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Positive Effects of Cement Kiln Exhausts on Legume Crops Under Simulation Study

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ABSTRACT

Soil application of cement kiln exhausts (electrostatic precipitator dust) at both lower and higher concentrations did not inhibit growth, nodule formation, and productivity in *Cajanus cajan*, *Vigna radiata*, and *Vigna mungo*. In fact, growth was promoted, possibly because of the dust containing most of the elements, such as N, Ca, Fe, Mg, Mn, K, Zn, P, S, and Cu, which are needed for plant growth and root nodulation. Foliar application of the dust did not affect chlorophylls and carotenoids. The rate of photosynthesis as measured by CO_2 uptake and stomatal diffusive resistance of all legumes were not affected. There was a biomagnification of Mg and K in leaves and seeds. Addition of the ESP dust did not affect either the soil or nodule rhizobial population. It is evident that the dust did not act as a phytotoxicant but as an elixir of plant life.

Index Entries: Electrostatic precipitator (ESP) dust; photosynthetic CO_2 absorption; phytotoxicants; cement kiln exhausts; plant-rhizobial symbiosis.

INTRODUCTION

Air pollution has become a serious problem in recent times as a result of the rapid growth of thermal power stations, cement factories, and steel and coal industries. As the growth of industries increases, the rate of pollution in the atmosphere also increases, steadily deteriorating the quality of air, water, and the agriculturally fertile lands by both gaseous

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as well as particulate pollutants. In comparison to gaseous pollutants, many of which are readily recognized as being the cause of injury to various types of vegetation through both field as well simulation studies, relatively little is known and limited studies have been carried out on the effects of particulate pollutants on vegetation (*1-3*). Most of the research done hitherto was on the direct effects of dust on leaves, twigs, and flowers as opposed to indirect effects from dust accumulation in the soil (*1*).

The harmful effects of cement exhausts (ESP dusts) on vegetation have not been fully substantiated and have been questioned by a number of investigators (*1,2*). The aim of the present simulation study is to find out whether soil or foliar application of dust could adversely affect root growth, nodulation, rhizobial population, photosynthesis, and productivity of certain legume crops, such as *Vigna radiata, Vigna mungo,* and *Cajanus cajan* (popularly grown in Tamilnadu, India).

It has become a conventional practice to understand the effects of gaseous pollutants through simulation study (*4*) to pinpoint the effects caused, delineating from other environmental effects that might operate at the pollution site. Similarly the present simulation study was conducted in the university botanical garden in open conditions to understand precisely the effects of soil and/or foliar application of ESP dust from that of gaseous kiln exhaust pollutants ($N_2 > CO_2 > O_2 > SO_2 > NO > NO_2 > CO > H_2S$) that operate at the location of the cement factory.

MATERIALS AND METHODS

In the present simulation study, the cement exhausts directly collected from the electrostatic precipitator (ESP dust) of the Ariyalur Cement Works (TANCEM), Ariyalur, Tiruchirapalli, Tamilnadu, India were used in all experiments. The raw materials that go into the making of cement are lime (calcareous), silica, alumina, and iron. The factory is continuously discharging a hugh volume of ESP dusts that are deposited all over the soil and plant cover, up to a 10–12 km radius from the cement plant. The ESP dusts were mixed thoroughly with the garden soil at different concentrations ranging from 10 to 200 g kg^{-1} garden soil. The garden soil was red sandy loam with pH and EC values of 8.0 ± 0.1 and 0.081 ± 0.005 mS cm^{-1}, respectively. The available soil nutrients were N (10.36 mg g^{-1}), P (0.63 mg g^{-1}), and K (0.88 mg g^{-1}), with total organic matter of 3.12% and total organic carbon of 1.99%. The soil had a bulk density of 0.62 g cc^{-1}, and water holding capacity of 21.87%, with percentage pore space of 36.67. The seeds of *Cajanus cajan* (L. Millsp var. SA-1), *Vigna mungo* (L. var. Vamban-1), and *Vigna radiata* (L. var-123) were collected from the National Pulses Research Centre, Vamban, Pudukkottai, Tamilnadu, India. Healthy seeds were selected and sown in earthen pots (20 cm in length and 19 cm in diam) containing garden soil with and without the ESP dust. The seedlings were raised in the earthen pots under natural photoperiod (26 ± 1 W

m^{-2}) with day and night temperature of 28–32°C and 22–25°C, respectively. The seedlings raised in dust-free soil were treated as control. After germination, the seedlings were thinned down to ten per pot. The 10-day-old seedlings were uniformly sprayed with the ESP dust (10 g pot^{-1}) using a hand sprayer at 2-d interval. Agrobotanical characters of 50-day-old plants grown independently in 50 and 200 g ESP dust kg^{-1} garden soil were analyzed. The pH and total electrical conductivity of the dust, and dusted-soil before and after plant growth were determined using Digital pH meter (Hanna Instruments, US) and Electronic Digital conductivity meter (Global Electronics, Hyderabad, India). Elemental analyses of cement exhausts, soil, and plant samples were carried out using atomic absorption spectrophotometer (GBC, Pty Ltd., Australia) by following the standard digestion procedure (*5*).

The routinely employed plant growth parameters like seedling vigor index (SVI), root tolerance index (RTI), and shoot tolerance index (STI) were analyzed by the formulae proposed by Abdul-Baki and Anderson (*6*) and Taylor and Foy (*7*). Relative growth rate (RGR), net assimilation rate (NAR), and leaf area index (LAI) were analyzed by following the methods of Williams (*8*). Leaf area was measured by using the portable leaf area meter (LICOR, Inc., US). Photosynthetic studies were carried out in 50-day-old legume crops by measuring the CO_2 uptake using Infra red gas analyzer (LICOR, Inc., US), and stomatal diffusive resistance and transpiration rate by portable steady state porometer (LICOR, Inc., US). The chloroplast pigments were extracted in 80% aqueous acetone and quantification was carried out by the method of Arnon (*9*). Assessment of nodule and soil rhizobial population was carried out in yeast extract mannitol agar medium by the methods suggested by Vincent et al. (*10*) and Somasegaran et al. (*11*). Seven-fold serial dilutions of four replications per dilution were used for MPN counts. Total organic carbon and total organic matter were determined by Walkey and Black's rapid titration method (*12*). Bulk density, porosity, and water holding capacity of the soil samples were determined by standard methods (*13*). All the data given in the Tables are mean values of three different experiments with SD and the range of values is given in parenthesis.

RESULTS AND DISCUSSION

The present study critically analyzes the effects of the ESP dust on a few economically important legumes popularly cultivated in and around the location of a cement factory to find out whether soil addition or foliar application of the dust is more harmful to plants, as well as to delineate the effects of one from the other, since both are operative under field conditions. Prior to use of the dust in experimental studies, elemental analyses of the pure dust, control, and dusted soil after plant harvest were carried out. The results are presented in Table 1. The dust contained

Table 1
Elemental Analyses of the ESP Dust, Garden, and Dusted Soils

Elements	Cement dust	Garden soil	Dusted garden soil
		($mg\ g^{-1}$)	
Copper	0.08 (0.07–0.09)	0.06 (0.05–0.07)	0.06 (0.05–0.07)
Zinc	.07 (0.06–0.08)	0.06 (0.05–0.07)	0.06 (0.05–0.07)
Lead	0.04 (0.02–0.06)	0.04 (0.05–0.06)	0.05 (0.02–0.06)
Magnesium	3.91 (3.41–4.21)	2.64 (1.94–3.24)	4.52 (4.12–4.72)
Managnese	1.94 (1.64–2.14)	0.28 (0.24–0.30)	1.36 (1.26–1.46)
Iron	38.50 (36.20–40.20)	2.44 (1.94–2.74)	25.97 (22.12–28.06)
Calcium	39.08 (38.12–40.72)	0.44 (0.42–0.46)	30.72 (29.12–31.80)
Potassium	1.48 (1.28–1.62)	0.88 (0.82–0.92)	2.57 (2.17–2.97)
Sodium	0.41 (0.39–0.43)	0.56 (0.50–0.64)	0.64 (0.44–0.84)
Sulfur	2.25 (2.15–2.35)	0.38 (0.33–0.42)	2.25 (2.15–2.35)
Nitrogen	1.54 (1.24–1.84)	10.36 (9.86–10.86)	10.46 (9.86–11.36)
Phosphorous	2.13 (2.03–2.23)	0.63 (0.61–0.65)	1.38 (1.18–1.48)

The data are mean values of three different experiments. The range of values is given in parenthesis.

most of the elements (Ca, Fe, Mg, Mn, K, P, S, N, Cu, and Zn) implicated in plant metabolism; Calcium (39.08 mg) was the highest, followed by Fe (38.50 mg), Mg (3.91 mg), S (2.25 mg), P (2.13 mg), Mn (1.94 mg), N (1.54 mg), and K (1.48 mg). The dust had an initial pH of 10.5 ± 0.2 and a total electrical conductivity of 0.928 ± 0.010 m S cm^{-1}; however, upon storage in about 3 mo time at laboratory temperature (25–33°C) and humidity (45–50%), the pH as well as EC values of the dust were found to be reduced (9.1 ± 0.1 and 0.459 ± 0.008 m S cm^{-1}, respectively). The dusted soil had an initial pH of 9.4 ± 0.1 and EC of 0.528 ± 0.007 m S cm^{-1}. However, after the plants attained 50 d of growth, the rhizosphere soil showed pH and EC values of 8.6 ± 0.1 and 0.348 ± 0.007 m S cm^{-1}, respectively. The reduction in pH and EC values of the soil may be a result of good buffering capacity and dynamic state of the soil, which confirms the findings of Franciszek and Drzas (*14*).

The effects of soil application of the dust on several plant growth parameters indicated that there was no significant difference in percentage of germination and seedling vigor index, with root and shoot tolerance indices of seedlings being moderately higher than the control. The agrobotanical characters of 50-day-old legumes were not found to be affected at all but showed better growth even up to an addition of 200 g dust kg^{-1} soil. Even in other plant growth parameters, such as relative growth rate (RGR), leaf area index (LAI), net assimilation rate (NAR), and harvest index, the experimental plants were found to be marginally superior to the control. The above findings are further supported by the works of Pajenkamp (*15*) and Lerman and Darley (*1*) that a considerable quantity of precipitator dust (pH 10.4) applied to the soil surface did not cause any harmful effect on crop yields of oats, ryegrass, red clover, and turnips. There was also a biomagnification of Mg and K in organs like leaves and seeds (Table 2), which confirms the reported increase in the foliar mineral contents of the polluted plants grown at the pollution site (*4,16,17*).

Root growth and nodulation were not found to be affected in any of the legumes, although nodulation has been reported in the literature to be affected (*18,19*). In the present study, root nodule number was not found to be affected. In fact, the number of root nodules of the experimental plants on an average was 37% higher than the control. The soil-application of the dust did not affect either root nodule or soil rhizobial population (Table 3). Direct addition of the dust to the YMA medium (2.5 to 20 mg/mL) also did not affect the rhizobial population. The possible explanation for the ESP dust not interfering with the formation of root nodule symbiosis as well as the growth of rhizobia in vitro is that the dust contained many elements needed for the growth of rhizobia as well as for the efficient functioning of the root nodule (*4,20,21,22*). Taylor and Karim Moshrefi (*23*) reported that calcium and nitrogen were found to strongly and independently influence plant nodulation.

Since soil application of the dust did not affect the plant growth and rhizobial population, foliar application was resorted to pari-passu with soil application of the dust. Addition of the ESP dust up to 200 g kg^{-1} soil plus the foliar spray of 10 g pot^{-1} on alternate days did not cause any significant effect on plant growth and economic productivity (Table 4). The finding that the foliar application of the dust is least harmful to plants is further supported by the observations of Pajenkamp (*15*), Darley (*2*), Lerman (*24*), and Lerman and Darley (*1*).

Application of the ESP dust either directly to the soil or by foliar spray coupled with soil dusting did not affect the chloroplast pigments such as Chl *a*, Chl *b* and carotenoids, which are generally used as an important marker for stress tolerance, although chloroplast pigments were reported to be affected (*19,25–27*). However, Oblisamy et al. (*16*) noted a significant increase in chlorophyll content in dust polluted cotton plants. No

Table 2
Elemental Analyses of Leaves and Seeds of Plants Grown in ESP Dusted Soil

	Cajanus cajan						*Vigna mungo*						*Vigna radiata*					
	Leaf			Seed			Leaf			Seed			Leaf			Seed		
	Treatment (g dust kg^{-1} soil)																	
Elements	0	50	200	0	50	200	0	50	200	0	50	200	0	50	200	0	50	200
	(mg g^{-1} dw)																	
Cu	0.05	0.06	0.07	0.03	0.04	0.05	0.06	0.07	0.08	0.07	0.09	0.09	0.03	0.04	0.05	0.04	0.05	0.08
Fe	1.53	1.68	1.84	1.20	1.28	1.44	1.32	1.48	1.50	0.36	0.38	0.40	1.20	1.24	1.37	0.64	0.77	1.16
K	4.44	6.53	7.08	2.89	3.23	3.42	6.52	7.32	7.54	4.08	4.12	5.55	8.04	8.07	8.50	3.08	3.36	4.76
Ca	2.74	2.75	2.79	2.45	2.46	2.49	2.42	2.54	2.65	2.35	2.45	2.75	2.76	2.78	2.91	2.25	2.34	2.36
Mn	1.42	1.43	1.44	1.35	1.38	1.83	1.18	1.38	1.42	0.21	0.30	0.38	1.65	1.68	1.70	0.09	0.10	0.20
Mg	1.04	2.24	2.76	1.77	1.99	2.04	0.73	3.20	3.82	0.80	1.32	1.40	5.80	5.82	6.72	2.75	2.79	3.21
Pb	0.04	0.05	0.06	0.07	0.08	0.09	0.06	0.07	0.08	0.08	0.09	0.09	0.02	0.03	0.04	0.01	0.02	0.04
Zn	0.08	0.09	0.09	0.08	0.08	0.09	0.05	0.06	0.07	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.16	0.18

The seeds were grown in pots containing garden soil mixed with varying concentrations of the ESP dust. When the plants attained 180 (*Cajanus cajan*) and 90 days (*Vigna mungo* and *Vigna radiata*) of growth, the leaves (3rd node from the top) and seeds were collected for elemental analyses. The data are the mean values of three different experiments.

Table 3
Effect of Addition of ESP Dust on Soil and Root Nodule Rhizobial Population

		Cajanus cajan	*Vigna mungo*	*Vigna radiata*
	Soil*		Nodule**	
g dust kg^{-1}soil		MPN-colonies	(10^7 g^{-1})	
0	382	68	69	78
10	378	69	89	79
50	390	69	89	78
100	380	69	89	79
200	390	69	89	79

The dust was added in different proportions to the garden soil and mixed thoroughly and the plants were raised in earthen pots as described under Materials and Methods. When the plants attained the age of 50 days they were uprooted for determination of root as well as soil rhizobial population. Incubation period on YMA was 48 h.

*Average SD ± 48
**Average SD ± 13

symptom of chlorosis was observed in any phase of the plant growth during the present investigation, irrespective of the mode of application of the dust. No doubt, the applied dust formed a thin layer of coating on the upper surface that did not interfere with chlorophyll formation (*28*). Similarly, the photosynthetic potential of the treated plants as measured by CO_2 uptake was not found to be affected at all (Table 5). On the other hand, increment in photosynthetic rate was evident in *Cajanus cajan* (41%), *Vigna mungo* (86%), and *Vigna radiata* (119%) as compared with the control. From the fact that the plants are fully complemented with unstinted growth characteristics and photosynthetic potential, it is evident that the formation of a thin coating of dust did not obstruct light penetration and its utilization in photosynthesis. Regarding stomatal diffusive resistance and rate of transpiration, no significant difference could be observed (Table 5), which is in consonance with the finding of Lerman (*24*) that only limited clogging of stomatal opening in bean leaves was observed and on the lower surface of the leaf only a few dust particles were found to be present. These observations clearly vouchsafe our finding that the ESP dust seldom interfered with the rate of photosynthesis, stomatal diffusive resistance, plant rhizobial interaction, elemental composition, and growth and development of plants. The field observations that all tree species (*Casuarina equisetifolia* forster and forster f., *Eucalyptus globosa* F. Muell., *Pongamia pinnata* (L.) Pierre, *Azadirachta indica* (L.) Adr. Jus, and *Polyalthia cerasoides* (Roxb.) Beddome) grew equally well, as they would normally grow in an unpolluted area, in and around the regions of the Ariyalar cement factory, lends further support to the above finding (*29*). In fact, Raymond and Nussbaum (*30*) observed that cement exhausts had little effect on wild plants.

Table 4
Agrobotanical Characters of Leguminous Crops as Affected by Soil Application of ESP Dust

Growth parameters	*Cajanus cajan*			*Vigna mungo*			*Vigna radiata*		
	Treatment (g dust kg^{-1} soil)								
	0	50	200	0	50	200	0	50	200
Germination percentage	99.5±0.2	99.5±0.2	99.5±0.2	99.0±0.1	99.0±0.1	99.5±0.1	99.5±0.1	99.5±0.1	99.5±0.1
Seedling vigor	1218±18	1222±15	1228±15	1989±14	2202±14	2288±15	1432±15	1502±11	1586±14
Shoot tolerance index	1.00±0.00	1.16±0.07	2.12±0.07	1.00±0.00	1.45±0.02	1.55±0.01	1.00±0.00	2.32±0.01	2.91±0.03
Root tolerance index	1.00±0.00	1.72±0.02	1.95±0.02	1.00±0.00	1.32±0.02	2.81±0.02	1.00±0.00	2.14±0.03	3.02±0.04
Leaf area index	0.21±0.04	0.26±0.04	0.34±0.06	0.09±0.01	0.20±0.02	0.34±0.02	0.14±0.02	0.26±0.03	0.36±0.03
Total number of root nodules	10.5±0.1	10.4±0.2	16.4±0.3	28.5±0.4	29.2±0.2	38.2±0.5	24.5±0.3	27.2±0.4	32.7±0.4
Relative growth rate, $\mu g\ day^{-1}$	540±7	767±9	1302±4	289±11	962±12	3744±22	960±5	6481±41	9232±39
Net assimilation rate, $\mu g\ m^{-2}\ day^{-1}$	382±12	430±18	690±17	720±11	790±12	1090±18	420±17	585±12	1120±20
*Harvest index, %	32.4±0.2	36.8±0.1	38.9±0.1	47.4±0.1	49.0±0.1	51.8±0.1	36.6±0.5	39.4±0.8	41.2±0.7

The data are the mean values of 5 different experiments ± SD of 20 plant samples each (Growth parameters were analyzed in 50-day-old plants).
*Analyzed at the time of harvest.

Table 5
Photosynthetic and Transpiration Characteristics of 50-day-old Legume Crops Grown in ESP Dusted Soil Coupled with Foliar Spray

Parameters	*Cajanus cajan* 1	*Cajanus cajan* 2	*Cajanus cajan* 3	*Vigna mungo* 1	*Vigna mungo* 2	*Vigna mungo* 3	*Vigna radiata* 1	*Vigna radiata* 2	*Vigna radiata* 3
Photosynthesis ($mg\ CO_2\ m^{-2}\ S^{-1}$)	0.27±0.01	0.38±0.03	0.38±0.03	0.37±0.01	0.68±0.02	0.69±0.02	0.37±0.03	0.79±0.01	0.81±0.01
Diffusive resistance ($S\ cm^{-1}$)	3.31±0.03	2.54±0.02	2.62±0.01	3.70±0.04	3.70±0.02	3.80±0.02	3.31±0.02	3.52±0.01	3.74±0.02
Transpiration ($\mu g\ H_2O\ cm^{-2}\ S^{-1}$)	8.8±0.2	8.9±0.2	9.0±0.1	6.6±0.1	6.7±0.2	6.7±0.2	7.2±0.1	7.4±0.1	7.8±0.1
Relative humidity (%)	37.6±0.1	31.2±0.2	42.0±0.1	33.6±0.1	36.6±0.1	36.6±0.1	37.6±0.2	38.6±0.1	38.6±0.1
Leaf temperature (°C)	39.1±0.1	39.1±0.1	39.5±0.1	39.4±0.1	39.4±0.1	39.5±0.1	39.2±0.1	39.4±0.1	39.6±0.1

The seeds were grown in pots containing garden soil mixed with varying concentrations of cement dust. After germination the plants were sprayed uniformly with the dust (10 g pot^{-1}) at 2-d interval. After the plants attained 50 days of growth, the photosynthetic and transpiration characteristics of leaves were carried out using portable IRGA and steady state porometer. The data are mean values of three different experiments ± SD.

1 Control
2 50 g dust kg^{-1} soil plus foliar application of dust
3 200 g dust kg^{-1} soil plus foliar application of dust

The significance of the present study is that the ESP dusts did not act as phytotoxicant when they were applied either directly to the soil or as a foliar spray, particularly during the vegetative growth phase of the cycle. However, it is our contention that further studies are needed to find out whether reproductive physiology is affected by dust as this facet of plant growth becomes susceptible in any air pollution study (*31–33*). It may be pointed out that in all members of Fabaceae wherein "cleistogamous" flowers are encountered even the reproductive phase of the plant may not be affected, since the stigma gets pollinated prior to the opening of the flowers. Therefore, this needs a closer study of pollen-stigma interaction and biochemical studies on stigmatic exudates and viability of pollen.

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REFERENCES

1. Lerman, S. L. and Darley, E. F. (1975), *Particulates*. In J. B. Mudd, T. T. Kozlowski, eds., *Responses of plants to air pollution*. Academic Press, New York, pp. 141–158.
2. Darley, E. F. (1966), *J. Air. Polit. Contr. Assn.* **16,** 145–150.
3. Auclair, D. (1976), *Ann. Sci. Forest.* **33,** 247–255.
4. Prasad, M. S. V., Subramanian, R. B., and Inamdhar, J. A. (1991), *Indian J. Environ. Health.* **33,** 11–21.
5. Umbriet, W. W., Burris, R. H., and Stauffer, J. F. (1972), *Methods for nitrogen.* In *Manometric and biochemical techniques* (5th ed.) Burgass Publishing Co., MN, 259–260.
6. Abdul-Baki, A. A. and Anderson, J. D. (1973), *Crop Sci.* **13,** 227–232.
7. Taylor, G. J. and Foy, C. D. (1985), *Amer. J. Bot.* **72(5),** 702–706.
8. Williams, R. F. (1946), *Ann. Bot. N.S.* **10,** 41–72.
9. Arnon, D. I. (1949), *Plant Physiol.* **24,** 1–15.
10. Vincent, J. M. (1970), *A manual for the practical study of the root nodule bacteria (IBP Hand Book 15).* Blackwell Scientific Publications Ltd., Oxford, UK.
11. Somasegaran, P., Hoben, H., and Halliday, J. (1982), *The Niftal manual for methods in legume-rhizobium technology,* University of Hawaii, Honolulu, HI.

12. Walkley, A. and Black, I. A. (1934), *Soil Sci.* **37,** 29–38.
13. Piper, C. S. (1966), In *Soil and Plant Analysis,* Inter. Sci. Publ. Inc., New York.
14. Franciszek, G. and Drzas, K. (1984), *Pamiet pulawskii.* **0(82),** 209–228.
15. Pajenkamp, H. (1961), *zen-kalf-Gips.* **14,** 88–95.
16. Oblisami, G., Pathmanabhan, G., and Padmanabhan, C. (1978), *Indian J. Air. Pollut. Contr.* **1,** 91–94.
17. Madhoolika Agrawal and Nandi, P. K. (1986), *Glimpses of air pollution researches in relation to plants in India. Recent advances in environmental biology,* Ecology research laboratory, Centre of Advanced Study in Botany, Banaras Hindu University, Varanasi, India.
18. Lie, T. A. (1969), The effect of pH on different phases of nodule formation in pea plants. *Plants and Soil,* **31,** 391–405.
19. Madhoolika Agrawal and Najma Khanam (1989), Impact of cement factory emission on vegetation and soil. Man and his ecosystem. *Proceedings of the 8th World Clean Air Congress 1989,* The Hague, The Netherlands, 11–15 September, Volume 2.
20. Emanuelsson, J. (1984), *Plant and soil.* **78,** 325–334.
21. Robson, A. D. (1978), *Mineral nutrients limiting nitrogen fixation in legumes.* In *mineral nutrition of legumes in tropical and subtropical soils.* C. S. Anderson and E. J. Kamprath, eds. Commonwealth scientific and industrial research organization, Melbourne, Australia, pp. 277–311.
22. Indhirabai, K., Dhanalakshmi, S., and Lakshmanan, K. K. (1989), *Geobios.* **16,** 189–196.
23. Taylor, R. G. and Karim Moshrefi (1987), *Peanut Science.* **14,** 31–33.
24. Lerman, S. (1972), *Cement kiln dust and the bean plant (Phaseolus vulgais L. Black valentine var.),* In *Depth Investigations into Plant Morphology, Physiology and Pathology.* Ph.D. dissertation, University of California, Riverside, CA.
25. Krishnamurthy, K. V. and Rajachidambaram, C. (1986), *Photosynthetica.* **20(2),** 164–168.
26. Pandey, D. D. and Simba, A. K. (1990), *Geobios.* **17,** 40–41.
27. Singh, S. N. and Rao, D. N. (1980), *Water Air Soil Pollut.* **14,** 241.
28. Nandi, P. K., Madhoolika, Agrawal, and Rao, D. N. (1987), *Monitoring of cement kiln emissions through plants: A case study. Proceedings of the 1987 EPA/APCA Symposium on Measurement of Toxic and Related Air Pollutants.* May 3–6, 1987, North Carolina.
29. Arul, A. and Vivekanandan, M. (1991), *Air and Its Management.* **1,** 1–7.
30. Raymond, V. and Nussbaum, R. (1966), *Pollut. Atmos.* **3,** 284–294.
31. Berge, H. (1966), *Z. Luftvereinigung (Dusseldorf)* **2,** 1–7.
32. Borka, G. (1986), *Acta. Agron. Hung.* **35,** 47–52.
33. Prasad, M. S. V. and Inamdar, J. A. (1990), *Proc. Indian Acad. Sci. (Plant Sci.),* **100,** 435–443.