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AMBIENT AND ELEVATED OZONE (O_3) IMPACTS ON POTATO GENOTYPES (*SOLANUM TUBEROSUM.L*) OVER A HIGH ALTITUDE WESTERN GHATS LOCATION IN SOUTHERN INDIA

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Abstract

Globally, next to CO_2 and Methane, raising levels of tropospheric ozone (O_3), acts as a secondary pollutant and greenhouse gas which is an upcoming hidden threat as well as one of the biggest challenges for the decrease in agricultural as well as horticultural 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 namely long-term indices (AOT40 and SUM60) and short-term indices (Daily AOT40 and Plant Exceedance Days) 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.
Keywords **:** Tropospheric Ozone, Secondary Air Pollutant, Ozone exposure indices, Elevated ozone, Potato yield

Introduction

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% 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% (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% 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 and elevated levels of 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 6^{th} in the developing countries, 4^{th} in developed countries, 4^{th} in the world and 3^{rd} in India (FAO, 2000). In India, about 8 % area under potato cultivation lies in the Nilgiris hills, it occupies approximately 33-49 % of total vegetable cultivated area every year. The average productivity of spring season (Jan-April) potato is about16.6 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.

Materials and Methods

(i) 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

(Long-Term 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:

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

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).

$$SUM60 \text{ (ppmh)} = \sum_{i=1}^{n} (C_{O3})i \quad \text{for } [C_{O3}] \geq 60 \text{ in 3 months}$$

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

(Short-Term Indices)

Daily AOT40 value is calculated in the same way as AOT40 values, which is 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.

$$\mathbf{AOT40 = \sum_{i=1}^{n} ([O_3] - 40)i \quad for\ [O_3] > 40\ ppb}$$

Where, n is the number of hours (*i*) that the threshold of 40 ppb is exceeded. Instead of adding the everyday AOT40 values cumulatively for crop period, daily AOT40 values can also taken into consideration because the critical stages of any crop is also important since the crop is more vulnerable to exposure to ozone exposure.

The short time cumulative index namely the daily AOT40 value for five consecutive days at low Vapor Pressure Deficit (< 1.5 k Pa, VPD) should be greater than 200 ppb h at low VPD (< 1.5 k Pa) and also should be greater than 500 ppph at high VPD (> 1.5 k Pa). For this purpose, it was necessary to calculate the vapor pressure deficit for all the potato growing seasons.

Vapor Pressure Deficit (VPD)

Vapor Pressure Deficit is calculated for the given temperature and relative humidity as below.

$$VPD = \frac{(100 - \text{Relative Humidity}) \times SVP}{100}$$

Where, VPD = Vapor Pressure Deficit and SVP = Saturated Vapor Pressure.

The average vapor pressure deficit ranged between the values 0.24 – 1.5 k Pa (over the years 2011-2013. Since, the average vapor pressure deficit calculated over all the four study seasons of potato was below 1.5 k Pa (Figure 4), the Daily AOT 40 values were calculated and analyzed for exceedance limits >200 ppbh for five consecutive days during the potato growing seasons.

For the four growing seasons of potato genotypes namely April-July 2011 (Summer), January-April 2012 (Spring), April-July 2012 (Summer) and January-April 2013 (Spring), the short time cumulative index/Daily AOT40 values were calculated and analyzed whether the critical stages of potato crop may be affected by high ambient ozone exposure. Moreover, to analyze which part of the critical stage of potato crop is mostly affected and also to know during the four growing seasons of potato crop, when more ozone exposures were happened.

Plant Exceedance Days (PED)

Plant Eaceedance Days (PED) are defined as generally, for crops the critical level of daily AOT40 value is around 33 ppbh which should not be exceeded (Beig *et al.,* 2008). So, Plant Exceedance Days were also calculated for the four growing seasons of potato genotypes April-July 2011 (Summer), January-April 2012 (Spring), April-July 2012 (Summer) and January-April 2013 (Spring) and analyzed for more number of PEDs for above mentioned potato growing seasons.

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 2^{nd} January and 1^{st} 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.

(ii) Impact of Elevated Ozone (O_3) On Potato Genotypes

An experiment was conducted under controlled open–top chamber condition to evaluate the impact of three elevated levels of ozone (O_3) (100,150 and 200 ppb @ 4 h d^{-1}) fumigated during the most important critical stage, tuber initiation stage of various genotypes of potato (*Solanum tuberosum L.*) on their physiological and yield characteristics. Moreover, the study is based on the fact that sudden exposure of ozone is more dangerous to crops than chronic long term exposure. The study aims to characterize the relative susceptibility / resistance of ten genotypes of potato (Kufri Surya, Kufri Swarna, Kufri Jyothi, Kufri Chipsona, Kufri Jawahar, Kufri Giriraj, Kufri Muthu, Kufri Himsona, Kufri Giridhari and Kufri Himalini). After exposure with elevated ozone levels @ 100, 150 and 200 ppb during the critical stage of crop (tuber initiation stage), the visible injury symptom of potato namely "speckle leaf" symptom were studied by the following visual scoring method (Burke *et al*., 2001). The fumigated potato plants were allowed to grow up to harvest and the yield parameters *viz.,* the number of tubers $plant^{-1}$ and tuber fresh weight $plant^{-1}$ were also calculated. A health set of potato plants were also maintained from planting to harvest for the purpose of comparison with performance of fumigated potato plants.

Results and Discussion

(i) Ambient O_3 Studies

The variation of O_3 as a function of time is expressed as contour maps (Figure 1(a) &(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.

Taking over the advantage of usage of long-term O_3 exposure indices viz., 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 (Figure 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). The observed SUM60 values (Figure 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 calculated short time cumulative index namely the daily AOT40 value for five consecutive days at low Vapor Pressure Deficit (<1.5 kPa, VPD) for four growing seasons of potato genotypes summer 2011, spring and summer 2012, spring 2013. This implies that during spring 2012 and 2013 showed more number of times (about 6 times), there was the occurrence of > 200 ppb of daily AOT40 values for 5 consecutive days. This short-term exposure of daily AOT40 values coincided with the various critical stages of potato crops for all the four growing seasons. But during summer 2011 and 2012 showed only once i.e., during the germination phase of potato crop there was an occurrence of daily AOT40 values >200 ppb for five consecutive days.

Moreover, number of days with daily AOT40 value >200 ppbh at low VPD <1.5 kPa for the month of March 2012 and 2013 were the same coinciding with the tuber initiation stage of potato crop. The detailed analysis on the study of daily AOT40 values showed that during the spring 2012 , about18-22, 64-71, 77-81, 82-86, 90-95 and 96-100 days of the potato crop were coincided with > 200ppb of ozone values whereas during spring 2013, about 52-62,76-84, 85-91,93-97,97-104 and 106-122 days of the potato genotypes were coincided with the short time ozone episodes.

Comparison of daily AOT40 values for the month of March

Even though, the daily AOT40 values >200 ppb at low VPD at <1.5 k Pa for five consecutive days during four potato growing seasons namely summer 2011, spring 2012 summer 2012 and spring 2013 were calculated, especially for the month of March has to be compared for this short-term critical index which are shown in fig. 5 and 6. Because this implies that during March, except few days, all the other days exhibited the daily AOT40 values >200ppb at low VPD < 1.5 kPa and moreover this criteria was higher for spring 2013 (January-April 2013) followed by spring 2012 (January-April 2012).

Regarding the calculation of the number of Plant Exceedance Days (PED) for the consecutive Summer 2011, Spring and Summer 2012 and Spring 2013 were 45 days, 99 days, 44 days and 107 days, respectively as shown in the fig. 7. So the present study clearly proved that almost 3/4th of spring potato crop period experienced above 33 ppbh of PED.

The results showed that both the long-term as well as short-term exposure of the ozone concentration values (AOT40, SUM60 & Daily AOT40, Pant Exceedance Days) might caused their long- term as well as short-term damage potato which led reduction in plant height, above ground biomass and tuber yield (Table1). Reduction in the yield may result from ozone exposures decreases the carbon assimilation and translocation, nutrient acquisition and / or other physiological processes (Heath 1996).

(ii) Elevated O_3 Studies

The results of the controlled open-top chamber experiment with three elevated O_3 levels (i.e., 100, 150 and 200 ppb) on ten potato genotypes showed that the number of tubers per plant was significantly the highest (6 / plant) at 100 ppb O_3 for Kufri Surya, followed by Kufri Swarna, Kufri Jyothi (4 / plant), and for Kufri Chipsona, Kufri Jawahar, Kufri Giriraj (3 / plant) whereas the lower number of tubers (2 / plant) was recorded by Kufri Muthu, Kufri Himsona, Kufri Giridhari and Kufri Himalini as shown in table 2.

At 150 ppb level of O_3, the number of tubers per plant was (4/plant) for Kufri Surya, and Kufri Swarna, Kufri Jyothi, Kufri Chipsona showed 2 per plant whereas Kufri Jawahar, Kufri Giriraj and Kufri Muthu and Kufri Himsona showed a single tuber per plant and tubers were not formed for Kufri Giridhari and Kufri Himalini genotypes.

At 200 ppb O_3 fumigation, significantly the highest tubers formed in Kufri Surya (3 / plant) and the minimum number of tubers were formed i.e., (1 / plant) for Kufri Swarna, Kufri Jyothi, Kufri Chipsona and there was no tubers formation in other potato genotypes Kufri Jawahar, Kufri Giriraj, Kufri Muthu, Kuffri Himsona, Kufri Giridhari and Kufri Himalini.

From the above results it was concluded that, the highest tuber formation was noticed in Kufri Surya at all three fumigation levels, whereas Kufri Giridhari and Kufri Himalini recorded significantly the lowest number of tuber per plant at 100 ppb O_3 and no tuber formation was noticed at 150 and 200 ppb O_3 levels. Moreover, majority of varieties did not show tuber formation at 200 ppb O_3 (Table 2).

Loss of photosynthetic capacity is an early effect of ozone exposure which is due to accelerated senescence which was indicated by “speckle leaf symptom” (necrotic leaf spots as shown in the Plate 1 and 2) along with down-regulation of photosynthetic genes (McKee *et al.* 1997). Inhibition of CO_2 assimilation can also result from direct or indirect inhibition of stomatal opening (Overmayer *et al.* 2008).

Plate 1. Fumigation at 200 ppb O_3 showed highest visible injury (99.5 %) Kufri Himalini

Plate 2. Kufri Surya showed the lowest (15.5%) visible injury

Reductions in carbon acquisition are likely to result in a reduction of whole plant biomass, inducing yield reduction in crops by reducing the availability of leaf surface area to fix and provide carbon for reproductive parts which is stemming from reduced photosynthetic efficiencies and/or stomatal conductances (Betzelberger *et al*., 2010). Ozone induced reductions in yield of potato tubers is the direct consequence of ozone-induced reductions in photosynthesis and photosynthate allocation to the reproductive structures (Wilkinson *et al*., 2011).

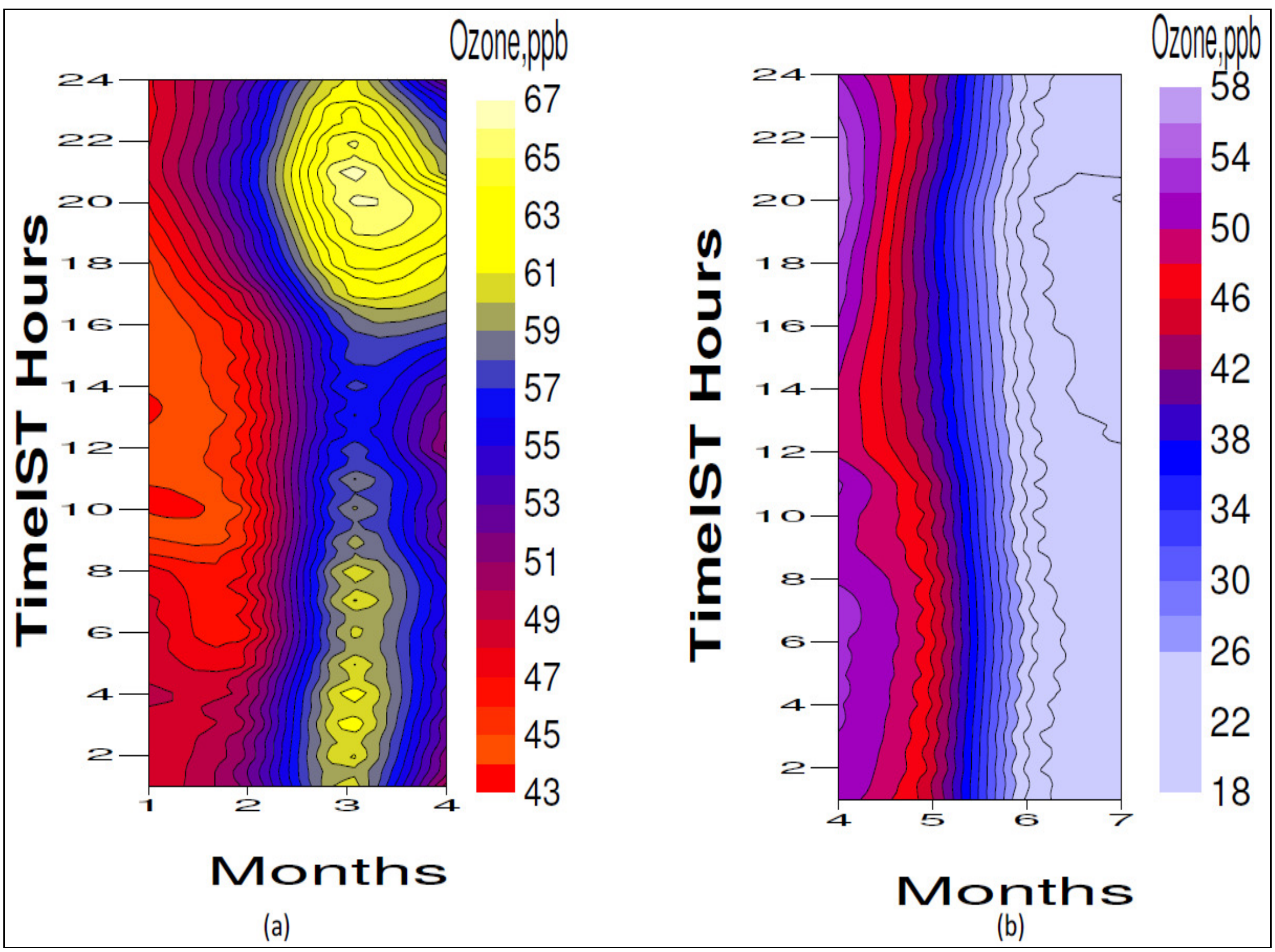

Fig 1 (a) : The hourly mean O_3 concentrations during January –April (2012-2013) (average of two seasons of spring grown potato genotypes)

1 (b) : Hourly mean O_3 concentration during April-July (2011-2012) (average of two seasons of summer grown potato genotypes)

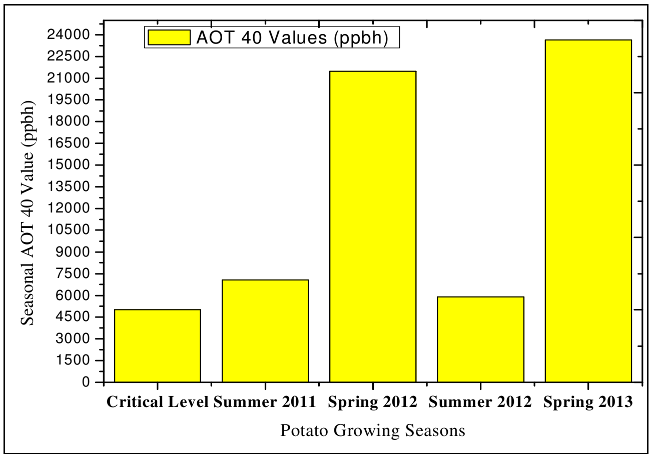

Fig. 2 : Calculated AOT40 values (ppbh) for four growing seasons of potato (2011-2013)

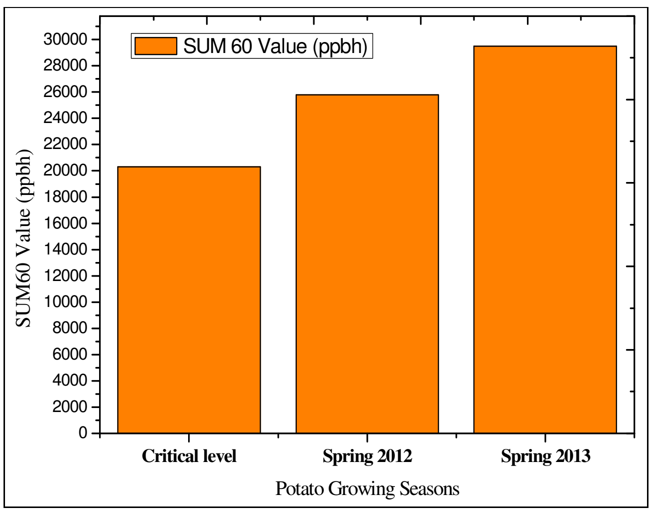

Fig. 3 : Calculated SUM 60 values (ppb h) during spring potato growing seasons (January to April) 2012-2013

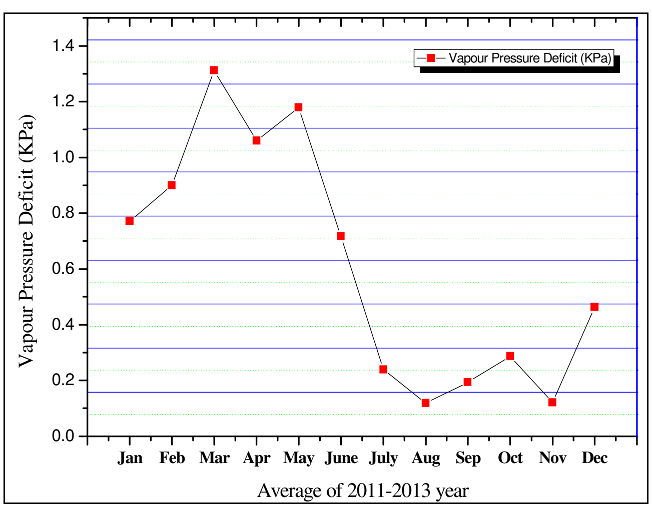

Fig. 4 : Average Vapor Pressure Deficit (VPD) calculated during the months of the year (2011-13)

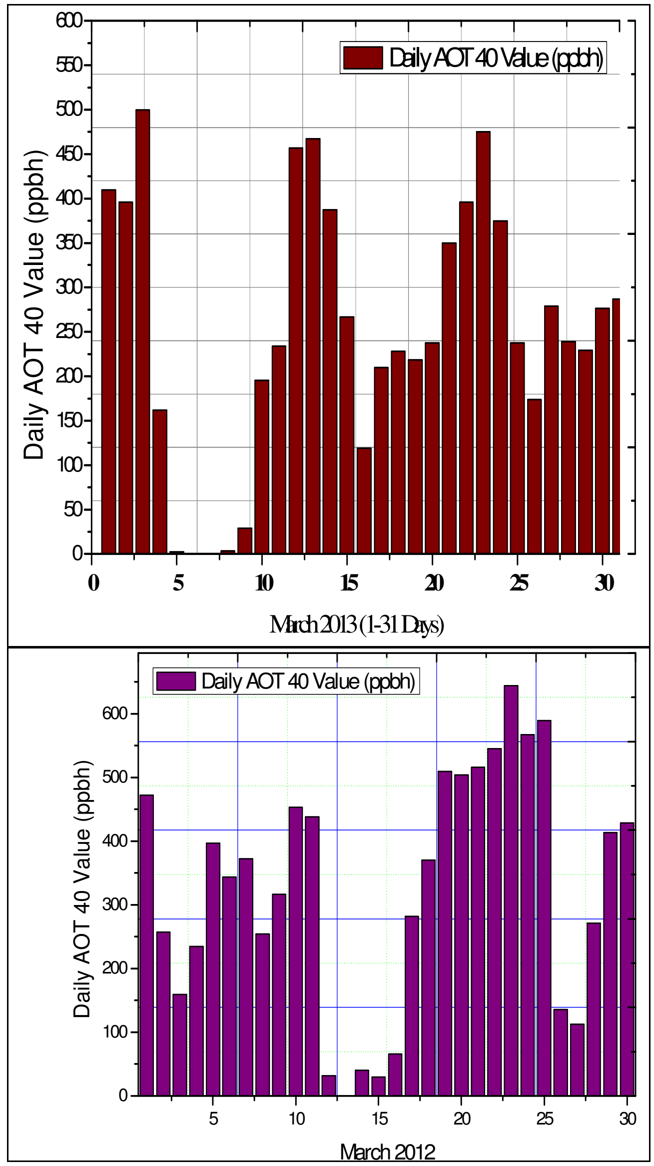

Fig. 5 & 6 : Calculated Daily AOT 40 values (ppbh) during the highest AOT 40 value months of March 2013 and 2012 respectively

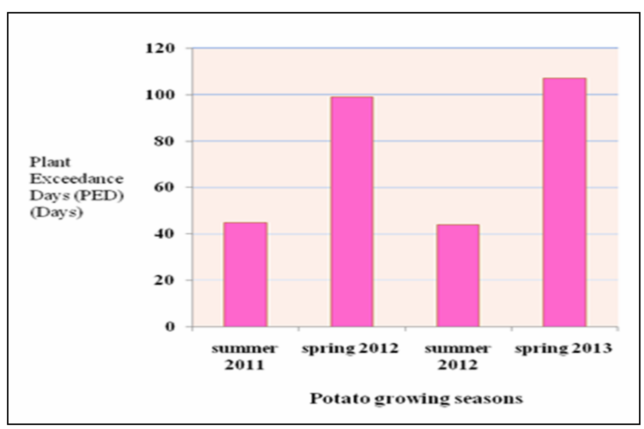

Fig. 7 : Potato growing seasons showing No of days with Daily AOT 40 values (ppbh) >200 ppbh at <1.5 KPa (Vapour Pressure Deficit)

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 $plant^{-1}$)**				**Mean**	**Yield (t ha^{-1})**				**Mean**	**Yield Reduction (%)**				**Mean**
Seasons	**S_1**	**S_2**	**S_3**	**S_4**		**S_1**	**S_2**	**S_3**	**S_4**		**S_1**	**S_2**	**S_3**	**S_4**	
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	
	SEd		CD(0.05%)			SEd	CD (0.05 %)				SEd	CD (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 x 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, S4- January – April 2013)

Table 2 : Impact of elevated ozone levels viz., 100, 150 and 200 ppb on the average no. of tubers plant⁻during tuber initiation stage of potato genotypes

Potato Genotypes	**Treatments**	**Average No of tubers $plant^{-1}$**	**Mean values**	**Per cent difference between healthy plant**	**Potato Genotypes**	**Treatments**	**Average No of tubers $plant^{-1}$**	**Mean values**	**Per cent difference between healthy plant**
Kufri Surya	T_1	6	4.33	-25	Kufri Giriraj	T_1	3	1.33	-57.14
	T_2	4		-50		T_2	1		-87.5
	T_3	3		-62.5		T_3	0		-100
	T_4	8				T_4	7		
Kufri Swarna	T_1	4	2.33	-50	Kufri Muthu	T_1	2	1.0	-66.66
	T_2	2		-75		T_2	1		-83.33
	T_3	1		-87.5		T_3	0		-100
	T_4	8				T_4	6		
Kufri Jyothi	T_1	4	2.33	-50	Kufri Himsona	T_1	2	1.0	-66.66
	T_2	2		-75		T_2	1		-83.33
	T_3	1		-87.5		T_3	0		-100
	T_4	8				T_4	6		
Kufri Chipsona	T_1	3	2.0	-57.14	Kufri Giridhari	T_1	2	0.66	-75
	T_2	2		-71.43		T_2	0		-100
	T_3	1		-87.5		T_3	0		-100
	T_4	7				T_4	8		
Kufri Jawahar	T_1	3	1.33	-57.14	Kufri Himalini	T_1	2	0.66	-75
	T_2	1		-87.5		T_2	0		-100
	T_3	0		-100		T_3	0		-100
	T_4	7				T_4	8		

	SEd	CD (0.05%)
Genotypes (G)	0.195	0.405
Treatments (T)	0.231	0.264
G x T	0.426	0.669

(T_1 - 100 ppb O_3 @ 4 h d^{-1}, T_2 - 150 ppb O_3 @ 4 h d^{-1}, T_3 -200 ppb O_3 @ 4 h d^{-1}, T_4 - Untreated). Mean values for T_1=3.1 T_2= 1.4 and T_3=0.6.

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