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RESEARCH ARTICLE

Assessing the impact of ambient ozone (O_3) on the growth and yield of potato genotypes (*Solanum tuberosum* L.) by using exposure indices over the high altitude of western Ghats location in Southern India

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ABSTRACT : Raising levels of tropospheric ozone (O_3), acts as a secondary pollutant and green - house gas which is a silent threat as well as one of the biggest challenges for the decrease in agricultural production. The diurnal and seasonal variation characteristics of ambient ozone (O_3) and its precursor NOx was investigated by their continuous measurements at ISRO-Climate Change Observatory situated in a high altitude Western Ghats location of Ooty. The impact of ambient O_3 on the growth and yield characteristics of various potato genotypes were assessed by the calculated higher ozone exposure indices AOT40 and SUM60 than critical levels by showing "latent injury" in the form of yield reduction (4.56 - 25.5 %) in potato genotypes. The impact of three elevated O_3 levels (100, 150 and 200 ppb for 4 hd^{-1}) on ten potato genotypes was done by fumigation under controlled open–top chamber during its critical stage namely the tuber initiation stage resulted that Kufri Surya proved to be moderately resistant by recording the highest yield.

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Ozone (O_3) is present throughout the atmosphere but can be either negative or positive depending on where it is found whether in troposphere or stratosphere, respectively (Colls, 1997). Tropospheric ozone is a powerful oxidant by causing damage to mucus and respiratory tissues in animals and also tissues in plants, above concentrations of about 100 ppb which makes ozone a potent respiratory hazard and pollutant near ground level (Bell *et al.*, 2005). Low level ozone (or tropospheric ozone) is not only a secondary air pollutant but also a green house gas, next to CO_2 and Methane affects the growth and yield of agricultural and horticultural crops in most parts of the world (IPCC, 2001). Low level or surface ozone is not emitted directly by car engines or industrial operations but formed by the reaction of sunlight on air containing hydrocarbons and nitrogen oxides that react to form ozone directly at the pollution site or many kilometers downwind (Hagerman *et al.*, 1997).

There is evidence of significant reduction in agricultural yields because of increased ground level ozone and pollution which interferes with photosynthesis and stunts overall growth of plant species (NASA, 2003). Inter-Governmental Panel on Climate Change (IPCC) and World Meteorological Organization (WMO) assessment reports had predicted O_3 concentration raised by 1-2 per cent in the industrialized countries. Due to rapid economic development during the past decades, surface O_3 increased at an annual rate of 0.5 - 2.0 per cent (Vingarzan, 2004) and has now reached a global mean of approximately 50 ppb for 8 h summer seasonal average (Anonymous, 2008). Increasing levels of O_3 are an additional and extremely important factor in reducing crop yields by 5-35 per cent of agriculturally important locations across South Asia (Emberson and Büker, 2008). Projections of future global O_3 trends show that O_3 concentration in the ambient air will increase rapidly over the next 20 to 30 years with South Asia projected to experience the highest increase in surface O_3 (average annual increases of 7.2 ppb occurring by 2030) (Dentener *et al.*, 2005). Studies showed that the impact of O_3 increased with developmental stages, and the largest detrimental effect during critical stage of crop (Feng *et al.*, 2010). Moreover, elevated O_3 tends to decrease stomatal functioning and photosynthetic rate leading to concurrent reduction of crop yield (Saurer *et al.*, 1991).

The present work was carried out to assess the impact of ambient ozone (O_3) on the growth and yield characteristics of potato (*Solanum tuberosum* L.) genotypes which is a is moderately sensitive to O_3 and it is an important food crop as well as stock feed and in the order of importance of food production it ranks 6th in the developing countries, 4th in developed countries, 4th in the world and 3rd in India (FAO, 2000). In India, about 8 per cent area under potato cultivation lies in the Nilgiris hills, it occupies approximately 33-49 per cent of total vegetable cultivated area every year. The average productivity of spring season (Jan-April) potato is about 16.6 t ha^{-1}, whereas the average productivity of summer (April-July) grown potato is about 22.5 t ha^{-1} with 5.9 t ha^{-1} of difference in productivity due to various reasons.

EXPERIMENTAL METHODOLOGY

Impact of ambient of ozone (O_3) on potato genotypes:

A continuous measurement of ozone was made at ISRO Climate Change Observatory, Tamil Nadu Agricultural University, Woodhouse farm, Ooty from January 2011 to April 2013 using ozone analyzer model 49i, which is based on UV absorption photometry, resting upon absorption of radiation of wavelength 254 nm by ozone in the analyzed sample. The impact of ambient ozone on different genotypes of potato were analyzed by the calculated AOT40 and SUM60 values by the method of cumulative ozone exposure-plant effect during its growing seasons.

Exposure indices :

AOT40 is calculated as the sum of differences between the hourly mean concentrations (O_3) and 40 ppb for hours when O_3 > 40 ppb, for each daylight hour with global radiation ≥ 50 Wm^{-2} over a 3 months period:

$$\text{AOT40} = \sum_{i=1}^{n} ([O_3]-40)_i \text{ for } [O_3] \geq 40 \text{ ppb.}$$

where, n is the number of hours (*i*) that the threshold of 40 ppb is exceeded.

SUM60 is defined as the sum, over a 3 months period, of the hourly O_3 concentration for daylight hours (0700-2100 h) when the concentration (O_3) is at or above 60 ppbh (0.06 ppmh) :

$$\text{SUM60 (ppmh)} = \sum_{i=1}^{n} (CO_3)_i \text{ for } [CO_3] \geq 60 \text{ in 3 months}$$

where, n is the number of hours(*i)* that the threshold is exceeded (Karenlampi and Skarby, 1996).

Simultaneously, the field experiments were conducted by the selected four genotypes of potato *viz.*, Kufri Swarna, Kufri Jyothi, Kufri Giridhari and Kufri Himalini for comparing the yield performances during the two growing seasons namely spring and summer of 2011-2013. For spring and summer cropping, planting was done on 2nd January and 1st April of the years 2011, 2012 and 2013 in a Randomized Block Design with three replications. Both the AOT40 and SUM60 values were calculated for the four seasons of potato genotypes namely, April-July 2011 (Summer), January-April 2012 (Spring), April-July 2012 (Summer) and January-April 2013 (Spring) and compared with the critical limits set for potato crop. The growth and yield characteristics of potato genotypes were compared and evaluated under four different ambient ozone levels by the calculated exposure indices.

EXPERIMENTAL FINDINGS AND DISCUSSION

The variation of O_3 as a function of time is expressed as contour maps (Fig. 1(a) and(b) for the different potato growing seasons of summer 2011, spring and summer 2012 and spring 2013. The hourly mean O_3 concentrations during January-April 2012 and 2013 (spring) were always > 40 ppb and reached maximum up to 67 ppb whereas April-July 2011 and 2012 (summer) were between18-59 ppb. The months of June and July recorded the lowest concentration of the hourly O_3 values which is ranged between 18-38 ppb.

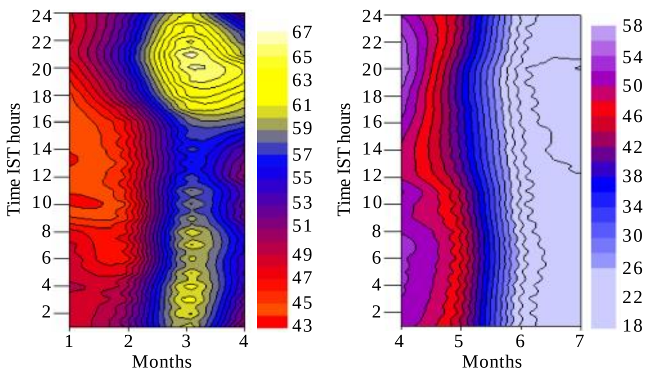

Fig. 1 : (a). The hourly mean O_3 concentrations during January–April (2012-2013) (average of two seasons of spring grown potato genotypes) 1 (b). Hourly mean O_3 concentration during April–July (2011-2012) (average of two seasons of summer grown potato genotypes)

Taking over the advantage of usage of AOT40 and SUM60 values on crop effects, in assessing the impact of ambient O_3 on the growth and yield characteristics of potato genotypes the cumulative values of AOT40 and SUM60 values were calculated for two seasons spring and summer (2011-2013) of potato crop. So, the calculated AOT40 value (Fig. 2) during consecutive four seasons of potato April-July 2011 (Summer), January-April 2012 (Spring), April-July 2012 (Summer) and January-April 2013 (Spring) were observed to be 7059, 21,479, 5901 and 23,625 ppb h. These cumulative values can be compared with the critical levels of 5000 ppb h (European Mapping Manual, 2010) for horticultural crops. The spring potato growing seasons of 2012 and 2013 showed manifold increase of values about 4.2 and 4.3 folds more than the critical level whereas the same method was used for assessment (Satsangi *et al.*, 2004).

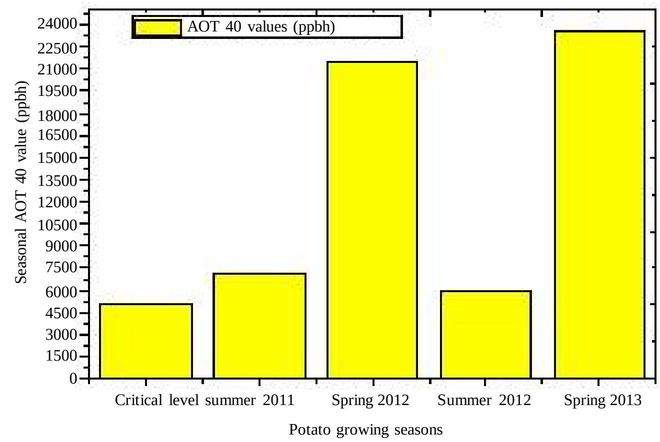

Fig. 2 : Calculated AOT40 values (ppbh) for four growing seasons of potato (2011-2013)

The observed SUM60 values (Fig. 3) for January-April 2012 and 2013 (spring) were found to be 25,800 ppbh and 29,483 ppbh which were much higher than the critical levels (9,900-20,300ppb) fixed for Norchip variety of potato (NAAQO, 1999). The results showed that the occurrence of more of the ozone concentration values (Higher AOT40 values and SUM60 values) might caused their long- term exposure on potato which led reduction

Table 1 : Evaluation of potato genotypes based on their average tuber fresh weight, yield (t ha^{-1}) and yield reduction per cent during spring (Jan.-Apr.) and summer (Apr.-July) seasons of the year 2011 to 2013

Potato genotypes	Average tuber fresh weight (kg plant^{-1})					Yield (t ha^{-1})					Yield reduction (%)				
Seasons	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
Kufri swarna	1.25	0.49	5.65	0.47	1.96	23.58	22.28	23.86	22.26	22.99	5.65	10.85	4.56	10.95	8.00
Kufri jyothi	1.08	0.42	5.70	0.40	1.90	23.57	22.19	23.84	22.01	22.90	5.70	11.25	4.66	11.95	8.39
Kufri giridhari	0.95	0.65	7.25	0.62	2.36	23.19	20.02	23.26	19.66	21.53	7.25	19.90	6.98	21.35	13.87
Kufri himalini	0.92	0.58	7.45	0.56	2.37	23.13	19.69	23.24	18.63	21.17	7.45	21.25	7.05	25.50	15.31
Mean	1.05	0.53	6.51	0.51		23.36	21.04	23.55	23.14		6.51	15.81	5.81	17.43	
	S.E. ±		C.D. (P=0.05)			S.E. ±		C.D. (P=0.05)			S.E. ±		C.D. (P=0.05)		
Genotypes	0.05		0.10			0.010		0.025			0.010		0.020		
Seasons	0.05		0.10			0.010		0.025			0.010		0.020		
G × S	0.10		0.20			0.020		0.050			0.020		0.040		

Seasons: S_1-April-July 2011, S_2- January-April 2012, S_3-April-July 2012, S_4- January-April 2013 in plant height, above ground biomass and tuber yield (Table 1). Reduction in the yield may result from ozone exposures decreases the carbon assimilation and translocation, nutrient acquisition and / or other physiological processes (Heath, 1996).

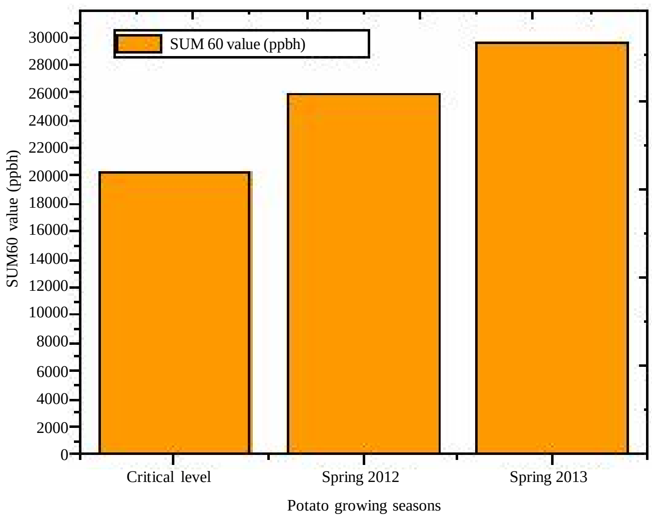

Fig. 3 : Calculated SUM 60 values (ppbh) during spring potato growing seasons (January to April) 2012-2013

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