GROWTH OF WHEAT PLANTS EXPOSED TO CEMENT DUST POLLUTION

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Abstract. Cement dust in the environment poses a threat to the proper functioning of plants in the vicinity of cement factories, as apparent from a field study conducted at different locations in the environs of Churk Cement Factory in Mirzapur District, U.P. Plant samples were collected at 100, 500, 1000, 1500, 2000, and 4000 m northeast of the factory, at three successive stages of plant growth. The plant samples collected at 4000 m distance were treated as control, as there was no apparent deposition of cement dust on their surface. The samples were analyzed with respect to foliar injury symptoms, chlorophyll concentration and phytomass accumulation. Only plants closest to the factory displayed symptoms of foliar injury. The results reveal that wheat plants at polluted sites contained decreased concentration of chlorophyll in their leaves and had reduced accumulation of phytomass, as compared to control. The grains obtained from affected sites showed quantitative and qualitative deterioration. Physico-chemical properties of the soils at polluted sites also underwent some undesirable changes. These effects had negative correlation with the distance from the factory.

1. Introduction

Dust enters the environment through operation of a cement factory and causes injury to vegetation in its vicinity (Peirce, 1910). Cement dust (predominantly particulates) is chemically a mixture of oxides of Ca, K, Al, Si and Na and varies in size from 0.1 to 100 μm (Faith and Atkisson, 1972). Bohne (1963) observed corrosion of tissues under the crust formed on oak leaves. Lerman (1972) reported damage to bean plants by cement dust through plugging of stomata, disorganization of cuticle and reduction in chlorophyll concentration of heavily dusted bean leaves. Sree Rangasamy and Jambulingam (1973) noted a remarkable reduction in grain yield of maize crops cultivated in cement dust-polluted areas. Sree Rangasamy *et al.* (1973) demonstrated that cement dust pollution changed the composition and frequency of plant ecotypes. The present study aims to evaluate the injury caused to the photosynthetic potential of wheat crop by cement dust as a function of distance from a cement factory.

2. Site Description

The cement factory is located at Churk in Mirzapur District of U.P., India. It is 70 km south from the campus of Banaras Hindu University. Churk is situated at 24° 42′ N latitude and 83° 5′ E longitude and is about 300 m above sea level. The area around the factory is mainly plain, interspersed with several small hills. The rocks contain principally shales, sandstone, limestone, quartzite, and dolerite ores. The

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soil of the area is sandy loam in texture. The climate is a general tropical type divided into three distinct seasons, rainy (mid-June to mid-October), winter (mid-October to mid-February) and summer (mid-February to mid-June). The prevalent wind direction is from southwest to northeast and an average wind velocity of 20 km h^{-1} was recorded during the study period in 1976. Wheat crop is extensively grown in plain areas in NE direction from the factory.

The gaseous pollutants in the stack exhausts are primarily the oxides of S (mainly SO_2). The particulate pollutants are mainly cement dust, accompanied by some fly ash from the pulverized coal. Since cement dust is the predominant air pollutant in the vicinity of a cement factory, its impact on the growth of wheat plants has been quantified in the present study.

3. Materials and Methods

Since *Triticum aestivum* is the main agricultural crop in the cultivated areas, it was selected for the present investigation. Six study sites, denoted as S_1, S_2, S_3, S_4, S_5, and C and located at the distances of 100, 500, 1000, 1500, 2000, and 4000 m, respectively, northeast from the factory, were selected for the collection of plant samples at stages of vegetative growth, ear formation and initiation of senescence. The plants at site C were treated as control, as there was no evidence of dust fall on them. Except site C, the plants at all sites had different amounts of dust. Monoliths of 10 plants were dug at each site at the above mentioned stages of plant growth and development, and washed gently under water in order to keep their root systems intact as far as practicable. These samples were treated for phytomass determination. Five samples of fresh leaves were also collected from each site at the same stages of plant growth and brought to the laboratory in an ice-box to determine the chlorophyll concentration. The grains were collected from the plants at different sites after harvesting and analyzed for various characteristics. The composite soil samples were also collected along with plant samples from all sites up to the depth of 30 cm and analyzed for their physico-chemical properties.

3.1. Soil analyses

3.1.1. *Porosity and Water Holding Capacity (WHC)*

Porosity and water holding capacity (%) of soil samples were determined following the standard methods (Piper, 1966).

3.1.2. *pH*

Soil pH was determined in the suspension of 1 : 5 (soil : water, W/V) with a pH-meter, model 110 (Piper, 1966).

3.1.3. *Nitrogen and Organic Carbon*

Nitrogen and organic C contents (%) in soil samples were estimated following

micro-Kjeldahl technique and Walkley and Black's rapid titration method, respectively (Piper, 1966).

3.1.4. *Exchangeable Calcium and Potassium*

Exchangeable Ca and K (m.e. %) in soil samples were determined by leaching with Ammo. acetate and using flamephotometer, type 121 (Jackson, 1962).

3.2. Plant Analyses

3.2.1. *Chlorophyll*

To determine the concentration of chlorophyll in the leaves, a 0.5 g leaf sample was ground with a pestle and mortar in 25 ml of 80% acetone (acetone : water, 4 : 1 V/V). The mixture was filtered through a double-layered muslin cloth and the filtrate was centrifuged at 3000 × g for 15 min. After centrifuging, the supernatant solution was decanted in a measuring cylinder and its volume was maintained at 50 ml with 80% acetone. The optical densities of chlorophyll solution were measured at 645 and 663 nm wavelengths with a spectronic-20 photoelectric colorimeter. The concentrations of chlorophyll *a* and *b* (mg g^{-1} fresh leaf) were obtained using the following formulae given by Maclachlan and Zalik (1963):

$$\text{Chlorophyll } a \text{ (mg g}^{-1}) = \frac{12.3\, D_{663} - 0.86\, D_{645}}{d \times 1000 \times W} \times V$$

$$\text{Chlorophyll } b \text{ (mg g}^{-1}) = \frac{19.3\, D_{645} - 3.6\, D_{663}}{d \times 1000 \times W} \times V$$

where, V is for volume (ml) of chlorophyll solution, d for length (cm) of light path and W for fresh weight (g) of leaves.

The amounts of chlorophyll *a* and *b* were added together to obtain the total chlorophyll.

3.2.2. *Phytomass*

Intact plant samples were oven-dried at 80°C for 24 h and then weighed separately to obtain phytomass which was expressed in g $plant^{-1}$.

3.3. Grain Analyses

The number of grains $spike^{-1}$ and weight and volume of 1000 grains were determined. For volume determination, the water displacement method was adopted.

The grain samples were dried in hot oven at 80°C for 24 h and then powdered. The dried and well powdered samples were processed for the determination of concentrations of N, P, protein, starch, carbohydrate, fat, and energy.

3.3.1. *Nitrogen and Protein*

The N content in grain samples was determined by micro-Kjeldahl technique (Piper, 1966). The N was multiplied by a factor 5.7 to obtain the protein content in grains.

3.3.2. *Phosphorus*

The grain samples were digested by wet digestion method and finally the content of P in the digested samples was determined colorimetrically (Misra, 1968).

3.3.3. *Starch and Fat*

The contents of starch and fat in grain samples were determined by the standard methods (Chopra and Kanwar, 1976).

3.3.4. *Total Carbohydrate*

The content of total carbohydrate in grain samples was determined by standard method outlined by Plummer (1971).

4. Results and Discussion

Cement dust, after hydration and crystallization, forms a hard crust on soil surface and thus affecting it physically, chemically and biologically (Przemeck, 1970). Such a crust tends to make the soil surface impervious to water by compacting soil particles and consequently reduces porosity and water holding capacity (WHC) of affected soil. The levels of porosity and WHC of soil at site S_1 were reduced to almost half of those at the control site C (Table I). The pH of polluted soil was invariably higher than that of the control soil (Singh, 1977). The soil pH decreased from 9.0 to 6.9 between site S_1 and site C. It may be explained that calcium and aluminum hydroxides formed during hydration of cement dust were responsible for an increase in soil pH.

Observing a gradual increase of soil pH from site C to site S_1, it is inferred that maximum dustfall occurred at site S_1 and minimum at site C. Similarly, the amount of organic C in the soil progressively decreased from site S_1 through site C (Table I).

TABLE I

Characteristics of soil samples collected from different sites

Site	Porosity (%)	WHC (%)	pH	Organic C (%)	N (%)	C/N ratio	Exchangeable Ca (m.e.%)	Exchangeable K (m.e.%)
S_1	32.4±3.2	21.4±1.6	9.0±0.6	0.822±0.003	0.016±0.002	51	7.52±0.05	0.31±0.01
S_2	44.3±2.4	28.7±1.5	8.6±0.1	0.805±0.006	0.018±0.001	45	6.41±0.04	0.28±0.02
S_3	49.8±2.7	32.5±1.6	8.1±0.2	0.672±0.004	0.030±0.002	22	5.04±0.06	0.22±0.01
S_4	52.4±1.8	40.2±1.2	7.6±0.1	0.561±0.003	0.028±0.003	20	4.35±0.08	0.22±0.03
S_5	58.3±2.5	43.4±1.8	7.2±0.2	0.448±0.005	0.032±0.002	14	3.82±0.07	0.20±0.01
C	60.6±2.4	45.1±1.5	6.9±0.2	0.434±0.005	0.040±0.004	11	3.56±0.08	0.15±0.03

Evidently, the decomposition rate of organic matter in polluted soils slowed down, perhaps due to decreased microbial activity under high pH conditions as evidenced from higher C/N ratios (Daji, 1970; Rao and Pal, 1978). There was also an appreciable difference in the soil N at sites S_1, S_2 and C which may be attributed to retarded microbial activity in soils at polluted sites and thereby leading to less release of N through decomposition of organic residues. However, the soils at heavily polluted sites were greatly enriched with exchangeable Ca^{2+} and K^+ ions (Singh, 1977). These elements seem to be added to the soil through cement dust being rich in Ca and K. This appears to be so, because the maximum amounts of Ca^{2+} and K^+ were present in the soil samples collected from site S_1 which being closest to the factory received maximum dust input.

Like soil, wheat plants at all affected sites showed a thick and hard incrustation of cement dust of varying thickness on their entire exposed surfaces. The plants grown at sites S_1 and S_2 particularly displayed foliar symptoms of cracking, peeling, and withering. Perhaps, hard setting of cement dust produced differential strains on cement-coated leaves, which caused them to crack, peel off and wither.

TABLE II

Concentrations (mg g^{-1} fresh leaf) of chl *a*, chl *b* and total in leaves and phytomass of wheat plants at different stages of growth and at different sites in the environs of the factory

Site		Chlorophyll			Phytomass		
		A	B	C	A	B	C
S_1	Chl *a*	0.44±0.08	2.02±0.05	0.58±0.04			
	Chl *b*	0.48±0.04	1.66±0.02	1.02±0.06	7.45±1.2	15.62±1.8	21.42±2.1*
	Total	0.92	3.68	1.60			
S_2	Chl *a*	0.98±0.03	2.66±0.03	1.02±0.03			
	Chl *b*	0.86±0.02	3.85±0.02	1.94±0.03	12.38±0.8	24.84±1.3	30.38±2.0*
	Total	1.84	6.51	2.96			
S_3	Chl *a*	1.10±0.04	2.88±0.02	1.18±0.05			
	Chl *b*	0.82±0.02	3.82±0.01	1.92±0.03	14.72±1.5	31.23±1.6	35.32±2.3*
	Total	1.92	6.70	3.10			
S_4	Chl *a*	1.22±0.03	3.37±0.04	1.32±0.04			
	Chl *b*	0.75±0.03	3.66±0.02	1.38±0.02	15.21±1.3	35.55±1.5	42.76±1.8*
	Total	1.97	7.03	3.14			
S_5	Chl *a*	1.34±0.04	3.81±0.03	1.48±0.05			
	Chl *b*	0.72±1.01	3.62±0.01	1.80±0.02	17.03±1.5	42.87±1.9	50.06±2.1*
	Total	2.06	7.43	3.28			
C	Chl *a*	1.44±0.02	4.62±0.05	1.57±0.03			
	Chl *b*	0.70±0.01	3.51±0.03	1.75±0.02	18.41±1.0	46.32±1.7	55.92±2.3
	Total	2.14	8.13	3.32			

* $P < 0.001$. A = Vegetative growth, B = Ear formation, C = Initiation of senescence.

It is evident from the results that plant leaves from all affected sites contained lower amounts of total chlorophyll than that from the control site (Singh and Rao, 1978). Further, the magnitude of reduction in total chlorophyll concentration of leaves decreased from site S_1 through S_5 and was due to progressively less accumulation of cement dust on plants from site S_1 to site S_5. In comparison to control, the concentration of total chlorophyll in wheat plants was reduced by 54.7% at site S_1, 20.0% at S_2, 17.5% at S_3, 13.5% at S_4 and 8.6% at S_5, at the stage of earing (Table II).

The chlorophyll *a* concentration also followed the above trend and was most reduced by 56.2% at site S_1, followed by 42.4% at S_2, 37.6% at S_3, 27.0% at S_4 and 17.5% at S_5, at the same stage of plant growth.

However, the amount of chlorophyll *b* was more in plant leaves from all affected sites than in that from control site, but it is not true for plants at site S_1 where maximum dust fall occurred. Perhaps, injury to chloroplasts by highly alkaline cement solution (pH 10.5) decreased the chlorophyll concentration in affected leaves (Czaja, 1962; Lerman, 1972). Also cement incrustation on leaf surface reduced the absorption of photons which might have retarded the synthesis of chlorophyll *a* but favoured chlorophyll *b* synthesis due to shading effect (Peirce, 1910; Bohne, 1963). This may be a reason for lower concentration of chlorophyll *a* but higher accumulation of chlorophyll *b* in affected leaves than that in control leaves. The maximum deposition of cement dust on plants at site S_1, perhaps, destroyed both chlorophyll *a* and *b*. However, these observations do not conform with that of Oblisami *et al.* (1978).

The phytomass of wheat plants increased as the amount of cement dust accumulated on plants decreased from site S_1 to Site S_5. The phytomass of affected plants was reduced by 61.6% at site S_1, 45.6% at S_2, 36.8% at S_3, 23.5% at S_4 and 10.4% at S_5, at the stage of beginning of senescence (Table II). The reduction in phytomass of plants at affected sites might be attributed to reduced photosynthetic potential of dusted plants, contributed by several factors including absorption of light by dust layer on photosynthetic leaves (Peirce, 1910; Czaja, 1962; Bohne, 1963), injury to chloroplats (Czaja, 1962; Lerman, 1972), interference in gaseous exchange through leaf stomata due to their plugging by cement particles (Czaja, 1966; Darley, 1966), reduced photosynthetic area and unfavorable changes in physico-chemical properties of affected soils for plant growth (Parthasarathy *et al.*, 1975).

There was also a considerable reduction in the grain-setting of wheat plants at all polluted sites as compared to plants at control site. The frequency of grain-setting increased, as one moves from site S_1 through C, due to progressive less and less deposition of cement dust with the increasing distance from the factory. The reductions in the number of grains spike^{-1} of affected plants were 55.5, 46.6, 33.3, 20.0, and 13.3% at sites S_1, S_2, S_3, S_4, and S_5, respectively (Table III). Perhaps, the alkaline solution of cement dust formed on cement-coated stigmata did not allow pollen grains to germinate and consequently lowered the grain-setting (Anderson, 1914; cf. Czaja, 1962). The weight and volume of grains produced by wheat plants at all polluted sites were also reduced with respect to control grains. The level of deterio-

TABLE III

Quantitative and qualitative characteristics of wheat grains collected from different sites

Grain characteristic	Site					
	S_1	S_2	S_3	S_4	S_5	C
Av. No. of grains/spike	20 ± 2*	24 ± 3*	30 ± 2*	36 ± 2*	39 ± 3	45 ± 3
Wt. of 100 grains (g)	26.22 ± 0.82	28.43 ± 0.42	30.61 ± 0.23	31.84 ± 0.34	32.21 ± 0.15	34.83 ± 0.18
Vol. of 1000 grains (cm^3)	24.62 ± 0.32	27.37 ± 0.25	28.15 ± 0.28	30.41 ± 0.25	31.76 ± 0.21	35.24 ± 0.28
Protein (%)	12.88 ± 0.09	13.11 ± 0.05	13.73 ± 0.08	13.96 ± 0.06	14.02 ± 0.05	14.25 ± 0.04
Starch (%)	52.62 ± 0.21	54.83 ± 0.18	57.35 ± 0.21	58.63 ± 0.25	60.28 ± 0.27	62.71 ± 0.24
Fat (%)	1.67 ± 0.01	1.67 ± 0.01	1.68 ± 0.02	1.68 ± 0.02	1.70 ± 0.01	1.68 ± 0.02
Total carbohydrate (%)	64.73 ± 0.08	65.56 ± 0.10	68.37 ± 0.15	70.44 ± 0.18	71.75 ± 0.16	75.13 ± 0.12
Nitrogen (%)	2.26 ± 0.02	2.30 ± 0.01	2.41 ± 0.01	2.45 ± 0.02	2.46 ± 0.01	2.50 ± 0.01
Phosphorus (%)	0.56 ± 0.01	0.56 ± 0.01	0.58 ± 0.02	0.61 ± 0.01	0.63 ± 0.02	0.67 ± 0.01
Energy cal g^{-1} dry wt.	3271 ± 198	3435 ± 108	3761 ± 116	3821 ± 162	4068 ± 178	4463 ± 125

* $P < 0.001$.

ration in grain quality of affected plants varied with distance from the factory. The grains, produced by plants at site S_1, were most degraded with respect to protein, starch, total carbohydrate, and energy concentrations, followed by that of plants at sites S_2, S_3, S_4, and S_5 in decreasing order. The respective reductions in protein, starch, total carbohydrate and energy concentrations were recorded 1.37, 10.09, 10.40, and 26.7% at site S_1, reducing to 0.23, 2.43, 3.38, and 8.8% at site S_5 (Table III). Probably, reduced photosynthetic efficiency of affected plants could reduce the accumulation of photosynthetates, leading to lower concentrations of protein, starch, total carbohydrate, and energy in their grains (Peirce, 1910; Czaja, 1962; Steinhubel, 1962; Bohne, 1963). Progressive less degradation of grains with respect to quantity and quality would have resulted from the decreased dust fall on plants from site S_1 through site S_5. Thus, the reductions in above growth parameters were negatively correlated with distance from the source of dust emission.

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