RESEARCH ARTICLE

RESPONSE OF *BRASSICA CAMPESTRIS* L. CV. *VARUNA* TO SIMULATED ACID RAIN

Rajesh Kumar*

Department of Botany, Meerut College, Meerut 250001 (U.P.) India
Email : rajeshmalik.mcm@gmail.com

Received-02.07.2016, Revised-26.07.2016

Abstract: The effects of simulated acid rain (pH 4, 0) have been studied on *Brassica campestris* L. cv. *varuna*. The plant growth in terms of shoot and root length, number of leaves per plant and number of lateral branches, was reduced significantly in HNO_3, H_2SO_4 and $HNO_3 + H_2SO_4$ simulated acid rain. Reduction in dry weight and net primary productivity were also observed and the effects were found to be age dependent. Flowering was delayed by simulated acid rain. There was also a significant reduction in yield. The effect of HNO_3 simulated acid rain was greater than H_2SO_4 simulated acid rain and $HNO_3 + H_2SO_4$ simulated acid rain caused maximum reduction in plant growth and yield. A reduction in chlorophyll a, chlorophyll b, and total chlorophyll contents of leaves was also observed after 10 days of treatment. The loss in chlorophyll a was higher than chlorophyll b. A significant increase was observed in nitrogen content on application of HNO_3 simulated acid rain and sulphur content in H_2SO_4 simulated acid rain. The plants subjected to simulated acid rain did not show any visible foliar injury symptoms up to 35 days but subsequently these symptoms appeared.

Keywords: *Brassica campestris*, Acid rain, Plant, Shoot, Root

INTRODUCTION

In the recent years, acid rain, a condition primarily characterized by elevated levels of hydrogen (H^+), sulphate (SO_4^{-2}) and nitrate (NO_3^-) ions, has become an environmental problem of great concern. This phenomenon has been attributed to acidification of atmosphere by gaseous pollutants, mainly sulphur dioxide and nitrogen dioxide, emitted from the combustion of fossil fuels. These gases when they come in contact with rain water result into formation of sulphuric acid (H_2SO_4) and nitric acid (HNO_3), respectively, thus lowering the pH of normal rain. Events of frequent acid rain are common in industrialized countries of Western Europe, America and Canada. Acid rain of as low as pH 3.8 has been reported in Mumbai.

Crowther and Rouston (1911) were amongst the pioneers to demonstrate the detrimental effects of acid rain on vegetation. Acid precipitation causes foliar injury (Evans *et al*., 1977; Evans, 1980; Evans and Curry, 1979; Keevar and Jacobson, 1983; Lee *et al*., 1981), reduction in leaf area and leaching of certain nutrients from the leaves (Adams *et al*., 1984; Evans, *et al.*, 1985; Scherbatskoy and Klein, 1983; Wood and Bormann, 1975) and the reduction in chlorophyll content (Ferrenbaugh, 1976; Thornton *et al*., 1990; Velikova *et al*., 1997). Although there are several studies on the effects of acid precipitation on crops in the West (Cohen *et al*., 1981; Jacobson, *et al*., 1980; Lee *et al*., 1981; Evans, 1982; Irving; 1983; Banwart *et al*., 1987 & 1990), the impact of acid precipitation on crop growth and yield has received little attention in India. Further, the present study was undertaken to study the effects of sulphuric acid and nitric acid alone and in combination in simulated acid rain on *Brassica campestris* L. cv. *varuna*, an important agricultural crop in India, The objective of this study was to get information of pratical use by assessing loss in yield due to acid precipitation.

MATERIAL AND METHOD

This study was conducted in rabi season in the research plot of Botany Department, C.C.S. University, Meerut. The soil was sandy loam and was fertilized with compost. Four replicates of four plots each of 5x5 m were selected. Seeds of *Brassica campestris* L. cv. *varuna*, obtained from NSC, Meerut, were sown in five vertical rows spaced 50 cm apart. Thinning of plants was done when seedlings were two weeks old. One plot from each replicate subjected to simulated rain of deionised water served as control. The other three plots were subjected to simulated acid rains of sulphuric acid, nitric acid and sulphuric acid and nitric acid in combination at pH 4.0. Solutions of 0.5 M sulphuric acid, 1 M nitric acid and both in combination (70:30 v/v) were added to deionised water. The pH was maintained at 4.0. The rainfall was simulated by distributing the solutions in each treatment from a Kisan- 76 Knapsack sprayer of 18 litre capacity with cone swirl type spraying nozzle. The nozzle discharge rate was 500 ml/min. Each rain event consisted of 30 minutes of rain. The treatment began after the plants were

*Corresponding Author

two weeks old. The plants were exposed to simulated acid rain twice a week till the harvest.

Regular destructive harvests of 10 plants from each plot were made at 15 days intervals till the harvest of the crop. The root and shoot lengths, numbers of leaves, branches, flowers and pods per plant, dry weight fractions, net primarily productivity (g/plant/day) and chlorophyll content (Arnon, 1949) were determined at each harvest. The dates of emergence and abscission of leaf were recorded. Senescent leaves were collected as they abscised. Observations were also made on visible foliar injury. The data were analyzed statistically applying ANOVA and then determining critical differences.

RESULT

Data on the effects of simulated acid rain on various growth and yield parameters and chlorophyll content of leaves of *Brassica campestris* L. cv. *varuna* are presented in Tables 1 to 3.

Plant height decreased significantly as a result of simulated acid rain and the decrease in plant was directly proportionate to the total acid rain received. The percentage reduction was greatest in 65 days old plants. The plant height decreased by 18.1% and 21.7% when subjected to sulphuric acid rain and nitric acid rain, respectively. However, their combined effect was less then additive (Table 1).

The lengths of both the root and shoot decreased due to acid rain but reduction in root length was lower in comparison to shoot length. In the initial stages of growth there was not any marked effect of simulated acid rain on the number of lateral branches but subsequently a decrease was recorded. Significant reduction in the number of leaves was observed in the plants subjected to simulated acid rain. The level of reduction of 32.95% was observed in 80 days old plants subjected to H_2SO_4 + HNO_3 simulated acid rain. The reduction was 22.7% in HNO_3 and 24.5% in H_2SO_4 simulated rain. Inhibition of initiation and premature abscission of leaves was observed in all the treatments.

Simulated acid rain caused highly significant reduction in dry weight fractions in treated plants at crop maturity. Dry weight fractions of the plants exposed to simulated acid rain of H_2SO_4, HNO_3 and H_2SO_4 + HNO_3 were 0.18, 0.18 and 0.18 g plant $^{-1}$, respectively as compared to 0.20 g plant $^{-1}$ in control in 20 day old plants and 9.275, 9.10 and 9.61 g plant^{-1}, respectively as compared to 11.63 g/ plant in control in 80 day old plants. The highest values for NPP recorded were 0.15, 0.12, 0.12 and 0.11 g in 65 day old plants in control and in simulated acid rains of H_2SO_4, HNO_3 and H_2SO_4 + HNO_3, respectively (Table 5).

Flowering was delayed in plants exposed to simulated acid rain, and so also there was a significant reduction in the total number of floral buds. The effect of H_2SO_4 + HNO_3 simulated acid rain was maximum on these parameters.

The average number of pods per plant also decreased significantly due to simulated acid rain. The maximum reduction was in H_2SO_4 + HNO_3 simulated acid rain and the minimum in H_2SO_4 simulated acid rain. At the time of harvest, the number of pods reduced by 12.8, 17.4 and 26.2 in H_2SO_4, HNO_3 and H_2SO_4 + HNO_3 simulated rain, respectively as compared to control (Table No. 4).

The yield was reduced by 19.59, 22.71 and 31.91% in the plants subjected to H_2SO_4, HNO_3 and H_2SO_4 + HNO_3 simulated acid rains, respectively (Table 4). Though the average number of seeds per pod was not affected, the weight of 100 seeds was reduced by 7.5, 6.1 and 8.2 per cent in H_2SO_4, HNO_3 and H_2SO_4 + HNO_3 simulated acid rain respectively.

There was a decrease in contents of chlorophyll ***a*** and ***b*** in leaves subjected to simulated acid rain. Maximum reduction was observed in 35 day old plants in all treatments. The decrease was lowest in H_2SO_4 and highest in H_2SO_4 + HNO_3 simulated acid rain treatments (Table 2).

Effect of simulated acid rain of HNO_3 and H_2SO_4 alone and in combination was also observed on sulphur and nitrogen contents of leaves at crop maturity.

There was a significant increase in nitrogen content and decrease in sulphur content when HNO_3 was applied singly. On the contrary, there was increase in sulphur contents and decrease in nitrogen content when H_2SO_4 was applied singly. There was increase in both nitrogen and sulphur contents when HNO_3 and H_2SO_4 were applied in combination (Table 3).

Periodical observations of the plants subjected to simulated acid rain revealed that there were no visible injury symptoms until the plants were 35 days old. There after chlorotic injury symptoms in the form of whitish yellow spots were observed in the marginal and interveinal areas of the leaf. The leaves which were expanding rapidly or recently expended were most sensitive in this regard. Very small and immature leaves and older leaves were found to be less sensitive.

Table 1. Effect of simulated acid rain (ph 4.0) on growth parameters of *Brassica Campestris* L. cv. *varuna*.

PLANT AGE (DAYS): 20 and 35

Parameters	20 Control	20 HNO_3	20 H_2SO_4	20 HNO_3 + H_2SO_4	20 C.D. at 5%	20 C.D. at 1%	35 Control	35 HNO_3	35 H_2SO_4	35 HNO_3 + H_2SO_4	35 C.D. at 5%	35 C.D. at 1%
1. Plant height	20.50	19.70	19.31	19.60	-	-	43.20	37.30*	37.60*	36.20*	5.12	-
2. Shoot length (CII.)	12.30	11.80	11.51	11.60	-	-	22.90	27.50**	27.70**	36.90**	2.70	3.93
3. Root length (CII.)	8.20	7.90	7.81	8.00	-	-	10.30	9.80	9.90	9.30*	0.97	-
4. Number of Branches/ Plant	-	-	-	-	-	-	2.20	2.10	2.20	2.10	-	-
5. Number of leaves/ plant	6.00	5.60	5.61	5.80	-	-	13.60	11.30*	12.80	10.90**	1.76	2.63
6. Number of buds/plant	-	-	-	-	-	-	32.40	26.70**	27.10*	24.20**	1.76	2.63
7. Number of flowers/ plant	-	-	-	-	-	-	-	-	-	-	-	-
8. Number of pods/plant	-	-	-	-	-	-	-	-	-	-	-	-

PLANT AGE (DAYS): 50 and 65

Parameters	50 Control	50 HNO_3	50 H_2SO_4	50 HNO_3 + H_2SO_4	50 C.D. at 5%	50 C.D. at 1%	65 Control	65 HNO_3	65 H_2SO_4	65 HNO_3 + H_2SO_4	65 C.D. at 5%	65 C.D. at 1%
1. Plant height	77.80	65.10*	67.20*	61.00**	9.36	13.94	111.40	87.20**	90.90**	83.00**	9.61	14.42
2. Shoot length (CII.)	64.70	53.70*	54.60*	49.20**	7.63	11..42	94.80	72.10**	75.60**	68.20**	7.63	11.42
3. Root length (CII.)	13.10	12.40	12.60	11.80*	1.14	-	16.60	15.10*	15.30	14.80*	1.46	-
4. Number of Branches/ Plant	3.70	3.60	3.60	3.50	-	-	5.40	4.90*	5.10	4.80*	0.48	-
5. Number of leaves/ plant	17.20	15.00*	15.10*	14.10**	1.83	2.74	20.20	15.40**	16.90**	14.80**	2.89	4.32
6. Number of buds/plant	62.90	46.80**	49.30**	44.10**	6.25	9.32	18.00	15.30**	16.10*	14.20**	2.47	3.73
7. Number of flowers/ plant	22.20	16.30**	17.80**	14.10**	2.83	4.20	21.30	16.00**	16.88**	14.30**	2.79	4.11
8. Number of pods/plant	21.80	17.10**	18.30**	16.20**	2.91*	4.31	80.00	65.90**	70.10*	60.20**	7.54	11.26

PLANT AGE (DAYS): 80

Parameters	80 Control	80 HNO_3	80 H_2SO_4	80 HNO_3 + H_2SO_4	80 C.D. at 5%	80 C.D. at 1%
1. Plant height	113.70	89.10**	93.50**	84.90**	10.14	15.22
2. Shoot length (CII.)	94.80	74.00**	77.10**	69.90**	10.87	16.30
3. Root length (CII.)	16.80	15.10*	15.40	15.00*	1.52	-
4. Number of Branches/ Plant	5.50	5.10	5.00	4.90*	0.46	-
5. Number of leaves/ plant	8.80	6.20**	6.80**	5.90**	1.27	1.88
6. Number of buds/plant	-	-	-	-	-	-
7. Number of flowers/ plant	-	-	-	-	-	-
8. Number of pods/plant	92.30	76.20**	80.40*	68.10**	9.40	13.78

Values are in mean : C.D. – Critical difference. *- Significant at 5% level ; ** - Significant at 1% level.

Table 2. Effect of simulated acid rain (pH 4.0) on chlorophyll content (mg/g) fresh weight of *Brassica campestris* L. cv. *varuna*.

PLANT AGE (DAYS): 20 and 35

	20 Control	20 HNO_3	20 H_2SO_4	20 HNO_3+ H_2SO_4	20 C.D. at 5%	20 C.D. at 1%	35 Control	35 HNO_3	35 H_2SO_4	35 HNO_3+ H_2SO_4	35 C.D. at 5%	35 C.D. at 1%
Chlorophyll *a*	4.044	3.665*	3.766	3.497*	0.370	-	6.176	5.275*	5.549*	4.961**	0.62	0.92
Chlorophyll *b*	3.715	3.485	3.544	3.356	0.350	-	5.477	4.971	5.093	4.679	0.505	-
Total Chlorophyll	7.759	7.150	7.310	6.853	0.870	-	11.653	10.246	10.642	9.640	1.350	-

PLANT AGE (DAYS): 50 and 65

	50 Control	50 HNO_3	50 H_2SO_4	50 HNO_3+ H_2SO_4	50 C.D. at 5%	50 C.D. at 1%	65 Control	65 HNO_3	65 H_2SO_4	65 HNO_3+ H_2SO_4	65 C.D. at 5%	65 C.D. at 1%
Chlorophyll *a*	6.234	4.964**	5.296*	4.391**	0.91	1.26	5.125	3.613**	4.111**	3.259**	0.67	0.99
Chlorophyll *b*	5.874	5.081	5.310	4.679	0.56	0.830	4.639	3.757	4.041	3.454	0.57	0.86
Total Chlorophyll	12.108	10.045	10.606	9.070	1.41	2.09	9.764	7.370	8.152	6.713	1.21	1.77

Values are in mean, C.D. – Critical difference: * - Significance at 5% level : ** - Significance at 1% level.

Table 3. Effect of simulated acid rain (pH 4.0) on the sulphur and nitrogen contents in the leaves of *Brassica campestris* at the maturity of the crop.

Character	Control	HNO_3	H_2SO_4	H2SO4 + HNO3	C.D. at5%	C.D. at 1%
Sulphur Content (mg/g dwt.)	0.616	0.522*	0.723**	0.669	0.083	0.102
Total nitrogen (mg/g dwt.)	5.752	6.630**	4.830*	6.010	0.660	0.950

Values are in mean, C.D. – Critical difference.
* - Significant at 5% level.
** - Significant at 1% level.

Table 4. Effect of simulated acid rain on yield of <u>*Brassica campestris*</u> L. cv. *varuna*.

Parameter	Control	H_2SO_4	HNO_3	H_2SO_4 +HNO3	C.D. at5%	C.D. at1%
Number of pods	92.3	80.4*	76.2**	68.4**	10.11	14.97
Weight of 100 Seeds (gm)	0.292	0.270	0.276	0.268*	0.021	-
Seed yield per plant (gm)	4.292	3.451**	3.317**	2.922**	0.550	0.810

Values are in mean ; C.D. – Critical difference
* - Significance at 5% level;
** - Significance at 1% level.

Table 5. Effect of simulated acid rain on dry weight fractions and net primary productivity of <u>*Brassica campestris*</u> cv. *varuna*.

		Dry weight fractions (gm/plant)				C.D.		Net primary productivity			
		Control	H_2SO_4	HNO_3	H_2SO_4+HNO_3	5%	1%	Control	H_2SO_4	HNO_3	H_2SO_4+HNO_3
20 days	Shoot	0.188	0.167*	0.169*	0.161*	0.018	-				
	Root	0.021	0.020	0.019*	0.019*	0.002	-				
	Total	0.209	0.181*	0.188*	0.180*	0.021	-	0.010	0.00935	0.00940	0.00900
35 days	Shoot	1.656	1.521	1.498*	1.423*	0.154	-				
	Root	0.338	0.321	0.319	0.318	-	-				
	Total	1.994	1.842*	1.817	1.741*	0.152	-	0.056	0.052	0.0519	0.049
50 days	Shoot	4.628	4.001*	3.998*	3.982*	0.610	-				
	Root	0.612	0.601	0.558	0.519*	0.08	-				
	Total	5.240	4.602*	4.556*	4.501*	0.61	-	0.104	0.082	0.082	0.090
65 days	Shoot	8.992	7.121**	6.981**	6.692**	1.140	1.680				
	Root	0.925	0.891	0.882	0.876	-	-				
	Total	9.912	8.012**	7.868**	7.568**	1.150	1.710	0.152	0.123	0.121	0.116
80 days	Shoot	10.513	8.253**	8.012**	7.121**	1.470	2.10				
	Root	1.22	1.022	0.998*	0.958*	0.123	-				
	Total	11.635	9.275**	9.010**	8.619**	1.490	2.22	0.145	0.115	0.112	0.107

Values are in mean ; C.D. – Critical difference.
* - Significance at 5% level; ** - Significance at 1% level

DISCUSSION

Plant height was reduced significantly due to simulated acid rain treatment as compared to the control and the decrease was due to reduction in both shoot and root lengths. Johnston *et. al.* (1982) and Norby and Moore (1983) reported that acid rain adversely affects bush bean and soybean growth if PH is low enough to cause physical injury to leaves. Forsline *et. al.* (1983) also observed significant growth reductions in apple seedlings at pH 3.25. Cohen *et. al.* (1982), Evans *et al*. (1981), Evans (1982), Irving (1983), Johnston and Sriner (1985), Musselman and Sterrett (1988), Reddy (1989), Shaukat *et al*. (2008) and Verma *et al*. (2010) also observed reductions in root and shoot lengths of diverse group of crops due to acid rain. Reduction in root growth may be due to decrease in translocation of photosynthates to the root from the shoot (Wardlaw, 1968).

Reduction in the number of leaves and lateral branches of the plants subjected to simulated acid rain was due to inhibition of leaf initiation and premature abscission of leaves.Ferrenbaugh (1976) observed premature abscission of leaves in *phaseolus vulgaris* due to acid rain treatment. Johnston *et al.* (1982) also demonstrated enhancement of senescence of leaves of *Phaseolus vulgaris* exposed to pH 4.0 and 3.2 sulphuric acid rain.

Reduction in the plant growth was accompanied by reduction in dry matter accumulation and net primary productivity. These may be attributed to altered rates of nutrient leaching, reduction in chlorophyll content, reduced leaf area and increased rate of respiration resulting from foliar injury. Reduction in the production of carbohydrates may account for decrease in dry weight (Ferrenbaugh, 1976).

Reduction in plant growth and seed yield was highest in HNO_3 + H_2SO_4 simulated acid rain than singly in HNO_3 and H_2SO_4, but it was less than additive. Cohen *et al*. (1981) also observed reduction in the yield of mustard green (*Brassica japonica*) in H_2SO_4 + NHO_3 acid rain but there was no significant effect when he applied them singly. In combination (HNO_3 + H_2SO_4), in addition to acidity, the sulphate to nitrate ratio also influences the response of the plants to simulated acid rain (Lee and Neely, 1980; Irving, 1985).

A significant reduction in seed yield was observed as a result of simulated acid rain. The reduction in the yield was not due to decrease in the number of seeds per pod, but it was as the result of decrease in the number of pods and in seed weight. Evans *et al.* (1981) also observed a decrease in seed yield of soybean subjected to simulated acid rain due to decrease in the number of pods, however, biomass per seed and number of seeds per pod did not vary from the control. Hindawi *et al*. (1980) in *Phaseolus vulgaris* and Reddy (1989) in soybean and snap bean cultivars have reported reduction in the size of seeds and pods due to acid rain. Cracker and Waldron (1989) also reported yield reduction in corn on exposure to simulated acid rain.

In the present study it has been observed that growth and yield were more adversely affected by nitric acid than sulphuric acid simulated acid rain. Irving (1985) also demonstrated greater effect of nitric acid in reduction of yield at pH 3.0 in radish. Porter and Sheridan (1981) abserved more foliar injury symptoms in alfalfa from exposure to HNO_3 than H_2SO_4. Higher adverse effect of nitric acid compared to sulphuric acid indicates that nitrate ions are more effective in leaf surface exchange reactions than sulphate ions. (Irving 1985).

Acid rain reduced the chlorophyll content of leaves. Ferrenbaugh (1976) reported reduction in chlorophyll content in the seedlings of *Phaseolus valgaris* exposed to simulated acid rain at pH 3.0. Uniform reductions in chlorophyll ***a*** and ***b*** across pH gradient in simulated acid rain were also reported by Hindawi *et al.* (1980) on bush bean but Thornton *et al.* (1990) did not observe significant reductions in chlorophyll content on acidic cloud deposition on plants. Accumulation of SO_4^{-2} and NO_3^- ions may lead to breakdown of chlorophyll and interaction between these acidic ions and chloroplast, results into inhibition of metabolic activities of the chloroplast. Sheridan and Rosenstreter (1973) reported that simulated acid rain destroyed chlorophyll and depressed photosynthesis in moss (*Tortula ruralis*). Decrease in the chlorophyll content was accompanied by reduction in the synthesis of photsynthates. Decrease in the production of photosynthate may also be attributed to reduced leaf area and increase in the rate of respiration due to metabolic perturbation in the leaves as a result of injury on exposure to simulated acid rain (Hindawi *et al*. 1980).

Increase in nitrogen and sulphur content can be attributed to increased inputs and the foliar incorporation of NO_3^- and SO_4^{-2} ions in simulated acid rain. Elevated levels of nitrogen and sulphur have also been observed by Wood and Bormann (1977) and Evans (1982) in plants exposed to simulated acid rain. Hindawi *et al.* observed marked increase in foliar sulphur and lower contents of nitrogen in *Phaseolus vulgaris* on exposure to acidic mists of H_2SO_4.

Simulated acid rain caused visible foliar injury in *Brassica campestris* L. cv. Varuna in the form of interveinal and marginal chlorosis on the adaxial surface. Evans *et al.* (1977) also observed interveinal chlorosis in the leaves of *Phaseolus vulgaris* and *Helianthus annuus* as the result of simulated acid rain. The extent of visible leaf injury is most pronounced just prior to full expansion of the leaf (Evans *et al.,* 1977 ; Evans and Curry, 1979). The lesion frequency was correlated with the degree of leaf expansion. Lesions, which developed due to acid rain, were localised and injury to adjacent cells occurs only in localised fashion. Once a lesion is formed it serves as a depression for collection of subsequent rain. Injury also developed in the marginal areas where droplets are retained after a rain event.

The appearance of foliar injury and reduction in growth and yield thus indicate that *Brassica campestris* L. cv. *varuna* is sussceptible to acid rain.

REFERENCES

Adams,C.M.; Dengler,N.G. and Hutchinson,T.C. (1984). Acid rain effects on foliar histology of *Artemisia tilesii. Canadian J. Bot.* 62: 463-474.

Arnon D.L. (1949). Copper enzymes in isolated chloroplasts, 1. poly- phenol oxidase in *Beta vulgaris. Plant Physiol.* 24: 1-15.

Banwart,W.L.; Porter,P.M; Hasset,J.J. and Walker W.M. (1987). Simulated acid rain effects on yield response of two corn cultivars. *Argon J.* 79: 497-501.

Banwart,W.L.; Finke,R.L.; Porter,A.M. and Hessett J.J. (1990). Sensitivity of twenty soybean cultivars to simulated acid rain. *J Environ Qual.* 19 : 339-346.

Buman,S. (1985). Environmental impact of acid rain. *Yojana* **5** 15-18.

Cohen,C.J.; Grothaus,L.C. and Perrigan,S.C. (1981). Effects of simulated sulphuric acid rain on crop plants; Agricultural Experiment Station Oregan State University Corvallis Special Report 619.

Cracker,L.E. and Waldron,P.F. (1989). Acid rain and seed yield reductions in corn. *J. Environ. Qual.* 18: 127-129.

Crowther,M.A and Rouston,A.G. (1911). The nature, distribution and effects upon vegetation of atmospheric pollutants in and near an industrial town ; *J. Agr. Sci.* 4 : 25-55.

Evans,L.S. (1980). Folaiar responses that determine plant injury by simulated acid rain. In Toribare,T.Y.Miller,M.W. and Morrow,P.E. (ed) Polluted Rain : 239-258 Plenum Publishing Corporation, New York.

Evan,L.S. (1982). Biological effects of acidity in precipitation. A Review. *Environ. Exp. Bot.* 22 : 155-169.

Evans,L.S. and Curry,T.M. (1979). Differentiated responses of plant foliage to simulated acid rain. *Amer. J. Bot.* 66: 953-962.

Evans,L.S.; Gmur,N.F. and Dacosta,F. (1977). Leaf surface and foliar perturbances of leaves of *Phaseolus vulgaris and Helianthus annuus* after exposure to simulated acid rain. *Amer. J. Bot.* 64: 903-913.

Evans,L.S.; Lewin,K.F.; Conway,C.A. and Patti,M.J. (1981). Seed yield (quantity and quality) of field grown soybean exposed to simulated acid rain. *New phytol.* 89: 459-470.

Evans,L.S.; Santucci,K.A. and Patti,M.J. (1985). Interaction of simulated rain solutions and leaves of *Phaseolus vulgaris. Environ. Exp. Bot.* 25: 31-40.

Ferrenbaugh,R.W. (1976). Effects of simulated acid rain on *Phaseolus vulgaris* L. (Fabaceae). *Amer. J. Bot.* 63: 383-388.

Forsline,P.L.; De,R.J. and Melious,R.E. (1983). Growth changes of apple (*Malus hupehensis*) seedlings in response to simulated acid rain. *J. Am. Hortic. Sci.* 108 : 202-207.

Hindawi,I.J.;Rea,J.E. and Griffis,W.L. (1980). Response of Bush bean (*Phaseolus vulgaris* cultivar Contender) exposed to acid mist. *Amer. J. Bot.* 67: 168-172.

Irving,P.M. (1985). Modelling the response of green house grown radish plants to acidic rain ; *Environ. Exp. Bot.* 25: 327-338.

Irving,P.M. (1983). Acidic precipitation effects on crops. A review and analysis of research. *J. Environ. Qual.* 12: 538-543.

Jacobson,J.S.; Troiono,J.; Calavito,L.J.; Heller,L.I.; McCune,D.C. and Miller,D.C. (1980). Polluted rain and plant growth. In Toribara,T.Y.; Miller,M.W. and Morrow,P.E. (ed) Polluted rain : 239-258 Plenum Publishing Corporation, New York.

Jacobson ,J.S.; Troiono,J.J.; Heller,L.I. and Osmeloski,J. (1986). Influence of sulphate, nitrate and chloride in simulated acidic rain on radish plants. *J. Environ. Qual.* 15: 301-304.

Johnston, J.W. Jr. and Shriner,D.S. (1985). Responses of three wheat cultivars to simulated acid rain. *Environ. Exp. Bot.* 25 : 349-353.

Johnston,J.W.; Shriner,D.S.; Klarer,C.I. and Lodge,D.M. (1982). Effect of rain pH on senescence, growth and yield of bush been (*Phaseolus vulgaris* cv. Blue Lake 274). *Environ. Exp. Bot.* 22 : 324-338.

Keever,G.J. and Jacobson,J.S. (1983). Response of Glycine (L.) Merril to simulated acid rain II. Localisation of foliar injury and growth response. *Field. Crops. Res.*6: 251-259.

Lee,J.J.; Neely,G.E. (1980). CERL-OSU acid rain crop study progress report *Air Pollution Effects Brands Corvallis Environ. Res. Lab U.S. Environmental Protection Agency Corvallis Ogeg.*

Lee,J.J.; Neely,G.E.; Perrigan,S.C. and Grotheus,L.C. (1981). Effects of simulated acid rain on yield growth and foliar injury of several crops. *Environ. Exp. Bot.* 21:171-185.

Musselman,R.C. and Sterrett,J.L. (1988). Sensitivity of plants to acidic fog. *J. Environ. Qual.* 17: 329-333.

Norby,R.S and Moore,L. (1983). Growth analysis of Soybean (*Glycine max* cv. Davis) exposed to simulated acid rain. *New. Phytol.* 95: 277-288.

Norman,R.G.; Glass,G.E. and Rennie,P.J. (1979). Effects of acid precipitation. *Environ. Sci.* and *Technol.* 13 :1350-1355.

Porter, J.R. and Sheridan,R.P. (1981). Inhibition of nitrogen fixation in alfalfa by arsenate, heavy metals, fluoride and simulated acid rain. *Plant. Physiol.* 68 : 143-148.

Reddy,M.R. (1989). Acid precipitation effects on growth and yield responses of twenty soybean and twelve snap bean cultivars. *J. Environ. Qual.* 18: 145-148.

Scherbatskoy,T. and Klein,R.M. (1983). Response of spruce (*Picea glauca* and *Betula alleghaniensis*) foliage to leaching by acidic mists. *J. Environ. Qual.* 12: 189-195.

Shaukat,S.S. and Khan,M.A. (2008). Growth and physiolosical responses of tomato (Lycopersicon esculentum Mill.) to simulated acid rain. *Pak. J. Bot.*, 40 (6): 2427-2435.

Sheridan,R.P. and Rosenstreter,R. (1973). The effect of hydrogen ion concentrations in simulated acid rain on the moss (*Tortula ruralis* Hedw.) *Sm. bryologist.* 76 :168-173.

Thornton,F.C.; Pier,P.A. and McDuffie,Jr.C (1990). Response of growth, photosynthesis and Mineral nutrition of red spruce seedlings to Ozone and acidic cloud deposition. *Environ. Exp. Bot.* 30 :313-323.

Velikova,V.; Yordanov,J.; Kurteva,M and Tsonev,T. (1997). Effects of simulated acid rain on photosynthetic characters of Phaseolus vulgaris L. *Photosynthetica* 34: 523-535.

Verma, A.; Tewari,A. and Azami,A. (2010). An impact of simulated acid rain on different pH- levels on some major vegetable plants in India. *Report and opinion* 2 (4): 38-40.

Wardlaw,D.F. (1968). The control and pattern of movement of carbohydrate in plants. *Bot. Rev.* 34: 79-105.

Wood,T. and Bormann,F.H. (1975). Increase in foliar leaching caused by acidification of an artificial mist. *Ambio* 4: 169-171.

Wood,T. and Bormann,F.H. (1977). Short-term effects of a simulated acid rain upon the growth and nutrient relations of *Pinus strobus* L. *Water Air and Soil Pollution* 7 : 479-488.