Potential of Amending Soil with Industrial Slags

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Introduction

Industries in the Great Lake States annually generate large quantities of waste materials that require disposal. However, many of the wastes can be recycled or used for productive purposes. For example, antibiotic production wastes, vegetable processing wastes, papermill lime sludges, and a variety of other industrial sludges have been added to soils to provide plant available nutrients and to increase organic matter levels (Nelson and Sommers, 1979); Simpson et al., 1979; Blondin et al., 1982; Smith and Peterson, 1982). Other wastes such as fly ash, cement kiln flue dusts, and blast furnace slags have been used as soil liming agents because they contain oxides, carbonates, or silicates of divalent alkaline earth metals (Tisdale and Nelson, 1956; Whittaker et al., 1959; Walker et al., 1979). A number of other industrial wastes (e.g., foundry slags, rockwool insulation wastes, and water softening waste slurries) may be potentially useful as liming materials (Goodwin et al., 1982). However, little is known about the effectiveness of most of industrial wastes in neutralizing soil acidity or about the phytotoxicity of the materials. The objective of this study was to determine the usefulness of two types of industrial wastes, foundry slags and rockwool manufacturing residuals, as soil liming agents through a combination of physical and chemical characterization and soil incubation studies. Since solubility (primarily particle size) and neutralizing potential (calcium carbonate equivalent) are important criteria in evaluating materials as liming agents, major emphasis was placed on physical and chemical characterization of wastes.

Materials and Methods

Samples of wastes were collected from manufacturing facilities in the Midwestern United States. The wastes were air-dried and the particle size distribution was determined by sieving. A subsample of each waste was ground to <0.5 mm and a portion of the ground sample was digested with $HF:HNO_3$ (Pratt, 1965). Calcium, Mg, Fe, Mn, Zn, and Cu concentrations in the digests were determined by atomic absorption and P and Si levels were determined by colorimetric methods (Sommers and Nelson, 1972; Kilmer, 1965). The calcium carbonate equivalent (CCE) was determined by equilibrating a sample of the ground waste with a known amount of 0.5 *N* HCl and backtitrating unreacted HCl with standard NaOH. The amount of HCl neutralized per unit weight of waste was expressed as a percentage of the HCl neutralized per unit weight of reagent grade $CaCO_3$.

Three moderately acidic surface horizons of Indiana soils were used in the incubation study. Maumee sandy loam (sandy, mixed, mesic Typic Haplaquoll) had the following characteristics: pH, 4.7; CEC, 18.1 meq/100 g; organic C, 1.64%; lime requirement, 10.4 Mtons $CaCO_3$/ha. Chalmers silty clay loam (fine silty, mixed, mesic Aeric Ochraqualf) had the following characateristics: pH, 5.9; CEC, 27 meq/100 g; organic C, 2.2%; lime requirement, 6.1 Mtons $CaCO_3$/ha. Russell silt loam (fine-silty, mixed mesic Typic Hapludalf) had the following characteristics (pH, 5.3; CEC, 21 meq/100 g; organic C, 1.6%; lime requirement, 7.5 Mtons $CaCO_3$/ha).

One hundred g samples of soil (<2 mm) were treated with variable amounts

of unground or ground (<0.86 mm wastes, reagent grade $CaCO_3$ (powder), or commercial agricultural limestone (28% was <0.23 mm) to provide from 1 to 4 times the lime requirement of the soil. The water content of the soil was maintained at -0.3 bar pressure 24% H_2O, w/w) and the samples were incubated at 24°C for up to 4 months. The pH of amended and unamended soils was periodically measured during the incubation by a glass electrode using a 1:1 soil:water ratio.

The phytotoxicity of wastes was evaluated by amending 1.5 kg samples of soil contained in plastic pots with rates of wastes or $CaCO_3$ similar to those used in soil incubation studies, adding adquate levels of N, P, and K to samples, and planting 4 corn or soybean seeds in each pot. Plants were grown in the greenhouse for 6 weeks at 26°C, the above ground portions of the plants were harvested, and dry matter yield per pot was determined.

Results and Discussion

Particle size analysis revealed that a small proportion (avg. = 6.5%) of foundry slag were >3.35 mm (>6 mesh) in diameter, whereas more than 30% of rockwool waste was >3.35 mm (Table 1). A high proportion (avg. = 61.1%) of slag particles had a diameter between 0.86 (20-mesh) and 3.35 mm, but only 23.4% of rockwool particles were in that size range. More than 46% of rockwool particles were < 0.86 mm, whereas an average of 32.4% of foundry slag particles were < 0.86 mm. From 25-35% of the particles in much of the agricultural limestone in Indiana are <0.23 mm (<60-mesh), whereas only 2.2% and 7% of slags and rockwool waste, respectively, were <0.23 mm. The low proportion of small particles (<0.23 mm) suggests that the wastes may have low solubility and, thus, be slow to react.

The CCE of rockwool waste and slags were 89 and 94.9%, respectively (Table 1). The Ca, Mg, and Si concentrations in the slags averaged 25.0, 0.5, and 19.3%, respectively, whereas the rockwool waste contained 13.7% Ca, 3.6% Mg, and 17.7% Si. The substantial amounts of Ca and Si in wastes suggest that the high CCE values originate largely from the presence of $CaSiO_3$ and CaO (the pure form of these compounds have CCE values of 86 and 179%, respectively). The rockwool waste may also contain MgO and/or $MgSiO_3$ (both good liming agents). The high CCE value of the wastes suggest that they may be useful as soil liming agents. The slags and rockwool waste contained 2.1 and 5.1% Fe, respectively, and trace amounts of Mn, Zn, Cu, and P (data not presented).

The addition of high rates (>11.4 Mton/ha) of the four slags resulted in modest increases in soil pH (Table 2). After 2 months of incubation the increases of pH obtained from addition of unground slag were 20% of those observed with similar

TABLE 1. *Physical and chemical characteristics of industrial wastes used in the study (all data are expressed on dry weight basis).*

Component	Slag 1	Slag 2	Slag 3	Slag 4	Rockwool waste
Particle size dist.					
>3.35 mm, %	7.6	2.1	10.9	5.3	30.3
0.86-3.35 mm, %	54.5	57.5	71.3	61.1	23.4
<0.86 mm, %	37.9	40.4	17.8	33.6	46.3
<0.23 mm, %	3.7	2.1	0.8	2.1	7.0
$CaCO_3$ equiv., %	91.5	109.5	89.5	89.0	89.0
Ca, %	25.0	25.5	22.5	26.8	13.7
Mg, %	0.6	0.4	0.4	0.5	3.6
Si, %	16.4	17.7	22.8	20.2	17.7

TABLE 2. *Increase in pH of two soils as affected by addition of variable rates of calcium carbonate, limestone, or slags.*

Material added		1 month incubation	2 month incubation	
Type	Amount	Maumee sl.+	Chalmers sicl.+	Maumee sl.+
	Mtons/ha	increase in pH		
$CaCO_3$	5.7	1.01	1.48	1.39
$CaCO_3$	11.4	1.75	1.67	2.02
$CaCO_3$	17.0	1.94	1.76	2.51
$CaCO_3$	22.7	2.09	1.78	2.69
Limestone	11.4	0.56	0.98	0.82
Limestone	22.7	0.95	1.09	1.11
Slag 1 (Orig.)	22.7	0.14	0.28	0.20
Slag 1 (<0.86 mm)	11.4	0.47	0.48	0.47
Slag 1 (<0.86 mm)	22.7	0.59	0.68	0.70
Slag 2 (Orig.)	22.7	0.19	0.19	0.21
Slag 2 (<0.86 mm)	11.4	0.20	0.25	0.38
Slag 2 (<0.86 mm)	22.7	0.28	0.36	0.50
Slag 3 (Orig.)	22.7	0.11	0.16	0.26
Slag 3 (<0.86 mm)	11.4	0.15	0.15	0.31
Slag 3 (<0.86 mm)	22.7	0.19	0.16	0.25
Slag 4 (Orig.)	22.7	0.13	0.23	0.22
Slag 4 (<0.86 mm)	11.4	0.21	0.19	0.30
Slag 4 (<0.86 mm)	22.7	0.31	0.27	0.38

+Lime requirements for Maumee sandy loam and Chalmers silty clay loam were 10.4 and 6.1 metric tons of $CaCO_3$ per hectare, respectively.

rates of limestone and only 8% of those attained from application of $CaCO_3$. Grinding slag to <0.86 mm increased the solubility such that addition of 22.7 Mtons/ha raised the pH of Maumee soil to 41% and 17% of that attained from limestone and $CaCO_3$, respectively. Similar results were attained with slag addition to Chalmers soil. The increase in soil pH observed during the period between 1 and 2 months of incubation suggests that the pH may have increased further if the incubation had continued. A number of studies with agricultural limestone have suggested that about 50% of the long term pH increase occurs in the first 2 months of incubation. The pH increase obtained with limestone was 50 and 41% of that with $CaCO_3$ (11.4 Mtons/ha rate) added to Chalmers and Maumee soil, respectively, indicating the effect of particle size on rate at which acidity is neutralized.

Calcium carbonate completely reacted in Russell silt loam soil during 8 weeks of incubation (Table 3) After 16 weeks of incubation unground rockwool waste (all rates) increased soil pH to 35% of that obtained with a 7.5 Mtons/ha addition of $CaCO_3$. The pH levels of soil treated with rockwool waste increased with increasing time of incubation suggesting that given enough time the waste may be a satisfactory liming agent. The rate of reaction of ground rockwool waste was faster than that of unground waste. After 16 weeks of incubation ground rockwool waste added to soil at rates of 8.4, 16.9, and 25.3 Mtons/ha increased pH to 38, 48, and 59% of that obtained from adding 7.5 Mtons of $CaCO_3$/ha.

Greenhouse experiments established that similar dry matter yields of corn and soybeans were obtained in soils treated with high rates (>20 Mtons/ha) of wastes plus NPK fertilizer and soils receiving only NPK (data not shown). However,

TABLE 3. *Increase in pH of Russell silt loam soil as affected by addition of varying rates of calcium carbonate or rockwool waste (soil had a lime requirement of 7.5 metric tons/ha).*

Material added		Incubation time, weeks			
Type	Amount	2	4	8	16
	Mtons/ha	increase in pH			
$CaCO_3$	7.5	0.79	1.94	2.01	2.01
	15.0	0.98	1.93	2.10	2.17
	22.5	1.13	1.98	2.31	2.32
Rockwood waste (Orig.)	8.4	0.05	0.10	0.37	0.70
	16.9	0.16	0.27	0.42	0.72
	25.3	0.23	0.42	0.43	0.72
Rockwool waste (ground)+	8.4	0.05	0.32	0.49	0.77
	16.9	0.24	0.50	0.64	0.97
	25.3	0.52	0.62	0.97	1.19

+Rockwool waste was ground such that 89% was <0.5 mm.

the NPK treatment gave higher yields than the unfertilized control. This finding indicates that slags and rockwool waste were not phytotoxic to plants and that it is likely these wastes can be safely applied to cropland.

The results of this study indicate that foundry slags and rockwool waste may be useful as soil liming agents if they are applied at high rates and long periods of time are allowed for neutralization of soil acidity. Grinding the wastes increases solubility and speeds up the rate at which soil acidity is neutralized.

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