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Air-Dried Chemical Sewage Sludge Disposal on Agricultural Land - Volume I

echnology Development
eport EPS 4-WP-78-3

Vater Pollution Control Directorate
ril 1978

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AIR-DRIED CHEMICAL SEWAGE SLUDGE DISPOSAL ON AGRICULTURAL LAND
VOLUME I

by

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FISHERIES AND ENVIRONMENT CANADA

Report No. EPS 4-WP-78-3
April 1978

SEI

Cat. No. En43-4/78-3

ISBN 0-662-01947-4

ABSTRACT

Storage, transport and handling of air-dried sludge is more convenient and potentially more economical than for fluid sludge. While soluble constituents such as nitrogen are generally leached from sludges during the drying process, most metals are retained in the dried residue. Recent studies suggest that zinc, copper and nickel toxicities to agricultural plants, such as wheat, are additive and may be the factors that most limit disposal of such sludge on agricultural land.

An experiment in which air-dried chemical sewage sludge was applied to two different soil types (sand and clay) in lysimeters was initiated at the Wastewater Technology Centre (WTC), Burlington, Ontario, in January, 1974. Nine sludge treatments consisting of three different sludges (alum, iron and lime), each applied at three different rates (57, 114 and 171 kg zinc equivalent/ha) were compared to two controls (with and without commercial fertilizer) for a total of eleven treatments. The treatments were replicated twice for each soil for a total of 44 lysimeters.

Spring wheat was seeded in May and harvested in August, 1974. Crop production (grain and straw), as well as nutrient and heavy metal concentrations in leachate and plant materials were determined.

Despite some initial inhibition of germination, alum and lime sludge treatments applied to clay increased yields of grain and straw, over those from non-fertilized controls. Increasing the rates of iron sludge to both soils resulted in decreased total yields (grain plus straw), compared to those from the fertilized control. Sludge applications to sand did not increase grain yields over those from controls.

Compared to the fertilized contol, concentrations of N, Ca, Na, Fe, Zn, and Cu in grain and N, P, Ca, Mg, Na, Zn, and Cu in straw increased with increasing sludge applications. The concentrations of all elements analyzed in both grain and straw were within the normal ranges in plants.

Leachate from all sludge treatments showed concentrations of NH_4-N, Cl, SO_4, Ca, Mg, Fe, Zn, Cu, Cr, Pb, and Cd that were within the maximum permissible limits (MPL) for drinking water, while Al, Mn, and

Ni were within the MPL for irrigation water. Only NO_3-N concentrations in leachate exceeded the MPL for drinking water. Potential contamination of groundwater by nitrates was the only environmental problem encountered during the first year of this long term study.

RÉSUMÉ

Il est plus pratique et peut-être plus économique d'entreposer, de transporter et de manipuler des boues séchées à l'air que des boues liquides. Quoique le séchage élimine généralement les produits solubles comme l'azote, la plupart des métaux demeurent. Des études récentes portent à croire que la toxicité du zinc, du cuivre et du nickel pour des cultures comme le blé s'additionne. Il pourrait s'agir du facteur qui limiterait le plus l'épandage de telles boues sur les terres agricoles.

En janvier 1974, on a entrepris, au Centre technique des eaux usées de Burlington (Ontario), une expérience en lysimètre avec deux différents types de sols (sableux et argileux) amendés avec des boues chimiques séchées à l'air. On a comparé neuf traitements, soit trois types différents de boues (alun, fer et chaux) à trois doses d'épandage (57, 114 et 171 kg/ha) d'équivalent en zinc, à deux témoins (avec et sans fertilisant commercial), soit 11 épandages au total. On a répété les traitements deux fois pour chaque type de sol, pour obtenir 44 lysimètres.

Le blé de printemps, semé en mai 1974, fut récolté en août. On a alors déterminé la production (de grain et de paille) ainsi que les teneurs en éléments nutritifs et en métaux lourds du percolat et des matières végétales.

Bien qu'ils aient d'abord nui à la germination, les sols argileux additionnés de boues à l'alun et à la chaux ont produit plus de grain et de paille que les sols témoins non fertilisés. En augmentant la concentration en boues ferriques des deux types de sols on a dimunié le rendement total (grain et paille) par rapport au sol témoin fertilisé. Les épandages de boues sur les sols sableux n'ont pas donné de rendement en grain supérieur à celui des sols témoins.

Comparées à celles obtenues en sol témoin fertilisé, les teneurs en N, Ca, Fe, Zn et Cu des grains et en N, P, Ca, Mg, Na, Zn et Cu de la paille ont augmenté avec la dose de boue. Les teneurs de tous les éléments, dans les grains et la paille, correspondaient à la gamme normale des valeurs observées chez les plantes.

Les percolats de tous les épandages contenaient moins d'azote ammoniacal, Cl, SO_4, Ca, Mg, Fe, Zn, Cu, Cr, Pb et Cd que les limites

maximales permises (LMP) pour les eaux potables, et plus d'Al, Mn et Ni que les LMP pour les eaux d'irrigation. Seules les teneurs en azote nitrique des percolats dépassaient la LMP pou les eaux potables. La contamination possible des eaux souterraines par les nitrates constitue le seul problème environnemental auquel on ait eu à faire face pendant la première année de cette étude à long terme.

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CONCLUSIONS

1. Wheat emergence was significantly inhibited by increasing application of all sludges to clay.
2. Inhibition of germination did not reduce crop yields from increasing rates of alum and lime sludge, but yields were depressed as the rate of iron sludge was increased.
3. Total yields (grain + straw) from sludge treatments to clay were significantly higher than from sand. Yields from sludge treatments were significantly higher than from the non-fertilized control with the exception of iron sludge applied to sand. Yields did not significantly increase as sludge application rates increased.
4. Sludge application significantly increased total Kjeldahl nitrogen (protein) contents of grain and straw over that from grain grown on NPK control soil.
5. Concentrations of Zn and Cu in straw and grain and N, Ca and Mg in straw increased with increasing rates of sludge application. All chemical constituents analyzed were within the normal range in plants.
6. Concentrations of the chemical constituents analyzed in leachate were within the MPL for drinking irrigation water, with the exception of NO_3-N.
7. Leachate from untreated controls had NO_3-N concentrations that were higher than the drinking water MPL (10 mg/l). The application of sludge increased these concentrations to >60 mg/l.

RECOMMENDATIONS

1. Long term monitoring of leachate and wheat crop quality should be continued to assess the effects of sludge decomposition following a single heavy application.
2. Surface soil samples (0 to 15 cm) should be analyzed annually to monitor the changing availability of constituents of

concern in the soil-sludge mixture and to relate these changes to plant and leachate quality.

1 INTRODUCTION

An increasing number of water pollution control plants (WPCP) are considering dewatering and air-drying of sludge to reduce its volume requirements and thus storage and ultimate disposal costs. Air-dried sludge can be stored indefinitely, handled conveniently, and when applied to land can be worked into the soil immediately with conventional farm machinery in contrast to the long drying periods required before fluid sludge can be worked into the soil.

Crop yield increases from sludge applications to soils have been documented by Lunt (1959), Hinesly and Sosewitz (1969), Milne and Graveland (1972) and Chawla et al (1976). These yield increases were proportional to the available nitrogen application rates. Day et al (1975) reported that crude protein contents were substantially greater in wheat grain grown on soil fertilized with wastewater than grain grown on soil to which chemical fertilizer (NPK) had been applied.

Sewage sludge may contain relatively large concentrations of heavy metals (Cohen and Bryant, 1978), some of which are essential in plant and animal nutrition. The concentrations of heavy metals in plants may increase to toxic levels if excessive concentrations are present in sludge applied to soil. Thus, sludge application rates may be limited by their heavy metal content.

Lunt (1959) attributed the poor growth of vegetables on sludge treated soils to Cu and Zn toxicity. Rhode (1962) also concluded that excessive amounts of Cu and Zn were responsible for poor crop growth from sludge treated soils, in the vicinity of Berlin and Paris. Patterson (1971) found that the yield of oats grown in acid soil (pH 5.3) treated with a high Ni sludge was reduced. Chaney (1973) indicated that high concentrations of Cd, Cu and Zn in sludge applied to soils can be a potential hazard to the food chain.

Cunningham et al (1975) concluded that high soluble salt concentrations in the soil solution can be detrimental to crop yields. Increasing sludge applications (up to 250 tonnes/ha) increased yields which decreased, however, at 500 tonnes/ha. Metal concentrations in plant tissue increased with increasing rates of sludge application.

Potentially toxic levels of Cu and Zn were observed at the highest sludge loadings. Le Riche (1968) found no adverse effects on yield from applying a total of 1272 tonnes/ha of sewage sludge over a 19-year period, but the Zn and Ni content of potato and carrot tops was increased. Studies at the University of Illinois (1976) show no indication of detrimental trace metal effects in plants when municipal sludges were applied to soil at recommended agronomic rates for nitrogen (100 to 300 lb N/acre/yr).

Berrow and Webber (1972) have concluded that Zn, Cu and Ni are the heavy metals most likely to cause toxicity problems in plants. Chumbley (1971) recommended that no more than 250 mg/kg "Zn equivalent" [Σ Zn + 2 (Cu) + 8 (Ni)] metals be added to agricultural soils. This loading amounts to 560 kg Zn equivalent/ha. Assuming a 30-year site life, the maximum allowable annual loading would be 19 kg Zn equivalent (Zn Eq/ha/yr).

The effects of applying 560 kg Zn equivalent/ha in a single application to various soils and crops have yet to be determined. To accomplish this objective, a lysimeter experiment was initiated in 1973 at the Wastewater Technology Centre (WTC), Burlington, Ontario using air-dried alum, ferric chloride and lime precipitated sewage sludges on two divergently textured soils (sand and clay), cropped to spring wheat. The experiment was designed to monitor the effects of various zinc equivalent loadings on soils, plant yields, plant chemical constituents and leachate quality. This report presents results obtained during 1973 to 1974.

2 MATERIALS AND METHODS

2.1 Experimental Design

The experiment was designed as a randomized block consisting of 22 treatments, replicated twice for a total of 44 lysimeters (Figure 1). Treatments consisted of three sludges, each at three zinc equivalent rates, plus two controls (with and without commercial (NPK) fertilizer) on two different soils. The rates of sludge application were 57, 114 and 171 kg Zn equivalent/ha (3, 6 and 9 Zn Eq/ha).

2.2 Soils

The sand soil from Norfolk County is derived from the Regosal Great Soil Group, Plainfield Series. The soil is developed from excessively drained dune sand, is droughty and subject to wind and water erosion.

The clay soil from the Timiskaming District is derived from the Dark Grey Gleisolic Group, New Liskeard Series. The soil is developed on lacustrine deposits, being poorly drained due to restricted percolation and flat topography.

The soil horizons (A, B and C) were collected, air-dried, screened and reconstituted in the lysimeters. A 10 cm layer of silica sand was used in the bottom of the lysimeters as a drainage bed. The soils were packed in 5 cm layers to their original field bulk density (Table 1).

Water was supplied to all lysimeters from the base drain connections until the soils were saturated. Free water was drained, to remove air pockets. The soils stabilized under ambient conditions from January to April, 1974.

Soil Chemical Analysis. Soil samples were air-dried, screened through a 60-mesh screen and analyzed (Table 2) according to standard methods (Black, 1965).

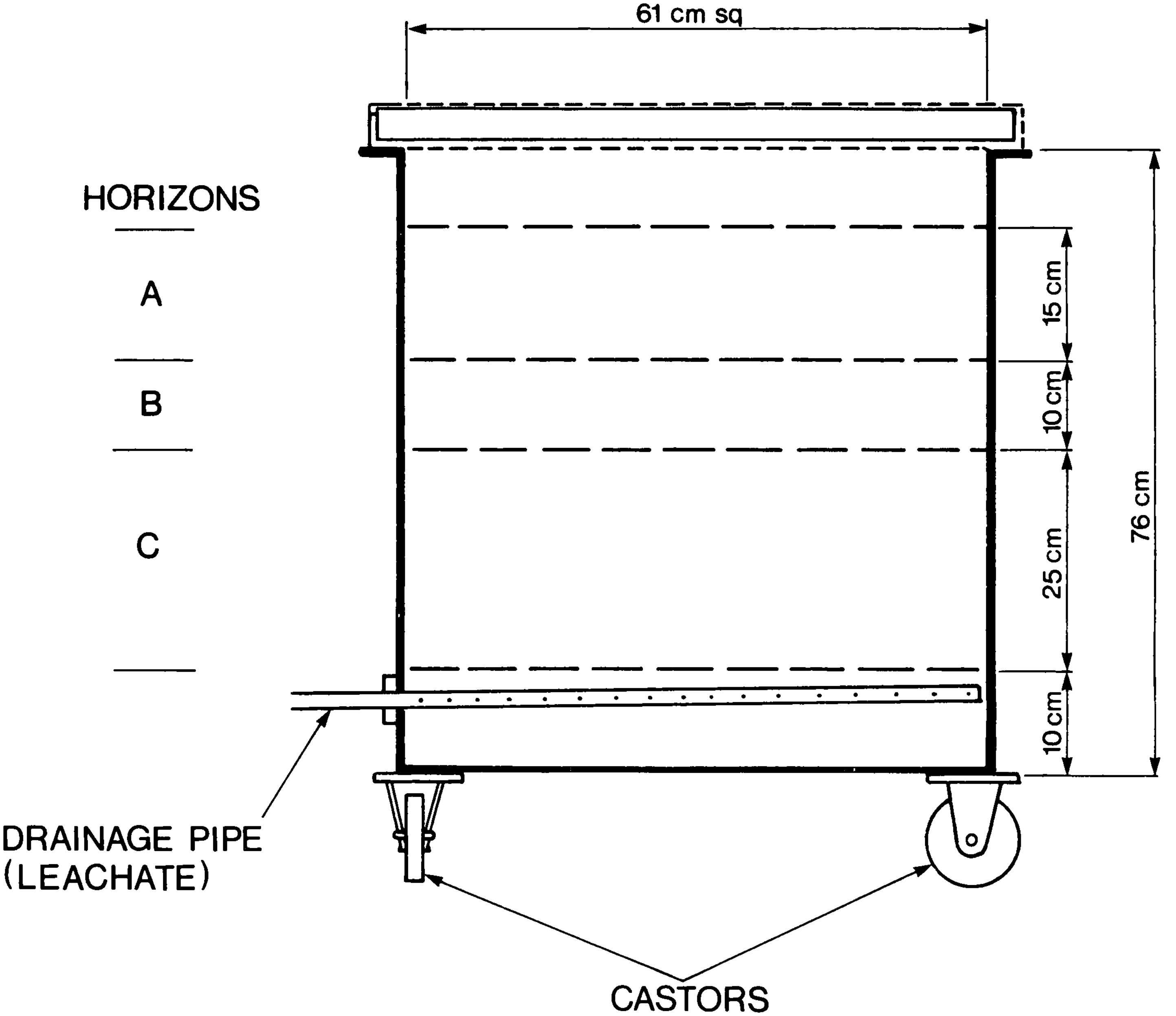

FIGURE 1. EXPERIMENTAL LYSIMETER

TABLE 1. SOIL TEXTURE AND BULK DENSITY

Soil Type	Horizon	% Particle Size			Bulk Density (g/cm^3)
		Sand	Silt	Clay	
Sand	A	97	3	0	1.5
	B	91	9	0	1.6
	C	98	2	0	1.6
Clay	A	8	59	33	1.2
	B	3	45	52	1.5
	C	4	23	73	1.7

TABLE 2. SOIL CHEMICAL ANALYSIS*

Constituents	Sand Horizons			Clay Horizons		
	A	B	C	A	B	C
TKN	1500	1000	500	3800	1500	800
Total P	700	600	400	900	500	400
Ca Total	15000	18000	19500	14500	12000	12000
Mg "	1200	1500	1500	3300	3000	4400
Na "	15600	16800	16200	14300	13600	12600
K "	10000	14300	10100	22100	19700	22200
Fe "	2900	12900	9200	29500	36500	43500
Mn "	145	190	55	515	540	630
Al "	22800	33900	29200	80000	78500	90300
Zn "	26	25	14	100	86	126
Cu "	4	4	3	26	26	45
Ni "	6	6	6	40	36	48
Cr "	15	18	13	63	72	78
Pb "	10	8	3	23	18	25
Cd "	0.7	0.8	0.5	1.0	0.8	0.8
pH (Units)	5.6	6.3	6.7	7.2	7.3	7.5
Organic Matter (%)	2.1	1.4	0.5	6.4	2.1	0.9
CEC (meq/100 g)	4.7	4.1	1.2	28.2	27.5	30.3

* mg/kg dry weight unless otherwise indicated.

2.3 Sludges

Anaerobically digested fluid chemical sewage sludges were acquired from Tillsonburg (alum), North Toronto (iron) and Newmarket (lime) WPCP's (Table 3). Sludges were mechanically dewatered at the WTC and spread on plastic sheets for air-drying at ambient temperatures.

TABLE 3. AIR-DRIED SLUDGE COMPOSITION (1974)

Constituent	Units	Sludge Type		
		Alum	Iron	Lime
TKN	%	3.7	3.1	1.70
Total P	"	4.9	2.0	0.90
TOC	"	18.4	14.7	6.6
Ca Total	"	5.7	5.0	23.0
Mg "	"	0.48	0.75	0.23
Fe "	"	0.98	6.00	0.58
Al "	"	6.60	1.1	0.30
Na "	mg/kg	490	650	324
K "	"	750	600	417
Mn "	"	290	470	456
Zn "	"	1050	1800	290
Cu "	"	539	858	140
Ni "	"	10	15	8
Cr "	"	165	510	37
Pb "	"	280	1480	119
Cd "	"	12	22	5.1
Cd/Zn Ratio	-	0.011	0.012	0.018

On May 1, 1974, these sludges were mixed with the surface 15 cm of the lysimeter soils. The constituent sludge loadings based on Zn equivalents are shown in Table 4.

TABLE 4. AIR-DRIED SLUDGE CONSTITUENT LOADINGS (kg/ha) AT THE LOWEST RATE*

Constituents	Sludge Types		
	Alum	Iron	Lime
Zn Equivalent	57	57	57
TKN	966	489	1498
Total P	1270	315	840
TOC	4743	2302	5825
Organic Matter	8158	3959	10019
Ca Total	1471	783	20512
Mg "	123	117	205
Na "	13	10	28
K "	19	9	37
Fe "	253	940	508
Mn "	8	7	40
Al "	1693	172	269
Zn "	27.1	28.2	28.7
Cu "	13.9	13.4	11.5
Ni "	0.26	0.23	0.65
Cr "	4.3	8.0	3.3
Pb "	7.2	23.0	10.6
Cd "	0.31	0.34	0.45
Total Solids (tonnes/ha)	25.8	15.7	82.0

* Medium rates are twice and high rates are three times these values.

2.4 Wheat Crop

Spring wheat (Glenlea variety) was seeded on May 23, 1974, 22 days after sludge application. The NPK chemical fertilizer was applied at 60N, 60P and 60K kg/ha. The wheat was harvested on August 22, 1974. The plants were clipped discarding vegetation within 2 cm from each end of the lysimeters to avoid border effects. The net harvested area was 0.35 m^2/lysimeter. The crop was threshed, grain and straw were oven dried (70°C), ground to pass through a 60-mesh screen and analyzed according to methods of the Laboratory Services Section, WTC, Burlington.

2.5 Leachate

There were three leachate collection periods between sludge application and harvest. Individual leachate collection periods were based on plant development. Period 1 was from sludge application until crop emergence (30 days); period 2 was from emergence until full fifth leaf (27 days); and period 3 was from fifth leaf until harvest (56 days).

Leachate volume, pH and conductivity were measured on unfiltered samples. Samples were filtered through a 0.45 micron filter and analyzed according to Standard Methods (APHA, 1971).

3 RESULTS AND DISCUSSION

3.1 Crop Germination and Yields

Germination. Satisfactory germination (>85%) was obtained from controls (with and without NPK treatment) on both soils as well as all sludge treatments on sand. Increased application of all sludge types to clay resulted in significant reductions in wheat emergence (Table 5). Germination from the highest rates of alum, iron and lime sludges on clay were only 44, 43 and 38%, respectively.

Sabey and Hart (1975) also noticed a severe inhibition of germination of sorghum sudan grass and millet when seeded shortly after sludge applications (25 to 125 tonnes/ha) to Truckston loamy sand as did Chaney et al (1975) with swiss chard from high rates of sludge (56 tonnes/ha) on Woodstown silt loam.

Growth Characteristics. Cereal crops have the ability to fill in void growing spaces (stool) when reduction in emergence occurs. The highest lime treatment on clay had the lowest germination (38%), but the highest weight for plant - 5.8 g/plant (Table 5).

No treatment produced grain of comparable weight to the plant seed (42 g/1000 kernels) used for the initial experiment. All sludge treatments to sand produced lower kernel weight than did sludge treatments on clay.

Grain Yields. Grain yields from all treatments were significantly higher on clay than on sand (Table 6). Yield differences due to sludge types or rates were not statistically significant. The highest rate of lime sludge on sand produced the highest yield (1.59 tonnes/ha), while the highest rates of alum and iron sludges produced the lowest yields (1.11 to 1.15 tonnes/ha) shown by a highly significant sludge types x rates interaction. All sludge treatments on clay increased yields, but not on sand, compared to the non-NPK control accounting for the significant treatment x soil type interaction. Yields from iron sludge on clay were highest at the lowest rate.

Straw Yields. Straw yields from all treatments on clay were significantly higher than on sand (Table 6) reflecting the higher initial productivity of the clay soil.

TABLE 5. WHEAT GERMINATION, PLANT AND KERNEL WEIGHTS, AND STATISTICAL RESULTS (1974)

Treatments	Rate (kg Zn Eq/ha)	Germination (%)		Weight/Plant (g)		Weight/10^3 Kernels (g)	
		Sand	Clay	Sand	Clay	Sand	Clay
Control	0	88	85	1.7	2.3	34	36
NPK (60, 60, 60)	0	90	86	1.9	2.5	28	35
Alum Sludge	57	90	60	1.9	3.4	22	38
	114	86	60	2.2	3.7	27	35
	171	84	44	2.1	5.3	27	35
Iron Sludge	57	87	80	1.9	2.9	24	38
	114	92	44	1.7	4.9	32	36
	171	89	43	1.7	4.8	26	32
Lime Sludge	57	83	52	2.0	4.2	26	35
	114	85	42	2.2	5.2	27	31
	171	87	38	2.3	5.8	25	36
Standard Error ±		4.7		0.58		1.7	
Treatments:		**		**		NS	
- Control vs others		**		**		NS	
- NPK vs sludges		**		**		NS	
- Sludge types		*		NS		NS	
- Sludge rates		**		*		NS	
- Sludge types x rates		NS		NS		NS	
Soil types		**		**		**	
Treatments x soil types		**		NS		*	

* Differences significant at 0.05 probability (F test).
** Differences significant at 0.01 probability (F test).
NS Differences not significant.

TABLE 6. WHEAT GRAIN AND STRAW YIELDS (tonnes dry matter/ha) (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw		Grain + Straw	
		Sand	Clay	Sand	Clay	Sand	Clay
Control	0	1.24	1.38	3.13	4.21	4.37	5.59
NPK (60, 60, 60)	0	1.42	1.68	3.59	4.45	5.01	6.13
Alum Sludge	57	1.26	1.50	3.52	4.36	4.78	5.86
	114	1.31	1.42	4.12	5.02	5.43	6.44
	171	1.15	1.65	3.96	5.07	5.11	6.72
Iron Sludge	57	1.23	2.03	3.42	4.48	4.71	6.51
	114	1.34	1.71	3.11	4.39	4.45	6.10
	171	1.11	1.41	3.22	4.48	4.33	5.89
Lime sludge	57	0.98	1.61	3.76	4.62	4.74	6.23
	114	1.30	1.65	4.13	4.64	5.43	6.29
	171	1.59	1.68	4.21	4.59	5.80	6.27
Standard Error ±		0.095		0.230		0.283	
Treatments:		**		**		*	
- Control vs others		NS		**		**	
- NPK vs sludges		NS		NS		NS	
- Sludge types		NS		**		*	
- Sludge rates		NS		NS		NS	
- Sludge types x rates		**		NS		NS	
Soil types		**		**		**	
Treatment x soil types		*		NS		NS	

* Differences significant at 0.05 probability (F test).
** Differences significant at 0.01 probability (F test).

Iron sludge treatment yields were significantly lower than were alum and lime straw yields from both soils, possibly reflecting the lower TKN rate from iron sludge at equal zinc equivalent rates (Table 4).

Total (Grain Plus Straw) Yields. Total yields of grain plus straw from all treatments were significantly higher on clay than on sand (Table 6) and were generally greater than the non-NPK control. Statistical analysis indicates that sludge application rates did not significantly affect the total yields, but yield trends affected by sludge rates within sludge types were observed. Increasing rates of lime sludge to sand appeared to increase yields as did alum sludge to clay. Increasing rates of iron sludge on both soils tended to decrease yields.

The constituents applied at higher rates from iron than from alum or lime sludges were Fe, Cr and Pb (Table 4). These constituents were applied at rates which are not considered to be phytotoxic to wheat. The detrimental effects of increasing rates of iron sludge cannot be explained at this time. If this trend continues in subsequent crops, investigation to identify potentially toxic components in the soil-sludge complex will be undertaken.

3.2 Chemical Constituents in Grain and Straw

Concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), manganese (Mn), aluminum (Al), zinc (Zn), copper (Cu), nickel (Ni), chromium (Cr), lead (Pb), and cadmium (Cd) were determined and statistically analyzed for both grain and straw (Tables 7 to 21).

Nitrogen. The N concentrations in both grain and straw were significantly higher from sludge treatments than from both controls (with and without fertilizer) (Table 7).

The lowest N concentration in grain (2.38%) was from the non-NPK control on sand, while the highest concentration in grain (4.38%) was from the lowest rate of alum sludge on sand.

TABLE 7. NITROGEN CONCENTRATION (%) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	2.38	3.38	0.70	0.96
NPK (60, 60, 60)	0	3.25	3.43	0.88	0.99
Alum Sludge	57	4.38	3.87	1.43	1.34
	114	4.21	3.89	1.53	1.62
	171	4.32	3.94	1.59	1.52
Iron Sludge	57	4.06	3.88	1.16	1.31
	114	4.00	3.75	1.42	1.24
	171	4.12	4.10	1.55	1.49
Lime Sludge	57	4.16	3.78	1.64	1.40
	114	4.04	3.88	1.41	1.21
	171	3.91	3.79	1.58	1.46
Standard Error ±		0.11		0.09	
Treatments:		**		**	
- Control vs others		**		**	
- NPK vs sludges		**		**	
- Sludge types		*		*	
- Sludge rates		NS		**	
- Sludge types x rates		NS		*	
Soil types		*		NS	
Treatment x soil types		**		NS	

* Differences significant at 0.05 probability (F test).
** Differences significant at 0.01 probability (F test).
NS Differences not significant.

TABLE 8. PHOSPHORUS CONCENTRATION (%) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	0.60	0.59	0.17	0.10
NPK (60, 60, 60)	0	0.59	0.51	0.07	0.07
Alum Sludge	57	0.56	0.59	0.10	0.09
	114	0.50	0.58	0.09	0.12
	171	0.60	0.55	0.11	0.10
Iron Sludge	57	0.52	0.52	0.07	0.08
	114	0.51	0.53	0.10	0.09
	171	0.55	0.57	0.09	0.09
Lime Sludge	57	0.55	0.58	0.10	0.08
	114	0.54	0.53	0.11	0.10
	171	0.53	0.55	0.13	0.09
Standard Error ±		0.021		0.012	
Treatments:		*		*	
- Control vs others		**		**	
- NPK vs sludges		NS		**	
- Sludge types		NS		NS	
- Sludge rates		NS		NS	
- Sludge types x rates		NS		NS	
Soil types		NS		*	
Treatment x soil types		NS		NS	

* Differences significant at 0.05 probability (F test).
** Differences significant at 0.01 probability (F test).
NS Differences not significant.

TABLE 9. POTASSIUM CONCENTRATION (%) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	0.35	0.35	1.57	1.92
NPK (60, 60, 60)	0	0.38	0.37	1.11	2.10
Alum Sludge	57	0.49	0.35	1.34	2.75
	114	0.38	0.37	0.91	2.48
	171	0.43	0.36	0.96	2.66
Iron Sludge	57	0.46	0.36	0.98	2.21
	114	0.45	0.36	0.90	2.54
	171	0.39	0.36	0.96	2.52
Lime Sludge	57	0.42	0.33	0.90	2.46
	114	0.43	0.38	0.78	2.59
	171	0.44	0.41	0.95	2.61
Standard Error ±		0.031		0.163	
Treatments:		NS		NS	
- Control vs others		*		NS	
- NPK vs sludges		NS		NS	
- Sludge types		NS		NS	
- Sludge rates		NS		NS	
- Sludge types x rates		NS		NS	
Soil types		**		**	
Treatment x soil types		NS		**	

* Differences significant at 0.05 probability (F test).
** Differences significant at 0.01 probability (F test).
NS Differences not significant.

TABLE 10. CALCIUM CONCENTRATION (µg/g) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	238	247	2439	3146
NPK (60, 60, 60)	0	338	387	3071	2954
Alum Sludge	57	505	262	3634	3661
	114	553	342	5451	4488
	171	619	356	7232	4844
Iron Sludge	57	575	333	3564	3413
	114	513	344	4754	4624
	171	640	381	5662	3398
Lime Sludge	57	659	367	5974	3505
	114	659	318	6135	3825
	171	769	395	7630	4151
Standard Error ±		32		349	
Treatments:		**		**	
- Control vs others		**		**	
- NPK vs sludges		**		**	
- Sludge types		**		**	
- Sludge rates		**		**	
- Sludge types x rates		NS		*	
Soil types		**		**	
Treatment x soil types		**		**	

* Differences significant at 0.05 probability (F test).
** Differences significant at 0.01 probability (F test).
NS Differences not significant.

TABLE 11. MAGNESIUM CONCENTRATION (μg/g) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	233	215	1067	1180
NPK (60, 60, 60)	0	208	220	1073	1134
Alum Sludge	57	399	199	1337	1422
	114	273	213	1574	1468
	171	215	206	1865	1393
Iron Sludge	57	221	202	1326	1374
	114	219	219	1753	1220
	171	215	217	1756	1285
Lime Sludge	57	200	200	1557	1190
	114	210	184	1761	1298
	171	235	214	1927	1297
Standard Error ±		30		119	
Treatments:		NS		**	
- Control vs others		NS		**	
- NPK vs sludges		NS		**	
- Sludge types		*		NS	
- Sludge rates		NS		**	
- Sludge types x rates		NS		**	
Soil types		*		**	
Treatment x soil types		NS		*	

* Differences significant at 0.05 probability (F test).
** Differences significant at 0.01 probability (F test).
NS Differences not significant.

TABLE 12. SODIUM CONCENTRATION (μg/g) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	10	7	139	191
NPK (60, 60, 60)	0	4	5	263	184
Alum Sludge	57	27	15	914	198
	114	22	15	984	167
	171	20	10	885	165
Iron Sludge	57	15	18	450	200
	114	17	20	859	209
	171	30	17	1077	173
Lime Sludge	57	17	18	976	165
	114	12	15	975	139
	171	25	14	1014	139
Standard Error ±		4		96	
Treatments:		**		**	
- Control vs others		NS		**	
- NPK vs sludges		**		**	
- Sludge types		NS		NS	
- Sludge rates		NS		NS	
- Sludge types x rates		*		NS	
Soil types		**		**	
Treatment x soil types		NS		**	

* Differences significant at 0.05 probability (F test).
** Differences significant at 0.01 probability (F test).
NS Differences not significant.

TABLE 13. IRON CONCENTRATION ($\mu g/g$) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	40	56	203	249
NPK (60, 60, 60)	0	42	53	218	250
Alum Sludge	57	27	45	259	251
	114	53	57	263	258
	171	60	62	253	205
Iron Sludge	57	48	62	261	262
	114	55	65	241	238
	171	58	57	226	224
Lime Sludge	57	56	55	245	241
	114	57	59	239	235
	171	57	65	240	261
Standard Error ±		14		NS	
Treatments:		NS		NS	
- Control vs others		NS		NS	
- NPK vs sludges		*		NS	
- Sludge types		NS		NS	
- Sludge rates		NS		NS	
- Sludge types x rates		NS		NS	
Soil types		*		NS	
Treatment x soil types		NS		NS	

* Differences significant at 0.05 probability (F test).
** Differences significant at 0.01 probability (F test).
NS Differences not significant.

TABLE 14. MANGANESE CONCENTRATION (μg/g) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	38	38	33	31
NPK (60, 60, 60)	0	40	53	30	27
Alum Sludge	57	27	45	31	40
	114	40	39	39	33
	171	43	39	53	29
Iron Sludge	57	31	41	24	39
	114	37	40	36	30
	171	36	37	32	26
Lime Sludge	57	31	38	23	35
	114	41	41	48	30
	171	45	37	66	23
Standard Error ±		4		7	
Treatments:		NS		NS	
- Control vs others		NS		NS	
- NPK vs sludges		*		NS	
- Sludge types		NS		NS	
- Sludge rates		NS		NS	
- Sludge types x rates		NS		NS	
Soil types		NS		*	
Treatment x soil types		NS		*	

* Differences significant at 0.05 probability (F test).
NS Differences not significant.

TABLE 15. ALUMINUM CONCENTRATION (μg/g) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	2	3	70	76
NPK (60, 60, 60)	0	3	3	67	78
Alum Sludge	57	3	2	62	65
	114	3	2	83	84
	171	5	2	94	69
Iron Sludge	57	4	4	85	85
	114	3	1	77	74
	171	3	2	67	90
Lime Sludge	57	2	3	83	71
	114	5	2	74	84
	171	3	5	67	74
Standard Error ±		NS		NS	

NS Differences not significant.

TABLE 16. ZINC CONCENTRATION (μg/g) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	44	56	23	23
NPK (60, 60, 60)	0	53	61	23	22
Alum Sludge	57	54	65	24	21
	114	59	73	24	24
	171	68	70	35	23
Iron Sludge	57	61	64	32	23
	114	69	62	38	21
	171	68	66	35	23
Lime Sludge	57	56	56	23	18
	114	58	58	25	20
	171	57	66	28	21
Standard Error ±		3		2	
Treatments:		**		**	
- Control vs others		**		NS	
- NPK vs sludges		*		*	
- Sludge types		**		**	
- Sludge rates		**		**	
- Sludge types x rates		NS		NS	
Soil types		**		*	
Treatment x soil types		*		**	

* Differences significant at 0.05 probability (F test).
** Differences significant at 0.01 probability (F test).
NS Differences not significant.

TABLE 17. COPPER CONCENTRATION (μg/g) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	5	7	4	4
NPK (60, 60, 60)	0	6	11	3	4
Alum Sludge	57	7	8	3	5
	114	7	8	5	5
	171	9	7	6	5
Iron Sludge	57	7	9	3	6
	114	8	8	3	4
	171	9	7	5	5
Lime Sludge	57	8	7	4	5
	114	8	7	4	5
	171	9	7	5	6
Standard Error ±		0.8		0.5	
Treatments:		NS		*	
- Control vs others		*		*	
- NPK vs sludges		NS		*	
- Sludge types		NS		NS	
- Sludge rates		NS		*	
- Sludge types x rates		NS		NS	
Soil types		NS		**	
Treatment x soil types		**		NS	

* Differences significant at 0.05 probability (F test).
** Differences significant at 0.01 probability (F test).
NS Differences not significant.

TABLE 18. NICKEL CONCENTRATION (µg/g) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	0.37	0.67	1.8	1.5
NPK (60, 60, 60)	0	0.66	1.37	2.8	2.6
Alum Sludge	57	0.50	0.44	1.7	3.1
	114	0.39	0.53	2.0	1.7
	171	0.54	0.53	1.7	1.6
Iron Sludge	57	0.42	0.40	1.6	1.4
	114	0.49	0.61	2.0	1.6
	171	0.49	0.62	2.7	2.8
Lime Sludge	57	0.43	0.71	1.5	2.4
	114	0.43	0.66	3.0	1.6
	171	1.01	1.31	1.9	4.1
Standard Error		NSA		NS	

NSA No statistical analysis due to compositing replications.
NS Differences not significant.

TABLE 19. CHROMIUM CONCENTRATION (μg/g) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	0.9	0.6	1.0	1.0
NPK (60, 60, 60)	0	0.9	0.2	1.0	1.2
Alum Sludge	57	0.4	0.3	1.2	1.0
	114	0.8	0.6	1.0	1.0
	171	0.6	0.7	1.0	1.0
Iron Sludge	57	0.7	0.6	1.0	1.0
	114	0.4	0.8	1.0	1.0
	171	0.3	0.9	1.0	1.0
Lime Sludge	57	0.7	0.7	1.0	1.0
	114	0.7	0.7	1.0	1.0
	171	0.7	0.7	1.0	1.0
Standard Error ±		NS		NS	

NS Differences not significant.

TABLE 20. LEAD CONCENTRATION ($\mu g/g$) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	0.35	0.35	6.7	5.1
NPK (60, 60, 60)	0	0.35	0.35	8.0	6.3
Alum Sludge	57	0.35	0.35	6.0	6.2
	114	0.35	0.35	5.2	9.0
	171	0.35	0.35	7.0	6.8
Iron Sludge	57	0.35	0.35	5.3	8.0
	114	0.35	0.35	5.9	8.3
	171	0.35	0.35	5.6	5.6
Lime Sludge	57	0.35	0.35	6.7	6.9
	114	0.35	0.35	6.1	6.2
	171	0.35	0.35	4.9	9.6
Standard Error ±		NS		NS	

NS Differences not significant.

TABLE 21. CADMIUM CONCENTRATION (μg/g) IN WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Grain		Straw	
		Sand	Clay	Sand	Clay
Control	0	0.08	0.11	0.24	0.22
NPK (60, 60, 60)	0	0.22	0.11	0.23	0.23
Alum Sludge	57	0.27	0.24	0.29	0.26
	114	0.28	0.14	0.22	0.27
	171	0.28	0.20	0.24	0.20
Iron Sludge	57	0.32	0.43	0.21	0.20
	114	0.33	0.14	0.20	0.23
	171	0.30	0.14	0.26	0.17
Lime Sludge	57	0.17	0.13	0.21	0.19
	114	0.21	0.07	0.23	0.23
	171	0.22	0.07	0.24	0.23
Standard Error ±		0.06		NS	
Treatments:		*		NS	
- Control vs others		**		NS	
- NPK vs sludges		NS		NS	
- Sludge types		**		NS	
- Sludge rates		NS		NS	
- Sludge types x rates		NS		NS	
Soil types		**		NS	
Treatment x soil types		NS		NS	

* Differences significant at 0.05 probability (F test).
** Differences significant at 0.01 probability (F test).
NS Differences not significant.

The calculated crude protein quality of the grain (N x 6.25) was significantly increased by sludge applications compared to NPK treatment. These results are similar to the findings of Day et al (1975). The N concentration increases (deviation from controls) in grain were higher from sludge applied to sand than to clay, but the differences in straw N concentrations between soil types were not significant.

Phosphorus. Concentrations of phosphorus in grain (0.50 to 0.60%) and straw (0.07 to 0.17%) were not affected by sludge types or rates (Table 8).

Potassium. Concentrations of potassium in grain (0.33 to 0.49%) and straw (0.78 to 2.75%) were significantly different between soils (Table 9). The significant difference in straw K concentration due to soil type x sludge treatment interaction is illustrated by the increase from clay (up to 2.75% K) and the decrease from sand (down to 0.78% K) compared to the controls. Differences in grain and straw K contents due to sludge types and rates were not significant. To maintain straw K concentration >1.0%, supplementary K application is required when sludges are applied to sandy soils to grow wheat.

Calcium. Concentrations of calcium in grain (238 to 769 μg/g) and straw (2439 to 7630 μg/g) were significantly different between soils, sludge types and sludge rates (Table 10). The highest sludge application rate usually produced grain and straw with the highest Ca concentrations with values invariably higher from sand than clay.

Magnesium. Concentrations of magnesium in grain (184 to 399 μg/g) and straw (1067 to 1927 μg/g) were significantly different between soils (Table 11). Grain Mg concentration differences due to sludge rates were not significant, but straw Mg concentrations were significantly increased as higher rates of sludge were applied on sand.

Sodium. Concentrations of sodium in grain (4 to 30 μg/g) and straw (139 to 1077 μg/g) were significantly different between soils (Table 12). Concentrations of Na in grain and straw from sludge treatments were higher on sand than on clay.

Iron. Concentrations of iron in grain (27 to 65 μg/g) were generally higher from clay than from sand (Table 13). Sludge application generally increased the grain Fe content compared to NPK treatment. There are no other statistically significant differences in either grain or straw due to treatments.

Manganese. Concentrations of manganese in grain (27 to 53 μg/g) were not affected by soil type, sludge type or rates (Table 14). Straw Mn concentrations were generally higher from sand than from clay, but were not significantly different due to sludge types or sludge rates.

Aluminum. Concentrations of aluminum in grain (1 to 5 μg/g) and straw (62 to 94 μg/g) were not affected by soil type, sludge type or rates (Table 15). Despite the wide variations in aluminum sludge loadings (Table 4), Al contents (grain and straw) were similar for all sludge types.

Zinc. Concentrations of zinc in grain (44 to 73 μg/g) and straw (18 to 38 μg/g) were significantly different due to soil types, sludge type and rates (Table 16). The grain Zn concentrations from sludge treatment were generally higher from clay than from sand, but the straw Zn concentrations were higher from sand. Increasing the rates of sludge generally increased the grain and straw Zn concentrations. As the rates of Zn application from all sludges were purposely kept similar (Table 4), differences in Zn concentrations due to sludge types are not directly related to total Zn loadings. Lime sludge applications on both soils produced grain and straw with the lowest Zn concentrations. Sabey and Hart (1975) found similar Zn concentrations (54.2 μg/g) in the wheat grain from a sludge application rate of 100 tonnes/ha. Zinc concentrations in both grain and straw were within the normal range (15 to 150 μg/g) reported by Melsted (1973).

Copper. Concentrations of copper in grain (5 to 11 μg/g) were not significantly different due to soil type, sludge type or rates (Table 17). Straw Cu concentrations (3 to 6 μg/g) were affected by soil type and sludge rate, but the range is too narrow to establish any significant trend. Concentrations in both grain and straw were within the normal range (3 to 40 μg/g) reported by Melsted (1973). Cunningham et al (1975) found that Cu concentrations in corn and rye increased from

7.4 μg/g (control) to a phytotoxic level of 23 μg/g at the highest sludge loading rate (502 tonnes/ha). Results of this experiment indicate that copper applied up to 42 kg/ha had no adverse effects on wheat during the first growing season.

Nickel. Concentrations of nickel in grain (0.37 to 1.37 μg/g) were generally higher from clay than from sand soils. The highest Ni concentrations in grain was from the highest rate of lime sludge to both soils. Straw Ni concentrations (1.5 to 4.1 μg/g) were not significantly different due to soil type, sludge type or rates (Table 18). Concentrations of Ni in grain and straw were within the normal range (0.1 to 5 μg/g) reported in the literature (Allaway, 1968). Kirkham (1975) did not observe any increase in Ni content of corn leaves grown on soil treated with sludge (28 tonnes/ha/yr) for 35 years. Chaney et al (1975) did not observe any significant increase in Ni content (0.48 to 0.56 μg/g) of corn ear leaves when the sludge loadings were increased from 0 to 224 tonnes/ha.

Chromium. Concentrations of chromium in grain (0.2 to 0.9 μg/g) and straw (1.0 to 1.2 μg/g) were not significantly different because soil type, sludge type or rates (Table 19) and were within the normal range of 0.1 to 2.0 μg/g (Allaway, 1968).

Lead. Concentrations of lead in grain (0.35 μg/g) and straw (4.9 to 9.6 μg/g) were unaffected by soil type, sludge type or rates (Table 20) and were within the normal range of 0.1 to 10 μg/g (Allaway, 1968). Levels of Pb in straw may have been affected by aerial contamination.

Cadmium. Concentrations of cadmium in grain (0.07 to 0.43 μg/g) were generally higher from sand than from clay (Table 21). Iron sludge applications generally produced grain with higher Cd concentrations than did alum or lime sludges, but increasing rates of iron sludges did not affect the grain Cd concentration. Concentrations of Cd in straw (0.17 to 0.29 μg/g) were unaffected by soil type, sludge type or rates. Concentrations of Cd in grain and straw from this study were within the normal range of 0.2 to 0.8 μg/g (Allaway, 1968). Sabey and Hart (1975) did not observe significant differences in Cd content of wheat grain when the sludge application rates were increased from 0 to 100 tonnes/ha.

Kirkham (1975), Cunningham et al (1975) and Jones et al (1975) found increased Cd content in corn grain and leaves with increasing sludge rates.

Cadmium/Zinc Ratio. Chaney (1974) has suggested that the Cd/Zn ratio in sludges, to be applied to agricultural land, should be <0.01 to avoid a Cd hazard in the food chain. All three sludges applied to soils had Cd/Zn ratios >0.01 (Table 22). Cadmium/zinc ratios of grain from non-sludged controls and sludge treatments ranged between 0.0018 to 0.0042 and 0.0011 to 0.0056, respectively. Cadmium/zinc ratios of straw from controls and sludge treatments ranged between 0.0096 to 0.0104 and 0.0053 to 0.0124, respectively. Both grain and straw generally had lower Cd/Zn ratios than those of the sludges applied indicating that this ratio in sludges added to soil does not necessarily correspond to the plant uptake Cd/Zn ratio in wheat grain or straw grown on sludged soil.

TABLE 22. CADMIUM/ZINC RATIO IN SLUDGE, WHEAT GRAIN AND STRAW (1974)

Treatments	Rate (kg Zn Eq/ha)	Sludges	Cadmium/Zinc Ratio			
			Grain		Straw	
			Sand	Clay	Sand	Clay
Control	0	-	0.0018	0.0020	0.0104	0.0096
NPK (60, 60, 60)	0	-	0.0042	0.0018	0.0100	0.0104
Alum Sludge	57	0.011	0.0050	0.0037	0.0121	0.0124
	114	0.011	0.0047	0.0015	0.0092	0.0112
	171	0.011	0.0041	0.0028	0.0069	0.0087
Iron Sludge	57	0.012	0.0052	0.0056	0.0066	0.0087
	114	0.012	0.0048	0.0022	0.0053	0.0109
	171	0.012	0.0044	0.0021	0.0074	0.0074
Lime Sludge	57	0.016	0.0030	0.0023	0.0091	0.0093
	114	0.016	0.0036	0.0012	0.0092	0.0115
	171	0.016	0.0039	0.0011	0.0086	0.0109

Summary of Chemical Constituents in Grain and Straw. Concentration of the chemical constituents N, Ca, Na, Fe and Zn in wheat grain increased while Mn concentrations decreased with sludge applications compared to NPK treatments. Only Zn and Ca concentrations in grain increased with increasing rates of sludge applications.

Concentrations of N, Ca, Mg, Zn and Cd in grain were influenced by sludge types. The highest level of N and Mg were observed from alum sludge on sand. Lime sludge on sand produced the highest Ca concentration, while alum and iron sludges on clay produced the highest concentrations in grain of Zn and Cd, respectively.

Concentrations of Ni and K in grain were affected by soil type only.

Concentrations of P, Al, Cu, Cr and Pb in grain were not affected by soil type, sludge type or rates of application.

Increasing rates of sludge application increased the N, Ca, Mg, Zn and Cu concentrations in straw. The highest levels of N and Ca observed resulted from lime sludges on sand while Zn concentrations were highest from iron sludge on sand. Iron, Al, Ni, Cr, Pb and Cd in straw were unaffected by soil type, sludge type or rates of application.

Concentrations of the chemical constituents in both grain and straw from sludge treatments are compared to non-sludge treatments (with and without NPK) and to the normal ranges in plants as reported in the literature (Table 23).

3.3 Leachate

Leachate collection periods were based on plant development. Leachate was available for the first period from sludge application until crop emergence (May 1 to 31, 1974) and from crop emergence until full fifth leaf (May 31 to June 27, 1974). No leaching occurred for the third period from fifth leaf until crop harvest (June 27 to August 22, 1974).

No crop was established for the period May 1 to 31, 1974 while the soil-sludge mixture was stabilizing. Leachate volumes collected during this period were unrepresentative and are not included in this report. Leachate measurement and analysis was, therefore, limited to the growing season only (May 31 to August 22, 1974).

TABLE 23. METAL CONCENTRATION IN WHEAT COMPARED TO NORMAL RANGES IN PLANTS

Constituents	Units	Concentrations in Grain or Straw		Normal Range (from the Literature)	Reference
		Controls	Sludge Treatments		
Fe	µg/g	40 - 250	27 - 263	50 - 250	1
Mn	"	30 - 53	27 - 66	20 - 500	1
Al	"	2 - 78	1 - 94	- 300	2
Cu	"	3 - 11	3 - 9	3 - 40	3
Zn	"	22 - 56	18 - 73	15 - 150	3
Ni	"	0.4 - 2.8	0.4 - 4.1	0.1 - 5	4
Cr	"	0.2 - 1.2	0.3 - 1.2	0.1 - 2.0	4
Pb	"	0.4 - 8.0	0.4 - 9.6	0.1 - 10.0	4
Cd	"	0.1 - 0.2	0.1 - 0.4	0.2 - 0.8	4

1. Jones (1972).
2. Jones (1961).
3. Melsted (1973).
4. Allaway (1968).

Leachate Volume, pH and Conductivity. Leachate volume, pH and conductivity were measured on unfiltered samples (Table 24). As statistical analysis of this short leachate period was impractical, quality trends only are presented in this report.

Little difference was observed in volumes leached for all treatments from either soil (Table 24).

TABLE 24. LEACHATE VOLUME, pH AND CONDUCTIVITY VALUES (1974)

Treatments	Rate (kg Zn Eq/ha)	Volume (m^3/ha)		pH (values)		Conductivity (μ mhos/cm)	
		Sand	Clay	Sand	Clay	Sand	Clay
Control	0	421	475	6.4	7.2	450	1250
NPK (60, 60, 60)	0	413	405	6.5	7.4	475	1150
Alum Sludge	57	402	462	6.6	7.4	575	1100
	114	489	467	6.6	7.4	610	1175
	171	446	532	6.4	7.3	725	1350
Iron Sludge	57	402	456	6.7	7.3	600	1300
	114	446	478	6.6	7.3	600	1175
	171	413	521	6.5	7.3	675	1325
Lime Sludge	57	437	516	6.6	7.4	600	1125
	114	440	518	6.6	7.4	600	1250
	171	413	386	6.9	7.4	575	1350

pH. pH values from sludge treatments to both soils were slightly higher than non-NPK controls, but were similar to NPK treatments (Table 24).

Conductivity. Leachate conductivity values from clay were approximately twice those from sand. Although sludge treatments to sand slightly increased leachate conductivity compared to that of the controls, sludge treatments to clay had virtually no effect on conductivity (Table 24).

Leachate Chemical Concentration. The sludge control (with and without NPK) leachate concentrations are compared with maximum permissible limits (MPL) for drinking water, irrigation water or sewage effluent standards where available (Table 25).

TABLE 25. LEACHATE CHEMICAL CONCENTRATIONS COMPARED TO WATER QUALITY STANDARDS (1974)

Constituents		Untreated Control Leachate	Sludge Treated Leachate	Maximum Permissible Limits	Reference
NH_4-N	(mg/l)	0.1 - 0.4	0.1 - 0.4	0.5	1
NO_3-N	"	14.7 - 49.0	23.8 - 61.4	10.0	1
Total P	"	0.3 - 0.6	0.2 - 0.8	1.0; <0.1	2; 1
TOC	"	11.0 - 15.0	10.0 - 21.8	-	NA
Cl	"	33 - 43	39 - 67	250	1
SO_4	"	38 - 111	30 - 126	500	1
Ca	"	58 - 158	75 - 179	200	1
Mg	"	14 - 64	16 - 70	150	1
Na	"	17 - 42	16 - 44	-	NA
K	"	1.7 - 4.6	1.6 - 5.3	-	NA
Al	(μg/l)	34 - 36	22 - 67	20,000	3
Fe	"	18 - 27	22 - 143	300	1
Mn	"	77 - 144	63 - 539	20,000	3
Zn	"	20 - 26	16 - 42	5,000	1
Cu	"	17 - 24	13 - 24	1,000	1
Ni	"	5 - 10	4 - 15	2,000	3
Cr	"	2*	2	50	1
Pb	"	10 - 31	13 - 36	50	1
Cd	"	1 - 3	1 - 3	10	1

NA Not available.
1. NH&W (1969) Canadian Drinking Water Standards.
2. Canada/US (1972) GLWQ Agreement, Effluent Requirement.
3. OMOE (1974) Water Quality Criteria for Agricultural Uses.
* Limit of detection.

Chemical concentrations of NH_4-N, NO_3-N, total P, TOC, Cl, SO_4, Ca, Mg, Na, K, Al, Fe, Mn, Zn, Cu, Ni, Cr, Pb and Cd in leachate are given in Table 26.

NH_4-N. Concentrations of NH_4-N in leachate were unaffected by soil types or sludge applications and ranged from 0.1 to 0.4 mg/l. All these values were within the MPL of 0.5 mg NH_4-N/l for drinking water (NH&W, 1969).

NO_3-N. The NO_3-N leachate values ranged from 14.7 to 61.4 mg/l and in all cases exceeded the MPL of 10 mg/l for drinking water (NH&W, 1969). Concentrations of NO_3-N from non-NPK clay control (49 mg/l) were approximately three times greater than those from sand control (14.7 mg/l). Sludge applications on sand increased the leachate NO_3-N concentrations up to 42.2 mg/l, but values were not significantly affected by sludge rates. These high NO_3-N concentrations in leachate may be the major limiting factor for land application of these air-dried sludges.

Total P. Concentrations of total P were unaffected by soil type, sludge type or rates of application.

Total P values ranged from 0.2 to 0.8 mg/l and were thus within the sewage effluent requirement of $\leq$1.0 mg P/l as set out in the Canada/US Great Lakes Water Quality Agreement (1972).

Total Organic Carbon. Concentrations of total organic carbon in leachate were unaffected by soil type. There are no standards available for TOC. The alum and lime sludge application at the high rates to both soils had leachate values (19.0 to 21.8 mg/l) slightly higher than the 10 to 15 mg/l from non-sludged controls.

Chloride. Concentrations of chloride in leachate increased slightly with sludge applications on both soils, compared to controls. These concentrations ranged from 33 to 67 mg/l and in all cases were within the MPL of 250 mg/l for drinking water (NH&W, 1969).

Sulphate. Concentrations of sulphate in leachate were higher from clay than from sand. Increasing alum or iron sludge application to sand increased the sulphate leachate concentrations, but the opposite effect was observed when lime sludge was applied to sand. Sulphate concentrations, which ranged from 30 to 126 mg/l, were within the MPL of 500 mg/l for drinking water (NH&W, 1969).

TABLE 26. CHEMICAL CONSTITUENTS IN LEACHATE (1974)

Treatments	Rate (kg Zn Eq/ha)	NH_4-N		NO_3-N		Total P		TOC		K	
		Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay
Control	0	0.4	0.2	14.7	49.0	0.3	0.5	13.5	14.5	4.3	1.7
NPK (60, 60, 60)	0	0.1	0.3	27.9	37.8	0.6	0.5	15.0	11.0	4.6	1.7
Alum Sludge	57	0.2	0.2	37.8	37.9	0.7	0.7	13.3	15.5	4.9	1.6
	114	0.1	0.3	35.9	41.6	0.5	0.4	20.0	13.3	5.1	1.8
	171	0.4	0.4	42.2	54.0	0.2	0.1	20.3	19.0	5.3	1.8
Iron Sludge	57	0.1	0.3	37.4	61.4	0.3	0.4	11.5	10.0	4.9	1.7
	114	-	0.4	38.5	39.0	0.6	0.5	12.0	13.0	4.7	1.6
	171	0.1	0.1	40.0	60.6	0.6	0.7	11.5	12.0	5.0	1.7
Lime Sluge	57	0.1	0.3	39.8	30.5	0.7	0.5	13.0	14.3	5.2	1.7
	114	0.1	0.4	23.8	37.7	0.8	0.4	15.3	18.0	4.9	1.7
	171	0.2	0.1	28.2	57.2	0.6	0.2	21.8	20.3	5.2	1.7

Note: Units are in mg/l.

TABLE 26 (CONT'D). CHEMICAL CONSTITUENTS IN LEACHATE (1974)

Treatments	Rate (kg Zn Eq/ha)	Ca		Mg		Na		Cl		SO_4	
		Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay
Control	0	58	158	14	64	17	42	33	43	39	111
NPK (60, 60, 60)	0	62	153	16	62	17	41	36	41	38	85
Alum Sludge	57	82	148	16	54	18	39	44	39	46	87
	114	91	163	17	61	19	41	47	46	66	72
	171	112	177	20	70	21	44	63	59	90	115
Iron Sludge	57	95	164	18	67	19	43	52	55	50	104
	114	83	149	17	55	16	40	52	58	55	95
	171	98	160	19	59	16	43	53	57	85	126
Lime Sludge	57	85	142	17	56	17	39	50	43	53	81
	114	75	159	18	64	19	41	67	53	103	
	171	75	179	17	68	20	43	46	55	30	67

Note: Units are in mg/l.

TABLE 26 (CONT'D). CHEMICAL CONSTITUENTS IN LEACHATE (1974)

Treatments	Rate (kg Zn Eq/ha)	Al		Fe		Mn		Zn		Cu		Ni		Cr		Pb		Cd	
		Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand	Clay
Control	0	36	34	21	18	90	109	22	20	24	19	10	5	2	2	10	31	1	3
NPK (60, 60, 60)	0	36	36	26	27	144	77	26	20	22	17	10	8	2	2	10	26	2	3
Alum Sludge	57	32	24	27	34	85	195	27	23	17	15	4	4	2	2	15	29	2	2
	114	37	26	36	25	206	157	23	20	16	16	12	6	2	2	13	27	1	2
	171	32	24	29	32	519	215	29	19	24	15	10	7	2	2	22	33	2	2
Iron Sludge	57	35	42	27	35	63	115	31	21	19	15	10	12	2	2	15	30	1	3
	114	47	33	38	44	126	86	24	31	15	18	15	6	2	2	17	29	2	2
	171	67	31	74	22	405	69	34	21	20	18	9	9	2	2	22	36	2	3
Lime Sludge	57	45	29	22	88	231	235	42	19	16	16	7	8	2	2	18	31	2	2
	114	48	22	32	37	240	95	26	18	18	13	8	10	2	2	14	31	1	3
	171	36	25	104	143	539	66	29	16	24	14	7	6	2	2	13	32	1	3

Note: Units are in μg/l.

Calcium. Concentrations of calcium in leachate were higher from clay than from sand. Sludge treatments to sand increased the leachate calcium concentrations, but to clay, no increases were observed. Calcium concentrations ranged from 58 to 179 mg/l and were thus within the MPL of 200 mg/l for drinking water (NH&W, 1969).

Magnesium. Concentrations of magnesium in leachate for all treatments from clay were approximately four times higher than from sand and appear to be related to the initial Mg content of soils (Table 2). Sludge types or rates did not affect the Mg concentrations in leachate from either soil. Magnesium concentrations ranged from 14 to 70 mg/l and were within the MPL of 150 mg/l for drinking water (NH&W, 1969).

Sodium. Concentrations of sodium in leachate were unaffected by sludge applications, but the values were higher from clay than from sand. There are no drinking water quality standards for Na in leachate, but sludge treated leachate values (16 to 44 mg/l) were comparable to control leachate concentrations (17 to 42 mg/l).

Potassium. Concentrations of potassium in leachate were unaffected by sludge application, but were slightly higher from sand than from clay. There are no drinking water quality standards for leachate K, but the sludge treated leachate values (1.6 to 5.3 mg/l) were similar to control leachate concentrations (1.7 to 4.6 mg/l).

Aluminum. Concentrations of aluminum in leachate were not affected by soil type or sludge application. Aluminum concentrations ranged from 22 to 67 μg/l and were within the MPL of 20 mg/l for irrigation water (OMOE, 1974).

Iron. Concentrations of iron in leachate were higher after sludge applications than those from controls. The highest rates of lime sludge on both soils produced the highest concentrations of Fe in the leachate. Leachate Fe concentrations ranged from 18 to 143 μg/l (Table 26) and were within the MPL of 300 μg/l for drinking water (NH&W, 1969).

Manganese. Concentrations of manganese in leachate were influenced by soil type, sludge type and rates. Increasing rates of sludge application to sand considerably increased the Mn concentrations in the leachate. On clay, the increasing rates of iron and lime sludges, decreased the Mn values. Manganese concentrations ranged from 63 to 539 μg/l (Table 26) and were within the MPL of 20 mg/l for irrigation water (OMOE, 1974).

Zinc. Concentrations of zinc in leachate were not affected by sludge application but were slightly higher from sand than from clay. Zinc concentrations ranged from 16 to 42 μg/l (Table 26) and were within the MPL of 5 mg/l for drinking water (NH&W, 1969).

Copper. Concentrations of copper in leachate were unaffected by sludge application, but were slightly higher from sand than from clay. Copper concentrations ranged from 13 to 24 μg/l (Table 26) and were within the MPL of 1 mg/l for drinking water (NH&W, 1969).

Chromium. Concentrations of chromium in leachate (2 μg/l) were not affected by any treatment. These values are within the MPL of 50 μg/l for drinking water (NH&W, 1969).

Lead. Concentrations of lead in leachate were not influenced by sludge application, but were higher from clay than from sand. Lead concentrations ranged from 10 to 36 μg/l (Table 26) and were within the MPL of 50 μg/l for drinking water (NH&W, 1969).

Cadmium. Concentrations of cadmium in leachate were unaffected by soil type or sludge application. Cadmium concentrations ranged from 1 to 3 μg/l and were within the MPL of 10 μg/l for drinking water (NH&W, 1969).

In summary, NH_4-N, Cl, SO_4, Ca, Mg, Fe, Zn, Cu, Cr, Pb and Cd concentrations in leachate were within the MPL for drinking water.

Concentrations of Al, Mn and Ni in the leachate were within the MPL for irrigation water.

Concentrations of TOC, Na and K in leachate from sludge treated soils were similar to control leachate values.

Concentrations of NO_3-N in leachate increased with sludge application rates and could present a potential groundwater contamination problem.

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ACKNOWLEDGEMENTS

The authors express their appreciation to farm managers Mr. M. Chwastriak (Norfolk County) and Mr. D. Cunnington (Timiskaming District) for their cooperation in providing the experimental soils.

The analytical support provided by the Laboratory Services Section and the assistance of the Facilities Services Section, Wastewater Technology Centre are gratefully acknowledged as is the technical support provided by Mr. T. Sway and Mr. J. Rajkumar.