Indian Journal of Agricultural Sciences **84** (7): 808–15, July 2014/Article
https://doi.org/10.56093/ijas.v84i7.41936

Influence of Pb toxicity on yield, yield attributing parameters and photosynthetic pigment of tomato (*Solanum lycopersicum*) and eggplant (*Solanum melongena*)

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Received: 3 January 2013; Revised accepted: 15 May 2014

ABSTRACT

A study was conducted to evaluate the effect of Pb on yield and yield attributing parameters of tomato (*Solanum lycopersicum* L. cv Pusa Rohini) and eggplant (*Solanum melongena* L. cv Pusa Upkar). The photosynthetic pigment content and lead accumulation in both crops were also quantified. Tomato and eggplant crops were irrigated with waters having four concentrations of Pb (2.5, 5.0, 7.5 and 10 ppm). Normal water was used as control (0 ppm) in both the crops. Application of Pb contaminated irrigation water decreased plant height, leaf area/plant, number of fruits/ plant, fresh fruit weight/plant, fruit yield/plant, dry weight/plant, above plant biomass/plant. The decrease ranged from 54% to 98% and 51% to 94% in tomato and eggplant, respectively, summarized for various parameters across treatments. The number of days to first fruit harvest increased by 1-2 days in 10 ppm treatment in both the crops. The inhibitory effects of photosynthetic pigments gradually increased with increase in concentration. 10 Pb ppm concentration resulted in the lowest pigment level (mg/g FW) and maximum inhibition rate compared to control. On the basis of the results obtained, it was concluded that tomato was more sensitive compared to eggplant. An attempt was also made to quantify the impact of Pb on the various parameters. The models used were linear, exponential, quadratic, and polynomial of degree 3. The responses could be described very satisfactorily by the polynomial of degree three with $R^2 > 99\%$ for the both crops for all the parameters.

Key words: Eggplant, Lead, Models, Photosynthetic pigment, Tomato, Yield and yield attributing parameters

Heavy metals are a group of non-biodegradable elements with the tendency of bioaccumulation in living systems. They are commonly encountered in industrial wastes and in recent times, have posed so much environmental problems that they can not be overlooked any longer (Krishnamurti and Naidu 2000, Guo *et al.* 2006). Though they occur naturally in rocks, soils and water, environmental contamination via anthropogenic sources due to increased industrialization has resulted in serious problems in the food chain and consequently, the health of organisms, including man (Antunes *et al.* 2003, Jamal *et al.* 2006). Also, exponential growth of the world's population over the past 20 years has resulted in environmental build-up of waste products of which heavy metals are of particular concern (Cossich *et al.* 2002, Vijayaraghavan *et al.* 2004).

Plants are important component of the ecosystems as they transfer the metals from abiotic into biotic environments (Maksymiec and Baszynski 1996, Mocquot *et al.* 1996, Chojnacki *et al.* 2005). The metals may enter the food chain either through water supplies and aquatic organisms or through arable produce and grazing animals (Thornton 1991). In peri urban areas most of the vegetables grown are very much prone to Pb, Cr, Ni and other heavy metal toxicity. The level of heavy metals in sewage-irrigated grown vegetables could be 2 to 40 times higher than that grown with tube well water (Alam *et al.* 2003, Faizan *et al.* 2012).

Lead is one of the heavy metals widely used in modern industry that has been recognized as highly toxic and carcinogenic. It can affect growth and metabolism of plant to varying degrees depending on the concentration and tissue types of plant species (Sharma and Dubey 2005). Environmental Protection Agency (EPA) had also reported that it is most common heavy metal contaminant in the environment (Lamhamdi *et al.* 2011). It was reported that excessive concentrations of Pb exhibit noxious effects to plants. It also results in phytotoxicity of cell membrane (William 1976). Possible causal mechanisms include changes in permeability of cell membrane, reactions of sulphydryl (-SH) groups with cations, possible affinity for

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reacting which phosphate groups and active groups of ADP and ATP (William 1976). A, pot culture experiment was designed to investigate the role of Pb and its sensitivity on growth and yield of tomato (*Solanum lycopersicum* L.) and eggplant (*Solanum melongena* L.) as it was very obvious from the literature search conducted on this topic that very limited work has been done on these aspects. The results obtained have been described and discussed in this paper. The models linear, exponential, quadratic, and polynomial of degree 3 were also used for quantifying the response of various parameters to increasing Pb concentration in the study.

MATERIALS AND METHODS

The pot experiment was conducted in the net house of Water Technology Centre, Indian Agricultural Research Institute, New Delhi. Two vegetables crops, viz. tomato cv Pusa Rohini and eggplant cv Pusa Upkar, were grown in the winter seasons of 2008-09 and 2009-10. Fifteen day old seedlings were transplanted in the pots on October 23 in 2008 and October 26 in 2009. The soil used in the experiment was sandy loam in texture (sand 76%, silt 10%, clay 14%). Initial pH, EC, organic carbon, available nitrogen, phosphorus and potassium contents were 7.8, 0.72 dS/m, 0.48%, 228 kg/ha, 22.2 kg/ha and 358 kg/ha, respectively.

The experiment was laid out in Completely Randomized Block Design (CRD) with three replications. The four Pb concentrations in irrigation water were 2.5, 5.0, 7.5 and 10 ppm in addition to control (0 ppm concentration). Recommended doses of fertilizers were applied to both the crops in all the treatments as basal dose. In tomato, the dose was 150 kg N/ha (3.28 g N/pot), 60 kg P_2O_5/ha (3.77 g P_2O_5/pot) and 60 kg K_2O/ha (1g K_2O/pot) while in eggplant, it was 50 kg N/ha (1.09 g N/pot), 370 kg P_2O_5/ha (23.23 g P_2O_5/pot) and 100 kg K_2O/ha (1.67 g K_2O/pot) through urea for nitrogen, single super phosphate (SSP) for phosphorus and muriate of potash (MOP) for potassium, respectively.

Lead acetate basic $[Pb_3(H_2O)(CH_3COO)_2]$ was used as source of Pb. The first irrigation was given with normal water at the time of transplanting but subsequent irrigations were with Pb enriched water at 5 day intervals in both tomato and eggplant crops.

The leaf samples were collected for the estimation of chlorophyll at the time of flowering. Fruits samples were collected as and when they ripened and analyzed for Pb accumulation. The number of days taken from the date of sowing to the harvest of first fruit was recorded in each treatment. Likewise, the plant height (cm), leaf area (cm^2) and number of fruits harvested per plant were also noted. The average fresh fruit weight (g) was calculated by dividing the total fruits yield (g) by the number of fruits harvested from each treatment. The fruits harvested in the different pickings were summed up to get average fruit yield per plant. After the harvest of crops, the above ground biomass was averaged for all treatments.

Chlorophyll a (Chl a), chlorophyll b (Chl b) and Chlorophyll (a+b){chl (a+b)} were extracted and estimated according to Arnon (1949). About 0.1 g of fresh leaves from each selected Pb treatment was cut into tiny segments and kept in 7 ml dimethyl sulphoxide (DMSO) and incubated at 65^{o} C for one hour. To this aliquot, 3 ml DMSO was added to make up the total volume to 10 ml. Optical densities were taken at 645 nm and 663 nm using UV-VIS Double Beam Spectrophotometer 2201(Hiscox and Israelstam 1979). Pigment contents were calculated in mg/g FW.

After harvesting of crop, ripened fruits were selected from each pot for the determination of lead content. Fruits were first rinsed 3-4 times with deionized water. They were oven-dried at 70°C for 48 h followed by di-acid digestion with $HNO_3/HClO_4$ (3:1, v/v) solution. The digested samples were dissolved in deionised water (25 ml) and stored at 4°C until analysis. An aliquot (2.0 ml) of the digest was analyzed for Pb using Atomic Absorption Spectrophotometer (AAS, Analytic Jena, and model Zeenit 007).

All the data were analyzed statistically using SAS version 9.2.

RESULTS AND DISCUSSION

The results of the experiments have been described and discussed in the following sections:

EFFECT OF LEAD

Days to first fruit harvest

In case of Pb contaminated irrigation water, the days to first fruit harvest increased in tomato from 61 days in control to 63 days in the treatment having Pb concentration of 10 ppm (Table 1). In eggplant, the impact was less and caused one day's delay only for the corresponding treatments. It can be concluded that contamination of Pb resulted in marginal delay only.

Plant height and leaf area

In case of Pb, though there was a decrease in plant height of tomato to the extent to 6% at Pb concentration of 2.5 ppm, the reduction in plant height was almost 54% at concentration of 10 ppm, compared to the control (Tables 1 and 2). In eggplant crop, there was a significant reduction in plant height up to Pb concentration by 9% at 5 ppm concentration, while the reduction was almost 51% at concentration of 10 ppm, compared to the control. In case of leaf area of tomato, the reduction was to the extent to 39% at Pb concentration of 2.5 ppm, while it was almost 59% at concentration of 10 ppm, compared to the control (Tables 1 and 2). In eggplant crop, there was a significant reduction by 37% in leaf area up to Pb concentration of 5 ppm, but the reduction in leaf area was almost 73% at concentration of 10 ppm, compared to the control. There was obviously a clear cut difference in the response of tomato vis-a-vis eggplant in case of Pb also.

Fresh fruit weight and dry fruit weight

It was observed that there was a significant reduction

Table 1 Effect of irrigation water containing varying levels of lead on yield and yield attributing characters of tomato

Parameters	Year	Treatments					Mean	CD	SE
		T_1	T_2	T_3	T_4	T_5			
Number of days to first fruit harvest	2008	60.89	61.35	61.85	62.24	63.40	61.95	0.36	0.16
	2009	60.79	61.40	61.75	62.19	63.39	61.90		
	Mean	60.84	61.38	61.80	62.22	63.40			
Plant height (cm)	2008	55.59	52.19	41.59	30.09	25.16	40.92	0.39	0.17
	2009	55.42	52.26	41.68	30.11	25.65	41.02		
	Mean	55.51	52.23	41.64	30.10	25.41			
Leaf area/plant (cm^2)	2008	9.42	5.75	5.20	4.49	3.87	5.75	0.11	0.05
	2009	9.38	5.79	5.35	4.50	3.90	5.78		
	Mean	9.40	5.77	5.28	4.50	3.89			
Fresh fruit weight/plant (g)	2008	335.10	254.80	199.00	161.20	43.00	198.62	9.20	4.05
	2009	335.00	246.40	178.40	147.00	35.90	188.54		
	Mean	335.00	250.60	188.70	154.10	39.50			
Fruit dry weight/plant (g)	2008	46.40	39.00	25.50	20.80	14.60	29.26	1.90	0.84
	2009	45.20	37.70	25.90	20.10	14.20	28.62		
	Mean	45.80	38.40	25.70	20.50	14.40			
Number of fruits/plant	2008	30.00	25.00	16.00	13.00	6.00	18.00	2.15	0.94
	2009	29.00	24.20	15.00	12.00	5.00	17.04		
	Mean	29.70	24.60	15.50	12.70	5.50			
Fruit yield/plant (kg)	2008	10.05	6.37	3.18	2.10	0.26	4.39	0.68	0.30
	2009	9.72	5.96	2.68	1.76	0.18	4.06		
	Mean	9.88	6.17	2.93	1.93	0.22			
Above ground biomass/ plant (g)	2008	93.78	78.53	49.62	33.79	24.41	56.03	0.70	0.31
	2009	94.59	77.46	51.36	30.25	22.46	55.22		
	Mean	94.19	78.00	50.49	32.02	23.44			

Values in parentheses are significant at $P \leq 0.01$.*T_0=0 ppm; T_1= 2.5 ppm; T_2= 5 ppm; T_3; =7.5 ppm; T_4= 10 ppm

in fresh weight and dry weight of fruits when the Pb concentration increased from 0 ppm to the level of 10 ppm compared to untreated plants (control). This signified a drastic reduction in fresh fruit weight of tomato by 88% while, in eggplant, the reduction was 77% at 10 ppm treatment compared to the control. In case of fruit dry weight in tomato, it decreased by 69% while in eggplant it decreased by 53% compared to the control. As recorded earlier, again tomato was more sensitive than eggplant with the difference ranging from 11% as far as fresh weight of fruits was concerned but 16% in case of dry weight of fruits between the two crops in 10 ppm treatment compared to the control.

Number of fruits and yield

Though there a decrease in number of fruits per plant of tomato to the extent of 17 % at Pb concentration of 2.5 ppm, the reduction was almost 81% at 10 ppm concentration, compared to the control (Tables 1 and 2). In eggplant crop, there was a significant reduction in number of fruits per plant by 44 % at 5 ppm Pb concentration which increased to almost 75% at 10 ppm concentration compared to the control. In case of fruit yield of tomato, the reduction was to the extent of 38% at Pb concentration of 2.5 ppm, while it was almost 98% at concentration of 10 ppm, compared to the control (Tables 1 and 2). In eggplant crop, there was a significant reduction in fruit yield by 48 % at 5 ppm Pb concentration, while it was almost 94% at concentration of 10 ppm, compared to the control.

Tomato was more sensitive than eggplant with the difference ranging from 7% as far as number of fruits was concerned but 4% in case of yield between the two crops in 10 ppm treatment compared to the control.

Above ground biomass

The impact of Pb on the above ground biomass has also been shown in Tables 1 and 2. The impact of Pb resulted in a significant reduction at all concentration in above ground biomass compared to the control. There was a drastic reduction in above ground biomass of tomato by 75% at 10 ppm concentration while in eggplant the reduction was 72% at the same concentration level compared to the control. Again, tomato was more sensitive than eggplant with the difference ranging from 3% as far as above ground biomass was concerned.

Comparison of the impact of lead on tomato and eggplant

Significant reducation in plant height, leaf area per plant, number of fruits per plant, fresh fruits weight, fruits yield per plant, fruits dry weight and above ground biomass

Table 2 Effect of irrigation water containing varying levels of Lead on yield and yield attributing characters of eggplant

Parameters	Year	Treatments					Mean	CD	SE
		T_1	T_2	T_3	T_4	T_5			
Number of days to first fruit harvest	2008	94.80	94.90	95.20	95.35	95.40	95.13	0.35	0.15
	2009	94.60	94.92	95.91	95.55	96.51	95.50		
	Mean	94.70	94.91	95.56	95.45	95.96			
Plant height (cm)	2008	38.96	36.98	34.96	31.97	19.00	32.37	0.21	0.09
	2009	37.99	36.99	34.89	32.00	18.99	32.17		
	Mean	38.48	36.99	34.93	31.99	19.00			
Leaf area/plant (cm^2)	2008	17.61	14.03	11.00	9.00	4.89	11.31	2.04	1.16
	2009	17.64	14.21	11.20	8.95	4.79	11.36		
	Mean	17.63	14.12	11.10	8.98	4.84			
Fresh fruit weight/plant (g)	2008	113.67	104.47	97.83	74.49	26.37	83.37	22.98	10.77
	2009	113.89	103.92	96.21	73.09	25.79	82.58		
	Mean	113.78	104.20	97.02	73.79	26.08			
Fruit dry weight/plant (g)	2008	15.50	13.79	9.26	8.61	7.66	10.96	2.00	0.88
	2009	15.20	13.38	8.20	7.70	6.80	10.26		
	Mean	15.35	13.59	8.73	8.16	7.23			
Number of fruits/plant	2008	10.00	8.50	5.67	4.67	2.00	6.17	1.53	0.67
	2009	9.67	8.30	5.40	5.00	3.00	6.27		
	Mean	9.84	8.40	5.54	4.84	2.50			
Fruit yield/plant (kg)	2008	1.14	0.89	0.55	0.35	0.05	0.60	0.24	0.11
	2009	1.10	0.86	0.61	0.37	0.08	0.60		
	Mean	1.12	0.88	0.58	0.36	0.07			
Above ground biomass/ plant (g)	2008	38.56	24.92	16.18	14.7	10.63	21.00	0.54	0.24
	2009	38.65	25.84	17.32	14.65	10.75	21.44		
	Mean	38.61	25.38	16.75	14.66	10.69			

Values in parentheses are significant at $P \leq 0.01$. * T_0=0 ppm; T_1= 2.5 ppm; T_2= 5 ppm; T_3; =7.5 ppm; T_4= 10 ppm

was recorded at 2.5 ppm and 7.5 ppm concentration of irrigation water compared to control for both the crops. In case of yield parameters such as number of fruits per plant and fruits yield, the number of fruits per plant decreased by 17% in tomato and 15% in eggplant at 2.5 ppm concentration, and 57% in tomato and 31% eggplant in 7.5 ppm treatment. Fruit yields decreased by 38% in tomato and 22% in eggplant at 2.5 ppm, and 80% in tomato and 68% in eggplant at 7.5 ppm concentration level compared to control. A similar trend had been observed in other parameters namely, plant height, leaf area per plant, fresh fruits weight, fruits dry weight and above ground biomass (Fig 1 and 2).

Photosynthetic pigments

The inhibitory effects of photosynthetic pigments gradually increased with increase in concentrations. 10 Pb ppm concentration resulted in the lowest pigment level (mg/g FW) and maximum inhibition rate compared to control. At this concentration (Pb 10 ppm), the pigment content and inhibition percent for chlorophyll a (0.85; 57.07%), chlorophyll b (0.69; 54.61%) and total chlorophyll (1.54; 56%), while the highest pigment content (mg/g FW) for chlorophyll a (1.98 mg/g FW), chlorophyll b (1.52 mg/g FW) and total chlorophyll (3.50 mg/g FW) was recorded in the control in tomato. Eggplant also showed a significant declining trend with increasing Pb concentration (0 to 10 ppm). The lowest pigment level (mg/g FW) and maximum inhibition rate for chlorophyll a (1.95; 24.42%), chlorophyll b (1.79; 15.57%) and total chlorophyll (3.75; 20.43%) were observed in eggplant leaves at 10 ppm Pb concentration. As expected, the highest pigment content in eggplant (mg/g FW) for chlorophyll a (2.58 mg/g FW), chlorophyll b (2.12 mg/g FW) and total chlorophyll (4.70 mg/g FW) were recorded in control.

Pb accumulation in tomato and eggplant fruit

Tomato and eggplant fruits accumulated Pb in concentration dependent manner. In tomato fruits, Pb concentration increased to 5.235 mg/g d.wt. in 10 ppm treatment in tomato and 5.060 mg/g d.wt. in the corresponding treatment in case of eggplant. From this figure, it is clear that tomato fruits accumulate more Pb compared to eggplant, which has adversely affected all the physiological process as discussed earlier

Response functions for yield attributing characters and yield parameters

An attempt was made to quantify the impact of Pb and Cr concentrations on yield attributing characters and yield

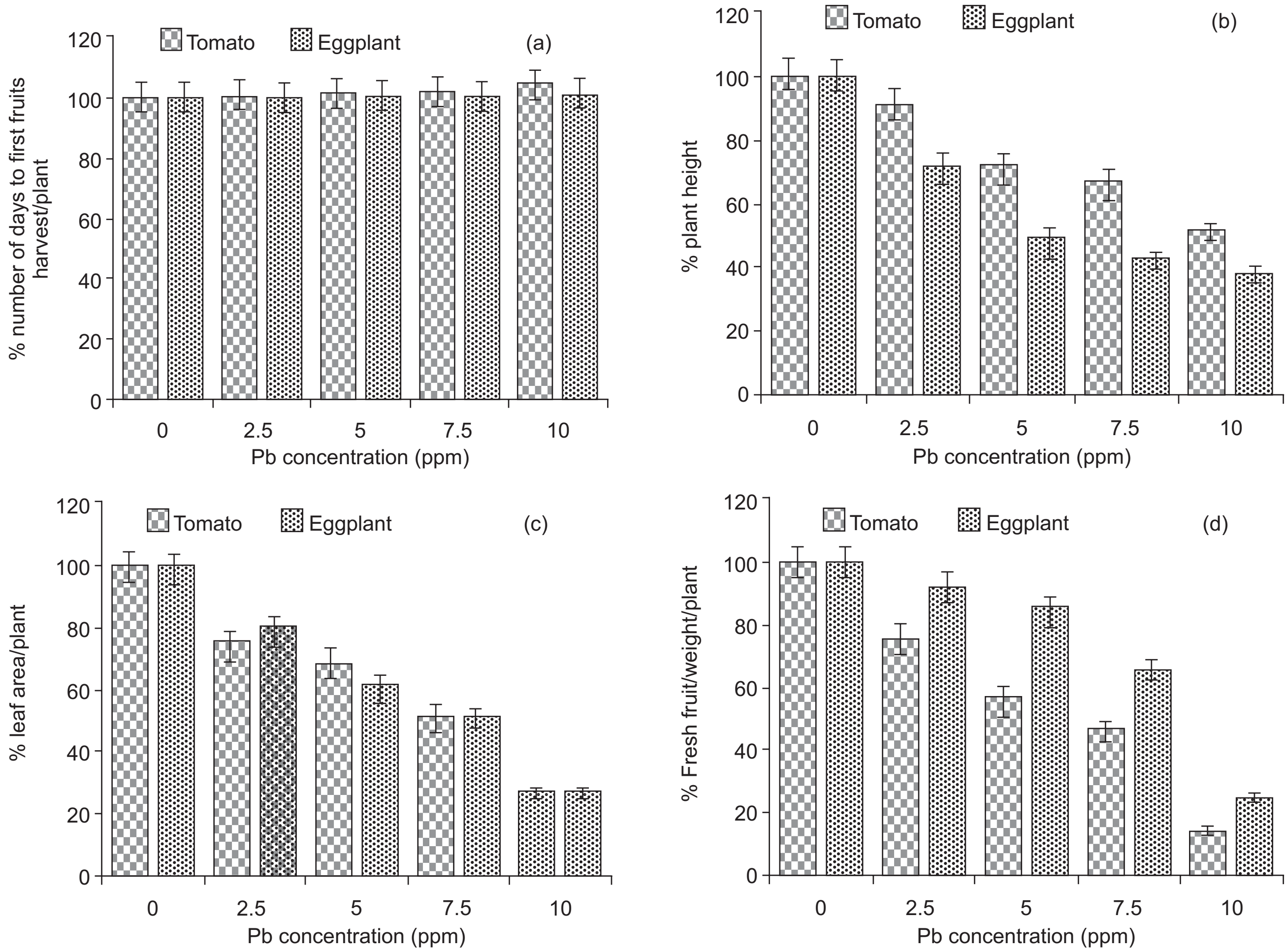

Fig 1 Comparison of Lead toxicity on the various plant parameters in tomato and eggplant (a) Number of days to first fruit harvest, (b) Plant height, (c) Leaf area per plant, and (d) Fresh Fruit weight per plant {All parameters are expressed as relative percentage of the value obtained in control (0 ppm) treatment}

parameters. The following models were used:

Linear: $y = a+bx$ (1)
Exponential: $y = a.e^{bx}$ (2)
Quadratic: $y = a+bx+cx^2$ (3)
Polynomial (Degree 3): $y = a+ bx+cx^2+dx^3$ (4)

In all the above equations, 'y' is the plant morphological parameter, viz. number of days to first fruit harvest/plant, plant height (cm), leaf area (cm^2), number of fruits/plant, fresh fruit weight/plant (g), fruit yield/plant (g), dry weight (g) and above ground plant biomass/plant (g), 'x' is Pb concentration, 'a' is the constant and 'b', 'c', 'd' are regression coefficients having different values in the different equations.

In the case of Pb, the performances of the various models have been presented in Tables 3 and 4.The R^2 values ranged from 0.945 to 0.982 in tomato and between 0.861 to 0.999 in eggplant when the linear model (eq 1) was used (Tables 3 and 4). In case of tomato, the use of exponential model (eq 2) resulted in R^2 values ranging from 0.830 to 0.988, while in eggplant the values ranged from 0.740 to 0.981. The use of quadratic (eq 3) resulted in R^2 values ranging from 0.966 to 0.992 in tomato, and from 0.905 to 0.999 in eggplant. The use of polynomial of degree 3 (eq 4) resulted in R^2 values ranging from 0.978 to 0.999 in tomato and 0.908 to 1.00 in eggplant. The best fit was obtained by the polynomial of degree 3 in both the crops with the quadratic form performing slightly better than the exponential form.

Metal toxicity is an important factor governing germination and growth of plants. The effects of toxic substances on plants are dependent on the amount of toxic substance taken up from the given environment. The toxicity of some of the metals may be large enough that, plant growth is retarded before large quantities of the element can be transferred (Haghiri 1973). We have investigated how lead treatment affected the yield, yield attributes parameters, photosynthetic pigment and lead accumulation, also used for quantifying the response of various parameters. A drastic reduction in plant height, leaf area/plant, number of fruits/plant, fresh fruits weight, fruits yield/plant, fruits dry weight and above ground biomass was recorded at 2.5 ppm and 7.5 ppm concentration of irrigation water compared to control for both the crops. In

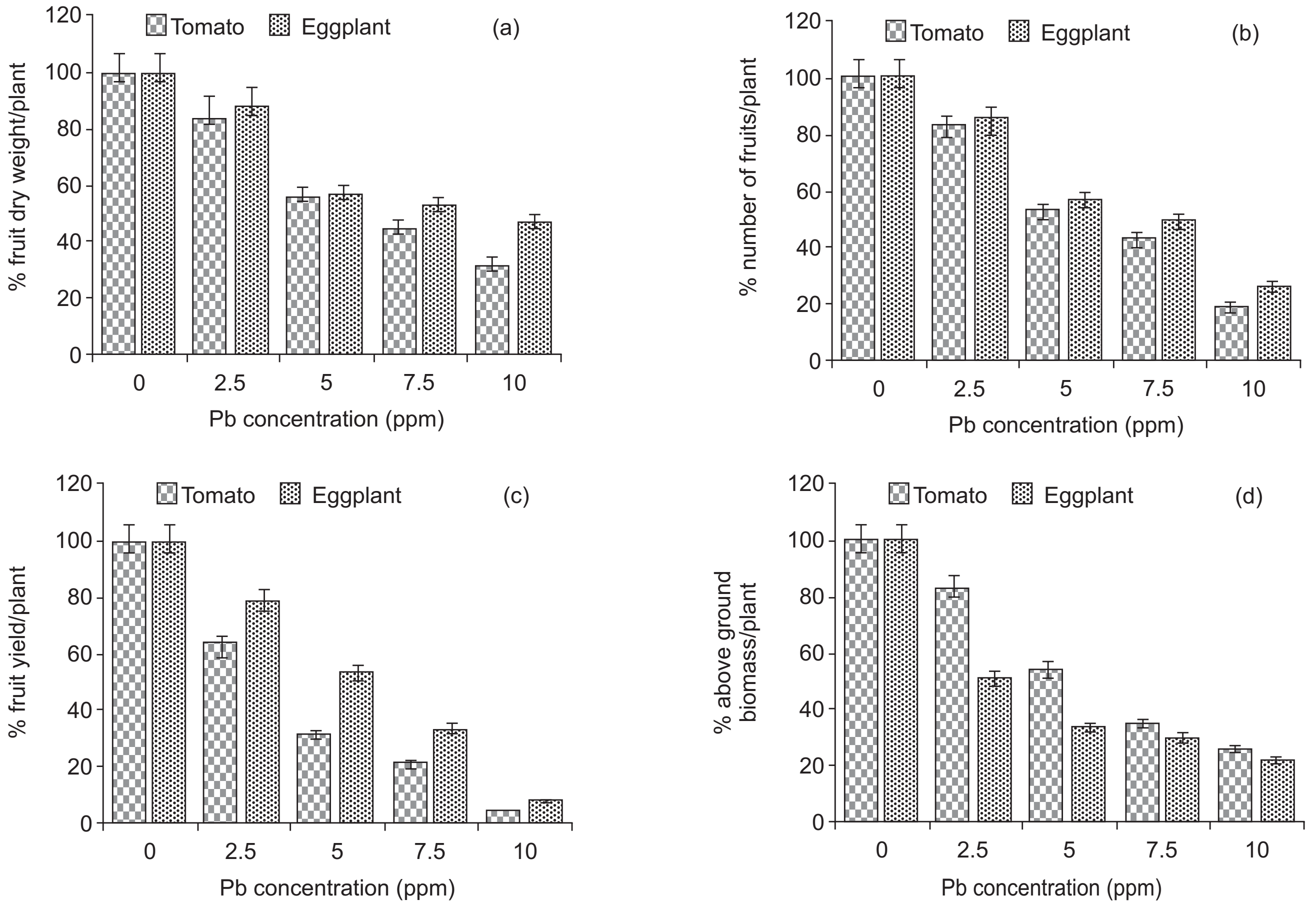

Fig 2 Comparison of lead toxicity on the various plant parameters in tomato and eggplant (a) Fruit dry weight per plant, (b) Number of fruits per plant, (c) Fruit yield per plant, and (d) Above ground plant biomass per plant {All parameters are expressed as relative percentage of the value obtained in control (0 ppm) treatment}

Table 4 Performance of various models (*) used for yield and yield attributing characters of eggplant

Models		Number of days to first fruit harvest	Plant height (cm)	Leaf area/ plant (cm)	Fruit fresh weight/ plant (g)	Fruit dry weight/ plant (g)	Number of fruits/ plant	Fruit yield/ plant (kg)	Above ground biomass/ plant (g)
Linear	a	94.398	9.183	20.550	144.720	17.113	11.696	1387.400	34.784
	b(x)	0.306	–1.300	–3.072	–20.581	–2.167	–1.824	–262.630	–5.054
	R^2	0.903	0.884	0.992	0.861	0.898	0.977	0.999	0.959
Exponential	a	94.401	–0.237	25.806	198.530	18.573	15.051	3037.500	40.502
	b(x)	0.003	10.111	–0.304	–0.329	–0.202	–0.329	–0.659	–0.265
	R^2	0.904	0.938	0.939	0.740**	0.920	0.939	0.849	0.981
Quadratic	a	94.318	11.928	20.370	98.562	20.088	11.876	1373.500	39.304
	b(x)	0.375	–3.653	–2.918	18.980	–4.717	–1.978	–250.730	–8.928
	c(x^2)	–0.011	0.392	–0.026	–6.594	0.425	0.026	–1.982	0.6457
	R^2	0.905	0.997	0.992	0.985	0.946	0.977	0.999	0981
Polynomial(3)	a	94.066	12.278	23.884	136.190	16.252	12.184	1396.400	37.232
	b(x)	0.729	–4.145	–7.854	–33.884	0.672	–2.411	–282.810	–6.018
	c(x^2)	–0.146	0.580	1.857	13.566x2	–1.630	0.191	10.250	–0.4643
	d(x^3)	0.015	–0.021	–0.209	–2.240	0.228	–0.018	–1.359	0.1233
	R^2	0.908	0.997	0.998	1.000	0.960	0.977	0.999	0.982

* R^2 values are significant at $P \leq 0.05$ level, ** not significant; 'a' is the constant and 'b', 'c',' d' are regression coefficients

Table 3 Performance of various models (*) used for yield and yield attributing characters of tomato

Models		Number of days to first fruit harvest	Plant height (cm)	Leaf area/ plant (cm)	Fruit fresh weight/ plant (g)	Fruit dry weight/ plant (g)	Number of fruits/ plant	Fruit yield/ plant (kg)	Above ground biomass/ plant (g)
Linear	a	60.120	40.960	10.305	399.830	53.170	35.690	11297	111.870
	b(x)	0.600	–4.300	–1.499	–68.750	–8.070	–6.030	–2356.900	–18.748
	R^2	0.945	0.978	0.962	0.973	0.977	0.982	0.945	0.974
Exponential	a	60.144	43.875	12.896	656.540	64.317	50.724	33100	147.020
	b(x)	0.010	–0.157	–0.294	–0.476	–0.294	–0.403	–0.878	–0.367
	R^2	0.948	0.971	0.898	0.830	0.988	0.932	0.885	0.985
Quadratic	a	60.720	41.260	9.760	383.280	58.220	36.740	14422	124.000
	b(x)	0.086	–4.557	–1.032	–54.564	–12.399	–6.930	–5035.900	–29.145
	$c(x^2)$	0.086	0.043	–0.078	–2.364	0.721	0.150	446.500	1.733
	R^2	0.972	0.978	0.966	0.975	0.988	0.983	0.992	0.986
Polynomial(3)	a	59.320	41.260	13.288	526.780	52.060	37.300	16090	94.308
	b(x)	2.052	–4.557	–5.988	–256.150	–3.745	–7.717	–7379.000	12.568
	$c(x^2)$	–0.664	0.043	1.812	74.511	–2.579	0.450	1340.000	–14.175
	$d(x^3)$	0.083	0.000	–0.210	–8.542	0.367	–0.033	–99.282	1.768
	R^2	0.999	0.978	0.993	0.996	0.990	0.983	0.995	0.999

*All R^2 values are significant at $P \leq 0.05$ level; 'a' is the constant and 'b', 'c', d' are regression coefficients

case of yield parameters such as number of fruits/plant and fruits yield, the number of fruits/plant decreased by 17% in tomato and 15% in eggplant at 2.5 ppm concentration, and 57% in tomato and 31% eggplant in 7.5 ppm treatment. Fruit yields decreased by 38% in tomato and 22% in eggplant at 2.5 ppm, and 80% in tomato and 68% in eggplant at 7.5 ppm concentration level compared to control. A similar trend had been observed in other parameters namely, plant height, leaf area per plant, fresh fruits weight, fruits dry weight and above ground biomass. Greater uptake of Pb retarded shoot growth due to the presence of excess Pb in the root environment which has also been mentioned by John *et al.* (2009) and Rossato *et al.* (2012). They are in agreement with the earlier work that Pb had a negative impact on growth, biomass, root and shoot length of *Brassica juncea* (John *et al.* 2009). Sharma and Agrawal (2010) found that bioaccumulation of both Zn and Cd adversely affected the growth, biochemical and physiological characteristics that resulted in reduced biomass production lady's finger. Similar results were obtained by several workers who had evaluated the impact of Pb concentration on root/shoot and leaf growth, and fresh-dry biomass, viz. *Paspalum distichum* and *Cynodon dactylon* (Shua *et al.* 2002), tomato (Jaja and Odomena 2004) and *Plantago major* (Kosobrukhov *et al.* 2004). Yaqvob *et al.* (2011) conducted a study to evaluate the response to two tomato varieties (Barakat and Local tomato) to ordinary heavy metals (Fe, Pb and Cu) in northern Iran. They observed that some heavy metals in higher doses may cause metabolic disorders and growth inhibition for most of the plant species.

The Chlorophyll a, b and total chlorophyll reduced from 1.98 to 0.85, 1.52 to 0.69 and 3.50 to 1.54(mg/g FW) in tomato and 2.58 to 1.95, 2.12 to 1.79 and 4.70 to 3.74 (mg/g FW) in eggplant, respectively, with increasing Pb concentration (0 to 10 ppm). There have been reports earlier also on Pb toxicity in plants, inhibition of root and shoot growth (Fargasova 1994), reduction in photosynthesis (Zengin and Munzuroglu 2005, Borah *et al.* 2012) and decrease in chlorophyll a, b, total chlorophyll and carotenoids (John *et al.* 2009).

The result obtained in this study are similar to the ones reported earlier by researchers on many other crops as for as the impact of Pb on various plant morphological parameters. However, quantitative studies on its effect on tomato and eggplant are not available. Regression and process based models have been used by many workers for soil and crop responses (Singh 1989, Rajarathinam *et al.* 2007, Verma *et al.* 2007) but not for such studies.

This study clearly revealed that presence of Pb in irrigation water significantly inhibited photosynthetic pigments through photosynthesis damage vis-à-vis alterations in chlorophyll, growth and yield in both tomato and eggplant crops. The results have conclusively established that increasing concentration of Pb in the irrigation water caused an increase in the accumulation of these heavy metals in the fruits. It was observed that between the two crops, tomato was relatively more sensitive than eggplant. The polynomial of degree three with $R^2 > 99\%$ was very effective in quantifying the response of both the crops to Pb. Tomato and eggplant both being fruity vegetables, should not be grown with Pb contaminated water as the consumption of these vegetables could cause food chain contamination in long term.

ACKNOWLEDGMENTS

The senior author would like to express her gratitude to the Project Director, Water Technology Centre, Director, Indian Agricultural Research Institute, New Delhi for providing necessary facilities and University Grants Commissions for providing Senior Research Fellowship through the study period.

REFERENCES

Alam M G M, Snow E T and Tanaka A. 2003. Arsenic and heavy metal contamination of vegetables grown in Samta village, Bangladesh. *Science of the Total Environment* **308:** 83–96.

Arnon D I. 1949. Copper enzymes in isolated chloroplasts, polyphenoxidase in *beta vulgaris. Plant Physiology* **24:** 1–15.

Antunes W. M, Luna A. S, Henriques C A and Da Costa A C A. 2003. An evaluation of copper biosorption by a brown seaweed under optimized conditions. *Electronic Journal of Biotechnology* **6(3):** 15.

Chojnacka K, Chojnacki A, Gorecka H and Gorecki H. 2005. Bioavailability of heavy metals from polluted soils to plants. *Science of the Total Environment* **337:** 175–82.

Cossich E S, Tavares C R G and Ravagnani T M K. 2002. Biosorption of chromium (III) by *Sargassum* sp. biomass. *Electronic Journal of Biotechnology* **5**(2), August 15 {cited 26 October, 2005}. Availabble from http// www.ejbiotechnology.info/ content/vol3/issue15/full15/index html. ISSN 0717-3458.

Faizan S, Kausar S and Perwean Q. 2012. Variation in growth, physiology and yield of four chickpes cultivation exposed to cadmium chloride. *Journal of Environmental Biology* **33:** 1 137–42.

Fargasova A. 1994. Effect of Pb, Cd, Hg, As and Cr on germination and root growth of *Sinapis alba* seeds. *Bulletin of Environmental Contamination and Toxicology* **52:** 452–6.

Guo G L, Zhou Q X, Koval P V and Belogolova G A. 2006. Speciation distribution of Cd, Pb, Cu and Zn in contaminated Phaeozem in north-east China using single and sequential extraction procedures. *Australian Journal of Soil Research* **44:** 135–42.

Haghiri F. 1973. Cadmium uptake by plants. *Journal of Environmental Quality* **2:** 93–6.

Hiscox and Israelstam 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. *Canadian Journal of Botany* **57**(12): 1 332–4.

Jaja E T. and Odoemena C S I. 2004. Effect of Pb, Cu and Fe compounds on the germination and early seedling growth of *L. esculentum* varieties. *Journal of Applied Sciences and Environmental Management* **8**(2): 51–3.

Jamal S N, Zafa I M and Athar M. 2006. Effect of aluminium and chromium on the germination and growth of two *Vigna* species. *International Journal of Environmental Science and Technology* **3**(1): 53–8.

John R, Ahmad P, Gadgil K and Sharma S. 2009. Heavy metal toxicity effect on plant growth, biochemical parameters and metal accumulation by *Brassica juncea* L. *International Journal of Plant Production* **3**(3): 1 735–6 814.

Kosobrukhov A, Knyazeva I and Mudrik V. 2004. *Plantago major* plants responses to increase content of lead in soil, growth and photosynthesis. *Plant Growth Regulation* **42**: 145–51.

Krishnamurti G S R and Naidu R. 2000. Speciation and phytoavailability of cadmium in selected surface soils of South Australian. *Australian Journal of Soil Research* **38**: 991–1 004.

Maksymiec W and Baszynski T. 1996. Chlorophyll fluorescence in primary leaves of excess Cu – treated runner bean plants depends on their growth stages and the duration of Cu – action. *Journal of Plant Physiology* **149:** 196–200.

Mocquit B, Vangronsveld J, Clijsters H and Mench M. 1996. Copper toxicity in young maize (*Zea mays* L.). Plants effects on growth, mineral and chlorophyll contents and enzymes activities. *Plant and Soil* **182**: 287–310.

Lamhamdi M, Bakrim A, Aarab A, Lafont R and Sayah F. 2011. Lead phytotoxicity on wheat (*Triticum aestivum* L.) seed germination and seedlings growth. *Comptes Rendus Biologies* **334**: 118–26.

Rossato L V, Nicoloso F T, Farias J G, Cargnelluti D, Tabaldi L A, Antes F G, Dressler V L, Morsch V M and Schetinger M R C. 2012. Effects of lead on the growth, lead accumulation and physiological responses of *Pluchea sagittalis*. *Ecotoxicology* **21**: 111–23.

Rajarathinam A, Dixit S K and Vaishnav P R. 2007. Fitting of sorghum (*Sorghum bicolor*) yield trends in long term fertilizer experiment. *Crop Research* **34**: 57–63.

Sharma R K, Agrawal M and Marshall F M. 2007. Heavy metals contamination of soil and vegetables in suburban areas of Varanasi, India. *Ecotoxicology and Environmental Safety* **66**: 258–66.

Sharma P and Dubey R S. 2005. Lead toxicity in plants. *Brazilian Journal of Plant Physiology* **17**: 35–52.

Shua W S, Yeb Z H, Lana C Y, Zhanga Z Q and Wongb M H. 2002. Lead, zinc and copper accumulation and tolerance in populations of *Paspalum distichum* and *Cynodon dactylon*. *Environmental Pollution* **120**: 445–53.

Singh A K. 1989. Modeling pF curve of soils. *Journal of the Indian Society of Soil Science* **37**: 216–22.

Thornton I. 1991. Metal contamination in soils of urban areas. (*In*) *Soils in the Urban Environment*, pp 47–75. Bullock P and Gregory P J (Eds). Blackwell, Oxford.

Verma P, George K V, Singh H V and Singh R N. 2007. Modeling cadmium accumulation in radish, carrot, spinach and cabbage. *Applied Mathematical Modelling* **31**: 1 652–61.

Vijayaraghavan K, Jegan J R, Palanivelu K and Velan M. 2004. Copper removal from aqueous solution by marine green algae (*Ulva reticulata*). (Cited 26 October, 2005) Available from http//www.ejbiotechnology.info/content/vol7/issue15/ full15/index html. ISSN 0717-3458. *Electronic Journal of Biotechnology* 61–71.

Williams R J P. 1976. Calcium chemistry and its relation to biological function. (*In*) *Calcium in Biological Systems.* Syp. Soc. Exp. Biol., 30th, 1-17. London, Cambridge University Press.

Yaqvob M, Golale A, Masoud, S and Ghorbani H R. 2011. Influence of different concentration of heavy metals on the seed germination and growth of tomato. *African Journal of Environmental Science and Technology* **5**(6): 420–6.

Zengin F K and Munzuroglu O. 2005. Effects of some heavy metals on content of chlorophyll, proline and some antioxidant chemicals in bean (*Phaseolus vulgaris* L.) seedlings. *Acta biologica Cracoviensia* **47**(2): 157–64.