1.2 Application of Saskatoon's Dewatered Sewage Sludge to Agricultural Land; Second Year Data

L.E. Cowell and E. de Jong

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INTRODUCTION

In 1989, research was initiated to evaluate Saskatoon's dewatered sewage sludge as an amendment to agricultural soils near the Warman sewage lagoons. The main points from the initial year were:

- a truck mounted manure spreader is a quick and reasonably accurate method of applying dewatered sewage sludge;
- a large portion of the dewatered sewage sludge is water (50%) and the remaining portion is over 60% inorganic. With each tonne of dewatered sewage sludge applied, only one-sixth of a tonne of organic waste is added;
- incorporation of sludge is recommended;
- the maximum rate of 30 tonnes/ha was too low to supply sufficient nutrients to reach the maximum crop yield potential;
- there are few, if any, concerns for human or environmental health from the application of Saskatoon's sludge to farmland;
- from the sludge analysis, nitrogen appeared to be element which will limit sludge application rates; levels of potentially toxic elements were very low.

In view of these results, the priorities for the second year of research were to:

- evaluate higher rates of sludge application
- measure the nitrogen fertilizer value of the sludge
- compare pelletized sludge to loose sludge
- continue to monitor the safety of sludge application

MATERIALS AND METHODS

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. 1.2.1).

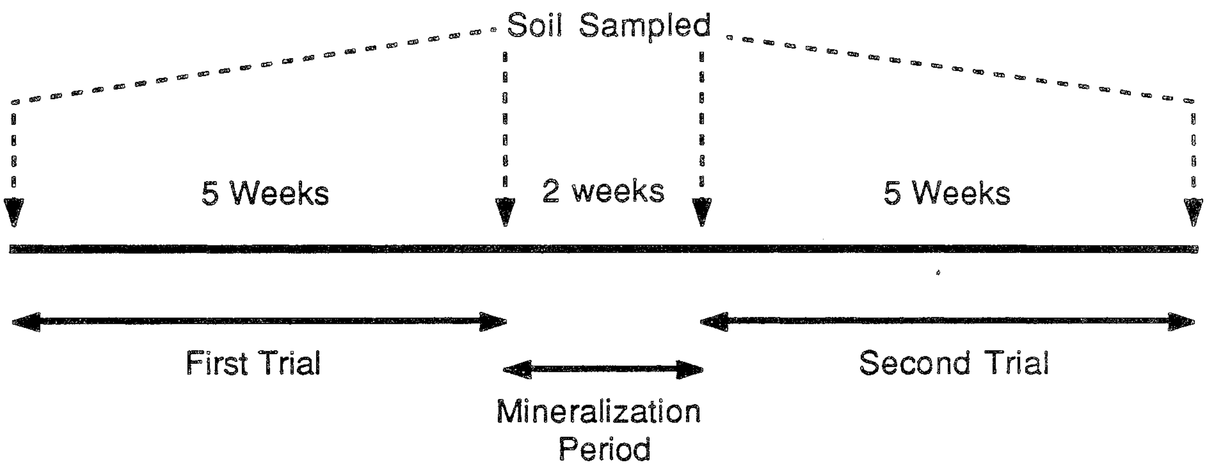


Figure 1.2.1 Time line of growth chamber experiment

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. 1.2.2).

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

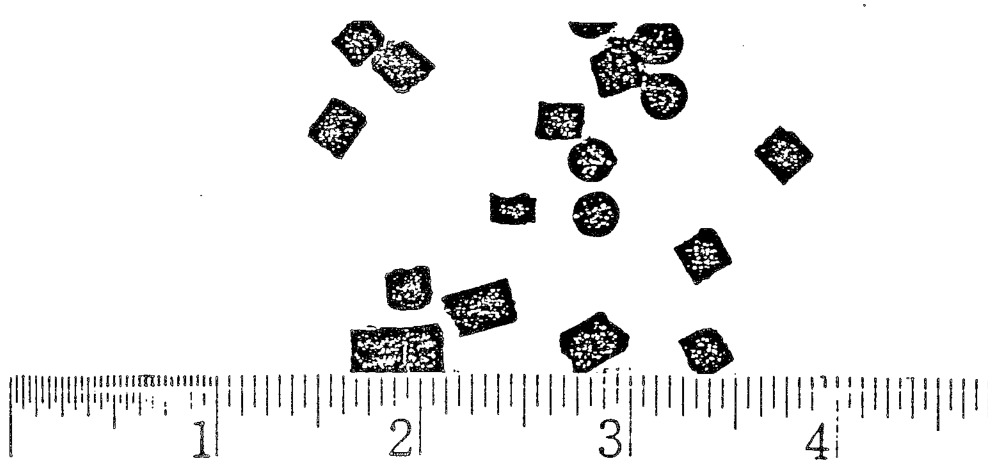


Figure 1.2.2 Pelletized sludge used in growth chamber trials

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

1990 Field Experiment

Growing Season Conditions and Spring Soil Moisture

The 1990 growing season was much wetter and cooler than in 1989. Between seeding and harvest, 21.1 cm of precipitation was received at the field plots (measured by the cooperating farmer). In spring, there was 8.5 cm of available soil water in the stubble plot and 12 cm of available soil water in the fallow plot.

Soil and Sludge Characteristics

Available nutrients were measured in each plot before seeding (Table 1.2.1). 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 1.2.2). Again the total nutrient concentration was low.

Table 1.2.1 Available nutrients in 1990 field plots

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

Table 1.2.2 Characteristics of sludge used in the 1990 field experiments

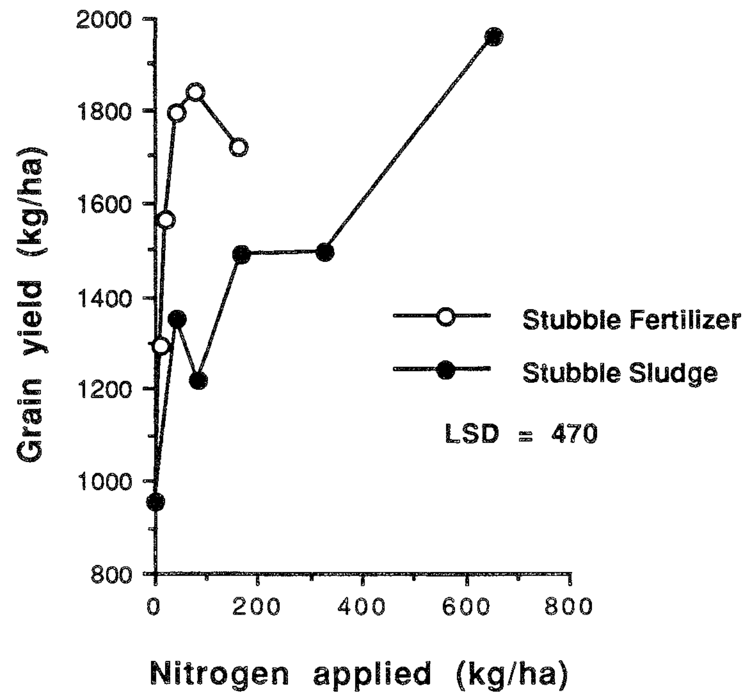
Element	Concentration (%, dry weight)
N	0.79
P	1.34
K	0.44
S	0.51
C	9.32
% inorganic	69

Crop Response

Grain yield increased with sludge and N fertilizer applications on both fallow and stubble sites (Fig. 1.2.3). Although crop yields were variable, significant grain yield increases were measured (Stubble; $F = 3.54$, $P>0.01$; Fallow; $F = 2.41$, $P>0.05$).

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.



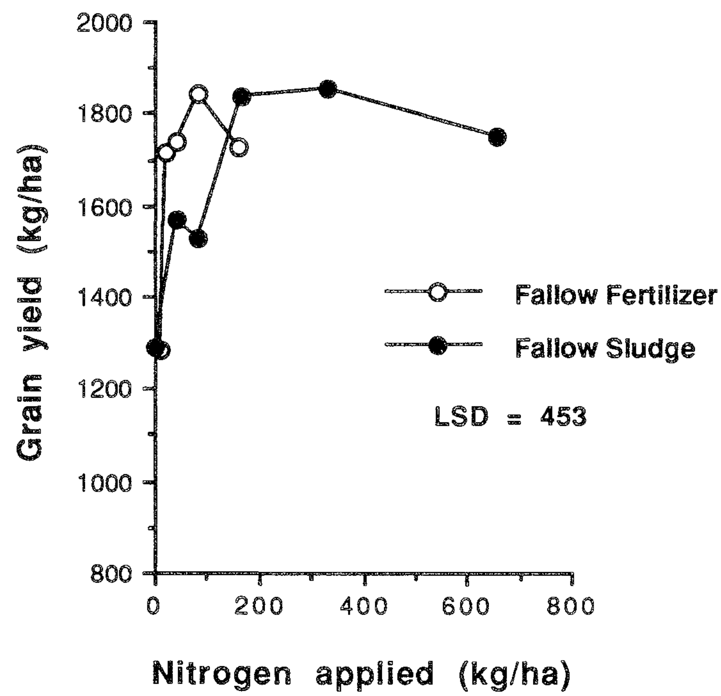


Figure 1.2.3 Grain yield response to N from urea fertilizer and sludge on stubble and fallow plots in 1990 field experiment

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. 1.2.4). 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.

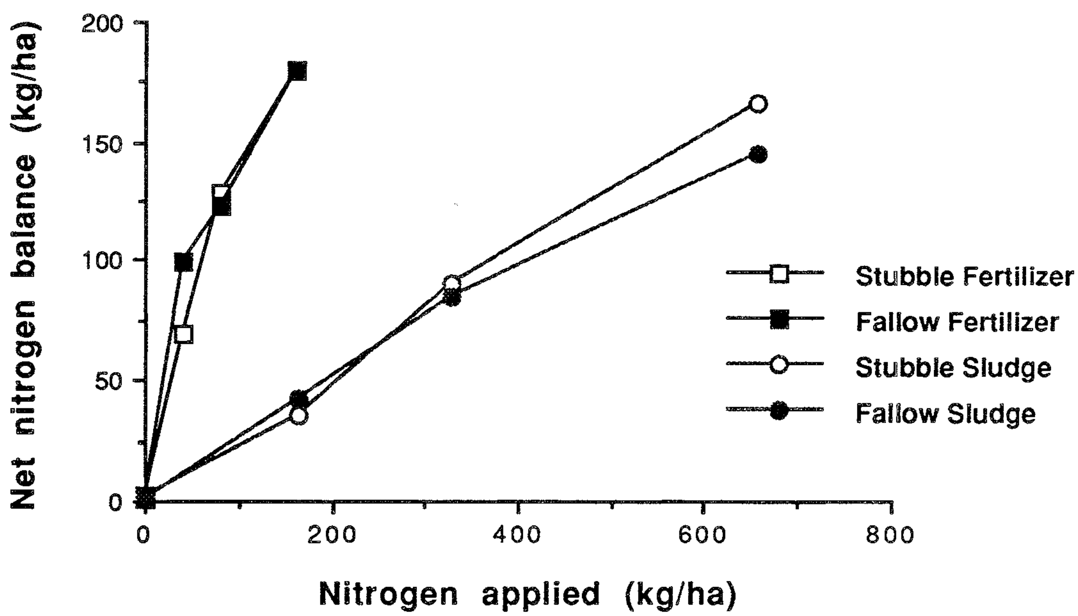


Figure 1.2.4 Nitrogen balance for plots treated with sludge or urea fertilizer on stubble and fallow plots over growing season in 1990 field experiments

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 1.2.3). 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.

Table 1.2.3 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

Grain Analysis

Grain from the 160 tonne/ha treatment generally had a higher concentration of nutrient elements than the check treatments (Table 1.2.4). These are again composite samples, so statistical significance cannot be assessed. Of the elements measured, only

Table 1.2.4 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

zinc content was substantially increased by sludge application, within the accuracy range of analysis.

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 1.2.5).

Table 1.2.5 Characteristics of sludge 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 1.2.6). No nutrients other than N should have been limiting.

Table 1.2.6. 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. 1.2.5). 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. 1.2.5). No residual effect was apparent in the urea treatments.

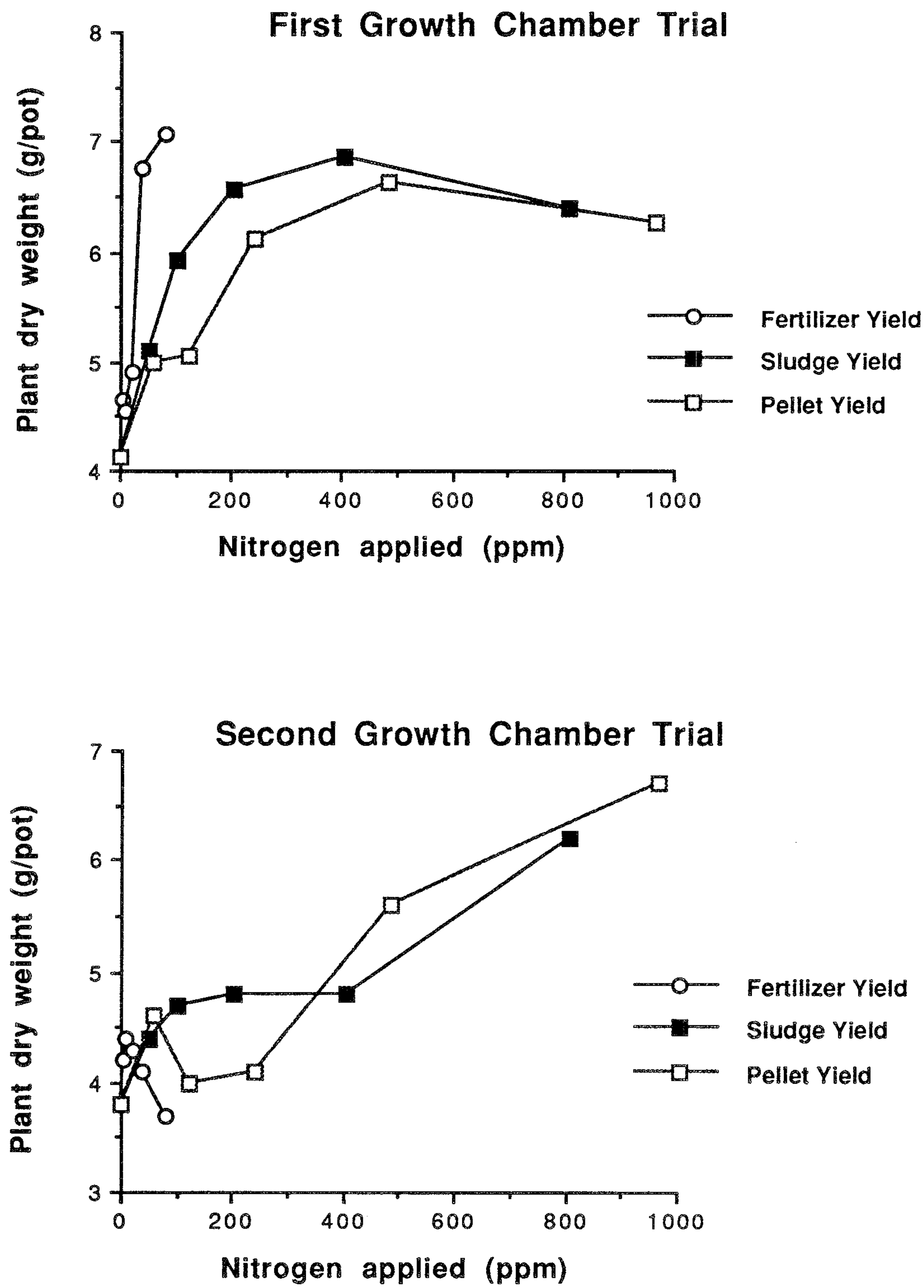


Figure 1.2.5 Plant dry weight as increased by additions of N from urea fertilizer and two forms of sludge for both growth chamber trials

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.

The fertilizer urea N was much more available than either sludge form (Fig. 1.2.6). Over the course of the two trials and mineralization period, the pelletized sludge released more available N than did the loose sludge.

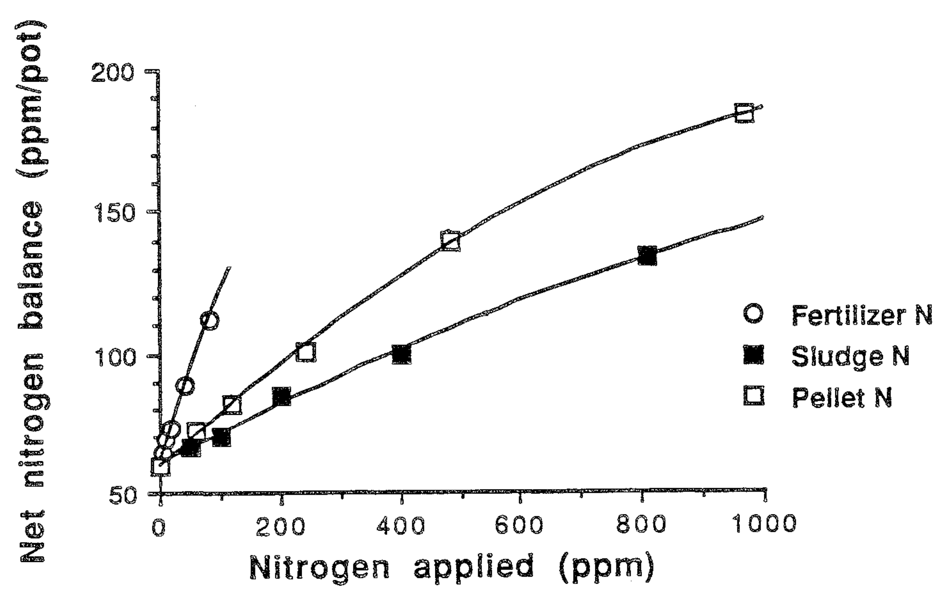


Figure 1.2.6 Net nitrogen released in pots treated with urea fertilizer and sludge during entire growth chamber experiment

The amount of N released was calculated at three stages; after each trial and after the mineralization period (Table 1.2.7). 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

Table 1.2.7 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.

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 1.2.7). 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 1.2.8). Zinc content was also increased with sludge addition.

Table 1.2.8 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 1.2.9). 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 1.2.9 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 current rate 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 probably economically sound practice.

FUTURE RESEARCH

The data and conclusions from the research reported here indicate Saskatoon's dewatered sewage sludge can be applied to farmland for cereal production. This data would be applicable for other seed crops such as oilseeds. Data from the Dept. of Agricultural Engineering indicates dewatered sludge or sludge effluent applied to alfalfa or oat forage does not increase plant chemical or biological properties past safe limits. Before sludge is applied to forage on a field scale, further work may be justified. Notably, the benefit of added N from sludge is somewhat lost when applied to forage legumes. Still, the high water and nutrient requirement of alfalfa make this crop an ideal candidate for sewage effluent irrigation . No field measurements for vegetables or other crops have been documented. Since the possibility of food contamination is much higher with these crops, dewatered sludge should be discouraged for this use.

If sludge is routinely applied to farmland in the future, the sludge and crop characteristics should be monitored. Changes in sludge quality may alter the recommended rates of sludge application.

In addition to dewatered sludge, Saskatoon sewage effluent should be considered for future irrigation development. If the entire sewage waste production can be safely applied to farmland, this would avoid the present dumping of sewage effluent into the South Saskatchewan River.

ACKNOWLEDGEMENTS

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