are favourable for better crop performance under enhanced CO_2 concentrations. Potato is expected to yield 10% higher total tuber for every 100 ppm increase in CO_2 concentration (Miglietta *et al.*, 12). The effect of increased CO_2 concentration on physiological parameters of potato plant, like photosynthetic rate, dry matter accumulation and partitioning, stomatal conductance etc. has been studied and reported (Bunce, 2; Chen and Setter, 3), however, most of these studies were carried out where potato is grown under long-day conditions. No such information is available for potato crop grown under short-day conditions, which is relevant in identifying the germplasm with suitable traits for developing varieties for future climatic scenario as well as for the potato crop growth modeling studies. Keeping these points in view, an experiment was conducted in the open–top chambers (OTCs) to study the effect of elevated CO_2 concentrations on the physiological parameters, growth and yield of potato under short day conditions.

MATERIALS AND METHODS

The experiment was conducted at the Research Farm of Central Potato Research Station, Jalandhar, Punjab (India) (31.16° N 75.32° E). The potato crop was raised in a transparent walled open-top chambers (OTCs) during winter season of 2014-15. The OTCs used were square in shape, 3 m long and 2.5 m tall with a 6.25 m square opening on the top. A total of 6 chambers were used in the present study which were 4.0 m apart from each other. Three OTCs were maintained at 600 ppm CO_2 between 8 am and 5 pm while the other three were kept as control (ambient: 400 ppm).

The soil in the OTCs was moderately alkaline in reaction (pH 7.9), low in available N (246 kg/ha) and medium in available P (18 kg/ha) and available K (184 kg/ha). In the present study, potato cultivar Kufri Jyoti was selected, which falls under the medium maturity group. The seed size tubers (50 g) of Kufri Jyoti were planted at 60 cm x 20 cm spacing on 7th October, 2014. The crop was supplied with 175 kg N, 100 kg P and 120 kg K through urea + di-ammonium phosphate, di-ammonium phosphate and muriate of potash, respectively. 50% N and full PK were applied at planting while the remaining N was applied at the time of earthing-up, *i.e.* 35 days after planting. The crop was raised with standard package of practices. The crop was harvested on 5th Jan 2015, *i.e.* 90 days

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after planting for recording the observation on final yield and above-ground biomass.

For morphological observations, ten plants were tagged from each chamber and observations on plant height and number of main stems were recorded at 7 day interval, starting from 15 days of planting till 72 days. Periodical sampling for dry matter partitioning was carried out at 10 days interval, starting from 20 days of planting till 90 days, by uprooting five plants from each chamber. The plants were separated into leaf, stem, root and tubers. Fresh and dry weights of plant parts were taken to study periodic growth and development and dry matter distribution among different plant parts. Fifty leaf discs of known diameter were punched from the leaves of each sample and dried. Leaf area per plant was calculated from the leaf dry weight using dry weight and area of leaf discs. Photosynthesis and stomatal conductance was measured at 40 days using portable photosynthesis system. One elevated CO_2 and one control OTC were left undisturbed for final tuber yield data. Meteorological parameters (minimum and maximum temperature, relative humidity) were recorded daily during the experimentation and depicted in Fig. 1. Statistical analysis: For all physiological parameter as well as fresh and dry weights, values recorded from one plant were considered as a replication. Standard error of mean was calculated and is shown in all the figures.

RESULTS AND DISCUSSION

Maximum and minimum temperature during the crop growth was 33.0/21.5 °C at the time of planting which dropped gradually to 11.8/6.8 °C at the time of haulm cutting. Relative humidity varied between 50 and 86% during this period (Fig. 1). The effects of elevated CO_2 on different plant species have been well documented. In the present study potato cultivar Kufri Jyoti was studied under ambient (400 ppm) and elevated (600 ppm) CO_2. Emergence was not affected by treatments and it took 14 days from planting to 95% emergence.

A 50% increase in CO_2 level showed a significant effect on plant height and stem numbers per plant. In general, a uniform increase in both the parameters was observed from emergence till the maturity of crop. At final stage of crop growth, an increase of 7.5% in plant height and 18.9% in stem number per plant was recorded (Figs. 2, 3). However, in some studies on potato in Europe under long day conditions, elevated CO_2 concentration did not affect or negatively affected plant height (Lawson *et al.*, 10). The stimulatory effect of CO_2 on plant growth includes increase in tiller number in wheat and rice (Allen and Prasad, 1). In potato we report a stimulatory effect of CO_2 on stem number/hill.

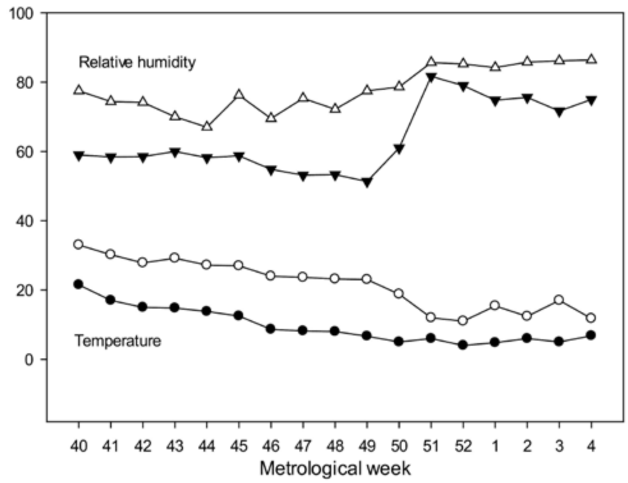

Fig. 1. Weather parameters during the crop season at Jalandhar, Punjab.

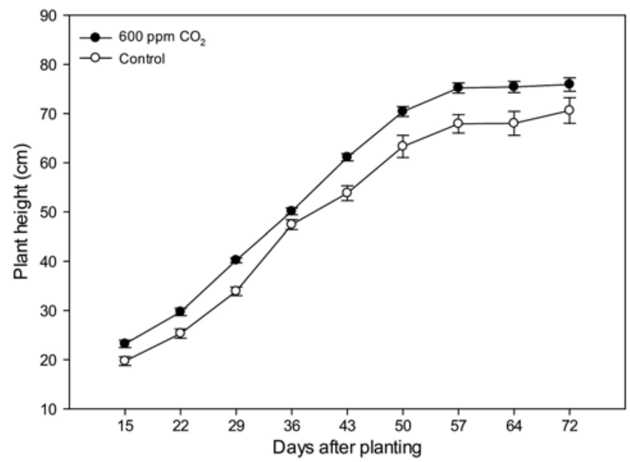

Fig. 2. Plant height in potato during plant development phase.

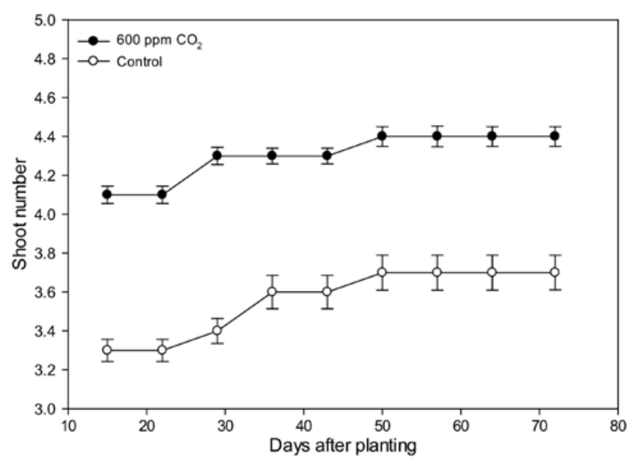

Fig. 3. Number of stems per hill in potato during development phase.

While control plants had an average 3.54 stems/hill, it was 4.28 stems per hill under 600 ppm CO_2.

Leaf Area Index (LAI) is a primary indicator of photosynthetic potentials. In our experiment, leaf area index (LAI) was not affected due to the exposure to elevated CO_2 concentration till 40 days but after that higher LAI was recorded under elevated CO_2 which increased till 80 days and then declined rapidly to 5.5 at harvest. However, in plants raised at ambient CO_2, the LAI achieved the peak at 70 days of planting and declined to 4.05 at harvest (Fig. 4). During early part of growing season, development of leaf area in soyabean was similar under ambient and enriched environments but later increased under elevated CO_2 which also delayed LAI loss (Dermody *et al.*, 4). A faster decline in LAI towards the end of growing season due to remobilization of leaf nitrogen has been reported by Miglietta *et al.* (12).

Specific leaf area or specific leaf mass is a measure of leaf thickness and it tended to increase under ambient CO_2 at 40 days of crop growth and then declined and remained below the crop raised at elevated CO_2 till 70 days (Fig. 5). The average specific leaf weight (SLW) during entire crop growth was lower under elevated CO_2 (3.76 mg/cm^2) than control (3.86 mg/cm^2) indicating faster removal of the photosynthates from the leaves. The results are in conformity with Maillard *et al.* (11). Yin (15) analyzed 170 published data sets from 62 species and showed that in majority of the cases SLW declines as CO_2 increases mainly due to decline in leaf nitrogen.

Photosynthesis is the primary driver of plant growth providing sugars and carbohydrates needed for producing biomass. Net photosynthesis was recorded 40 days after planting. The photosynthesis was 21% higher in forenoon and 27% higher in afternoon under elevated CO_2 (Fig. 6). At atmospheric CO_2 concentrations, C_3 plants like potato lose carbon through photorespiration because of the affinity of ribulose 1-5 bi-phosphate carboxylase/oxygenase (RUBP) to oxygen as well. Therefore under increasing CO_2 concentration more carbon is available at the RUBP site than oxygen leading to reduced photorespiration and increased photosynthesis. Photosynthesis on a leaf area bases is regarded as the most important attribute which can explain the observed yield increase. However, Donnelly *et al.* (5) had attributed tuber yield stimulation to LAI as they did not find elevated CO_2 to increase photosynthetic rate. In our case, LAI and photosynthetic rate both increase significantly and might have contributed together in increasing the potato tuber yield under the CO_2 enriched environment.

The CO_2 enhancement recorded a significant decrease in stomatal conductance. A 19 % decrease

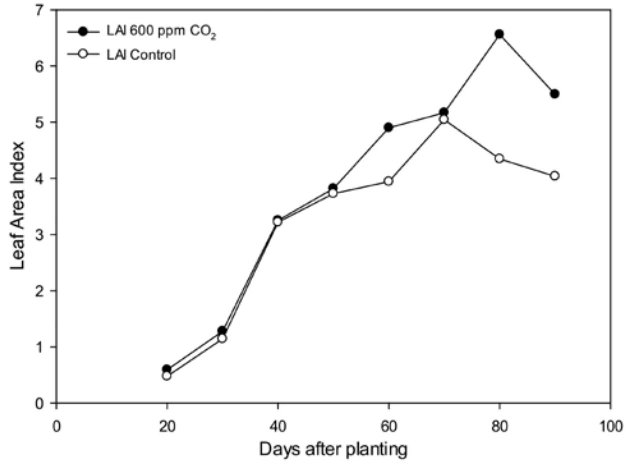

Fig. 4. Leaf area index during crop development in potato.

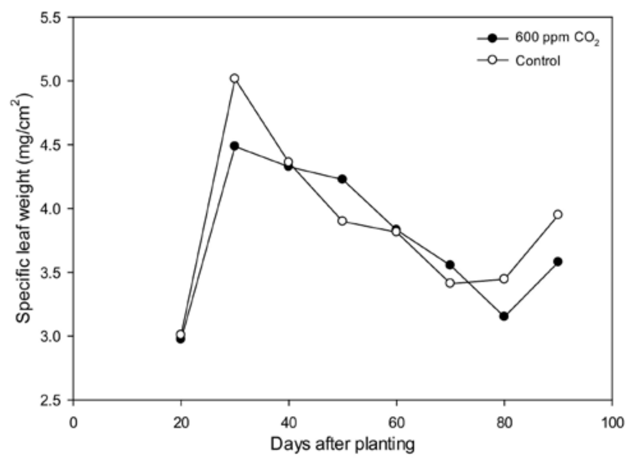

Fig. 5. Specific leaf weight during crop development in potato.

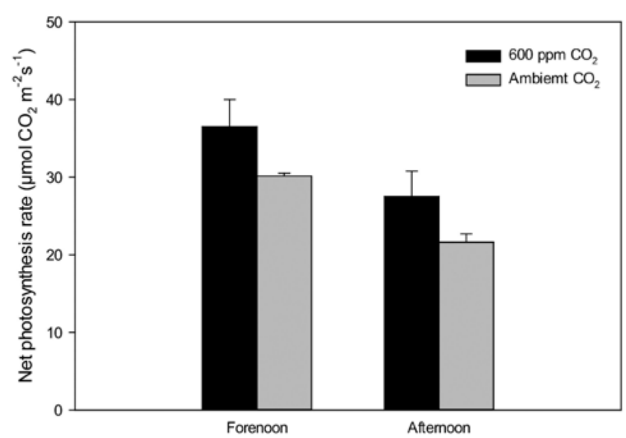

Fig. 6. Net photosynthesis in potato plants 40 days after planting.

in stomatal conductance was observed in the forenoon and 40% in the afternoon at 40 days of planting (Fig. 7). Increased ambient CO_2 leads to partial stomatal closure due to high malate concentration in the apoplast that activates anion channels in the guard cell and many workers have reported a reduction in stomatal conductance up to 700 ppm (Taub, 14).

The increase in Carbon dioxide level caused a significant increase in tuber yield. Final fresh tuber yield obtained in the undisturbed OTC was 3.27 kg/m^2 under elevated CO_2 compared to 2.54 kg/m^2 under ambient conditions which is 28% higher under elevated CO_2 (Fig. 8). Partitioning of dry matter to tubers at 30 days after planting was similar under ambient as well as elevated CO_2. However, as the growth progressed, the higher partitioning of dry matter to tuber was observed under elevated CO_2 condition and the gap widened till the harvesting of crop when the final dry matter portioned to tubers was 94.74 g/plant under elevated CO_2 levels, which was 16% higher over ambient CO_2 at 81.68 g/plant (Figs. 9, 10). A positive response of potato to elevated CO_2 in terms of final tuber yield has been reported by Jaggard *et al.* (8). Tuber dry matter percentage under elevated CO_2 was lower (15.3%) than under control (16.8%). Sink strength is the major determinant of dry matter partitioning and potato has large below-ground sinks for carbon along with apoplastic mechanism of phloem loading and therefore, it is probably the best candidate for a large response to rising atmospheric CO_2 (Miglietta *et al.*, 12). Total plant biomass accumulated during the growth period was 111.48 g/ plant in control at 90 days after planting compared to (130.34 g/ plant) under elevated CO_2. The results are in conformity with the finding of Hogy and Fangmieier (6) who have also recorded an increase in absolute biomass production under elevated CO_2. However, tuber to whole plant dry weight ratio (harvest index) was not affected due to change in CO_2 concentration (72.7 under 600 ppm CO_2 compared to 73.3 for control), showing thereby

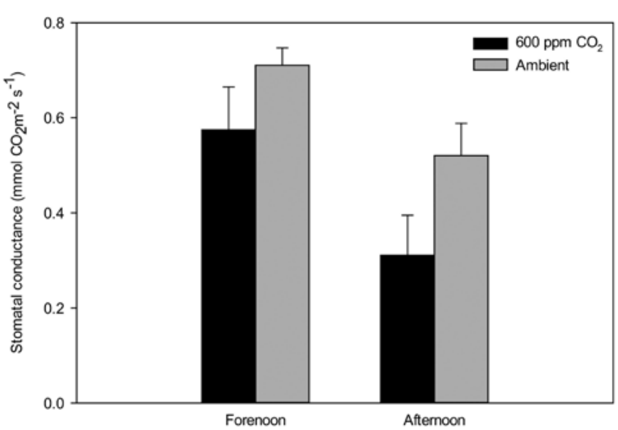

Fig. 7. Stomatal conductance in potato plants 40 days after planting.

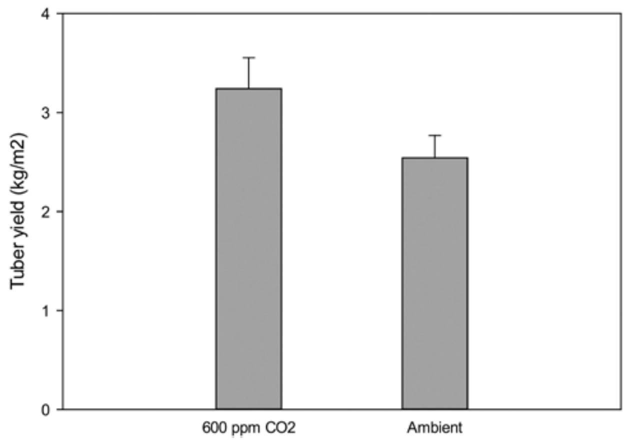

Fig. 8. Tuber yield (kg/m^2) under elevated and ambient CO_2.

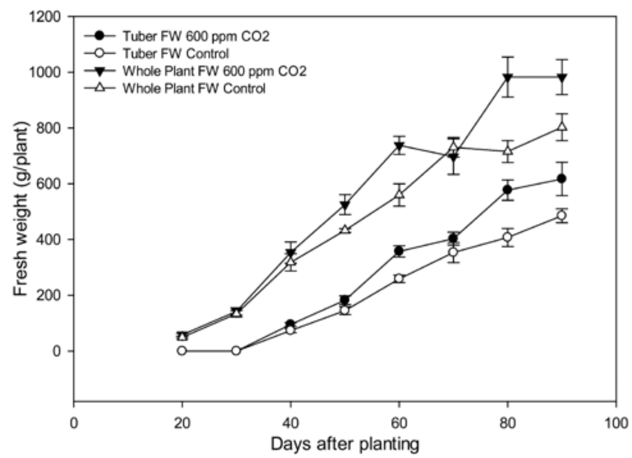

Fig. 9. Tuber fresh weight during crop development in potato.

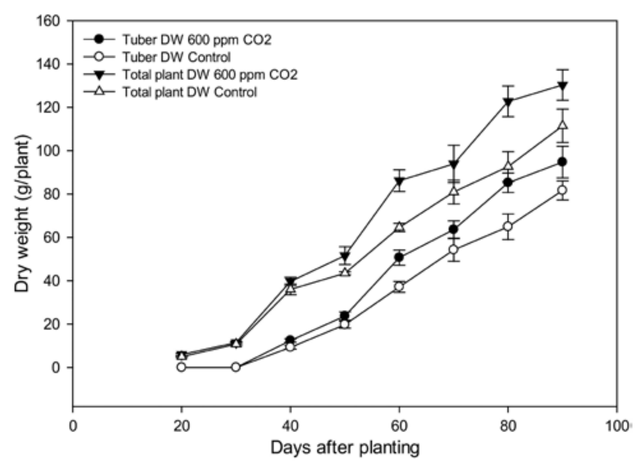

Fig. 10. Tuber dry weight during crop development in potato.

that the CO_2 enrichment did not alter the allocation pattern of dry matter to tubers and above ground biomass. Consistent trend has not been observed for harvest index under elevated CO_2, however Allen and Prasad (1) have reported a decrease in Harvest index in soybean. However, the partitioning of the above ground biomass to leaves and stem was altered due to CO_2 fertilization. A perusal of data on leaf and stem dry weight showed that CO_2 enrichment affected favorably the leaf and stem dry weight. The leaves were benefited more under elevated CO_2 than the stems as the increase in leaf dry matter was more (24.8 g/ plant 38% higher) than stem (9.84 g/ plant 35.9% higher). Higher dry matter partitioning to leaves coupled with lower specific leaf weight explains the increase in leaf area under CO_2 enrichment in potato.

The CO_2 enrichment increased the overall growth of the potato crop under the short day condition. A 200 ppm increase brought about a significant increase in the plant height, stem number and the above ground biomass of the potato crop. The increase in LAI in combination with significantly higher net photosynthetic rate lead to an overall increase in the total tuber yield of potato crop grown under the winter season.

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