THE USE OF CEMENT KILN BY-PASS DUST AS A LIMING MATERIAL IN THE REVEGETATION OF ACID, METAL-CONTAMINATED LAND.

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ABSTRACT

Cement kiln by-pass dusts from Canada Cement Lafarge Ltd. plants at Woodstock and Bath, Ontario, respectively, were tested as limestone substitutes in reclaiming acid, metal-contaminated soils from the Sudbury area. Laboratory, growth chamber and field trials showed that both dusts constituted effective liming materials at an application rate of approximately 10 t/ha. Toxic effects were found only in the case of Bath dust, at an application rate of 50 t/ha. In sandy soil, Bath dust at 50 t/ha also inhibited seed germination. This inhibition disappeared after a few days, presumably due to the leaching of soluble alkaline materials and chlorides. In pots, the addition of N-P-K fertilizer lessened the toxic effect of Bath dust, while in the field it converted the effect of the dust from inhibition to stimulation. These by-pass dusts have good potential as liming materials in reclaiming Sudbury's industrial barrens, but their caustic nature precludes their use at this time, in view of the predominantly manual application techniques that prevail.

INTRODUCTION

One hundred years of logging, fire, acidification by sulphur dioxide, particulate metal deposition and erosion have created extensive tracts of barren land surrounding the Sudbury nickel and copper smelters (Winterhalder, 1984). Following recent improvement in atmospheric quality, the principal factors limiting colonization now reside in the soil, mainly in the form of copper, nickel and aluminum toxicity. The soil can be detoxified by limestone application (Winterhalder, 1974), and since 1978 approximately 1000 hectares (2500 acres) have been revegetated by manual liming, fertilization and seeding (Winterhalder, 1983a). It has been shown (Winterhalder, 1983b) that both the calcium ions and the neutralization component of limestone are operative in the detoxification of Sudbury's toxic soils.

Fortunately, Sudbury's mining and smelting industry has been able to minimize the emission of toxic particulate wastes by the use of efficient electrostatic precipitators, making the soil toxicity problem a residual one that can be dealt with by the measures outlined above. Mill tailings, another major solid waste product, can also be rendered innocuous by revegetation (Peters, 1984), while slag is utilized as road building material. In the case of the cement industry, the major solid waste, highly alkaline by-pass dust, creates its own disposal problem. In Derbyshire, England, an effective solution has been to cover the lime waste with spent mushroom compost (Bradshaw & Chadwick, 1980). A 10 cm layer increases the carbonation rate of the underlying lime waste, allowing plants to root into it and producing excellent agricultural land.

In Ontario, it seemed appropriate to explore the possibility of another type of "recycling", once again using one waste product to counteract the effects of another one. Since the Sudbury barrens are in need of a material that provides both calcium ions and hydroxyl ions, it seemed logical to test cement kiln by-pass dust, an alkaline, calcium-rich material, as an ameliorant and limestone substitute.

MATERIALS AND METHODS - POT TRIALS

Soils.

Four soils were chosen to represent different sand, clay and organic matter contents. Each was both acid and metal-contaminated, and was taken from a barren or semi-barren site. The sample was taken from what might be considered as the "rooting zone" of most herbaceous plants (0-15 cm).

The soils were as follows:

Soil 1. A silty fine sand from the valley of Coniston Creek, 2 miles northeast of the Coniston smelter (Barren ground, pH 4.5).

Soil 2. A clay soil from Coniston, 1 mile south of the smelter (Barren ground, pH 4.5).

Soil 3. A sandy soil containing some organic matter, from near Wahnapitae, 3½ miles northeast of the Coniston smelter (semi-barren, pH 4.1).

Soil 4. A sandy soil containing some organic matter from the Skead area, 4 miles north-northeast of the Falconbridge smelter (semi-barren, pH 4.5).

Each soil was passed through a coarse sieve in order to remove large stones. A small sample of each soil was kept for later analysis if necessary.

Neutralizing Materials.

Two samples of by-pass dust were provided by Canada Cement Lafarge Ltd.. Chemical data on the materials, as provided by the company, are given in Table 1. In addition to the two dust samples, analytical grade calcium carbonate was used as a control liming material.

TABLE 1. Partial Chemical Analysis of By-pass Dust Samples

Component	Bath Dust	Woodstock Dust
SiO_2	11.3	16.0
Al_2O_3	2.5	2.3
Fe_2O_3	1.3	1.4
CaO	36.5	39.6
MgO	1.4	2.1
K_2O	5.0	7.7
Na_2O	1.2	0.8
SO_4	8.6	12.7
Cl	9.7	not determined
CO_2	10.4	not determined
pH	12.6	not determined

(pH determinations carried out at Laurentian University gave values of 11.2 $\pm$ 0.2 for both dusts)

The above data are not complete enough to predict the relative neutralizing power and toxicity of the two by-products.

Pots.

Three-inch plastic plant pots (soil capacity 160 ml) were used, the three drainage holes being covered by filter paper.

Incorporation of neutralizing materials.

The neutralizing material was thoroughly mixed into the dry soil by shaking them together in a plastic bag before replacing the soil in its pot.

Soil pH Determination.

Soil was wetted to the saturation percentage point (Jackson, 1958), and the pH determined on the paste with a glass electrode pH meter.

Plants.

Redtop (Agrostis gigantea), a grass species widely used in land reclamation, was grown from commercially available seed. A standard measure of seeds (0.2 ml) was sprinkled onto the soil surface.

Incubation and Growth Conditions.

Incubation without seed and initial germination of seed were carried out on a laboratory bench at approximately 25°C, the pots being covered by dark plastic sheeting.

Growth was carried out in a growth chamber set for a 16 hours of daylight/8 hours of darkness cycle, the day temperature being 25°C, the night temperature 15°C.

Criteria of Plant Growth.

At the end of six weeks, plants were observed for average height, maximum leaf width, purpling, chlorosis, and chlorotic banding. The tops were clipped as close as possible to the soil surface, dried in an oven at 80°C and weighed.

INCUBATION EXPERIMENTS

In the first experiment, each of the four soils was incubated with eight levels of by-product, varying from zero to an equivalent of 50 t/ha, for a period of five days. Final soil pH values are given in Tables 2a - 2d.

TABLE 2a. FINAL pH OF CLAY SOIL FROM SOUTH OF CONISTON AFTER INCUBATING WITH VARIED AMOUNTS OF DUST. (n=1)

g of dust	Equivalent in t/ha	Woodstock dust	Bath dust
0	0	(5.4)*	4.5
0.1	1.0	4.5	4.4
0.25	2.5	5.3	4.8
0.5	5.0	5.5	5.5
1.0	10.0	6.0	6.1
1.5	15.0	6.2	7.0
2.0	20.0	7.1	(6.2)*
5.0	50.0	7.4	7.7

TABLE 2b. FINAL pH OF SANDY SOIL FROM CONISTON-GARSON ROAD AFTER INCUBATING WITH VARIED AMOUNTS OF DUST. (n=1)

g of dust	Equivalent in t/ha	Woodstock dust	Bath dust
0	0	4.8	5.0
0.1	1.0	5.6	5.2
0.25	2.5	5.8	5.6
0.5	5.0	6.3	6.2
1.0	10.0	6.6	6.6
1.5	15.0	6.9	7.1
2.0	20.0	6.9	7.3
5.0	50.0	7.7	8.6

TABLE 2c. FINAL pH OF SANDY, HUMIC SOIL FROM SOUTH OF SKEAD (n = 1)

g of dust	Equivalent in t/ha	Woodstock dust	Bath dust
0	0	4.5	4.7
0.1	1.0	4.7	4.7
0.25	2.5	5.1	5.1
0.5	5.0	5.7	5.4
1.0	10.0	6.3	6.0
1.5	15.0	6.6	6.2
2.0	20.0	6.8	6.7
5.0	50.0	7.4	8.1

TABLE 2d. FINAL pH OF SANDY, HUMIC SOIL FROM NORTH OF WAHNAPITAE (n = 1)

0	0	4.1	4.2
0.1	1.0	4.6	4.6
0.25	2.5	(4.1)*	4.6
0.5	5.0	5.1	5.0
1.0	10.0	5.9	5.7
1.5	15.0	6.8	6.2
2.0	20.0	7.0	6.3
5.0	50.0	7.3	8.0

* These highly inconsistent values are almost certainly due to experimental error.

A desirable pH of around 6.5 was obtained at between 5 and 10 t/ha in the sandy soil, between 10 and 20 t/ha in the clay soil and between 15 and 20 t/ha in the soil with high organic content. At 50 t/ha, excessively high pHs for plant growth (pH 8 and above) were obtained with the Bath product.

At the termination of this trial, it was converted into a preliminary growth trial by applying Redtop seeds and growing the plants for 30 days. Since the experiment was not replicated, results are not tabulated in this report, but some definite trends were evident. In general, Woodstock dust gave increased plant growth up to at least 10 t/ha, with no significant growth depression even at a 50 t/ha application rate. The Bath product gave a similar growth increase up to 10 t/ha, but at 50 t/ha showed a highly toxic reaction, with plant growth reduced below the control level.

In the second incubation experiment, calcium carbonate was included as a control ameliorant, and was compared with the Bath dust only. Each of the four soils was incubated with four levels of additive, representing the equivalent of 10 t/ha to 25 t/ha. This experiment was designed to work within the non-toxic range, so that the effectiveness of the by-product could be compared with that of calcium carbonate. After five days, pH was measured in each pot. Final soil pH levels are shown in Tables 3a to 3d..

Calcium carbonate appeared to be somewhat more effective than Bath dust in neutralizing the soil, e.g. in the clay soil, 15 t/ha of Bath dust were required to achieve a desirable pH of 6.5, whereas only 10 t/ha of $CaCO_3$ were required to achieve an almost equivalent pH of 6.3.

Once again, seeds were sown and the plants grown for 30 days. Within the limits of this unreplicated experiment, growth was quite good

TABLE 3a. FINAL pH OF CLAY SOIL FROM SOUTH OF CONISTON AFTER INCUBATING WITH VARIED AMOUNTS OF BATH DUST AND $CaCO_3$ (n = 1)

g of dust	Equivalent in t/ha	Bath dust	$CaCO_3$
1.0	10.0	5.6	6.3
1.5	15.0	6.5	7.1
2.0	20.0	6.1	7.2
2.5	25.0	6.8	6.8

TABLE 3b. FINAL pH OF SANDY SOIL FROM CONISTON-GARSON ROAD AFTER INCUBATING WITH VARIED AMOUNTS OF BATH DUST AND $CaCO_3$ (n = 1)

g of dust	Equivalent t/ha	Bath dust	$CaCO_3$
1.0	10.0	6.5	7.3
1.5	15.0	7.0	7.3
2.0	20.0	7.5	7.5
2.5	25.0	7.5	7.5

TABLE 3c. FINAL pH OF SANDY, HUMIC SOIL FROM SOUTH OF SKEAD AFTER INCUBATING WITH VARYING AMOUNTS OF BATH DUST AND $CaCO_3$ (n = 1)

g of dust	Equivalent in t/ha	Bath dust	$CaCO_3$
1.0	10.0	6.2	7.2
1.5	15.0	6.8	7.4
2.0	20.0	7.0	7.5
2.5	25.0	7.3	7.5

TABLE 3d. FINAL pH OF SANDY, HUMIC SOIL FROM NORTH OF WAHNAPITAE AFTER INCUBATING WITH VARYING AMOUNTS OF BATH DUST AND $CaCO_3$ (n = 1)

g of dust	Equivalent in t/ha	Bath dust	$CaCO_3$
1.0	10.0	5.9	6.8
1.5	15.0	6.3	7.3
2.0	20.0	6.8	7.6
2.5	25.0	7.2	7.6

under all treatments and no definite trends emerged, suggesting that by-pass dust and calcium carbonate are equally effective liming materials when application rates are kept within the by-product's non-toxic range.

GROWTH EXPERIMENT AT OPTIMAL AMELIORANT LEVELS

Each soil was mixed with calcium carbonate, Woodstock dust and Bath dust equivalent to 5, 10 and 20 t/ha, respectively and sown with Redtop seed. Each treatment was replicated five times. Final soil pH values and dry weight production of tops are given in Tables 4a to 4d.

In all cases, the cement kiln dusts were effective in promoting plant growth at the levels used. Woodstock dust was approximately equal to calcium carbonate in its effectiveness, Bath dust slightly less so.

GROWTH EXPERIMENT AT POTENTIALLY TOXIC AMELIORANT LEVELS

This experiment was designed to explore the relative toxicities of the by-products at high application rates. Each soil was treated with calcium carbonate, Woodstock dust and Bath dust at levels equivalent to 30, 40 and 50 t/ha, respectively, and sown with Redtop seed. Final soil pH values and dry weight of tops are shown in Tables 5a to 5d.

In all soils growth enhancement was found in all treatments except Bath dust at 40 and 50 t/ha, which depressed growth. In the sandy Coniston soil, 50 t/ha of Bath dust even inhibited germination.

GROWTH EXPERIMENT AT POTENTIALLY TOXIC AMELIORANT LEVELS, WITH VARIED LEACHING REGIMES AND INCUBATION TIMES

This experiment was designed to test two hypotheses. It has been

TABLE 4a. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON CLAY SOIL FROM SOUTH OF CONISTON AFTER TREATMENT WITH VARYING AMOUNT OF CALCIUM CARBONATE, BATH DUST AND WOODSTOCK DUST. (n = 5)

g of material	Equivalent in t/ha	$CaCO_3$		Bath		Woodstock	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
0.5	5.0	5.4	0.514 ± 0.025	4.7	0.400 ± 0.045	4.9	0.484 ± 0.035
1.0	10.0	6.6	0.538 ± 0.039	5.3	0.408 ± 0.032	5.4	0.500 ± 0.013
2.0	20.0	7.5	0.632 ± 0.027	6.4	0.404 ± 0.029	6.5	0.548 ± 0.021

TABLE 4b. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON SANDY SOIL FROM THE CONISTON-GARSON ROAD AFTER TREATMENT WITH VARYING AMOUNTS OF CALCIUM CARBONATE, BATH DUST AND WOODSTOCK DUST. (n = 5)

g of material	Equivalent in t/ha	$CaCO_3$		Bath		Woodstock	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
0.5	5.0	6.6	0.072 ± 0.006	6.1	0.110 ± 0.003	6.2	0.066 ± 0.007
1.0	10.0	7.5	0.068 ± 0.007	6.7	0.088 ± 0.002	6.8	0.074 ± 0.011
2.0	20.0	7.6	0.048 ± 0.004	7.2	0.054 ± 0.007	7.2	0.092 ± 0.009

TABLE 4c. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON SANDY, HUMIC SOIL FROM SOUTH OF SKEAD AFTER TREATMENT WITH VARYING AMOUNTS OF CALCIUM CARBONATE, BATH DUST AND WOODSTOCK DUST. (n=5)

g of material	Equivalent in t/ha	$CaCO_3$		Bath		Woodstock	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
0.5	5.0	6.0	0.378 ± 0.023	5.2	0.268 ± 0.011	5.3	0.310 ± 0.009
1.0	10.0	6.9	0.316 ± 0.012	6.1	0.286 ± 0.025	6.0	0.360 ± 0.016
2.0	20.0	7.5	0.308 ± 0.011	6.8	0.308 ± 0.023	6.7	0.356 ± 0.017

TABLE 4d. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON SANDY, HUMIC SOIL FRON NORTH OF WAHNAPITAE AFTER TREATMENT WITH VARYING AMOUNTS OF CALCIUM CARBONATE' BATH DUST AND WOODSTOCK DUST (n=5)

g of material	Equivalent in t/ha	$CaCO_3$		Bath		Woodstock	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
0.5	5.0	5.3	0.304 ± 0.026	5.0	0.378 ± 0.060	4.8	0.600 ± 0.023
1.0	10.0	6.2	0.540 ± 0.017	5.4	0.544 ± 0.058	5.2	0.642 ± 0.011
2.0	20.0	7.3	0.492 ± 0.023	6.2	0.632 ± 0.032	6.4	0.750 ± 0.044

In an Analysis of Variance, soil, neutralizer type and application rate effects were highly significant with respect to biomass production, as were soil-neutralizer and soil-application rate interactions. Although the neutralizer type-application rate interaction was non-significant, the soil-neutralizer type-application rate interaction was highly significant.* *($p < 0.01$)

TABLE 5a. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON CLAY SOIL FROM SOUTH OF CONISTON AFTER TREATMENT WITH VARYING HIGH LEVELS OF CALCIUM CARBONATE AND KILN DUST. REPLICATED THREE TIMES.

g of material	Equivalent in t/ha	$CaCO_3$		Woodstock		Bath	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
3.0	30	7.4	0.777 ± 0.015	7.0	0.680 ± 0.049	7.0	0.570 ± 0.006
4.0	40	7.5	0.740 ± 0.026	7.2	0.647 ± 0.032	7.0	0.320 ± 0.058
5.0	50	7.5	0.727 ± 0.048	7.0	0.733 ± 0.086	7.0	0.190 ± 0.059

TABLE 5b. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON SANDY SOIL FROM THE CONISTON-GARSON ROAD AFTER TREATMENT WITH VARYING HIGH LEVELS OF CALCIUM CARBONATE AND KILN DUST. REPLICATED THREE TIMES.

g of material	Equivalent in t/ha	$CaCO_3$		Woodstock		Bath	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
3.0	30	7.5	0.050 ± 0.006	7.2	0.097 ± 0.007	7.3	0.080 ± 0.012
4.0	40	7.5	0.040 ± 0.006	7.2	0.100 ± 0.006	7.4	0.023 ± 0.003
5.0	50	7.3	0.067 ± 0.012	7.3	0.087 ± 0.003	7.5	0.003 ± 0.003

TABLE 5c. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON SANDY, HUMIC SOIL FROM SOUTH OF SKEAD AFTER TREATMENT WITH VARYING HIGH LEVELS OF CALCIUM CARBONATE AND KILN DUST. REPLICATED THREE TIMES.

g of material	Equivalent in t/ha	$CaCO_3$		Woodstock		Bath	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
3.0	15	6.2	0.313 ± 0.007	6.7	0.513 ± 0.037	6.5	0.317 ± 0.015
4.0	20	6.6	0.330 ± 0.023	6.8	0.437 ± 0.026	6.7	0.113 ± 0.020
5.0	25	6.9	0.320 ± 0.000	6.9	0.460 ± 0.030	7.1	0.053 ± 0.039

TABLE 5d. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON SANDY SOIL FROM THE CONISTON-GARSON ROAD AFTER TREATMENT WITH VARYING HIGH LEVELS OF CALCIUM CARBONATE AND KILN DUST. REPLICATED THREE TIMES.

g of material	Equivalent in t/ha	$CaCO_3$		Woodstock		Bath	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
3.0	15	7.6	0.580 ± 0.026	7.0	0.937 ± 0.045	7.0	0.453 ± 0.059
4.0	20	7.6	0.527 ± 0.038	7.0	0.803 ± 0.030	7.0	0.177 ± 0.032
5.0	25	7.5	0.507 ± 0.032	7.1	0.840 ± 0.025	7.0	0.107 ± 0.037

In an Analysis of Variance, soil, neutralizer and level were highly significant effects ($p < .01$) with respect to biomass, as were the soil-neutralizer and neutralizer-level interactions, while the soil-neutralizer-level interaction was significant at the 0.1 probability level. With respect to pH, soil, neutralizer, level, soil-neutralizer, soil-level, neutralizer-level and soil-neutralizer-level effects were all highly significant ($p < .01$)

observed that germination is delayed at high levels of Bath dust application, but that it does finally occur. There are two possible explanations for this:

1. That the free alkali initially inhibiting germination reacts with the acid soil over a period of time. Once neutralized, the alkali is no longer inhibitory.
2. That the toxic principle, which may be alkali, chloride or both, is leached out of the soil after a period of time.

Bath and Woodstock dusts were separately mixed with Skead soil at a rate equivalent to 50 t/ha. Two leaching regimes were used, one with free drainage, the other with recycling of leachate. Furthermore, the incubation period prior to sowing seeds was varied from zero to 12 days.

Mean soil pH values at the end of the experiment are shown in Table 6, while Table 7 depicts dry weights of tops. In terms of soil pH, leaching regime appears to have no effect in the case of Woodstock dust. In the case of Bath dust, however, it seems, rather surprisingly, that the recycling treatment produces a slightly lower pH than does the free drainage treatment. This suggests that chloride, rather than alkali, is being leached.

Dry weight data shown in Table 7 indicate a very different response to leaching regime in the two dust treatments. In the case of the Woodstock dust treatment, recycling is consistently beneficial to dry weight production, whereas in the case of the Bath dust treatment it is consistently deleterious. This is consistent with the idea that the leaching out of soluble materials, probably chlorides, is the most important explanation of delayed germination. Incubation time, in itself, does not appear to influence dry weight production.

TABLE 6. MEAN pH OF SKEAD SOIL AFTER TREATMENT WITH FIVE GRAMS PER POT (= 50 t/ha) OF WOODSTOCK KILN DUST AND BATH KILN DUST, RESPECTIVELY, UNDER TWO LEACHING REGIMES.

DUST TYPE	LEACHING REGIME	INCUBATION TIME BEFORE SOWING SEEDS IN DAYS					$\bar{x}$
		0	3	6	9	12	
Woodstock	Free	7.3	7.4	7.6	7.5	7.3	7.5
	Recycled	7.3	7.4	7.6	7.4	7.3	7.4
Bath	Free	7.9	8.0	7.8	7.-	6.8	7.6
	Recycled	7.5	7.7	7.5	7.1	7.0	7.4

In an Analysis of Variance, dust type, leaching regime and incubation time all had a highly significant effect on pH ($p < .01$), as did all two and three-way interactions.

TABLE 7. MEAN DRY WEIGHT IN GRAMS PER POT OF REDTOP PLANTS GROWN IN SKEAD SOIL UNDER TWO LEACHING REGIMES AND FIVE INCUBATION PERIODS BEFORE SOWING (MEAN OF FIVE REPLICATES ± STANDARD ERROR).

DUST TYPE	LEACHING REGIME	INCUBATION TIME BEFORE SOWING (DAYS)				
		0	3	6	9	12
Woodstock	Free	.518 ± .022	.434 ± .029	.474 ± .025	.548 ± .032	.512 ± .028
	Recycled	.534 ± .048	.460 ± .027	.604 ± .027	.652 ± .027	.642 ± .055
Bath	Free	.132 ± .022	.162 ± .028	.226 ± .025	.184 ± .004	.168 ± .028
	Recycled	.104 ± .015	.080 ± .024	.210 ± .038	.106 ± .016	.060 ± .027

In an Analysis of Variance, dust type and incubation time both had a highly significant effect on biomass ($p < .01$), as did dust type/incubation time and dust type/leaching regime interactions.

GROWTH EXPERIMENT IN FERTILIZED SOIL

Previous experiments have been carried out on unfertilized soil, since liming alone is sufficient to overcome the single overriding factor limiting plant establishment and growth - soil toxicity. The normal practice in reclaiming these soils, however, is to apply an N-P-K fertilizer in addition to the limestone, phosphorus deficiency being a secondary limiting factor (Winterhalder, 1975). Since a number of interactions are possible between liming material and fertilizer, it seemed desirable to determine whether the effects of the ameliorants on plant growth were any different in a fertilized soil from those in an unfertilized soil.

Each soil was treated with calcium carbonate, Bath dust and Woodstock dust, respectively, at levels equivalent to 0, 20 and 50 t/ha, and sown with Redtop seed. 0.1 g pulverized C.I.L. "Gardenite" was mixed into each pot, which was then seeded to Redtop. Mean final soil pH values are shown in Table 8 and mean dry weights of tops in Table 9.

Once again, pH figures show Bath dust to be the most effective neutralizer. At high levels, however, it is clearly deleterious to plant growth, particularly in sandy soils that lack humus or clay. The moderating effect of fertilizer on Bath dust toxicity can be seen, however, if we compare dry weight reduction from 20 t/ha to 50 t/ha in the first incubation experiment (no fertilizer) with the dry weight reduction from 20 to 50 t/ha in the fertilizer experiment (Table 10).

TABLE 8. MEAN pH OF FOUR FERTILIZED SUDBURY AREA SOILS AFTER INCUBATION WITH THREE LEVELS OF CALCIUM CARBONATE, WOODSTOCK KILN DUST AND BATH KILN DUST, RESPECTIVELY. (MEAN OF THREE REPLICATES).

SOIL TYPE	LOCATION	RATE	NEUTRALIZER		
			$CaCO_3$	Woodstock dust	Bath dust
Clay	Coniston	0 t/ha	3.6	4.2	3.7
		20 t/ha	6.5	5.9	6.1
		50 t/ha	6.8	7.0	7.2
Sand	Coniston-Garson	0 t/ha	5.3	4.8	5.4
		20 t/ha	7.3	7.1	7.1
		50 t/ha	7.5	7.5	7.7
Sand with Humus	Skead	0 t/ha	4.6	4.6	5.2
		20 t/ha	7.4	7.0	6.9
		50 t/ha	7.4	7.6	8.0
Sand with Humus	Wahnapitae	0 t/ha	4.8	4.6	4.5
		20 t/ha	7.5	6.7	6.2
		50 t/ha	7.6	7.4	7.7

In an Analysis of Variance, soil and level effects, as well as soil-level, soil-neutralizer, neutralizer-level and soil-neutralizer-level interactions are highly significant ($p < .01$), while neutralizer alone is only significant at the $p < .05$ level.

TABLE 9. MEAN DRY WEIGHTS IN GRAMS OF REDTOP PLANTS GROWN IN FOUR FERTILIZED SUDBURY AREA SOILS TREATED WITH THREE LEVELS OF CALCIUM CARBONATE, WOODSTOCK KILN DUST AND BATH KILN DUST, RESPECTIVELY. MEANS ARE OF THREE REPLICATES (± STANDARD ERROR).

SOIL TYPE	LOCATION	RATE	NEUTRALIZER		
			$CaCO_3$	Woodstock dust	Bath dust
Clay	Coniston	0 t/ha	0.240±.036	0.267±.052	0.210±.032
		20 t/ha	1.080±.232	1.033±.137	0.840±.106
		50 t/ha	1.127±.119	0.877±.201	0.623±.145
Sand	Coniston-Garson	0 t/ha	0.207±.024	0.153±.003	0.187±.041
		20 t/ha	0.237±.023	0.207±.063	0.203±.049
		50 t/ha	0.230±.020	0.170±.012	0.133±.020
Sand with Humus	Skead	0 t/ha	0.207±.052	0.237±.035	0.237±.066
		20 t/ha	0.403±.072	0.380±.042	0.300±.031
		50 t/ha	0.430±.075	0.380±.069	0.323±.052
Sand with Humus	Wahnapitae	0 t/ha	0.170±.015	0.147±.047	0.127±.023
		20 t/ha	1.020±.147	0.967±.145	0.497±.027
		50 t/ha	1.063±.167	0.910±.123	0.410±.096

In an Analysis of Variance, soil, neutralizer and level effects, as well as soil-neutralizer, soil-level and neutralizer-level interactions are highly significant ($p < .01$), while the soil-neutralizer-level interaction is significant at the $p < .05$ level.

TABLE 10. DRY WEIGHT PRODUCTION BY REDTOP SHOOTS AT 50 t/ha BATH DUST APPLICATION RATE EXPRESSED AS A PERCENTAGE OF DRY WEIGHT PRODUCTION AT 20 t/ha BATH DUST APPLICATION RATE

	Unfertilized	Fertilized
Clay Soil	5.2	74.0
Sandy Soil	20.0	65.0
Sandy, Humic Soil	22.0	104.0
Sandy, Humic Soil	5.9	84.0
Mean	13.3	80.1

It seems clear from this rather crude comparison that the depressive effect of fresh Bath dust on growth is much less severe when fertilizer is also used.

FIELD EXPERIMENTS

Materials and Methods.

Sites.

Two field sites were chosen, one being a level sandy area in the Coniston Creek valley, four km northeast of Coniston (called the "Coniston site"). The second site, also barren, was a stony hilltop 7 km northeast of Coniston (called the "Garson site").

Neutralizing materials.

The two kiln dusts used were from Woodstock and Bath, as described in the section on Pot Trials. The calcium carbonate was in this case pulverized limestone as used in the Sudbury Regional Land Reclamation

Programme. All three neutralizing materials were applied at a rate of 4.94 t/ha (2 tons/acre) at the Coniston site and 12.35 t/ha (5 tons/acre) at the more colloid-rich Garson site (i.e., .49 & 1.24 kg/m^2 respectively).

Fertilizer.

F.I.L. "Seeder-Sodder" (5-20-0) at a rate of 560 kg/ha (i.e., 56 g/m^2).

Incorporation of fertilizer and neutralizing materials.

In the case of the stone-free Coniston site, the soil was roughened by raking to a depth of 10 - 15 cm, then the ameliorant was raked in. In the case of the stony Garson site, however, the ameliorant was applied to the surface.

Plants.

As in the case of Pot Trials, Redtop was used. Seed was applied at 45 kg/ha (i.e., 4.5 g/m^2). At the Coniston site they were raked in to a depth of 2.5 cm, while at the Garson site they were applied to the surface.

C/W Factor.

Since percent cover and dry weight production represent two different and equally important criteria of revegetational success, a factor was devised in which each criterion was represented at equal weight. This Cover/Dry Weight (C/W) factor was derived as follows:

$$\text{C/W Factor} = \frac{\text{Relative \% cover + Relative Dry Weight}}{2}$$

The Relative Percent Cover was obtained as follows:

$$\text{R.P.C.} = \frac{\text{Mean \% cover for one treatment}}{\text{Total of all mean percent covers}} \times 100$$

Relative Dry Weight was calculated in the same way. Note that R.P.C., R.D.W. and C/W Factor are all percentages.

Experimental Design.

The experiment was set up using 1 m^2 plots in a randomized block design, and 5 replicates of each treatment combination at Coniston, 2 replicates at Garson (due to lack of space).

1 species x 2 fertilizer regimes x 4 neutralizer regimes
x 5 replicates = 40 plots (Coniston)

1 species x 2 fertilizer regimes x 4 neutralizer regimes
x 2 replicates = 16 plots (Garson)

The experiments were set up and seeded in late August, 1980. This has been found to be the best season for establishing herbaceous plants in the Sudbury area. Percent cover was determined in each plot, and above-ground parts harvested for biomass (standing crop) determination in July, 1981.

Results.

Percent cover, biomass and cover/weight factors are shown in Tables 11 & 12.

In Coniston soil, the importance of low nutrient status is obvious from the great differential in response to neutralization between unfertilized and fertilized soils. In both unfertilized and fertilized soil, the best response is to Woodstock dust.

In Garson soil, the response differential between unfertilized and fertilized soil is not so great, but it still exists. It is interesting to note, however, that in the case of Bath dust, the effect seems to be transformed from an inhibitory one to a stimulatory one by the addition of fertilizer. In fact, the best growth of all treatments is obtained on fertilized soil treated with Bath dust. Although only based on two replicates, the difference between unfertilized/Bath and fertilized/Bath treatments is striking and, as far as it goes, consistent.

The results of this trial point to the value of using the kiln dusts along with fertilizer, not only for the sake of increased yields, but because the ferlitizer appears to have a modifying effect on the potentially toxic properties of the Bath dust.

TABLE 11. MEAN PERCENT COVER AND MEAN ABOVE GROUND DRY WEIGHT OF PLANTS FROM CONISTON FIELD EXPERIMENT (BASED ON FIVE REPLICATES)

FERTILIZER REGIME	NEUTRALIZER	$\bar{x}$ % COVER AND S.E.	$\bar{x}$ DRY WEIGHT (g) AND S.E.	C/W FACTOR
Not Fertilized	Control	1.4 ± 0.4	0.6 ± 0.3	0.3
	Limestone	10.8 ± 3.1	6.8 ± 2.0	2.6
	Woodstock	13.8 ± 5.8	9.3 ± 3.7	3.3
	Bath	8.2 ± 3.4	6.4 ± 1.8	2.0
Fertilized	Control	39 ± 7.8	62.6 ± 9.7	12.3
	Limestone	69 ± 7.0	133.6 ± 25.9	25.2
	Woodstock	72 ± 3.7	206.0 ± 16.6	30.3
	Bath	58 ± 10.1	162.6 ± 32.5	24.2

In an analysis of variance, fertilizer and neutralizer effects, as well as fertilizer-neutralizer interaction, were significant ($p > .012$) in the case of biomass, while only fertilizer and neutralizer were significant ($p > .012$) in the case of percent cover. Using Duncan's Multiple Range Test ($p > .1$), on unfertilized and fertilized plots, mean biomass values fall into two subsets, indicating that the effects of the three neutralizers on biomass do not differ significantly from one another, whereas they all difer significantly from that of the control.

TABLE 12. MEAN PERCENT COVER AND MEAN ABOVE-GROUND DRY WEIGHT OF PLANTS FROM GARSON FIELD EXPERIMENT (BASED ON TWO REPLICATES).

FERTILIZER REGIME	NEUTRALIZER	$\bar{x}$ % COVER	$\bar{x}$ DRY WEIGHT (g)	C/W FACTOR
Not Fertilized	Control	0.5	0	0.1
	Limestone	30	34	12.9
	Woodstock	44	14	13.2
	Bath	8	14	4.3
Fertilized	Control	2	5	1.3
	Limestone	20	50	13.4
	Woodstock	45	94	26.2
	Bath	50	102	28.8

DISCUSSION

Both growth chamber and field trials suggest that cement kiln by-pass dusts have good potential as limestone substitutes in the revegetation of acid, metal-contaminated land. There are, however, several aspects of the kiln dusts' properties that necessitate somewhat more care in their use than that required in the case of ground limestone. For example:

a. Because of the potential for inhibiting germination and growth that some dusts (e.g. Bath) possess, the application level should be kept within the non-toxic limits (below 50 t/ha) or application should be carried out several weeks before seeding or both of the above. Purdy (1980), in growth chamber trials on sand and tailings at Falconbridge Nickel Mines Ltd., reached a similar conclusion. Indeed, he found that the germination and survival rates of Fall Rye (Secale cereale) were reduced at or about an application rate as low as 10 t/ha.

b. The crusting on the surface of the soil that occurs on contact with moisture has the potential to create a barrier to germination and growth, which may mean that the dusts do not lend themselves to surface application at high application rates. In the Garson field trial, which employed surface application, crusting did occur, but the crust soon cracked and seedlings were able to emerge. Allowing several weeks to elapse between dust application and seeding, as suggested above, might ensure that some breakup of the crust had occurred by this time. In non-stony areas, where the neutralizing agent is worked into the soil, the crusting problem does not arise. As pointed out by Purdy, however, the tendency of the dust to crust on contact with moisture might create serious problems in machine spreading. He suggests that the dust might be pelletized for spreading, but such a process would probably be technically difficult and therefore expensive.

C. Because of its caustic nature, the material could not be used in the current Sudbury Regional Land Reclamation Programme, in which limestone is spread by hand. Even loading and spreading such a material would be a potential health hazard to operators because of its dusty consistency.

d. As pointed out by Purdy, the by-pass dust possesses one third the density of ground limestone, increasing spreading costs.

e. In view of the significant alkali and chloride content of the waste, there is some potential for a salinity problem, but this is unlikely to be a serious consideration in a climate in which precipitation exceeds evapotranspiration such as that of the Sudbury area.

On the positive side, it should be noted that the dusts would be available without cost from the cement manufacturer, although the transportation costs would probably limit the economic feasibility of their use in the Sudbury area. Perhaps more important is the fact that the use of these dusts to counteract smelter-emitted pollution would be a fine example of appropriate technology, in which one waste product is used to counteract the harmful effects of another waste product, thereby achieving two waste disposal objectives in a single act. Such procedures, while desirable, are rare in waste disposal practice, except in the case of sewage sludge, either in raw or in composted form (e.g. Murray, Townsend & Sopper, 1981; Stucky, Bauer & Lindsey, 1980; Sutton & Vimmerstedt, 1973). In fact, in 1973 a consultant's report (Dillon, 1973) recommended the installation of a garbage grinding facility and ground garbage/sewage sludge composting plant for Sudbury, the resulting compost to be used in land reclamation. Although the project was never funded, preliminary work by the present author (Winterhalder, et al., 1976 and unpublished data) indicate that such a compost would be highly beneficial in reclaiming Sudbury's acid, metal-contaminated soils. With respect to the use of cement kiln dusts in land reclamation, however, no previously published reports on this subject exist, to the knowledge of the present author. The closest parallel can be drawn with the work of Gemmell (1981), who used two types of industrial lime waste ("dried calcareous slurry" and Leblanc wastes, respectively) in reclamation experiments on colliery spoil in the U.K. The success of their experiments was later confirmed by large-scale reclamation. Their wastes lacked the potentially toxic alkalies and chlorides present in cement kiln wastes, and they found that particle size, a factor not considered in the present report, was the largest single arbiter of short-term effectivity.

In conclusion, it appears that the possibility of utilizing industrial lime wastes, particularly those from the cement industry, has not received the attention that it deserves. This preliminary investigation strongly supports the feasibility of using cement kiln by-pass dust as a limestone substitute, but draws attention to certain economic and technological problems that would have to be overcome before its use would be appropriate in the Sudbury Regional Land Reclamation Programme.

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CANADIAN LAND RECLAMATION ASSOCIATION
PROCEEDINGS OF THE NINTH ANNUAL MEETING

TABLE OF CONTENTS

Thursday, August 23

13. Managing Minesoil Development for Productive Reclaimed Lands
(W. SCHAFER)

14. Reclamation Monitoring: The Critical Elements of a Reclamation Monitorin Program
(R.L. JOHNSON, P.J. BURTON, V. KLASSEN, P.D. LULMAN, D.R. DORAM)

15. Plains Hydrology and Reclamation Project: Results of Five Years Study
(S.R. MORAN, M.R. TRUDELL, A. MASLOWSKI-SCHUTZE, A.E. HOWARD, T.M. MACYK, E.I. WALLICK)

16. Highvale Soil Reconstruction Reclamation Research Program
(M.M. BOEHM, V.E. KLASSEN, L.A. PANEK)

17. Battle River Soil Reconstruction Project: Results Three Years Afte Construction
(L.A. LESKIW)

18. Gas Research Institute Pipeline Right of Way Research Activities
(C.A. CAHILL, R.P. CARTER)

19. Subsoiling to Mitigate Compaction on the North Bay Shortcut Project
(W.H. WATT)

20. Effects of Time and Grazing Regime on Revegetation of Native Range Afte Pipeline Installation
(M.A. NAETH, A.W. BAILEY)

21. Revegetation Monitoring of the Alaska Highway Gas Pipeline Prebuild
(R. HERMESH)

22. Post-Mining Groundwater Chemistry and the Effects of In-Pit Coal Ash Disposal
(M.R. TRUDELL, D. CHEEL, S.R. MORAN)

23. Assessment of Horizontal and Vertical Permeability and Vertical Flow Rates fo the Rosebud - McKay Interburden, Colstrip, Montana
(P. NORBECK)

24. Accumulation of Metals and Radium - 226 by Water Sedge Growing on Uranium Mil Tailings in Northern Saskatchewan
(F.T. FRANKLING, R.E. REDMANN)

25. How Successful is the Sudbury (Ontario) Land Reclamation Program?
(P. BECKETT, K. WINTERHALDER, B. McILVEEN)

26. Methodology for Assessing Pre-Mine Agricultural Productivity
(T.A. ODDIE, D.R. DORAM, H.J. QUAN)

27. An Agricultural Capability Rating System for Reconstructed Soils
(T.M. MACYK)