APPLICATION OF SASKATOON'S DEWATERED SEWAGE SLUDGE TO AGRICULTURAL LAND

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INTRODUCTION

In 1989, research was initiated to evaluate Saskatoon's dewatered sewage sludge as an amendment to agricultural soils. At present, Saskatoon uses a secondary sewage treatment process. The sewage is screened, settled and anaerobically digested at the sewage treatment plant near Silverwood Heights. From there, the sewage is pumped to a series of sewage lagoons 12 km north of the city. Solids are settled out of the sewage and the liquid is pumped to the South Saskatchewan River. The water content of the solids is further reduced by evaporation; the 'dewatered sludge' which is typically 50% water is then piled nearby. Nearly 4,000 tonnes of dewatered sludge accumulate each year.

Dewatered sludge has been used for turfgrass establishment on city land, but large scale disposal onto farmland has not been attempted. The Asquith soil near the sewage lagoons is typically infertile, coarse textured, and susceptible to erosion. The addition of nutrients and organic matter as dewatered sludge may alleviate these soil problems. This project was established to measure the nitrogen fertilizer value and potential toxicity of sewage sludge to cereal grain.

MATERIALS AND METHODS

1989 Field Experiment

Sites were chosen near Warman (NE7-38-4-W3) and Pike Lake (SE21-34-6). The Warman site was adjacent to the Saskatoon sewage lagoons. At both sites the soil texture was sandy loam. The plots covered all slope positions over an eroded knoll. The trial was designed to compare the method of sludge application and the rate of application. The treatments were set out in a split plot with four replicates. Slope position was the main plot and sludge application method the subplot.

Dewatered sewage sludge was applied at 10, 20 and 30 tonnes/ha (wet weight) either before or after seeding. The pre-seeding sludge was incorporated into the soil with a cultivator. The post-seeding sludge was applied one day after seeding.

The sludge was applied with a truck mounted manure spreader with a load capacity of 10 to 12 tonnes of dewatered sludge. The rate of application was monitored by catching sludge on 1 m^2 plywood squares. The sludge was then weighed and subsampled for later analyses.

Check and fertilizer treatments were compared to the sludge amended plots. On the fertilized 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).

Harrington barley was seeded at 75 kg/ha with a double disc drill. Weeds were controlled with herbicides.

At harvest, 5 m^2 samples were taken at the crest, upper, mid and lower slope positions. Total and grain weights were measured and composite grain samples were saved for analyses.

1990 Field Experiment

The 1989 results showed the need to better measure the N fertilizer value of dewatered sludge, and to evaluate higher application rates. The 1990 research was designed to meet these goals.

Two adjacent sites for field measurements were chosen near the 1989 Warman site. The field trials were limited to this area, as any future large scale sludge applications would probably be limited to within a short radius of the sewage lagoons. The first site was seeded on summerfallow and the second site on wheat stubble.

Each site compared treatments of 0, 10, 20, 40, 80 and 160 tonnes (wet weight) of sludge per ha to treatments of 10, 20, 40, 80 and 160 kg of N per ha as urea fertilizer. The sludge was again broadcast with a truck mounted manure spreader and incorporated with a cultivator. The fertilizer was also broadcast and incorporated. The treatments were laid out in a RCBD with three replicates.

Spring wheat (var. Laura) was seeded at 75 kg/ha. At maturity, 8 m^2 samples were harvested from each plot. Total weight and grain weight were measured. Nitrogen content was measured on composite grain samples of each treatment. Other nutrient and metal analyses were done on composite grain samples of the check and 160 tonne/ha treatments.

Four soil cores were taken from each rep before seeding and from each treatment after harvest for analyses.

Growth Chamber Trials

A three phase growth chamber experiment measured crop growth and nitrogen balances. After the treatments were applied a trial measured plant response. This trial was followed by a mineralization period, then a second trial (Fig. 1).

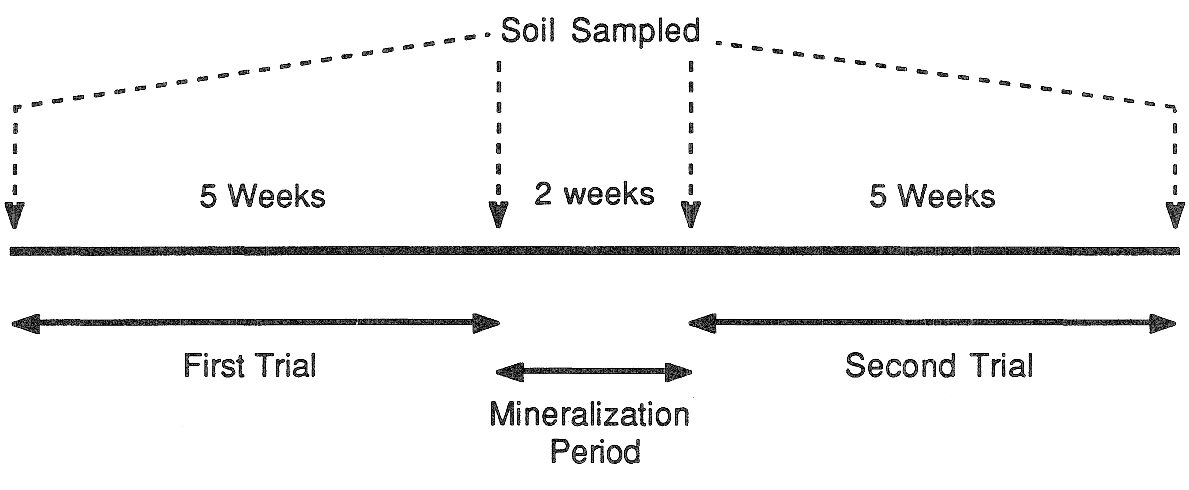


Fig. 1. Time line of growth chamber experiment.

Soil from near the Warman field plots (Asquith fine sandy loam) was collected for the growth chamber experiment. Two forms of sludge were used. The first form was the loose sludge used in the field plots. The second was a pelletized form developed by the Department of Agricultural Engineering at the University of Saskatchewan (Hulit et al., 1989). The small, cylindrical pellets are formed with an animal feed pelletizer (Fig. 2).

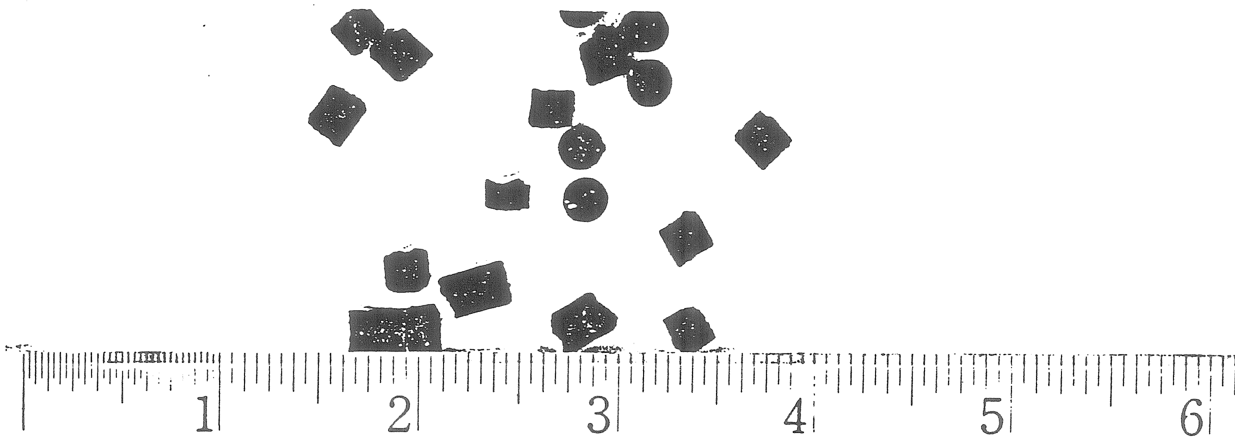


Fig. 2. Pelletized sludge used in growth chamber trials.

The loose sludge and pellets were each added at rates of 0, 5, 10, 20, 40 and 80 g/kg soil. The sludge weights were corrected to an oven dry basis; the moisture content of the loose sludge was 50% and for the pellets was 10.5%. Each pot was prepared separately by mixing 1500 g of soil with the correct amount of sludge. The sludge amended pots were compared to treatments of urea applied at rates of 5, 10, 20, 40 and 80 ppm N to each pot. To correct for a potential phosphorus deficiency, 50 ppm of P was added as $Ca(H_2PO_4)_2{\cdot}H_2O$ to each pot. The experiment was arranged in a RCBD with three replicates.

Barley (var. Argyle) was seeded and thinned to three plants per pot after emergence. The pots were watered to 80% field capacity every second day. The whole plants were harvested after 55 days at Zadoks 69 (anthesis complete). The plants from each pot were combined and dried at 65°C. Both fresh and dry plant weights were recorded for each pot.

The soil from each pot was air-dried and 50 g was subsampled for later analysis. Each soil was mixed, placed back into the original pot, then rewetted to 80% field capacity. The soils were left in the growth chamber for two weeks to allow mineralization of organic N. A small core of soil was then taken from each pot for analysis of available N. The pots were then reseeded to barley for a second growth trial. None of the pots received additional sludge or urea before the second trial. The plants were harvested and weighed and the soil was air dried and saved for analysis.

The original soil, sludge and pellets were analyzed for total N, P and C and the inorganic fraction was separated for particle size analysis.

Soil nitrates and ammonium were measured before the experiment, after each trial and after the mineralization period. The total N in composite plant tissue samples was also measured. Composite plant samples of the check and 80 g rates of loose and pelletized sludge were measured for pollutant elements.

RESULTS

1989 Field Experiment

Sludge Application

The loose sewage sludge was easily applied with the truck mounted spreader. Some problems occurred with ice blocks and rocks in the sludge piles. Calibration of the spreader to the exact rates required several trials. The unloading rate varied somewhat with the size of load and the slope of land. Visually, the rates were low. Only the 30 tonne/ha rate fully covered the soil. In comparison, the truck operator estimated that feedlot manure is usually spread at 100 tonnes/ha.

Sludge Characteristics and Soil Loading Limits

The elemental content of N, P and K, and most pollutant elements was low compared to other sewage sludge, including other samples from Saskatoon (Table 1). This discrepancy may be partly explained by the high level of inorganic material in the sludge.

Using the elemental composition and the guidelines provided by the Saskatchewan Environment and Public Safety, the maximum annual application rate of sludge was calculated (Table 1). These values are based on the dry weight of the sludge. At over 50% moisture only, 16 tonnes of dry weight sludge were applied at the 30 tonne/ha rate. Based on these values the highest rate of sludge that could be applied in 24 tonnes/ha dry weight, or 45 tonnes/ha wet weight. This limit would be based on % N, not a toxic element. The elements of most concern to human health (Cd, Mo, Se and Co) were notably low.

Characteristics of Soil

Soil sampled before sludge application and after harvest was measured for available nutrients and a number of potential pollutant elements (Table 2). Only soil from the 30 tonne/ha rate applied pre-seeding was analyzed after harvest.

Of the nutrient elements, available P increased the most. NO_3-N was not elevated by the 30 tonne/ha rate, despite a low crop yield.

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.

Table 1. Analysis of dewatered sewage sludge from the 1989 field experiment.

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	1.9×10^{-3}	1.3	684
B	NA	NA	2.0	
Ca	13,300	13.3		
Cd	<0.3	$<0.3 \times 10^{-3}$	0.13	433
Co	2	2×10^{-3}	3.3	1650
Cr	28.3	2.8×10^{-2}	11.1	3964
Cu	72.5	7.2×10^{-2}	13.3	1847
Fe	4550	4.6		
Hg	1.37	1.4×10^{-3}	0.044	31.4
Mg	3410	3.4		
Mn	123	1.2×10^{-1}		
Mo	<2	$<2 \times 10^{-3}$	0.44	220
Na	384	3.8×10^{-1}		
Ni	20	2.0×10^{-2}	3.3	1650
Pb	95	9.5×10^{-2}	8.9	937
Se	0.15	1.5×10^{-4}	0.22	1467
Zn	246	2.5×10^{-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	1.3×10^{-3} }	60	17,143
NH_4^+-N	22.1	2.2×10^{-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.

Table 2. 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 (ppm)	7520	7540	9930	6840	9920	14,100
As (ppm)	6.9	8.4	8.0	6.3	6.9	10.4
Ca (ppm)	28,800	26,300	22,700	28,000	31,900	24,700
Cd (ppm)	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Co (ppm)	7	8	9	5	5	6
Cr (ppm)	11.7	10.9	13	11.3	15.5	20.7
Cu (ppm)	15	18.3	16.2	11.7	17.6	14.8
Fe (ppm)	13,600	14,300	17,700	11,600	13,400	16,700
Hg (ppm)	0.03	0.03	0.05	0.05	0.03	0.07
Mg (ppm)	9540	91,600	8630	8740	8620	8520
Mn (ppm)	315	325	412	258	279	354
Mo (ppm)	<2	<2	<2	<2	<2	<2
Na (ppm)	178	161	146	104	138	138
Ni (ppm)	33	34	34	16	19	20
Pb (ppm)	35	35	42	19	26	34
Se (ppm)	0.11	0.15	0.35	0.3	0.4	0.4
Zn (ppm)	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 (ppm)	4640	5640	6500	6060	7210	7930
As (ppm)	3.5	4.0	3.5	3.0	3.1	3.2
Ca (ppm)	1990	2240	2660	2500	2640	3610
Cd (ppm)	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Co (ppm)	2.9	4	4	3	3	3
Cr (ppm)	7.2	7.8	9.4	8.7	10.6	11.3
Cu (ppm)	3.1	3.1	3.7	2.5	3.5	3.9
Fe (ppm)	7950	8630	9890	8030	8470	9220
Hg (ppm)	0.01	0.02	0.01	<0.01	0.02	0.03
Mg (ppm)	1500	1450	2110	1610	1710	2200
Mn (ppm)	211	258	304	253	238	327
Mo (ppm)	<2	<2	<2	<2	<2	<2
Na (ppm)	111	119	115	95	103	110
Ni (ppm)	22	26	22	5	5	6
Pb (ppm)	18	22	24	14	17	18
Se (ppm)	0.14	0.14	0.04	0.24	0.16	0.27
Zn (ppm)	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			

Grain Analysis

There was little increase in either nutrient or pollutant elements in barley grain from the 30 tonne/ha treatment (Table 3). Single composite samples were analyzed, so no statistical significance could be assigned. At both sites grain Fe increased, while at Warman Zn may have increased and at Pike Lake both Al and Se levels were higher in grain from sludge treated plots.

Table 3. Analyses of grain from 30 tonne/ha (pre-seeding) treatment, compared to the check treatment from the midslope position.

	Warman		Pike Lake	
	Mid	Check	Mid	Check
% N	1.94	2.08	2.62	2.65
% P	0.25	0.26	0.29	0.32
% K	0.5	0.5	0.5	0.5
Al	6	6	19	12
As	22	32	27	31
Ca %	<0.1	<0.1	<0.1	<0.1
Cd	<0.3	<0.3	<0.3	<0.3
Co	<0.6	<0.6	<0.6	<0.6
Cr	<0.6	<0.6	<0.6	<0.6
Cu	4.4	4.2	6.5	6.9
Fe	61	62	109	83
Hg	0.03	0.03	0.07	0.11
Mg %	0.15	0.15	0.13	0.14
Mn	15.8	16.7	17.0	17.5
Mo	<0.1	<0.1	2.5	1.7
Na %	0.06	0.06	0.05	0.05
Ni	2	2	2	2
Pb	4	4	4	4
Se	193	164	728	367
Zn	40	40	69	62

Crop Response

Total yields in 1989 were severely reduced by a prolonged hot and dry period during crop anthesis. At both sites the fertilizer treatment had the highest total yield (Table 4). At Warman the 30 tonne/ha rates of sludge were next highest in total yield, though 40% less than the fertilizer treatment. The remaining sludge treatments did not increase total yield.

Grain yield was increased by fertilizer application at Warman, but not in any other cases (data not shown).

Table 4. 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					

1990 Field Experiment

Soil and Sludge Characteristics

Available nutrients were measured in each plot before seeding (Table 5). Triple superphosphate fertilizer (0-45-0 at 50 kg/ha) was seed-placed to prevent phosphorus deficiency. N was therefore the only limiting nutrient. At the measured soil nitrate level, 20 to 30 kg N/ha would have been recommended under normal soil moisture conditions.

The sludge applied had very similar characteristics to that used in 1989 (Table 6). Again the total nutrient concentration was low.

Table 5. Available nutrients in 1990 field plots.

	Nutrient level (kg/ha)			
	NO_3-N	SO_4-S	P	K
	0-60 cm	0-60 cm	0-15 cm	0-15 cm
Stubble	50±5	>96	12±3	503±72
Fallow	57±12	51±8	9±2	430±25

Table 6. Characteristics of sludge used in the 1990 field experiments.

Element	Concentration (%, dry weight)
N	0.79
P	1.34
K	0.44
S	0.51
C	9.32
% inorganic	69

Crop Response

Grain yield increased with sludge and N fertilizer applications on both fallow and stubble sites (Fig. 3). The inherent soil conditions in this area led to variable crop yields. However, significant yield increases were measured.

Similar to the growth chamber study, the urea fertilizer N increased yield more rapidly than N from sludge. The maximum yield achieved with 40 kg N/ha from urea required over 200 kg/ha of N as sludge. The yield response curve to urea N was similar for both stubble and fallow plots. For sludge, the yield response was less in the stubble plot than in the fallow plot. The combination of drier soil conditions in spring and more crop residues in the stubble plot probably delayed mineralization of sludge.

Sludge application did not reduce yield at any rate, and no visual reductions in plant growth were observed. In terms of crop growth, sludge was not toxic at the rates applied.

Field Nitrogen Balance

A crude estimate of the net N released from sludge or fertilizer could be calculated as:

$$\text{Net N} = (N_{S2} + N_G) - N_{S1}$$

where N_{S1} and N_{S2} = available soil N before and after the growing season, and
N_G = total N in grain at harvest.

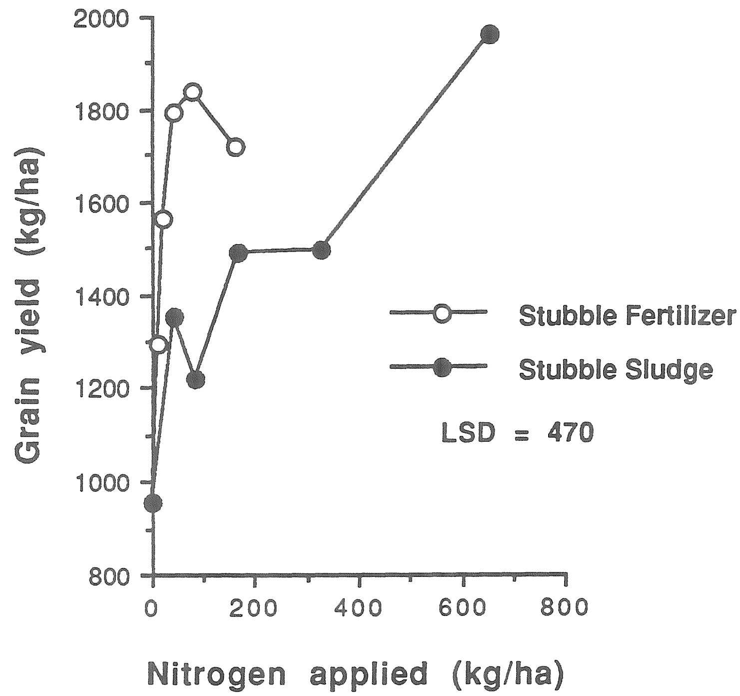
The net N balance was nearly identical in fallow and stubble plots for urea fertilizer and sludge (Fig. 4). From this N balance, 24.8±2.5% of the total N in the sludge was released and accounted for. This value should be conservative, as straw N was not measured.

Residual Soil N

A concern with addition of sludge is leaching of nitrates to the groundwater. The soil measurements immediately after harvest indicate a substantial amount of nitrates remaining (Table 7). However, the nitrates were concentrated in the topsoil, with little movement to the 30-60 cm depth. Furthermore, the sludge treatments generally showed less nitrate leaching than the fertilizer treatments.

Grain Analysis

Grain from the 160 tonne/ha treatment generally had a higher concentration of nutrient elements than the check treatments (Table 8). These are again composite samples, so statistical significance cannot be assessed. Of the elements measured, only zinc content was substantially increased by sludge application, within the accuracy range of analysis.



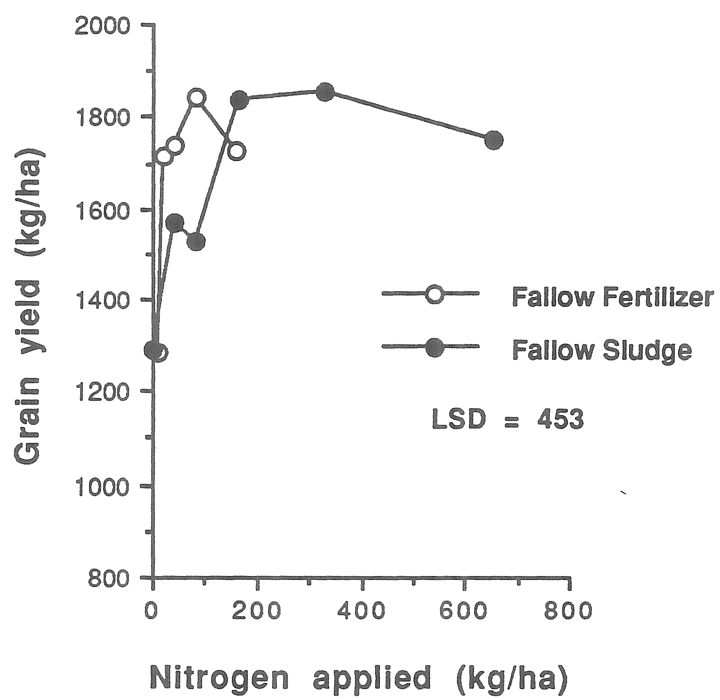


Fig. 3. Grain yield response to N from urea fertilizer and sludge on stubble and fallow plots in 1990 field experiment.

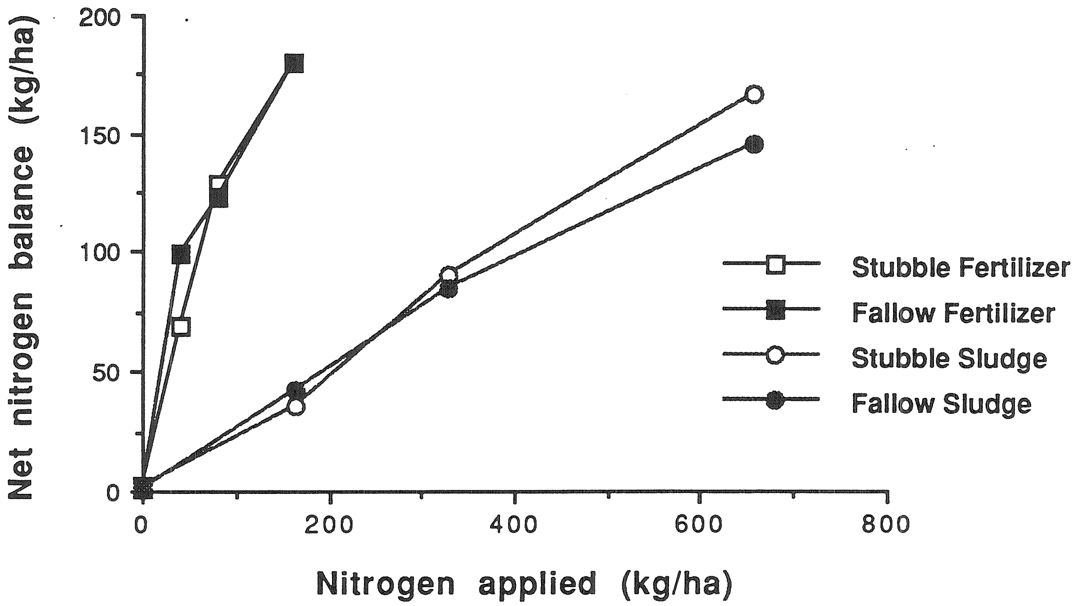


Fig. 4. Nitrogen balance for plots treated with sludge or urea fertilizer on stubble and fallow plots over growing season in 1990 field experiments.

Table 7. Nitrates in soil profile after harvest of 1990 field experiments.

	N applied (kg/ha)	Nitrates with soil depth (ppm) 0-15 cm	15-30 cm	30-60 cm
		Fallow		
Control	0	3	2	2
Urea fertilizer	40	22	14	6
	80	25	22	5
	160	36	38	7
Sludge	164	7	7	2
	329	11	15	6
	657	23	21	5
		Stubble		
Control	0	2	3	3
Urea fertilizer	40	12	5	5
	80	30	10	5
	160	48	16	8
Sludge	164	3	4	3
	329	13	8	10
	657	50	12	13

Table 8. Elemental composition of composite grain samples from the 160 tonne/ha and check treatments.

	Concentration in grain			
Element	Fallow-Check	Fallow-Sludge	Stubble-Check	Stubble-Sludge
Al, ppm	24	29	22	25
As, ppm	<9.8	10	<9.8	<9.8
Cd, ppm	<.75	1.5	<.75	<.75
Co, ppm	<1.5	<1.5	<1.5	<1.5
Cr, ppm	4.5	3.0	3.8	3.8
Mo, ppm	11	12	11	11
Ni, ppm	3.0	2.3	2.3	2.3
Se, ppm	<19	<19	<19	<19
Zn, ppm	42	71	47	70
% N	3.2	3.6	2.9	3.5
% P	0.39	0.45	0.47	0.41
% K	0.51	0.58	0.54	0.41
% S	0.19	0.21	0.18	0.21

1990 Growth Chamber Experiment

Sludge and Soil Characteristics

The total N, P and organic C content of the loose sludge and sludge pellets was higher than in sludge used in the field experiments, but the inorganic fraction was still large (Table 9).

Table 9. Characteristics of sludged pellets used in growth chamber trials.

	% N	% P	% C	% inorganic	% sand	% silt	% clay
Pellets	1.21	2.00	13.6	68	42	36	22
Loose sludge	1.01	1.71	12.5	49	46	28	28

The nutrient status of the soil was measured before adding treatments (Table 10). No nutrients other than N should have been limiting.

Table 10. Nutrient status of potting soil before adding treatments.

pH	6.2
Conductivity (mS/cm)	0.4
Total N (%)	0.30
Total P (%)	0.16
Total C (%)	2.30
NO_3-N (ppm)	9.6
NH_4-N (ppm)	5.0
Available P (ppm)	48.0
Available K (ppm)	450
Texture	Loamy sand

Plant Yields

The plant dry weight per pot in the first trial significantly increased with additions of urea, loose sludge and sludge pellets (Fig. 5). The yield response curves for both forms of sludge were similar. In comparison, yield increased much quicker with increments of fertilizer N. The peak yield was reached with approximately 300 ppm N as sludge. The same yield was attained with only 40 ppm N added as urea fertilizer.

The yield curves for sludge decreased at the highest rate. This was likely an anomaly resulting from slightly delayed maturity at harvest. None of the treatments visually inhibited plant growth.

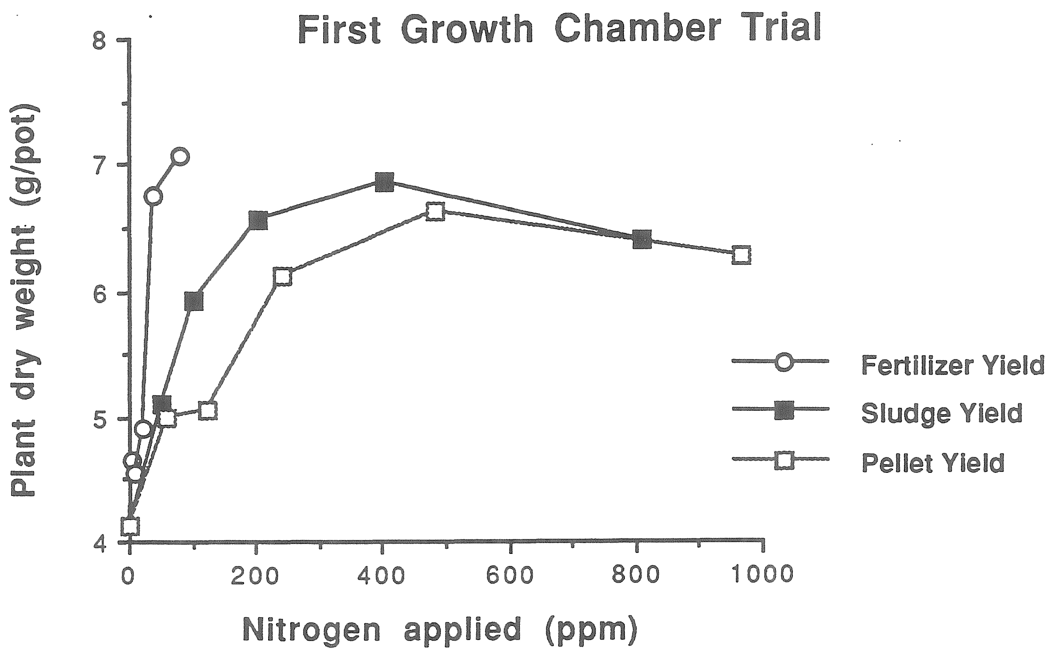
The residual effect of the treatments were measured in the second trial. Both sludge forms continued to increase plant yield (Fig. 5). No residual effect was apparent in the urea treatments.

Soil and Plant Nitrogen

Plant growth rapidly increased with additions of sludge or urea N. The plant N concentration also increased. The net release of N in each treatment was estimated by:

$$\text{Net N} = (N_{P1} + N_{S1}) + (N_{P2} + N_{S2})$$

where: N_{P1} and N_{P2} = total N in plant tissue in trial 1 and 2, and
N_{S1} and N_{S2} = net change of ammonium and nitrate N in soil over trial 1 and 2.



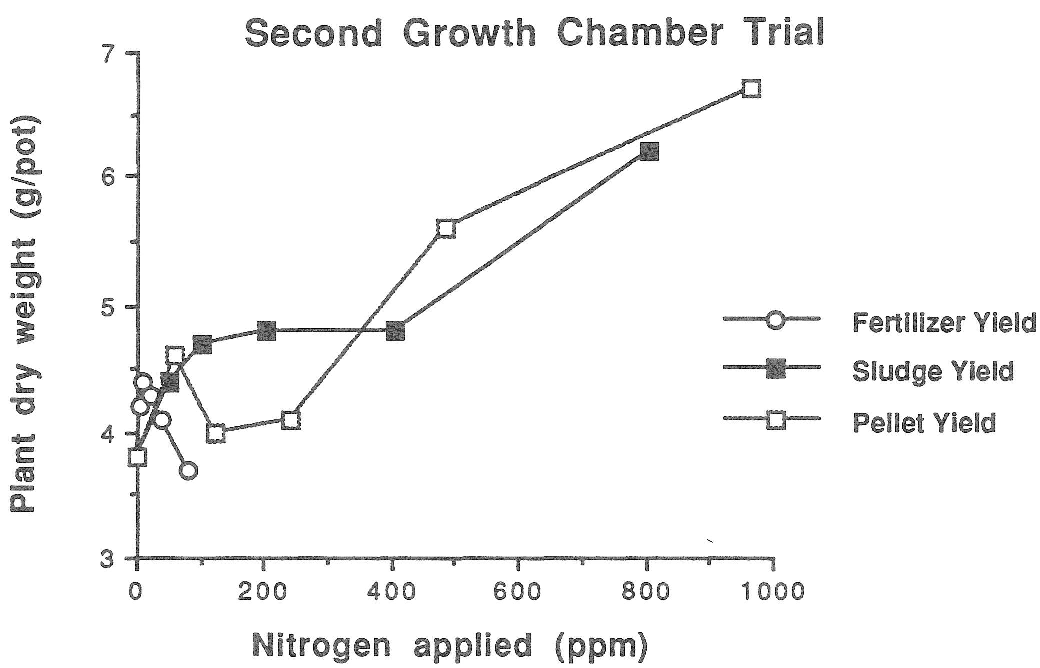


Fig. 5. Plant dry weight as increased by additions of N from urea fertilizer and two forms of sludge for both growth chamber trials.

The fertilizer urea N was much more available than either sludge form (Fig. 6). Over the course of the two trials and mineralization period, the pelletized sludge released more available N than did the loose sludge.

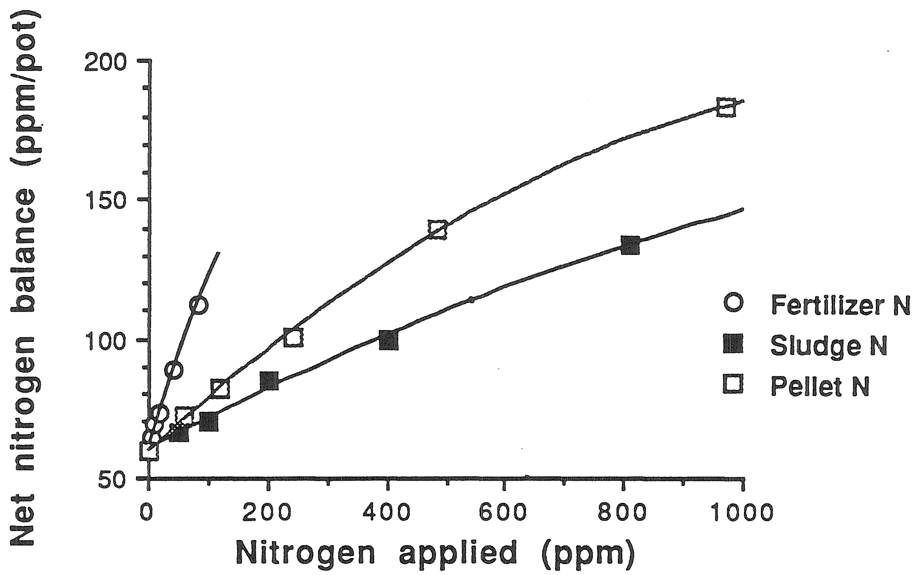


Fig. 6. Net nitrogen released in pots treated with urea fertilizer and sludge during entire growth chamber experiment.

The amount of N released was calculated at three stages; after each trial and after the mineralization period (Table 11). All treatments released most N during the first trial. In the two week mineralization period, few treatments released more N than the check treatment. This trend persisted in the second trial. Very little N was mineralized relative to the check treatment for any of the fertilizer or sludge additions. The bulk of available N for all treatments was in fact released quickly during Trial 1.

From these values, a crude estimate of the total N released from the treatments can be calculated (Table 11). It must be emphasized that several components of the soil nitrogen balance such as denitrification are ignored in this estimate. However, a relative comparison among treatments is possible. The urea fertilizer N was quickly released, and a large percentage of the total N added is accounted for. At the higher rates of urea N, denitrification and immobilization of available N probably reduced the apparent amounts of N released. Neither sludge form released a large portion of the total N added. On average, 11% of the N from the loose sludge and 17% of the N from the pelletized sludge was apparently released over the 12 week period of the experiment. Sewage sludge obviously cannot be considered to be a large nor very long term source of available N.

Tissue Analyses

Composite tissue samples from the treatments with the highest rates of sludge (80 g sludge/kg soil) contained more nitrogen, potassium and sulphur (Table 12). Zinc content was also increased with sludge addition.

Table 11. Nitrogen released during each stage of the growth chamber trial and the % of the total N released.

	N added (ppm)	N released in trial 1 (ppm)	N released in mineralization period (ppm)	N released in trial 2 (ppm)	Total N* released (%)
Check	0	36	17	24	-
Urea fertilizer	5	35	21	36	100
	10	34	18	34	100
	20	40	21	35	95
	40	53	18	36	75
	80	80	14	32	61
Loose sludge	50	32	15	35	10
	101	36	19	33	11
	202	48	12	37	10
	404	62	24	37	11
	808	84	28	51	11
Pelletized sludge	61	36	18	36	21
	121	47	16	35	17
	242	69	11	32	14
	484	107	12	33	15
	968	148	56	35	17

* Total N released is the sum of N released less the N released in the check treatment.

Table 12. Elemental content of tissue from the check and highest sludge treatments in the growth chamber experiment.

Element	Concentration (ppm)		
	Check	Sludge pellets	Loose sludge
Al	99	86	65
As	11	16	13
Cd	1.5	1.5	1.5
Co	<1.5	2.3	<1.5
Cr	4.5	2.3	3.8
Mo	12	18	15
Se	<19	<19	<19
Zn	23	77	80
N	0.8	2.3	1.4
P	0.30	0.37	0.27
K	2.3	4.4	3.8
S	0.16	0.35	0.25

Mean Weight Diameter

The focus of these experiments was to evaluate the fertility value of sludge. The sludge may also provide physical benefits in aggregate stability and erosion protection. The soil surface, when covered by sludge, is visually protected with a friable crust. To further assess these physical benefits, the mean weight diameter of soil from the pots amended with loose sludge was measured by wet sieving (Table 13). There was a significant increase in mean weight diameter achieved with rates as low as 20 g sludge/kg soil. The soil near the Saskatoon sewage lagoons is coarse textured and subject to erosion, so this may be an important benefit.

Table 13. Mean weight-diameter of soil from pots amended with loose sludge. Measurements were made after the second trial of the growth chamber experiment.

Sludge rate (g/kg soil)	Mean weight-diameter (mm)
0	0.23
5	0.24
10	0.25
20	0.31
40	0.31
80	0.32

LSD = 0.057 ($F = 4.64$; $P < 0.05$).

DISCUSSION

Plant growth in field and growth chamber conditions was increased by additions of dewatered sludge. With large sludge additions, plant yield reached the maximum yield attained with urea fertilizer application. Crop yields will certainly benefit from sludge application.

Before the sludge N is available for plant use, it must be converted to inorganic forms by microbial mineralization. In the growth chamber experiment, about 11% of loose sludge N and 17% of pelletized sludge N were accounted for as net N release. In the field, the N balance indicated about 25% of sludge N was mineralized. Denitrification could probably account for this discrepancy. In the growth chamber the ideal conditions for rapid N mineralization plus frequent flood-watering could have lead to a large gaseous loss of N. The 25% fraction mineralized in the field is probably realistic. However, it must be emphasized that this estimate would vary with climatic conditions and sludge characteristics. The N content of the sludge averaged less than 1%. A sludge with a higher N content would release a larger portion of N.

The sludge was mineralized fast enough to provide plants with sufficient N for growth. In the growth chamber trial, most N mineralization occurred in the first five week growth trial. Little N was released in the remaining 7 weeks of the experiment. Sludge should not be expected to continue releasing sufficient N for several crop years.

The purported residual effect of sludge application to succeeding crops is questioned. However, a residual effect may occur if nitrate that is released from the sludge is not used by the first crop. Residual nitrates did increase plant yield in the second phase of the growth chamber experiment. In the 1990 field experiment, there were substantial residual nitrates left in the surface soil of the sludge treated plots. This would probably lead to a residual crop yield increase.

The present Saskatchewan guidelines assume 25% of sludge N is mineralized in the first year, 12.5% in the second year, and 6% in the third year (Anon., 1987). The data in this paper supports the first year estimate, but continued release of substantial N may be optimistic.

Several other nutrients, notably phosphorus, are also added with sludge. For the sludge used in these experiments, about 4 kg P/ha would be added with each dry weight tonne of sludge. The plant availability of the sludge P would again depend on microbial mineralization. This cannot be estimated from these experiments.

The pelletized sludge did release slightly more N than the loose sludge. This probably reflects the higher N content of the sample of sludge pellets used, compared to loose sludge. The pellets were very recalcitrant; they were physically unchanged after the 12 week growth chamber experiment. No obvious benefit was observed in using pelletized sludge compared to loose sludge for cereal crop production. The pellets may be more useful and economical for production of high value vegetable and horticultural crops, or as an amendment to stabilize erodible soils.

No rates of sludge application reduced crop growth. In terms of cereal crop production, there appears to be no problem within reasonable limits of sludge application. The present Saskatchewan guidelines which would limit sludge application according to nitrogen addition appear accurate and sufficient.

Spreading loose dewatered sludge with truck mounted manure spreaders appears feasible. These spreaders can handle over 10 tonnes of sludge per load. If the hauling distance is within two miles and if two or three large spreaders are used, the yearly accumulation of 4000 tonnes could be spread in a month. Fall would be the preferable time to spread the sludge; the sludge would be fully thawed, would contain less water, and there would be less soil compaction by sludge spreaders. Incorporation of the sludge should be encouraged to reduce nitrogen losses. At the currentrate of production, about 100 hectares (250 acres) per year could be covered with sludge at a 40 tonne/ha rate. If sludge is limited to one application every three to four years, at least 500 ha (1200 acres) should be marked for future sludge application.

CONCLUSIONS

Sewage sludge application onto agricultural land nearby the Saskatoon sewage lagoons is a feasible and recommended practice. The financial requirements would be relatively low compared to other means of sludge disposal, and the farm community would benefit. There appear to be no toxic limitations to sludge application within reasonable limits for crop production. Application rates should be based on total N content and available soil N, to meet crop N requirements. A mineralizable fraction of 25% of total sludge N should be accurate unless sludge qualities change. Means should be investigated to reduce the inorganic fraction and water content of the sludge. According to this study, application of Saskatoon's dewatered sewage sludge to nearby farmland is an agronomically, ecologically and economically sound practice.

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REFERENCES

Anon. 1987. Saskatchewan's Guidelines for the Use of Sewage Sludge on Agricultural Lands. Draft. Saskatchewan Environment and Public Safety. 29 p.