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The Growth of *Phaseolus vulgaris* L. cv. Ife Brown (Leguminosae) in a Cement Site Rich in Heavy Metals

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Abstract: Seeds of *Phaseolus vulgaris* L. cv. Ife Brown sown in the site at close proximity to a cement factory (polluted), produced sprawling plants with their life span shortened by 28 days, a low pod yield, few and small sized seeds. The time of flower initiation, pod formation to pod ripening was markedly reduced. These plants accumulated a significantly high (17.01 μmol mol^{-1}) concentration of aluminium (a constituent of cement) in the leaves and copper (13.68 μmol mol^{-1}) in the seeds. Furthermore, the plants showed a low uptake of iron (a prominent constituent of cement) from the iron-rich polluted site. The heavy metals present in cement dust also induced a deficiency in phosphorus, magnesium and ammonia; and synergistically attracted the presence of other heavy metals such as zinc, copper, lead, nickel, chromium, silver and cadmium in significantly high quantities ($p = 0.05$).

Key words: Cement polluted site, heavy metals, aluminium, iron, copper, zinc

INTRODUCTION

Cement factories in Nigeria are usually located a few kilometers away from human dwellings. Many of the original settlers of such factory sites carry out subsistence farming on a small fraction of vast land around the cement factory. Portland cement contains 3-8% aluminium oxide, 0.5-0.6% iron-oxide, 60-70% calcium oxide, 17-25% silicon oxide, 0.1-4% magnesium oxide and 1-3 % sulphur trioxide (Lea, 1970). Cement dust has been found to cause anatomical changes in plant organs (Setia and Bala 1994; Uma *et al*., 1994). Of these metals, aluminium and iron are heavy metals that affect plant growth adversely, when present at toxic levels (Shellie-Desert and Bliss, 1991; Alloway, 1990). Iron is essential in plant growth and its presence in cement dust could be of advantage especially when cultivating legumes that are naturally sourced for their iron content. However, the presence of other heavy metals like zinc and copper which could be present in the soil due to synergistic effects (metal-metal attraction and association) as pointed out by Forstner (1995) can reduce the translocation of iron in plants.

In comparison with gaseous air pollutant, many of which are readily recognised as being the cause of injury to various types of vegetations, relatively little is known and limited studies have been carried out on the effect of cement dust pollution on the growth of plants (Iqbal and Shafiq, 2001). Amongst the works carried out on the effect of cement dust on plant growth and development are Brandt and Rhoades (1972), Prasad and Inamdar (1990), Abdullahi and Iqbal (1991), Gupta and Mishra (1994) and Iqbal and Shafiq (2001). All the reports showed that cement dust pollution is detrimental to plant growth and development. These experiments have focussed on the effect of cement dust has an entity on plant growth and attention has not been on analysing the effects observed as being due to the resultant effects of the constituent elements in the cement dust, heavy metals in particular as earlier pointed out. The experiments were carried out by periodical dusting of cement over potted plants, a kind of *ex situ* methodology. However, we decided to carry out our investigation *in situ*, by cultivating plants in soils beside a long existing and functional cement factory which has been and is still being polluted by cement dust over many years.

This study investigates the growth of *Phaseolus vulgaris* L. in a cement dust ecosystem and the effect of the pollutant (in relation to its constituent heavy metals, aluminium and iron) on the yield of the plant.

MATERIALS AND METHODS

Seeds of *Phaseolus vulgaris* L. cv. Ife brown, collected from the Institute of Agricultural Research and Training (IAR and T), Moor plantation, Ibadan, Nigeria.

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The experimental site was 15 m from a cement factory (Ewekoro, Ogun-State, Nigeria) while the experimental site was located 80 km from the cement factory (University of Lagos, Akoka-Yaba, Lagos Nigeria). Experiment was carried out between 2001 and 2002.

Metal constituents in the soils: Soil samples were collected from each experimental site. The soil pHs were measured using a pH meter (Jenway model). The concentration of aluminium, iron, copper and zinc in the soil were determined according to the procedures outlined by Allen *et al.* (1974).

Growth experiment: Bean seeds were sown in holes (0.3 m apart, 6 seeds per hole) on three planting beds (taken as replicates), each measuring 0.7×0.9 m, per experimental sites. Bean cultivation lasted about 3 months.

Phenological studies: The time of germination, flower initiation, pod formation, pod ripening and plant senescence were recorded.

Morphological observations and yield measurements: The level of plant spread and the colour of leaves were observed. The number of seeds per pod was recorded. The mean dry weights of pods and seeds of plants grown in the polluted and control sites were determined after oven drying at 80°C for 72 h.

Plant heavy metal uptake: Three replicates each of leaves and seeds of mature plants grown at the two experimental sites (polluted and control) were air dried for 96 h and digested as outlined by Jones (1984). The concentrations of aluminium, iron, zinc and copper in the leaves and seeds were determined as in Allen *et al.* (1974), using atomic absorption spectrophotometry.

Statistical analysis: Twenty replicates were used for the analysis. Data were analysed for each plant. Descriptive and regression analyses were carried out using Excel 2000. Statistical analyses were carried out using the New Duncan's Multiple Range test at 0.5 and 0.01% levels of significance.

RESULTS AND DISCUSSION

Table 1 show the pH and chemical constituent of soils from heavy metals-rich (15 m from the cement factory) and control (80 km from the cement factory) sites. There is no significant difference between the pH of soils from both sites and they are within the permissible range (pH 6.5-7.5) for the cultivation of *Phaseolus vulgaris* (Howeler, 1985). The different soil types making up the different soils are also not markedly different except for coarse sand and silt content. Effects of difference in soil profile would therefore not be an issue in this analysis.

Figure 1 shows the concentration of aluminium, iron, zinc and copper in the soil from the polluted and control sites. Soil from both sites had high concentrations of heavy metals analysed, however the polluted soil had significant quantities of aluminium (8.08 μmol mol^{-1}), iron (22.20 μmol mol^{-1}), zinc (20.31 μmol mol^{-1}) and copper (36.50 μmol mol^{-1}). The first two elements are constituents of cement which is richly abundant in the site area while the zinc and copper may be present as natural constituents of the soil. According to Nriagu (1988), there is a natural presence of heavy metals in soil in the absence of significant input from external sources. Such heavy metals result from weathering and other

Table 1: Profile and pH of soils from polluted and control sites

	Soil component (%)	
Soil type	Polluted area	Control area
pH	6.24a	6.57b
Coarse sand	36.56b	28.57a
Sand	45.16a	49.52b
Silt	12.90a	17.14b
Clay	3.81a	3.82a
Humus	0.92a	0.99a

Means followed by similar letter(s) on the horizontal axis are not significantly different at p = 0.05 according to the New Duncan's Multiple Range test

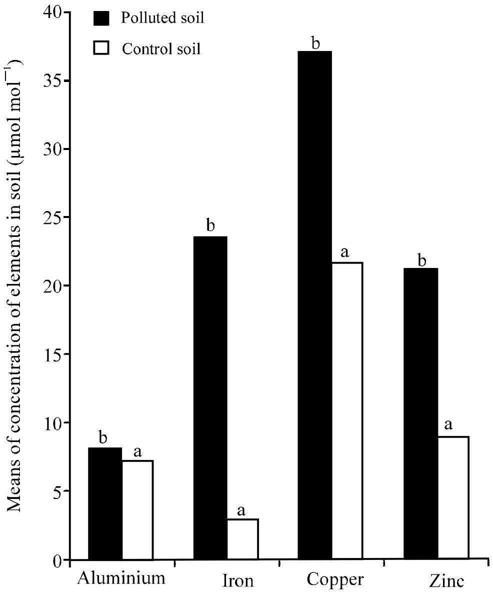

Fig. 1: Aluminium, iron, copper and zinc concentrations (μmol mol^{-1}) in soils from polluted and control sites. Mean of same elements followed by same letters are not significantly different at p = 0.05, according to the New Duncan's Multiple Range tests

pedogenic processes acting in the rock fragments of the parent materials. However, the reason for their significant residence in the polluted site could be due to the synergistic effect that metals have on each other. According to Forstner (1995), metal-to-metal association (a kind of synergistic effect) could cause the abundance of the various elements in a polluted soil. He reported that 70% of metal-contaminated soils involve two or more metals that are present through synergistic effects.

Table 2 show the phenology and yield (number of seeds per pod, mean dry weights of pods and seeds) of plants grown under both growth conditions. Aside from the fact that plants grown in polluted area had slender sprawling stem, pale green leaves and the pods contained few and small sized seeds. Though, it took 21 days on the average from flower initiation, pod formation to pod ripening in bean plants cultivated in both polluted and control areas, however flower initiation took off rather very early (28 days) in plants grown in polluted area and plants started senescing just immediately after pod ripening; thereby reducing the life span of plants grown in polluted area by 30 days. The emergence of slender sprawling stems in plants grown in the polluted site is probably due to the low concentration of phosphorus in the soil. Izquierdo and Hosfield (1983) have shown that plant morphology can influence photosynthesis and carbon transport and also the physiological behaviour in varying degrees during the seed development period, resulting in the yields differences. Erectness was shown to cause a better light penetration, higher rates of net carbon fixation and a more efficient transfer of photosynthates into the seeds with a resulting high yield. This probably explains the higher yield (number of seeds per pod, mean dry weights of pods and seeds) of plants from the control, which remained erect long before fruiting. The longer life span of such plants extends the duration of growth and pod production according to Laing *et al.* (1984).

Figure 2 and 3 show the mean concentration of aluminium, iron, zinc and copper in the leaves and seeds

Table 2: Phenology and pod yield (quantity) of *Phaseolus vulgaris* cv. IFE Brown, sown in polluted and control sites

	Plants sown in	
Parameters	Polluted soil	Control soil
Phenology (days after sowing)		
Germination	3	3
Flower initiation	28	42
Pod formation	35	49
Pod ripening	49	63
Plant senescence	47	77
Pod yield		
Dry weight of pod (g)	1.55±0.86	2.81±1.15*
Number of seeds/pod	1-10	2-15
Mean dry weight of seed (mg)	96.83±1.30	116.67±6.80*

Means followed by * is significantly higher at p = 0.01 according to the New Duncan's Multiple Range test

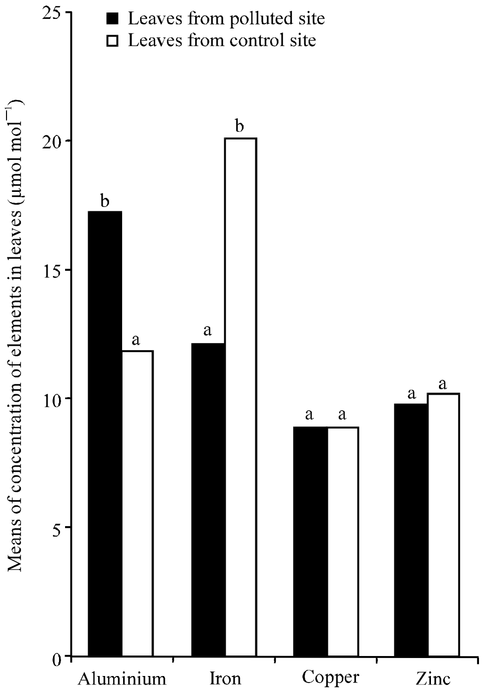

Fig. 2: Aluminium, iron, copper and zinc concentrations (µmol mol^{-1}) in leaves from polluted and control sites. Mean of same elements followed by same letters are not significantly different at p = 0.05, according to the New Duncan's Multiple Range tests

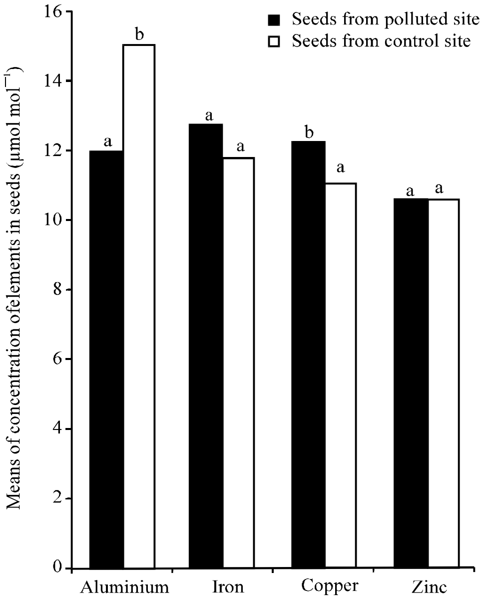

Fig. 3: Aluminium, iron, copper and zinc concentrations (µmol mol^{-1}) in seeds from polluted and control sites. Mean of same elements followed by same letters are not significantly different at p = 0.05, according to the New Duncan's Multiple Range tests

of the plants from both polluted and control sites, respectively. The results show that the presence of significantly higher ($p = 0.05$) amounts of these metals in the polluted soils did not result in the accumulation of significantly higher ($p = 0.05$) quantities in the leaves and seeds of plants grown in the site. Only aluminium in the leaves (17.01 μmol mol^{-1}) and seeds (11.74 μmol mol^{-1}) as well ass copper in the seeds (12.68 μmol mol^{-1}) were accumulated at a significantly higher ($p = 0.05$) level by the plants grown in polluted site. The concentrations of iron in leaves (10.12 μmol mol^{-1}) and seeds (8.23 μmol mol^{-1}) of plants grown in the polluted site was significantly lower ($p = 0.05$) than that of plants from the control. The significantly high concentration ($p = 0.05$) of zinc and copper in the polluted soil (Fig. 1) may have inhibited the intake and translocation of iron from the iron-rich polluted soil. This finds support in the reports of Ebb and Kochian (1997) which stated that high concentration of zinc and copper inhibits intake and translocation of iron even where iron is abundant. Hewitt (1963) also reported that the presence of high concentrations of heavy metals could induce iron deficiency in plants due to competition by the heavy metals for functional sites of iron binding.

It is now evident that soils in cement rich sites cause phenological changes in *Phaseolus vulgaris* L. plants that result in a drastic reduction in the life span and a resultant reduction in quantity yield. Heavy metals induce iron deficiency in the seeds thereby reducing the nutritional value of the bean seeds. Furthermore, accumulation of aluminium in the leaves and copper in the seeds could be hazardous to human health when such leaves and seeds are consumed. This is due to the fact that heavy metals become bio-accumulated in the body, that is, they remain in the body in an unchanged state and are continually accumulated during the life of an organism causing bio-magnification (Clark, 1995).

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