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EFFECT OF WATER TREATMENT SLUDGE ON GROWTH AND ELEMENTAL COMPOSITION OF TOMATO (LYCOPERSICON ESCULENTUM) SHOOTS [1]

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ABSTRACT

The impact of a water treatment sludge on the fertility of a silt loam soil was assessed by monitoring the yield and elemental composition of tomato (Lycopersicon esculentum) shoots in a greenhouse study. Application of sludge at rates from 2-10% (air dry weight basis) raised the soil pH from 5.3 to 8.0 which enhanced plant growth. A substantial reduction in metal (Cd, Zn, Cu, Ni) uptake was observed with sludge amendments, even at the highest rates. The alkaline nature of this sludge (pH=9.3, calcium carbonate equivalence=53%) suggests its potential use as a liming material for agricultural soils. Overly alkaline conditions should be avoided however, as high application rates combined with ammonia fertilization had an antagonistic effect on plant growth, possibly from P deficiency induced by struvite ($MgNH_4PO_4$) formation.

INTRODUCTION

Purification of water for human consumption usually involves addition of coagulants (iron salts, lime, alum) with a resulting production of sludge. Although the nature and quantity depend on the purpose of coagulation (i.e., turbidity, hardness, Fe/Mn removal), such sludges consist primarily of the precipitated hydroxide of the coagulant (e.g., $Fe(OH)_3$) along with material (sand, silt, clay, bacteria, color-forming compounds) removed from the raw water. Barring a grossly contaminated water source, water treatment residuals have a relatively low potential for adverse environmental effects compared to wastewater sludges.

Since water treatment sludges are relatively innocuous, the predominant disposal method, at least prior to the Water Pollution Control Act Amendments of 1972 (PL 92-500), was direct discharge to surface waters. This law, however, along with many state regulations, classified coagulation sludges under the broad category of "industrial wastes," thereby necessitating stringent disposal requirements. Some cities dispose of coagulation sludges in the municipal sewage system, a practice which transfers the burden of ultimate disposal. Landfilling, the other major alternative, is becoming more difficult as space becomes limited. Another disadvantage is the costly dewatering required before acceptance by landfills.

Compared to the wealth of research on wastewater sludges, land application of water treatment residues has received little attention. Accordingly, the objective of the current study was to investigate the feasibility of ultimate disposal of water treatment sludges through land application, using a ferric chloride sludge from Philadelphia's Torresdale treatment plant. The effect on soil fertility was studied by monitoring the growth and elemental composition of tomato (*Lycopersicon esculentum*) shoots. Two disposal scenarios were studied. First, sludge was applied at high rates (2-10% air dry weight sludge: air dry weight soil) to assess the use of land strictly as a disposal site, without regard to maintaining optimum soil fertility conditions. Second, the sludge was applied at low rates (0.5%) to investigate its possible use as a liming agent for agricultural land.

TABLE 1

Chemical Analysis (Dry Weight Basis) of Soil and Sludge

Element		Soil	Fe Sludge
Cd	ppm	0.95	1.30
Cr	ppm	65.2	432.2
Cu	ppm	72.4	125.4
Mn	ppm	408.1	4826.8
Mo	ppm	0.53	4.85
Na	ppm	3486.1	461.8
Ni	ppm	154.6	306.8
Zn	ppm	82.2	408.8
Al	%	4.4	1.6
Ca	%	0.2	15.0
Fe	%	1.9	10.9
K	%	1.6	0.3
Mg	%	0.3	1.6
$CaCO_3$ equivalence (%)		-	52.9
pH		5.3	9.3
Kjeldahl N (ppm)		117	554

MATERIALS AND METHODS

An Elkton silt loam (clayey, mixed, mesic typic Ochraquult) collected from an uncultivated area covered by natural vegetation was used in this study. The soil was air-dried, ground, and sieved to remove stones, large clods, and undecayed organic matter. The sludge was generated from a ferric chloride coagulation process in which lime was used for pH control. After air-drying, the sludge was ground, sieved, and homogeneously incorporated into the soil. The chemical analysis of soil and sludge is shown in Table 1.

Marglobe tomato (*Lycopersicon esculentum*) seeds were sown in vermiculite and seedlings were transplanted at the first true leaf stage into standard 10 cm diameter plastic pots containing a total of 450 g (air dry) of soil or sludge-soil mixtures. Seedlings were grown under natural light in a glass-covered greenhouse and were watered as needed. Shoots were cut at the growth medium surface approximately 7 weeks after transplanting and the fresh weight was determined. Shoots were oven-dried, ground (40-mesh screen), and dry-ashed in a muffle furnace at 450^{o}C for 12 hours. The ash was dissolved in 6 N HCl and diluted to a constant volume of 50 ml with distilled-deionized water. For limed treatments, reagent-grade $CaCO_3$ was added in amounts to attain the same final pH as the sludge treatments.

The soil and sludge were dissolved using an aqua regia-hydrofluoric digestion procedure (3). Elemental analysis of the solutions from digestion of the soil, sludge and plant materials was performed using flame or flameless (Cd, Cr, Mo) atomic absorption spectrophotometry. Plant P levels were evaluated using the vanadium-molybdate colorimetric method (4).

RESULTS AND DISCUSSION

Application of the sludge at rates from 2-10% by weight raised the pH of the soil from 5.3 to 8.0 (Table 2). Concomittant with the elevation in pH was a significant enhancement in shoot fresh weight (Table 2). The idea that the stimulatory effect was due to reduced elemental (Al and Mn) toxicity was initially entertained. But dramatic growth response to liming is usually associated with more acidic soils (5). Furthermore, Mn tissue concentrations for the 10% sludge treatments (pH 8.01) were significantly higher than the unamended soil (pH 5.33).

A second possibility for the growth increase with sludge incorporation was a response to N contained in the sludge. The sludge contains very low levels of N (0.06% - Table 1) compared to the 2-4% levels typically found in sewage sludges. Clearly, the sludge cannot be considered as a N fertilizer, but since the soil was collected from a previously unfertilized location, the plants may have responded to these small N additions.

TABLE 2. Soil-Sludge Mixture, pH, Shoot Fresh Weight, and Concentration of Selected Elements in Tomato Shoots (Study 1 - high application rates, no fertilization)

% Sludge	pH	Fresh Weight (grams)	Al	Cd	Cu	Fe	Mn	Ni	Zn	Ca	K	Mg
			ppm							(%)		
0	5.33^{a*}	3.56^{a}	275.7^{a}	1.49^{a}	41.0^{a}	273.7^{a}	135.2^{a}	14.91^{a}	334.6^{a}	2.20^{a}	3.60^{a}	0.69^{a}
2	7.96^{b}	8.82^{b}	104.2^{b}	0.14^{b}	24.6^{b}	160.1^{b}	53.8^{b}	8.81^{b}	87.5^{b}	3.16^{b}	2.50^{b}	0.81^{a}
4	8.04^{bed}	9.54^{b}	152.0^{b}	0.11^{b}	24.0^{b}	219.1^{ab}	88.5^{ab}	8.34^{b}	92.4^{b}	2.90^{c}	2.44^{b}	1.06^{b}
6	8.09^{cd}	10.36^{b}	73.4^{b}	0.10^{b}	27.1^{b}	144.1^{b}	111.3^{ac}	8.84^{b}	101.4^{bc}	2.63^{d}	2.48^{b}	1.30^{c}
8	8.11^{d}	9.86^{b}	146.2^{b}	0.08^{b}	30.9^{c}	209.7^{ab}	159.9^{cd}	10.68^{b}	114.0^{cd}	2.49^{d}	2.80^{b}	1.62^{d}
10	8.01^{bc}	9.36^{b}	135.3^{b}	0.09^{b}	33.8^{c}	242.7^{a}	194.3^{d}	9.82^{b}	119.2^{d}	2.41^{ab}	2.84^{b}	2.00^{e}

*Values followed by the same notation within a column do not differ at the 0.05 significance level according to Duncan's Multiple Range test.

TABLE 3. Effect of Fertilization and Liming on Shoot Fresh Weight, P, and Mg

Description		pH	Fresh Weight (gm)	P (%)	Mg (%)
Study 2a (unfertilized)	Control	5.75a*	6.93a	0.22a	0.36a
	Limed	7.81b	8.63a	0.33b	0.30a
	6% sludge	8.08b	14.13b	0.21a	0.74b
Study 2b (fertilized)	Control	4.99a	8.38a	0.50a	0.27a
	Limed	7.51b	6.63a	0.44a	0.24a
	6% sludge	7.68b	3.40b	0.24b	0.74a

* Values followed by the same notation within a column do not differ at the 0.05 significance level, according to Duncan's Multiple Range Test.

To test the N response hypothesis, Study 2 was initiated to investigate the effect of weekly growth medium saturation with 20-20-20 (%N-P-K) fertilizer at 100 ppm N on three treatments (control, limed, 6% sludge addition). Rather unexpectedly, fertilizer application gave reduced growth in the sludge-amended pots compared to the controls (Table 3). Leaves showed purple venation, characteristic of P deficiency. Shoots from the sludge treatments did, in fact, have significantly lower P contents (Table 3).

In basic soils, P deficiency can result from formation of sparingly soluble phosphate compounds. Data in Tables 2 and 3, however, suggest that these differences in shoot P content reflected more than strictly a pH effect. For example, high pH values were accompanied by increased growth in Study 1 (Table 2), and in Study 2a (Table 3) liming with $CaCO_3$ did not stimulate plant growth to the same extent as addition of sludge. In addition, fertilized treatments limed to the same pH as the sludge-amended pots had significantly higher tissue P contents (Table 3). This fact, coupled with the lack of significance difference in tissue P contents in control versus sludge-amended treatments in the unfertilized study (Table 3), suggests that this apparent P deficiency results from a sludge constituent interacting in some manner with the fertilizer .

Reduced availability of P could be due to its precipitative immobilization as magnesium ammonia phosphate, struvite ($MgNH_4PO_4$). This compound is very insoluble (K_{so}=$2.5x10^{-13}$) under the alkaline conditions induced by sludge addition (6). The sludge, with a considerable Mg content (Table 1), could easily serve as the source of Mg for struvite formation, while the ammonium ion is provided by the fertilizer. Struvite precipitation is a recognized problem in anaerobic digesters at sludge treatment facilities where elevated pH levels are accompanied by sufficient Mg^{2+}, NH_4^+, and PO_4^{3-} activities to exceed the solubility product (7). An antagonistic effect of ammonium addition on crop uptake of Mg has been documented (8).

If water treatment sludges were applied to cropland, application of additional nutrients (N, P, K) would be essential. Since such sludges are likely to have substantial Mg content, avoiding elevated pH conditions is important in preventing precipitation-induced deficiencies. To this end, another study was initiated wherein the sludge application rate (0.5%) raised the soil pH to about 6.4, a typical target value in liming of agricultural soils. The treatments were fertilized weekly with 100 ppm N ammonium sulfate solutions. In this experiment, the addition of sludge significantly enhanced plant growth (Table 4). Since the limed treatments had greater shoot fresh weight than the controls, reduced Mn toxicity through elevated pH may be responsible, in part, for this effect. Manganese toxicity may have occurred in the control treatments with a pH of 4.9, as 1000 ppm Mn in tomato shoots (Table 4) could be toxic (5). The inability to predict and therefore equalize the final pH values made it difficult to precisely identify the cause of increased growth in sludge-amended compared to the limed treatment. Two

TABLE 4. Content of Selected Elements in Tomato Plants (Study 3 - low application rates, with N fertilization)

	pH	Fresh Weight (grams)	Al	Cd	Cu	Fe	Mn	Ni	Zn	P
			ppm							%
Control (no sludge)	4.92^{a}*	2.03^{a}	129.4^{a}	1.37^{a}	50.2^{a}	214.5^{a}	991.2^{a}	6.14^{a}	334.7^{a}	0.14^{a}
Limed	6.12^{b}	4.80^{b}	73.4^{b}	0.22^{b}	17.1^{b}	180.3^{a}	94.1^{b}	4.88^{a}	79.7^{b}	0.19^{b}
0.5% sludge	6.38^{c}	6.97^{c}	52.4^{c}	0.10^{b}	15.4^{b}	140.1^{a}	47.3^{b}	4.80^{a}	76.6^{b}	0.17^{ab}

*Values followed by the same notation within a column do not differ at the 0.05 significance level, according to Duncan's Multiple Range Test.

possibilities exist: a further reduction in elemental toxicity or a response to some undetermined micronutrient (e.g. Mo) in the sludge.

A substantial reduction in heavy metal (Cd, Zn, Cu, Ni) uptake was observed with the addition of sludge (Table 4), even at high application rates (Table 2). The sludge itself does not contain excessive heavy metal concentrations (Table 1). Solid phase precipitation at elevated pH values rendered the metals less available to plants. This is supported by the fact that lime alone had the same ability to reduce tissue metal concentrations (Table 4). Under the conditions of this study, plant uptake of heavy metals from sludge-amended soils was minimal. The finding that uptake of heavy metals is generally greater in greenhouse versus field experiments (9) would indicate even lower metal uptake under actual field conditions.

Because of the alkaline nature of this sludge (pH 9.3, calcium carbonate equivalence=53%), it has potential use as a liming material for agricultural soils. Water treatment residues, particularly lime softening sludges, have been substituted for commercial lime in the past (10). This research indicates that sludges generated from $FeCl_3$ - lime addition may also be suitable for this purpose.

CONCLUSIONS

Land application may be a feasible disposal method for residues generated at water treatment works which use iron salts as the primary coagulant. While containing essential macro- and micronutrients, the sludge used in this study did not contain excessively high concentrations of toxic metals. The naturally alkaline condition of the sludge should help to immobilize toxic heavy metals, thereby reducing the potential for plant uptake or leaching to groundwater. A possible beneficial use of the sludge would be as a lime substitute for agricultural purposes. As with other liming materials, overly-alkaline conditions must be avoided to insure that precipitation-induced nutrient deficiencies do not occur.

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