2.4 Application of Saskatoon's Dewatered Sewage Sludge to Agricultural Land

L.E. Cowell and E. de Jong

(Project funded by Natural Science and Engineering Research Council of Canada)

INTRODUCTION

The application of sewage sludge to agricultural land is not a new idea; numerous large cities are already successfully disposing of sewage in this way. The City of Philadelphia (population 1.7 million) has been a leader in this work, with production of composted sludge for use in greenhouses, gardens, parks and sports fields, farmland and strip-mine reclamation projects (Miller, 1986). In Ontario, over one-third of the province's sewage sludge is used for crop production (Environment Ontario, 1984). In Saskatchewan, the Cities of Swift Current and Moose Jaw have supplied effluent for irrigation for several years. The City of Yorkton disposes of all sewage wastes by using tanker trucks to apply sewage to farmland. The Saskatchewan Department of Environment and Public Safety and the Saskatchewan Water Corporation have recognized the value of sewage disposal on agricultural land, and will assist in preparation of such projects (Saskatchewan Water Corporation, year unknown). Unfortunately, the major urban centers of Saskatoon and Regina have lagged behind in this technology.

In Saskatoon, a secondary sewage treatment process is used. The sewage is screened, settled and anaerobically digested at the sewage plant near Silverwood Heights. From here the sludge is pumped to the Warman sewage lagoons, 12 km north of the sewage plant. Here the solids are settled out in a series of lagoons. The liquid is returned to Saskatoon to be disposed of into the South Saskatchewan River. After further evaporation the solids are carried out of the lagoons to be dumped in piles nearby. The solids are allowed to accumulate, with sporadic removal for application to City land. No large scale agricultural use has been attempted nor is there any long term management of the dewatered sludge.

Some evaluation of the sludge for crop application has been carried out by the Department of Agricultural Engineering, University of Saskatchewan (Gillies et al., 1988; Hulit et al., 1989). If further development of Saskatoon sewage sludge is to occur, the crop response to sludge application and any environmental and health risks must be measured. A project was thus conducted in 1989 to evaluate the value and effect of dewatered sewage sludge on agricultural crops. A brief review of relevant literature is included.

BENEFITS FROM LAND APPLICATION OF SEWAGE SLUDGE

Soil Quality

Numerous sources attribute improved soil quality to application of sewage sludge. Sewage sludge applied at 50 to 100 tonnes/ha reduced bulk density and increased porosity (Wei et al., 1985; Pagliai et al., 1981). Epstein and co-workers (1976) measured a 300% increase in CEC and a 20% increase in water holding capacity for a soil after application of 240 tonnes/ha of sludge. Increased nitrogen (N) mineralization is a benefit which may be realized for several years after sludge application (Boyle and Paul, 1989; Ndayegamiye and Côte, 1989). The only measured negative effect of sewage sludge on a soil's quality has been increased soil salinity and sodium adsorption ratio (SAR). Depending on sludge characteristics and application rates, salts from the sludge may increase soil salinity and reduce crop growth (Epstein et al., 1976; Westerman et al., 1973).

Soil Erosion Control

Sewage sludge has been used as a soil amendment to reduce erosion in land reclamation projects. A primary use of sewage sludge is in reclamation of mine spoils. At rates as low as 14 tonnes/ha, sewage sludge has improved vegetation more than fertilizer applications (Topper and Sabey, 1986; Seaker and Sopper, 1988). In the Netherlands, sewage compost mixed with water and grass seed is often used for 'hydro-seeding' to stabilize and revegetate eroded areas (Knotterus, 1976). Sludge could be effective in restoring eroded agricultural land. At Lethbridge, manure was used to restore productivity to artificially eroded soils with resulting yield increases larger than with fertilizer applications (Dormaar et al., 1988). Sewage sludge may have a similar effect on eroded soils.

Environmental Quality

Contamination of the environment is of primary concern in sewage disposal. Disposal of wastes into waterbodies or landfills provides a concentrated source of contaminants which may seriously damage the immediate area. At present, Saskatoon disposes of treated sewage effluent into the South Saskatchewan River. Solids are largely removed, but a long term disposal scheme for the solids has not been developed. Application to agricultural land is probably the most environmentally sound alternative. By application of relatively small amounts of sewage sludge to farmland, there is no danger of polluting the surrounding environment nor the crop. The rivers and other waterbodies are spared, no landfills are required, and the crop may benefit from the sewage application.

Potential of Sewage Sludge as a Fertilizer

If sewage sludge is to be considered for agricultural use, its relative fertilizer value must be known. Certainly, large crop yield responses have been measured after sludge application, but this is often on rates of over 100 tonnes/ha. To be practically considered as a fertilizer source, lower rates need to be applied.

Most often, sewage sludge is considered a source of available N. The total amount of N and the rate of organic N mineralization to plant available forms will largely determine the crop response to sludge application. The total N is easily determined but the rate of N release is difficult to ascertain.

Total amounts of N, P and K (the principal nutrient elements) in sludge vary substantially (Table 2.4.1). Levels depends on the source of sludge and degree of digestion. composted sludge, immediately available N tends to be low due to immobilization to organic compounds and loss by volatilization of NH_3.

Table 2.4.1 Amounts of total N, P and K and of available NO_3^--N and NH_4^+-N in sewage sludge.

Nutrient	Range†	Saskatoon‡	Regina§
% N	3-7	1.5	0.5-2
% P	1-3	2-3	0.2-1.3
% K	0.1-3	NA	0.2-0.6
NH_4^+-N (ppm)	10-2,000	360	NA
NO_3^--N (ppm)	1-500	71	NA

† From Boyle and Paul (1989), Elliott (1986), Hornick et al. (1984).
‡ From Gillies et al. (1989).
§ From Viraraghaven and Rana (1987).

A few papers emphasize the total amounts of N and other nutrients in sludge in describing the nutrient value of the sludge for agriculture (Viraraghaven and Rana, 1987). This is an error, for two reasons; the amount of total N added with the sludge is very small compared to the total N present in the soil, and the N present in the sludge may be recalcitrant to release of the N to plant available forms. Therefore, the potential N availability is more important than the total N. Unfortunately, this value is rarely measured. For manures, the Saskatchewan Soil Testing Laboratory suggests that 50% of the total N is available for crop uptake in the first crop year, 10% in the second year and 5% the third year. In addition, 40% of the total phosphate and 90% of the total potassium is assumed available (Harder, 1989). The proposed Saskatchewan guidelines for sewage sludge application to agricultural land assumes that 25% of the organic N in sewage sludge will be available in the first year, 12.5% the second year, and 6% the third year (Saskatchewan Environment and Public Safety, 1987). Other sources consider a 20% release of N in the first year to be optimistic, with actual release in the field to approach 5 to 10% (Halderson and Zenz, 1978; Hornick et al., 1984). The rate of release depends on the degree of sewage treatment. Raw sewage or primary treated sewage will be much more degradable than digested sludge (Sommers and Berbarick, 1986). After anaerobic bacterial digestion, sludge resembles a stable humus which resists rapid decomposition (Elliott, 1986). Hence, digested sludge is often considered a soil conditioner more than a fertilizer.

Nevertheless, sewage sludge has been prepared and marketed for application to crops. Several commercial products have been developed from sewage sludge. The City of Philadelphia produces "Earthlife" (for greenhouses and landscaping), "Philorganic" (for farmland application), and "Mine Mix" (for strip mine reclamation) (Miller, 1986). Seattle produces "Silvigro" for timberland application. Milwaukee delivers "Agri-Life" to farmers for land applications, and sells "Milorganite" for greenhouse use. Los Angeles County similarly sells "Nitro-humus" and Houston "Hou-Actinite" and Oakland "Comgro". Sludge 'fortified" with inorganic fertilizers is also produced and sold from a number of urban centers (Bastion and Ryan, 1986). Production and even sale of sewage sludge for crop or turf application is not a new idea, but one that has recently become well accepted.

PROBLEMS ASSOCIATED WITH SLUDGE APPLICATION

Sewage sludge, despite its positive attributes, is often viewed as a pollutant. Concerns including heavy metal contamination, organic chemicals, and pathogenic organisms often limit the use of sewage sludge.

Heavy Metals from Sewage Sludge

Sewage sludge, especially from industrialized urban centers, may contain elevated amounts of heavy metals. Crops contaminated with heavy metals could cause serious health problems. Fortunately, most of the harmful elements are not readily transferred to the edible plant parts, or are phytotoxic at lower levels than they are toxic to mammals. However, cadmium, molybdenum, selenium and cobalt can reach levels in crops that are harmful to mammals without affecting crop growth. Cadmium presents the most risk to human health through liver and kidney damage. The level of heavy metals in sewage sludge varies widely between sources of sludge and timing of sampling. Typical values are difficult to derive (Table 2.4.2).

Saskatoon, being a relatively non-industrialized center, has the advantage of low levels of heavy metals and other elemental contaminants in the sewage sludge.

Table 2.4.2 Typical heavy metal content of digested sewage sludge.

Element	Range†	Average†	Saskatoon, 1987‡
	----------	µg/g, dry weight basis	----------
Ag	5-150	20	NA
As	<1-250	10	7.3
B	4-1000	40	41
Cd	<1-3000	15	<2.5
Co	<1-2000	15	4.3
Cu	60-10,000	800	152
Fe	500-150,000	20,000	NA
Hg	0.5-50	6	2.3
Mn	30-7000	300	219
Mo	0.1-400	5	7.7
Ni	2-5000	80	20
Pb	10-20,000	500	86
Se	<1-20	5	6.3
Zn	100-50,000	2000	328

† From Bastion and Ryan (1986), Elliott (1986), Halderson and Zenz (1978).
‡ From Gilles et al. (1987); this is the average of monthly values for 1987.

Native Levels of Heavy Metals in Soil

The native content of elements in the soil must be known before determining the effect of sludge application (Table 2.4.3).

Table 2.4.3 Approximate content of several elements in Saskatchewan and Alberta soils

Element	Saskatchewan soils†	Alberta soils†
	µg/g	
As	6	0-10
Cd	0.6	0.4-0.5
Co	11	6-10
Cu	20	19-29
Cr	48	40
Hg	0.05	0.02-0.04
Mo	4	1-3
Ni	26	NA
Pb	16	14-17
Se	<1	0.1-2.0
Zn	90	85-105

† (From Abboud (1986) and Saskatchewan Environment and Public Safety (1987).

Heavy Metals in Crops

Unfortunately, little data relevant to sludge application refers to safe levels of heavy metals in terms of crop growth or human health. Logan and Chaney (1983) measured sensitivity of some crops to heavy metals from sludge. They found alfalfa and clovers to be generally more sensitive than grasses and corn. Halderson and Zenz (1978), in review, suggest there is no direct relationship between accumulative sludge application and grain metal levels, and that repeated heavy applications of sludge did not necessarily contaminate the grain. Work in Alberta showed no increase of heavy metals in barley grain or alfalfa hay after application of over 20 tonnes of sludge/ha (McCoy, 1977; as cited by Environment Canada, 1984).

The ultimate test of the safety of sludge application should be the effect on the crop grown. Unfortunately, none of the guidelines for sludge application reviewed used crop contamination as a parameter in deciding safe rates. The Food and Drug Regulations for permissible levels of toxic elements in food provide only a skeletal guideline and does not include Cd, Mo, Se and Co, the elements of most concern (Table 2.4.4). More information is needed to assess the real effect of sewage sludge on crop growth.

Table 2.4.4 Permissible levels of elements in food.

Element	Permissible level† (µg/g)
As	0.1-3.5
Pb	0.15-10
Fl	150-650
Cu	50
Sn	250

† From Department of Health and Welfare (1986).

Organic Pollutants in Sewage Sludge

Industrial and household wastewater contains organic compounds, some of which are toxic at high levels. Cleaning products, laundry soaps, paint, polishes, deodorants, cosmetics and pesticides all become part of the sewage sludge (Kowal, 1986). Measurement of specific organic compounds is costly and time consuming. Rather, an estimate of total organics is used. The reaction of specific organics in the soil, their persistence and effect on crops is not well documented. Many of these compounds are subject to volatilization or microbial degradation, and few are easily translocated in plants. However, organics could contaminate root crops and could enter the milk fat of dairy cattle (Elliott, 1986). None of the literature reviewed suggested safe levels of specific organics, nor provided any guidelines for monitoring toxic organic contamination of soil or crops.

Pathogens in Sewage Sludge

Pathogenic bacteria, viruses, protozoa and helminths may all be present in sewage sludge. Anaerobic digestion of sludge will substantially reduce, but probably not eliminate, these pathogens. Few of them can survive in the soil environment. Application of dewatered sewage sludge provides less exposure to pathogens by inhalation than irrigation with sewage effluent (Elliott, 1986). The most persistent of the pathogens in soil is the helminth eggs and larvae. Measurement of specific pathogens is practically impossible, and infection would depend on exposure. None of the case studies reviewed considered exposure to pathogens to be a problem. Any sludge application program must simply minimize direct exposure to the sludge.

Guidelines for Sewage Sludge Application

The rate of sludge application and the location of application must be regulated with guidelines to ensure public safety. The Saskatchewan government has prepared a draft guideline for use of sewage sludge on agricultural land (Saskatchewan Environment and Public Safety, 1987). The document provides guidelines for maximum annual heavy metal loading rates and maximum cumulative heavy metals (Table 2.4.5). Compared to other jurisdictions, theses guidelines are quite stringent (Environment Canada, 1984).

The guidelines also suggest that no more than 180 kg of total N/ha and less than 60 kg of NH_4-N and NO_3-N/ha be applied per year. Available soil P should be less than 100 ppm. Soil pH should be greater than 6.5 and salt loading should not exceed

Table 2.4.5 Saskatchewan guidelines for pollutant metal application from sewage sludge†.

Element	Maximum annual loading rate	Maximum cumulative amount
	kg/ha	
As	1.3	12
B	2.0	NA
Cd	0.13	1.2
Co	3.3	30
Cu	13.3	120
Cr	11.1	100
Hg	0.044	0.4
Mo	0.44	4
Ni	3.3	30
Pb	8.9	80
Se	0.22	2
Zn	33.3	300

† From Saskatchewan Environment and Public Safety (1987).

300 kg/ha. The guidelines also describe the preferred land location in terms of distance to residences, public places, wells, and waterbodies, and to depth of groundwater. Unlike some guidelines, soil CEC is not considered. The Saskatchewan guidelines provide a good speculative framework for application of sludge, but data is required to substantiate the recommendations for Saskatchewan conditions.

Application of Dewatered Sewage Sludge

The large volumes of sewage sludge produced by a city requires equipment which is capable of quickly applying sludge. In Saskatchewan the problem is complicated in that only two short application seasons may be available, before crop seeding in spring and between harvest and fall freeze-up. In other municipalities, large truck-mounted spreaders (capacity of over 10 tonnes of sewage sludge) are used, which can quickly transport the sludge to the field and dump the sludge uniformly and quickly. This, in addition to loading equipment, would be the main cost of disposing of sewage sludge on agricultural land. Disposal of dewatered sewage sludge from the Saskatoon drying beds to nearby fields with similar equipment would probably be a viable method.

METHODS

Dewatered sewage sludge from the Saskatoon drying beds was applied in the spring of 1989 to fields near Warman (NE7-38-4-W3) and Pike Lake (SE21-34-6). Both soils were a sandy loam and each site covered an eroded slope including all slope positions. Each site was planted on wheat stubble. Both sites were preworked by the cooperating farmer.

The treatments were set out in a split plot with four replicates. Slope position was considered the main plot and sludge application the subplots.

The sludge was applied at 10, 20 and 30 tonnes/ha (wet weight) either pre-seeding or post-seeding. If applied pre-seeding the sludge was incorporated into the soil with a cultivator before seeding. The sludge was applied with a truck-mounted manure spreader with a load capacity of 10 to 12 tonnes. The rate of sludge application was calibrated by placing 1 m^2 plywood squares on the plot while spreading. The sludge collected from the plywood was weighted, then subsampled. Samples were composited and kept for subsequent analysis.

In addition to the sludge treated plots, check plots were included, and a treatment with high rates of N, P, K fertilizer. On these plots 100 kg/ha of N, P_2O_5 and K_2O were each applied as urea (46-0-0), triple superphosphate (0-45-0) and potash (0-0-60). No fertilizer was applied to the check plot nor the sludge treated plots. In addition, at the Pike

Lake site, nonreplicated treatments of 50, 75 and 100 tonnes of sludge/ha were applied adjacent to the main plots.

Harrington barley was seeded at 75 kg/ha in all plots. A 2.3 m double disc drill with 18 cm row spacings was used to seed the sites.

At harvest, 5 m^2 samples were taken at the crest, upper, mid and lower slope positions in each treatment. These samples were threshed and measured for total and grain weight. Composite samples of grain were taken for heavy metal analyses.

Soil samples were collected in spring for sludge application from the upper, mid and lower slope positions for analysis of gravimetric soil moisture, available nutrients and heavy metals. After harvest, soil samples were collected from each treatment for similar analyses. All chemical analyses were carried out by Norwest Laboratories of Edmonton.

RESULTS

Application of Sludge

The sewage sludge was easily applied with the truck-mounted spreader. Some problems were encountered with ice blocks in the sludge piles, but these were easily handled by the truck spreader. Calibration of the spreader to exact rates required several trials. The rate of unloading for truck spreaders is controlled by a hydraulic ram which pushes the load to the rotating beaters. The hydraulics are sensitive to small changes in flow rate. Therefore the actual rates at Warman were 7, 18 and 30 tonnes/ha. The unloading rate, however, varied somewhat with the size of the load and the slope of the land. Visually, the rates were low; only the 30 tonnes/ha rate fully covered the soil surface. In comparison, the truck operator estimated that feedlot manure is usually spread at 100 tonnes/ha.

Sludge Characteristics and Soil Loading Potential

Analysis of the sewage sludge included % water, pH, conductivity, % organic carbon, % total N, P and K, available NO_3-N and NH_4-N, and a number of potentially pollutant elements, mainly heavy metals (Table 2.4.6).

Table 2.4.6 Analysis of dewatered sewage sludge.

Metal	Concentration in sludge (ppm)	kg element/ tonne sludge	Maximum loading rate of element (kg/ha/yr)†	Maximum tonnes sludge application (tonnes/ha/yr)‡
Al	8580	8.6		
As	1.9	$1.9x10^{-3}$	1.3	684
B	NA	NA	2.0	
Ca	13,300	13.3		
Cd	<0.3	$<0.3x10^{-3}$	0.13	433
Co	2	$2x10^{-3}$	3.3	1650
Cr	28.3	$2.8x10^{-2}$	11.1	3964
Cu	72.5	$7.2x10^{-2}$	13.3	1847
Fe	4550	4.6		
Hg	1.37	$1.4x10^{-3}$	0.044	31.4
Mg	3410	3.4		
Mn	123	$1.2x10^{-1}$		
Mo	<2	$<2x10^{-3}$	0.44	220
Na	384	$3.8x10^{-1}$		
Ni	20	$2.0x10^{-2}$	3.3	1650
Pb	95	$9.5x10^{-2}$	8.9	937
Se	0.15	$1.5x10^{-4}$	0.22	1467
Zn	246	$2.5x10^{-1}$	33.3	133
% N	0.75	7.5	180	24
% P	0.68	6.8		
% K	0.09	0.9		
% C	10.5	105		
% Inorganic	65			
NO_3^--N	1.3	$1.3x10^{-3}$ }	60	17,143
NH_4^+-N	22.1	$2.2x10^{-3}$ }		
% H_2O	53			
pH	7.9			
Cond.	1.76	1.70	300	176
SAR	0.77			

† From Saskatchewan Environment and Public Safety (1987).
‡ Tonnes of sludge, dry weight basis.

The values of elemental composition are low compared to other sewage sludge, including other samples from Saskatoon (Tables 2.4.1 and 2.4.2). This discrepancy can be partly explained by the high level of inorganic material (soil) in the sludge (65%). Soil may have been mixed with the sludge when the drying beds were scraped out. The high proportion of inorganics must be viewed as a problem, as it will increase the handling requirements of the sludge, and reduce its value as a soil amendment.

Using the value of elemental composition and the guidelines provided by the Saskatchewan government, the maximum safe annual application rate of sludge was calculated (Table 2.4.6). The safe levels of sludge application by these calculations are quite high. It should be noted that these values are based on the dry weight of sludge. The sludge applied was over 50% moisture, so the 30 tonne rate applied only 16 tonnes of dry weight sludge. Based on these values, the highest rate of sludge that should be applied is 24 tonnes/ha dry weight, or 45 tonnes/ha wet weight. Thus, the 30 tonne rate of sludge was well within safe limits for the sludge used.

Compared to other analyses of sewage sludge, the values for total N, P and K, and for all other elements are very low (Tables 2.4.1 and 2.4.2). The elements of most concern to human health (Cd, Mo, Se and Co) are notably low compared to other sewage sludge. Unfortunately the values for the total N, P and K, and for NO_3-N and NH_4-N are also low. The sludge used was anaerobically digested, and had been left in the pile for nearly a year. This may partially explain the low values for inorganic N, as it was probably volatilized and immobilized to organic N over this period.

Characteristics of Soil

Soil sampled before sludge application and after harvest was measured for available nutrients and a number of heavy metals and other potentially pollutant elements (Tables 2.4.7). Only soil from the 30 tonne/ha rate applied pre-seeding was analyzed after harvest, since this treatment would be most likely to increase the parameters measured.

Table 2.4.7 Characteristics of soils before (in spring) and after (in fall) application of sludge at Pike Lake and Warman. (Data for fall is the 30 tonne/ha preseeding application)

	Spring			Fall		
	Upper	Mid	Lower	Upper	Mid	Lower
			Pike Lake site			
Al	7520	7540	9930	6840	9920	14,100
As	6.9	8.4	8.0	6.3	6.9	10.4
Ca	28,800	26,300	22,700	28,000	31,900	24,700
Cd	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Co	7	8	9	5	5	6
Cr	11.7	10.9	13	11.3	15.5	20.7
Cu	15	18.3	16.2	11.7	17.6	14.8
Fe	13,600	14,300	17,700	11,600	13,400	16,700
Hg	0.03	0.03	0.05	0.05	0.03	0.07
Mg	9540	91,600	8630	8740	8620	8520
Mn	315	325	412	258	279	354
Mo	<2	<2	<2	<2	<2	<2
Na	178	161	146	104	138	138
Ni	33	34	34	16	19	20
Pb	35	35	42	19	26	34
Se	0.11	0.15	0.35	0.3	0.4	0.4
Zn	47.5	53.7	77.8	49.7	58	86
NO_3-N	83	27	35	12	15	22
Available P	17	24	15	20	54	95
Available K	850	670	850	392	209	543
% C	1.2	1.8	2.4			
CEC	16.7	21.9	28.5			
pH	7.8	7.8	7.6			
			Warman site			
Al	4640	5640	6500	6060	7210	7930
As	3.5	4.0	3.5	3.0	3.1	3.2
Ca	1990	2240	2660	2500	2640	3610
Cd	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Co	2.9	4	4	3	3	3
Cr	7.2	7.8	9.4	8.7	10.6	11.3
Cu	3.1	3.1	3.7	2.5	3.5	3.9
Fe	7950	8630	9890	8030	8470	9220
Hg	0.01	0.02	0.01	<0.01	0.02	0.03
Mg	1500	1450	2110	1610	1710	2200
Mn	211	258	304	253	238	327
Mo	<2	<2	<2	<2	<2	<2
Na	111	119	115	95	103	110
Ni	22	26	22	5	5	6
Pb	18	22	24	14	17	18
Se	0.14	0.14	0.04	0.24	0.16	0.27
Zn	29.8	34.9	41.4	36.1	41.6	49.6
NO_3-N	40	11	42	3.8	4.5	4.9
Available P	20	11	13	22	84	49
Available K	505	192	387	198	139	229
% C	1.21	1.58	1.37			
CEC	9.9	11.1	13.3			
pH	7.0	6.9	7.4			

Of the nutrient elements, available P was increased the most. NO_3-N was not elevated by the 30 tonne/ha rate. The levels of heavy metals were low compared to other Saskatchewan soils (Table 2.4.3).

Both Cr and Se seemed to be increased after sludge application. This could be of concern since Se can be toxic to mammals at lower levels than to plants. This contrasts the analysis of the sludge which, according to provincial regulations, showed Se and Cr levels to be of little concern (Table 2.4.6). Future work may need to document the effect of sludge on soil Se levels.

At Pike Lake, where single application of sludge were made at 50, 75 and 100 tonnes/ha, both soil NO_3-N and available P were increased (Table 2.4.8). Very high rates of sludge should be avoided, to prevent excessive nutrient levels and avoid groundwater contamination.

Table 2.4.8 Nutrient levels in soil after applying high rates of sewage sludge (Data is from soil sampled after harvest).

		50 tonnes/ha	75 tonnes/ha	100 tonnes/ha
			kg/ha	
NO_3-N	(0-15 cm)	134	140	142
	(15-30 cm)	11	9	16
	(30-60 cm)	18	13	25
P	(0-15 cm)	52	78	120

Grain Analysis

At both sites there was little increase in either nutrient or pollutant elements in the barley grain after application of 30 tonnes of sludge/ha pre-seeding (Table 2.4.9). Single composite samples were analyzed, so no statistical significance could be assigned. At both

Table 2.4.9 Analyses of grain from 30 tonne/ha (pre-seeding) treatment, compared to the check treatment.

	Warman				Pike Lake			
	Upper	Mid	Lower	Check	Upper	Mid	Lower	Check
% N	2.43	1.94	1.98	2.08	2.96	2.62	2.47	2.65
% P	0.35	0.25	0.25	0.26	0.36	0.29	0.31	0.32
% K	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Al	6	6	9	6	37	19	37	12
As	27	22	27	32	29	27	35	31
Ca %	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cd	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Co	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Cr	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Cu	4.4	4.4	4.3	4.2	6.8	6.5	7.0	6.9
Fe	92	61	70	62	92	109	96	83
Hg	0.05	0.03	0.05	0.03	0.04	0.07	0.03	0.11
Mg %	0.16	0.15	0.14	0.15	0.14	0.13	0.14	0.14
Mn	20.8	15.8	16.8	16.7	18.4	17.0	17.8	17.5
Mo	<0.1	<0.1	<0.1	<0.1	<0.1	2.5	<0.1	1.7
Na %	0.05	0.06	0.06	0.06	0.05	0.05	0.05	0.05
Ni	2	2	2	2	2	2	2	2
Pb	4	4	4	4	4	4	4	4
Se	150	193	127	164	458	728	464	367
Zn	52	40	72	40	59	69	56	62

sites, grain Fe was increased, while at Warman Zn may have increased and at Pike Lake both Al and Se levels were higher in grain from the sludge treated plots. The elevated Se levels concurs with the soil analyses, and are of most concern.

Crop Response

Total yields of all treatments were reduced by a prolonged hot and dry period during crop anthesis. At both sites the fertilizer treatment had the highest total yield (Table 2.4.10). The strongest response was at Warman, which also had the lowest soil NO_3-N in spring. At Warman, the 30 tonne/ha rates of sludge were next highest yielding, though 40% less than the fertilizer treatment. The remaining sludge treatments did not have a total yield significantly higher than the check yield. At Pike Lake total yields did not differ as

Table 2.4.10 Total yield of grain and straw as affected by slope and treatment.

Treatment	Total yield (kg/ha)				
	Crest	Upper	Mid	Lower	Mean
		Warman site			
Check	1037	1065	863	1799	1167
Fertilizer	1775	2263	1917	3468	2323
Pre-10	726	1123	992	2416	1407
Pre-20	1775	1277	871	2095	1486
Pre-30	1400	1605	1240	2334	1632
Post-10	1649	1361	1286	1982	1424
Post-20	1179	1239	791	1820	1244
Post-30	1560	1189	627	2439	1559
Mean	1388	1390	1073	2294	
LSD (<0.05) (slope) = 1018					
LSD (<0.05) (treatment) = 400					
		Pike Lake site			
Check	981	933	1047	4076	1631
Fertilizer	1085	1051	1221	4325	1827
Pre-10	820	747	940	4277	1567
Pre-20	820	693	1054	3848	1473
Pre-30	781	753	901	4677	1618
Post-10	915	861	1006	4833	1760
Post-20	971	1091	983	4284	1681
Post-30	889	921	1029	4111	1602
Mean	908	881	1023	4304	
LSD (<0.05) (slope) = 665					
LSD (<0.05) (treatment) = 226					

much between treatments. Yields were not increased significantly above the check yield. Spring levels of soil NO_3-N were high and were able to supply this low yielding crop.

At both sites, the lower slopes were highest yielding, but the response to treatment was not different among slopes.

The hot dry weather during anthesis prevented full development of the barley heads, and reduced the grain yield response to treatment (Table 2.4.11). At Warman the

Table 2.4.11 Grain yield of barley affected by fertilizer and sewage sludge applications.

Treatment	Grain yield (bu/ha)				
	Crest	Upper	Mid	Lower	Mean
		Warman site			
Check	7.4	8.1	6.0	12.8	8.5
Fertilizer	10.1	14.0	11.1	22.8	14.2
Pre-10	5.6	7.5	5.6	16.4	9.2
Pre-20	11.7	9.4	7.4	15.0	10.5
Pre-30	8.2	10.6	8.2	14.1	9.8
Post-10	11.7	8.8	8.2	13.2	9.7
Post-20	7.9	9.0	6.0	12.5	8.8
Post-30	10.5	7.6	3.2	17.0	9.5
Mean	9.2	9.4	7.0	15.5	
LSD (<0.05) (slope) = 6.9					
LSD (<0.05) (treatment) = 2.8					
		Pike Lake site			
Check	4.6	5.8	4.2	26.0	8.8
Fertilizer	4.4	4.8	4.3	28.2	9.3
Pre-10	3.7	6.0	1.3	25.7	7.7
Pre-20	3.0	3.8	3.4	26.6	7.8
Pre-30	2.8	3.4	1.8	28.9	8.1
Post-10	4.4	5.0	2.9	29.4	9.2
Post-20	4.3	7.5	3.2	27.8	9.2
Post-30	4.4	7.5	3.2	27.8	9.2
Mean	4.0	5.0	3.0	27.4	
LSD (<0.05) (slope) = 7.0 (P >0.99)					
LSD (<0.05) (treatment) = NS					

fertilizer treatment yielded over 30% more than all other treatments. There was no grain yield increase after sludge application. The significant interaction of slope position and treatment indicated a larger yield increase with fertilizer application on the upper and lower slope positions. These were also the highest yielding positions. At Pike Lake the only significant yield difference was the higher yield on the lower slope position.

Trends in water use efficiency (WUE) were not clearly defined (Table 2.4.12). The post-seeding treatments of sludge seemed to improve WUE at Warman, but at Pike Lake

Table 2.4.12 Water use efficiency of barley crop affected by slope and fertilizer or sewage sludge treatment.

Treatment	WUE (kg/ha/cm)				
	Crest	Upper	Mid	Lower	Mean
		Warman site			
Check	26.7	33.9	28.3	79.6	37.2
Fertilizer	37.3	38.4	30.7	78.9	43.0
Pre-10	36.7	59.8	13.8	83.9	41.5
Pre-20	29.0	36.2	23.1	78.4	36.4
Pre-30	26.7	32.4	11.0	80.7	34.8
Post-10	48.8	54.8	21.8	87.1	47.0
Post-20	40.9	71.4	20.2	86.1	47.7
Post-30	38.9	33.6	17.5	78.0	37.1
Mean	35.6	45.0	20.8	81.6	
LSD (<0.05) (slope) = 20.1					
LSD (<0.05) (treatment) = 9.6					
		Pike Lake site			
Check	25.3	27.6	19.7	37.4	27.0
Fertilizer	30.2	41.7	36.7	63.4	42.0
Pre-10	16.2	21.6	19.5	44.6	28.0
Pre-20	36.5	29.5	23.8	38.1	31.0
Pre-30	40.2	32.4	27.1	37.0	34.2
Post-10	34.0	25.5	28.0	35.4	28.6
Post-20	26.9	30.6	20.3	34.2	27.9
Post-30	31.5	22.8	10.3	48.2	27.8
Mean	30.1	29.0	23.2	42.3	
LSD (<0.05) (slope) = NS					
LSD (<0.05) (treatment) = 2.8					

the fertilizer treatment and 30 tonne/ha pre-seeding treatment of sludge had the highest WUE. Sludge may affect WUE both by increasing yield and reducing evapotranspiration.

DISCUSSION

Application of Saskatoon sewage sludge to agricultural land near the drying beds is a potential method of disposal. The truck-mounted spreader was capable of quickly and accurately applying the sludge.

The fertilizer value of the sludge is low. The sludge contained 50% water and of the remaining portion, 65% was soil. Thus, for every tonne of sludge handled, less than one-sixth tonne of dry weight sewage sludge was included. For this reason, the actual rates of sludge applied in the project were low. These ratios should be improved, with emphasis on reducing the proportion of soil. The levels of potentially toxic elements, notably Cd, Se, Mo and Co were low in the Saskatoon sewage sludge used in this project. Unfortunately, the nutrient levels were also low. Total weight and grain yield of the barley crop was not increased after sludge application as much as with fertilizer application. Much higher rates of sludge would be needed to sufficiently supply a crop with nutrients. The question of soil and crop contamination must then be addressed. Potential development of the sludge for crop application might need to consider the sludge as a soil conditioner more than as a fertilizer.

Application of the sludge increased soil Cr and Se, and grain Se. Future work with the sludge must monitor the crop elemental content. Unfortunately, government guidelines regarding safe levels of toxic elements in foods are vague and incomplete.

Additional projects should estimate the actual equivalence of sludge to N fertilizer, and perhaps include treatments of sludge and fertilizer combinations. The residual effect of sludge treatments and the result of applying high rates of sludge should be measured.

REFERENCES

Abboud, S.A. 1986. Are heavy metals a problem in Alberta? *In* 23rd Annual Alberta Soil Science Workshop Proceedings. pp. 217-223.

Bastian, R.K. and J.A. Ryan. 1986. Design and management of successful land application systems. *In* Utilization, Treatment and Disposal of Water on Land. Soil Sci. Soc. Am. Workshop Proc., Madison. pp. 217-234.

Boyle, M. and E.A. Paul. 1989. Carbon and nitrogen mineralization kinetics in soil previously amended with sewage sludge. Soil Sci. Soc. Am. J. 53: 99-103.

Department of Health and Welfare. 1986. Food and Drug Act Dir. 15, Government of Canada. pp. 65-65B.

Dormaar, J.F., C.F. Lindwall and G.C. Kozub. 1988. Effectiveness of manure and commerical fertilizer in restoring productivity of an artificially eroded Dark Brown chernozem soil under dryland conditions. Can. J. Soil Sci. 68: 669-679.

Environment Ontario. 1984. Sewage sludge can be a good fertilizer. Government of Ontario pamphlet.

Elliott, H.A. 1986. Land application of municipal sewage sludge. J. Water Soil Cons. 42: 5-10.

Environment Canada. 1984. Manual for Land Application of Treated Municipal Wastewater and Sludge. Environmental Protection Service Manual 6-EP-84-1.

Epstein, E., J.M. Taylor and R.L. Chaney. 1976. Effects of sewage sludge and sludge compost applied to soil on some soil physical and chemical properties. J. Environ. Qual. 5:422-426.

Gillies, J.A., R.L. Kushwaha, C.P. Hwang and R.J. Ford. 1988. Heavy metal residues in soil and crops resulting from heavy applications of dried anaerobically digested sewage sludge used as a soil amendment. Report on Research, Dept. Agricultural Engineering, Univ. of Saskatchewan, Saskatoon.

Halderson, J.L. and D.R. Zenz. 1978. Use of municipal sludge in reclamation of soils. *In* Reclamation of Drastically Disturbed Lands. S. Mathias (ed.). ASA, CSA, SSSA, Madison. pp. 355-377.

Harder, H. 1989. Field applications of farmyard manure. Information leaflet, Sask. Soil Testing Laboratory, Univ. of Saskatchewan, Saskatoon.

Hornick, S.B., L.J. Skiora and S.B. Sterett. 1984. Utilization of sewage sludge compost as a soil conditioner and fertilizer for plant growth. USDA Bull. No. 464.

Hulit, J., J.A. Gillies and C.P. Hwang.. 1989. Digested Dried Municipal Sewage Sludge as a Soil Amendment. Report on Research, Dept. of Agricultural Engineering, Univ. of Saskatchewan, Saskatoon.

Knottnerus, D.J.C. 1976. Med. Fac. Landbouww. Rijksuniv. Gent. 41: 69-71.

Kowal, N.E. 1986. Health considerations in applying minimum treated wastewater to land. *In* Utilization, Treatment and Disposal of Waste on Land. Soil Sci. Soc. Am. Proc. Workshop, Madison. pp. 27-55.

Logan, L. and R.L. Chaney. 1983. Utilization of municipal wastewater and sludge on land-metals. *In* Utilization of Municipal Wastewater and Sludge on Land. A.L. Page (ed.). Univ. of California, Riverside. pp. 235-323.

Miller, M. 1986. Sludge compost recycling: The Philadelphia story. J. Soil Water. Cons. 41: 292-296.

Ndayegamiye, A. and D. Côte. 1989. Effect of long-term pig slurry and solid cattle manure application on soil chemical and biological properties. Can. J. Soil Sci. 69: 39-47.

Pagliai, M., G. Guidi, M. La Marca, M. Giachetti and G. Lucamante. 1981. Effects of sewage sludges and composts on soil porosity and aggregation. J. Environ. Qual. 10: 556-561.

Saskatchewan Environment and Public Safety. 1987. Saskatchewan's Guidelines for the Use of Sewage Sludge on Agricultural Lands. Draft copy, Government of Saskatchewan, Regina.

Saskatchewan Water Corporation. Year unknown. Sewage Effluent Irrigation. Government of Saskatchewan pamphlet.

Seaker, E.M. and W.E. Sopper. 1988. Municipal sludge for minespoil reclamation. II. Effects on organic matter. J. Environ. Qual. 17: 598-602.

Sommers, L.D. and K.A. Barbarick. 1986. Constraints to land application of sewage sludge. *In* Utilization, Treatment and Disposal of Waste on Land. Soil Sci. Soc. Am. Proc. Workshop, Madison. pp. 193-215.

Topper, K.F. and B.R. Sabey. 1986. Sewage sludge as a coal mine spoil amendment for revegetation in Colorado. J. Environ. Qual. 15: 44-49.

Viraraghaven, T. and S.M. Rana. 1987. Agricultural Use of Sludge from the Regina Wastewater Treatment Plant. Technical/Final Report to Saskatchewan Agriculture Research Fund.

Wei, Q.F., B. Lowery and A.E. Peterson. 1985. Effect of sludge application on physical properties of a silty clay loam soil. J. Environ. Qual. 4: 178-180.

Westerman, P.W., L.M. Safley and J.C. Barker. 1983. Potential harmful effects from land applying animal wastes. *In* Proc. 1983 Winter meeting of Amer. Soc. Engineers.