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Effect of Variation in Harvest Time on the Uptake of Metals by Barley Plants from Soil Amended with Sludge and Compost

J. Nouri, [1]P. J. Peterson and [2]B. J. Alloway
Department of Environmental Health Engineering, School of Public Health, Tehran, University of Medical Sciences, P.O.B. 14155-6446, Tehran, Iran, [1]King's College London, Strand, London WC2R 2LS , England, U.K. [2]Department of Soil Science, University of Reading, Whiteknights, P.O.Box 233, Reading, RG6 6DW, UK

Abstract: Increasing the metal concentrations by amending the sewage sludge increased the metal content in barley leaves. The yield of the 100 % sludge was the lowest and the soil pH was lowered as well. With the increase in time, the metal removal by plants is also increased. Chromium in barley behaved differently to the other metals studied, showing a declination with time. High voltage application of soluble chromium in solution culture resulted in decreased concentration of nitrogen, phosphorous, potassium , copper, iron, magnesium and zinc in barley and produced toxic effects and reduced growth. The metal uptake by plants from sludge amended soil was influenced by time of harvesting and stage of growth.

Key words: Heavy metals, harvest , uptake , barley , compost

Introduction

The uptake of metals by crop plants from sludge amended soil may be deleterious to crop growth and soil productivity and may also produce crop containing unacceptably high metal level for animal and human health (Nouri, 1980). The uptake of metals by crop plants from sludge amended soils has been the subject of a great deal of study (Cunningham *et al.*, 1975a; Anderson and Nilsson, 1972; Hooda and Alloway, 1994; Hooda *et al.*, 1997). Sewage sludges containing large amounts of heavy metals may be deleterious to crop growth and long term soil productivity, but may also produce crops containing unacceptably high metal levels for animal and human health. Many factors may determine the extent of absorption of elements by plants and their phytotoxic effects. It is necessary to know how the metal content of different plants varies with the time of harvesting and stage of maturity (Sauerbeck, 1991). When the plants are young, mineral absorption is relatively rapid and dry matter production rather slow, but later, when large and active photosynthetic areas are being formed, dry matter production may outstrip absorption of mineral elements, leading to a reduction in their level when calculated on a dry matter basis. During this time there is also a redistribution of elements within the plant, variation between and within different organs may be quite large (Moreno, 1996). In this experiment higher rates of sludge or compost applications to soils were made to examine whether phytotoxic effects occurred. The experiment was conducted to assess the effects of sewage sludge on plant growth; to examine any variation with time in the concentrations of cadmium, lead, nickel and chromium accumulated by barley seedlings under greenhouse conditions and to make a comparative study of heavy metal uptake by barley from sludge and compost amended soil.

Materials and Methods

The soil and sludge were collected and prepared in London in 1990. The following five treatments were used at this experiment:

Deephams digested sludge	(100 %)
Sandy clay loam soil	(100 %)
John Innes Compost No.2	(100 %)
Sludge/soil mixtures	(50/50 %)
Sludge/compost mixtures	(50/50 %)

Table 1: Total metal content of sludge, soil and compost ($\mu g\ g^{-1}$)

Element	Sludge	Soil	Compost[2]
Cadmium	52+0.61[3]	0.39+0.02	0.3+0.02
Lead	430+10.0	12.9+0.3	14.6+0.29
Nickel	860+12.0	14.0+0.08	12.12+0.07
Chromium	335+6.0	21.0+0.5	25.0+0.58

[1]Total based on concentrated nitric acid digestion
[2]John Innes Potting Compost.
[3]Each value represents the mean and standard error of 12 replicates for sludge and replicates for soil and compost.

Table 2: pH values of soil, sludge and compost at the beginning and end of experiment

Treatment (%)	Beginning	End
Soil (100)	6.8	6.9
Sludge (100)	5.4	5.9
Compost (100)	6.8	6.9
Soil, sludge (50/50)	5.8	6.1
Compost, sludge (50/50)	6.0	6.3

Barley (*Hordeum vulgar* L. cv. Julia) was used as the test plant.

Potting compost and digested sewage sludge from Deephams (Enfield) sewage works (pH 5.5 and organic matter 32 %) were mixed with sandy clay loam soil (pH 6.3 and organic matter 4 %) in the above proportions. This sewage sludge was selected to provide metal concentrations which are within the range normally observed (Berrow & Webber, 1972; Dean and Smith, 1973; Page, 1974). The total metal concentrations in the sludge, soil and compost are shown in Table 1. The pH values of dried sludge, soil and compost were determined at the beginning and end of the experiment (Table 2). The barley seeds were pre- germinated and 40-50 uniform seedlings were planted in each pot and places in a greenhouse.

Each tray was divided into 4 sections and 10 seedlings were planted in each section. The seedlings in first, second, third and fourth tray were harvested twice at intervals of 1, 2, 3 and 4 weeks respectively and ten plants were harvested once per week, for four successive weeks. The leaf lengths were measured, then the leaves were washed with distilled water, dried and then analyzed for cadmium, lead, nickel and chromium as mentioned earlier. The results for each pot were expressed as the mean dry weight and $\mu g\ g^{-1}$ of metal in the combined dry matter of all plants.

Results

Leaf length measurements: In the first harvest leaf length increase most for plants grown in compost and compost/sludge mixtures (Fig. 1). This was probably caused by the high availability of nutrients in potting compost (Nouri, 1980) and sludge. Leaf length increased least in the 100 % sludge treatment which was perhaps due to the toxicity of heavy metals or to a nutritional imbalance. A deficiency of potassium was suggested by terminal necrosis of the leaves which is a characteristic symptom shown by the leaves, but this seems most unlikely.

In the second harvest, variations in leaf length were different to those of the first harvest. By the second week all leaf lengths were less than those of the first week, this difference was perhaps due to an environmental effect as it occurred in all the treatments. During the third week the leaf lengths increased markedly in the sludge/ compost and sludge/ soil treatments and this continued in the fourth week for plants in sludge/ compost mixtures (total increase about 30 cm), but sludge/ soil plants decreased in the fourth week. In other treatments there was a general decrease in leaf lengths.

Metal concentrations in barley leaves: The lowest concentrations of metals were found in the soil and compost treatments. The first harvest showed differences between metals, cadmium increased markedly but both lead and nickel remained relatively constant with small fluctuations and chromium decreased.

In the second harvest the concentrations of all four elements remained relatively constant, but the plants growing in sludge and sludge amended soils had higher metal concentrations. The highest metal concentrations were found in the plants growing in sludge only. The concentration of cadmium in plants growing in the sludge and sludge mixtures was similar in both first and second harvests (Fig. 2). The initial uptake of cadmium in the second harvest was higher than in the first, but the cadmium concentration remained relatively constant except for plants grown in 100 % sludge which showed a slight increase after the second week.

The highest cadmium concentration was in barley grown in 100% sludge with 5 $\mu g\ g^{-1}$ at the end of harvest 2 and the lowest was for plants grown in soil and compost treatments which had only 0.3 $\mu g\ g^{-1}$ at this time. The latter value was similar to the mean concentration of cadmium in barley cultivars grown in uncontaminated soils reported by other workers (Fig. 2). Lead showed more erratic changes in both first and second harvests (Fig. 3). The plants in sludge showed an overall slight decrease in lead concentration whereas the sludge/ soil plants had marked fluctuations. In the second harvest, the maximum lead concentration was found in 100 % sludge treatment which by the end of four weeks was 13.5 $\mu g\ g^{-1}$. The maximum nickel concentration in barley leaves from the first harvest was found in plants grown in 100 % sludge. However, the concentrations for plants growing in sludge/soil and sludge/compost treatments remained relatively constant (Fig. 4). In the second harvest nickel concentrations remained relatively constant in all treatments, but increased markedly for sludge only treatments. The highest nickel concentration (13.0 $\mu g\ g^{-1}$) was found in barley grown in 100 % sludge. In harvest 1, the variations in chromium concentration in barley leaves were different from those of the other metals. Chromium concentrations decreased in all cases and concentrations for plants grown in sludge, sludge/soil and

Table 3: Metal concentrations in barley leaves grown in normal soil

Element	Concentration ($\mu g\ g^{-1}$)
Cadmium	0.25
Nickel	1-2
Lead	1-1.5
Chromium	0.03-1

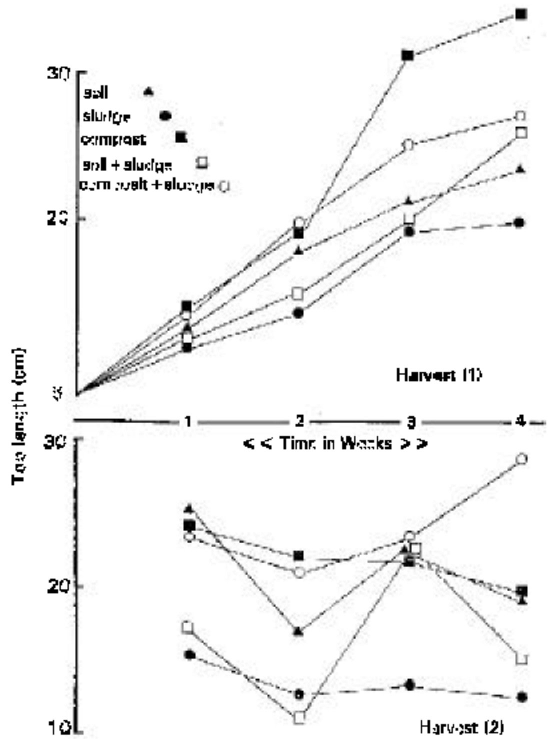

Fig. 1: Variations in leaf length of barley with time (Each symbol represents the man of 10 replicates)

sludge/compost were fairly close to each other.

In the second harvest, the highest metal concentration was found by the end of week 2 in plants growing in the sludge/soil treatment, but this decreased in weeks 3 and 4. The highest chromium concentration was 2.4 $\mu g\ g^{-1}$ for the sludge treatment (Fig. 5). Application of sludge leads to a lowering of the soil pH due to nitrification of the large amount of NH_4-N added. Table 2 shows the pH values of sludge, soil and compost treatment at the beginning and end of the experiment. They all showed an increase in pH with time.

Discussion

Increasing the metal concentrations of the treatments by amending with sewage sludge significantly increased the metal content in the barley leaves. This was most marked for 100 % sludge, which produced the lowest yields. The yield was highest for compost treatments due to the readily available nutrients (Moreno, 1996). The yield reductions arising from sludge application probably resulted from subtoxic levels of several elements interacting to reduce growth (Sims and Kline, 1991). CAST (1976); Baerugard and Martinsen (1977) reported that the application of sewage sludge dry matter,

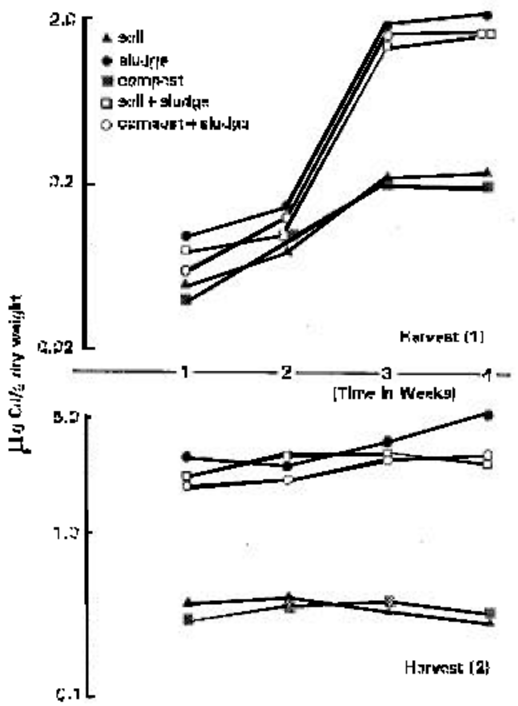

Fig. 2: Variations with time, in the cadmium concentration of barley leaves

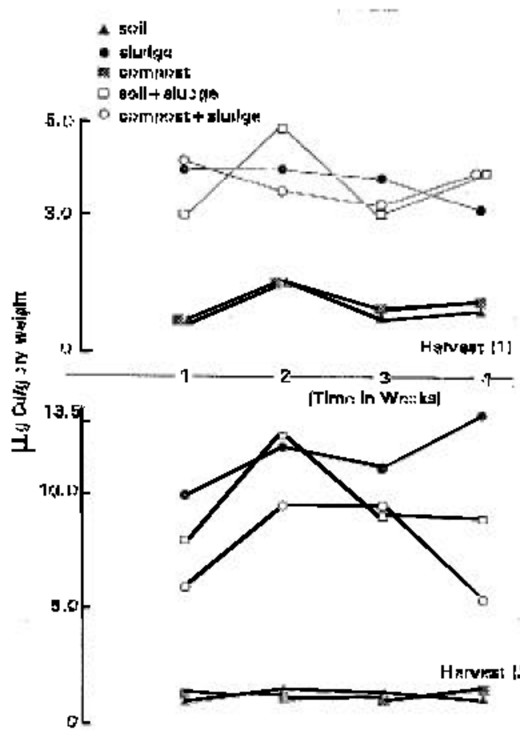

Fig. 3: Variations with time, in the lead concentration of barley leaves

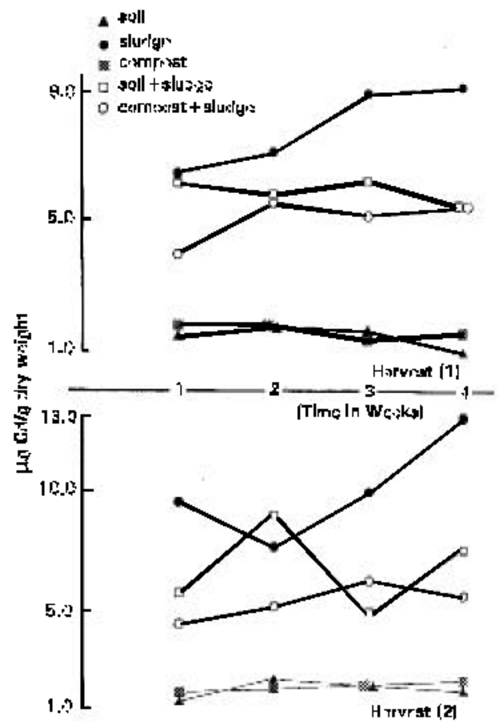

Fig. 4: Variations with time, in the nickel concentration of barley leaves

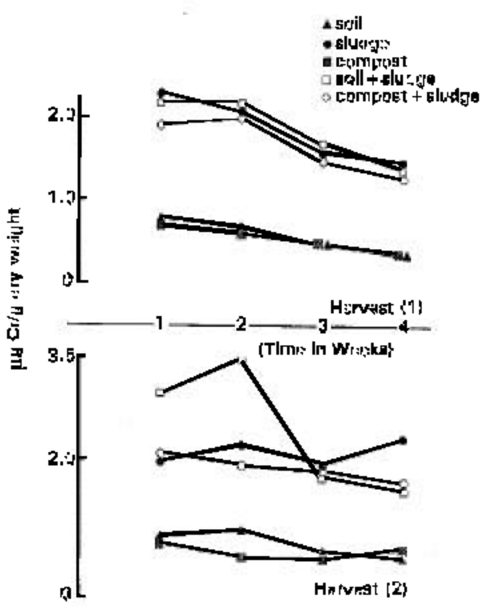

Fig. 5: Variations with time, in the chromium concentration of barley leaves

which was rich in heavy metals, to land at a high ratio considerably increased the concentrations of some metals in plan ts. However, Lepp and Eardley (1978) indicated that increasing the proportion of metal- rich sewage sludge had no detrimental effect on plant growth and increasing the ratio of sludge to soil raised the pH status of the growing medium from mildly acidic to slightly alkaline. In this work, sludge application lead to a lowering of the soil pH, due to nitrification of the large amount of NH_4-N present, but it must be noted that soils receiving sludge should not be permitted to become acidic. It is therefore important to maintain soil pH above 6.5 by frequent liming in all situations where sewage sludge has been applied to agricultural land (Chumbley, 1971; Sauerbeck, 1991). Robinson (1972) indicated that crops differ in their tolerance to activity, and barley requires a pH of 6.5 for good growth. The metal removal by plants from sludge and sludge amended soil increased with time. In the second harvest where the uptake of metals was higher than in the first harvest which could be due to reduced growth dilution effects or increased levels of exchangeable metals in the soil/ sludge. Chromium in barley behaved differently to the other metals studied, its foliar concentration in the leaves declined with time and the sludge application had comparatively little effect on uptake. It seems likely that chromium is interacting with the soil to decrease its availability. The unavailability of chromium might be expected since it was probably in the Cr^{3+} state which is relatively unavailable to plants (Lisk, 1972, Hooda *et al.*, 1997). Mortvedt and Giordano (1975); Kelling *et al.*(1977) found that the concentration of chromium in maize tissue was not affected by sludge application even when the sludge was applied at a rate of 25 times greater than that recommended for sludge. Lahouti (1977) indicated that high application of soluble chromium at ≥ 5 $\mu g\ ml^{-1}$ in solution culture resulted in decreased concentrations of nitrogen, phosphorus, potassium, iron, magnesium and zinc in barley and produced toxic effects and reduced growth.

So it is concluded, the pH values of the soil and compost growth media were lowered by t he addition of sewage sludge, thus the pH of sludge amended soils should be carefully monitored. This is especially important as availability generally in creases with decreasing pH. Measurements following the harvest indicated greater leaf growth and a higher leaf number for plants grown in compost, with plants grown in compost/sludge and soil/ sludge mixtures showing second and third best growth respectively. Concentrations of cadmium, lead, nickel in the plant tissue increased for plants grown with sludge, though this was much less marked in the case of chromium. Plants growing in higher proportions of sludge generally showed depression of growth probably indicating toxic effects arising from the metals contained in the sludge. The metal uptake by plants from sludge amended soil was influenced by time of harvesting and stage of growth.

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