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Project Summary

Cropping Systems for Treatment and Utilization of Municipal Wastewater and Sludge

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Land renovation of municipal wastewaters is an attractive treatment alternative to conventional sewage treatment since the treatment achieved is generally equal in quality to that of conventional sewage treatment systems and is generally lower in cost. In addition, many of the nutrients in the wastewater applied to the land can be removed through crop assimilation. Additional treatment occurs as the wastewater percolates through the soil profile toward the groundwater.

The crops produced can be marketed and their cash value applied toward the capital cost, operation, and maintenance of the system. Corn is grown as the major cash crop at the Muskegon County Wastewater Treatment Facility in Michigan. Experience has shown that corn is efficient in removing nitrogen from applied wastewater only during a few weeks during its growing season. This lack of nitrogen removal and elevated nitrogen levels in the groundwater prompted this study by Michigan State University to develop more effective crop management systems to remove nitrogen from wastewater over a longer period of time during the growing season. A number of selective forages were evaluated for their nitrogen removal efficiency and effect on yield due to competition with the corn. These forages were sown in corn during August, allowing them to become established and provide winter cover and also provide them an opportunity for early emergence in the spring. The corn was no-till planted in these forage plots in the spring. During the planting process, a strip of forage about 14 inches wide was killed with paraquat, thus allowing the corn to begin growing without competition.

Corn interplanted with one of the forages was effective in removing nitrogen from the wastewater but in many cases, the corn yield was reduced because of the competition of the forage with corn for nitrogen. Corn in rye yielded about the same as corn alone, but corn in ryegrass yielded considerably less than corn alone.

Treatment of applied wastewater also occurs as the water percolates through the soil profile. Intense monitoring of the soil, soil water, and groundwater was conducted at multiple depths for a number of applied nutrients and trace metals in all the test plots throughout the study period.

At the beginning of the second year, the project was expanded to include an evaluation of wastewater spiked with nitrogen to concentrations representative of most wastewaters since Muskegon wastewater is normally low in nitrogen because it contains industrial wastewater. Nitrogen, in the form of liquid fertilizer, was injected into the wastewater distribution line whenever half a revolution of the

center pivot rig was completed. Thus, half of Circle 26 received nitrogen-spiked effluent and half received wastewater of the concentration of the normal treatment system.

In addition to nitrogen stripping studies, sludge compatibility and metal contaminated sludge studies were conducted to determine the feasibility of applying sludge to land which is being used in a wastewater treatment system. These sludge studies contained completely separate objectives. One of the objectives was to determine the loss of nitrogen by leaching from sludge applied to land which is being irrigated with wastewater. The other objective was to determine the compatibility of application of metal contaminated sludge to land being used for wastewater treatment. This sludge was generally high in Copper (Cu), Iron (Fe), Nickel (Ni), Chromium (Cr), and Zinc (Zn); above average in Cadmium (Cd) and Lead (Pb); and about average in Manganese (Mg).

Yield of corn was increased an average of about 20 hectoliters per hectare (23 bushels/acre) for the range of sludge loadings. It was determined that there was little advantage in applying greater than 11 tons per hectare (T/ha) of sludge as far as yield was concerned. Although some yield increase was obtained with addition of 22 T/ha, economically the returns would favor the lower application rates over larger acreage.

The only heavy metal to be increased significantly in the grain was Zn. Three heavy metals, Zn, Cu, and Ni were shown to leach in the soil and to give increased levels in the groundwater under the highest sludge application rate. Low rates of sludge application (i.e. less than 54 T/ha) did not appear to be a hazard to either the crop or to groundwater contamination by leaching through these sandy soils.

The full project report (see next paragraph), describes the experiments and results in detail and recommends management practices for nitrogen control at the Muskegon Wastewater Treatment Facility.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Wastewater renovation by application to land has been practiced in many small communities throughout the United States at increasing numbers of locations for the past fifty to sixty years. Most of the systems have either been operated as high-rate infiltration systems for disposal, or as irrigation systems in water-deficient regions for increased crop yield through use of both water and nutrients. Little regard in either operation was given to the actual land treatment capability until recent years. Investigation of systems in operation illustrated clearly that a high degree of wastewater treatment actually does occur as the water percolates through soils combined with various plants utilizing available nutrients. The applied nutrients in the wastewater can be utilized in the production of cash crops, thereby providing a portion of the funds for operation and maintenance of total treatment systems.

These facts prompted the construction of the largest municipal wastewater land treatment system in the United States. The system, located in Muskegon County, Michigan, collects municipal sewage from the entire county, aerates it, and places it in large storage lagoons where it is used to irrigate over 5,000 acres of corn and a few other crops during the months of May through October each year.

Corn, however, the high value cash crop grown on the farm has been found to actually be effective in removing nitrogen from the applied wastewater only for a short period of time during the corn's growing season. Therefore, significant amounts of nitrogen are leached through the soil profile as wastewater is applied during the rest of the irrigation season. Lack of adequate nitrogen removal prompted this study by Michigan State University as detailed in the following discussion.

Technical Approach

Michigan State University's three-year study of nitrogen management of applied municipal wastewater through special cropping practices was conducted at Circle 26 of the Muskegon Wastewater Treatment Facility for the growing seasons of 1976, 1977, and 1978 (Figure 1). The prime objective of this study was to develop more effective crop management practices to remove nitrogen from the municipal wastewater used to irrigate crops for the total irrigation season. The soils at this sit are sandy and quickly react to loading c wastewaters and sludge. During th course of this study, evaluations wer made of nitrogen uptake and reduce corn yield when forage crops such a rye, ryegrass, and oats were intercrop ped with corn. These studies include evaluation of the soil nitrogen statu and nitrate movement to groundwate

A crop management system in whic corn is no-till planted into fall establishe oats, rye, or ryegrass cover crop wa developed. This technique require spraying a strip of forage about 1 inches wide with a herbicide (paraqua to kill the strip of forage so the plante corn could become established wit little competition. The remaining forag could then remove nitrogen until bot the forage and corn competed for th available nitrogen.

Rye is a winter grain which is plante in the late summer and is used as forage for livestock during winter month It germinates and grows in the fall and i dormant or slow growing in the winte In the spring the rye grows rapidly an matures in early summer. Its period c maturing and reseeding is the sam period in which corn is growing mo rapidly and adsorbing nutrients at th greatest rate. Since the two crop generally do not accelerate in growth a the same time, corn and rye shoul compliment each other almost perfect

Other forage selectivity studies wer also performed to determine their pc tential for nitrogen stripping whe intercropped with corn. These forage included red clover, alfalfa, birdsfoc trefoil, tall fescue, orchard grass, quack grass, and reed canary grass. The firs three of those forages, when intercrop ped with corn, resulted in effectiv nitrogen removal without appreciabl reduction in corn yield due to forag competition. However, yield of corn wa drastically reduced when tall fescue c orchard grass was the forage of choic because the herbicide used with the nc till planter failed to give a satisfactor stand. Quackgrass and reed canar grasses were intermediate in their yiel reducing efficiency.

At the beginning of the second yea (1977), the project was expanded t include an evaluation of wastewate with a higher nitrogen content whic would be representative of most waste waters since Muskegon wastewater i lower than normal in nitrogen. Nitroge was injected in the form of liquid fertil zer, into the wastewater distributio line whenever the center pivot irrigation rig completed a half revolution. Thus, half of Circle 26 received nitrogen spiked effluent, and half received normal wastewater. The nitrogen injection for the high-nitrogen studies boosted the average total nitrogen from 16 to about 25 parts per million, which was less than anticipated. Apparently, a portion of the nitrogen in the spiked wastewater was lost by volatilization during spraying. Corn yield, nitrogen stripping with intercropped forages, and nitrogen leaching were compared for both levels of nitrogen concentrations on separate halves of the study area. All the evaluations performed on the normal wastewater study plots were also performed on the nitrogen spiked half of the study area.

In addition to the low and high nitrogen stripping studies utilizing forage crops for wastewater treatment, two studies were conducted to evaluate the application of sewage sludge to agricultural land. One of these studies was designed to evaluate the compatibility of applying sludge to lands used for wastewater treatment. The evaluation was conducted on plots on which only corn was grown during the last two years of the study. This sludge study was initiated in 1977 at the beginning of the nitrogen-spiked wastewater studies previously described, and continued through the 1978 growing season. The major goal of the study was to determine the added effect of sludge application on corn yield, compared to the selected corn and forage nitrogen-stripping studies. This study also includes a comparison of the fate of nitrogen added to the ecosystem by the sludge and applied wastewater at two different nitrogen concentrations. Prior to crop planting each spring, a selected number of high nitrogen tests plots were loaded with sludge at two rates, 7 and 22 T/ha. The changes in the soil, plant tissue, and groundwater were monitored through time and compared with data from plots where both low and high nitrogen wastewater was applied.

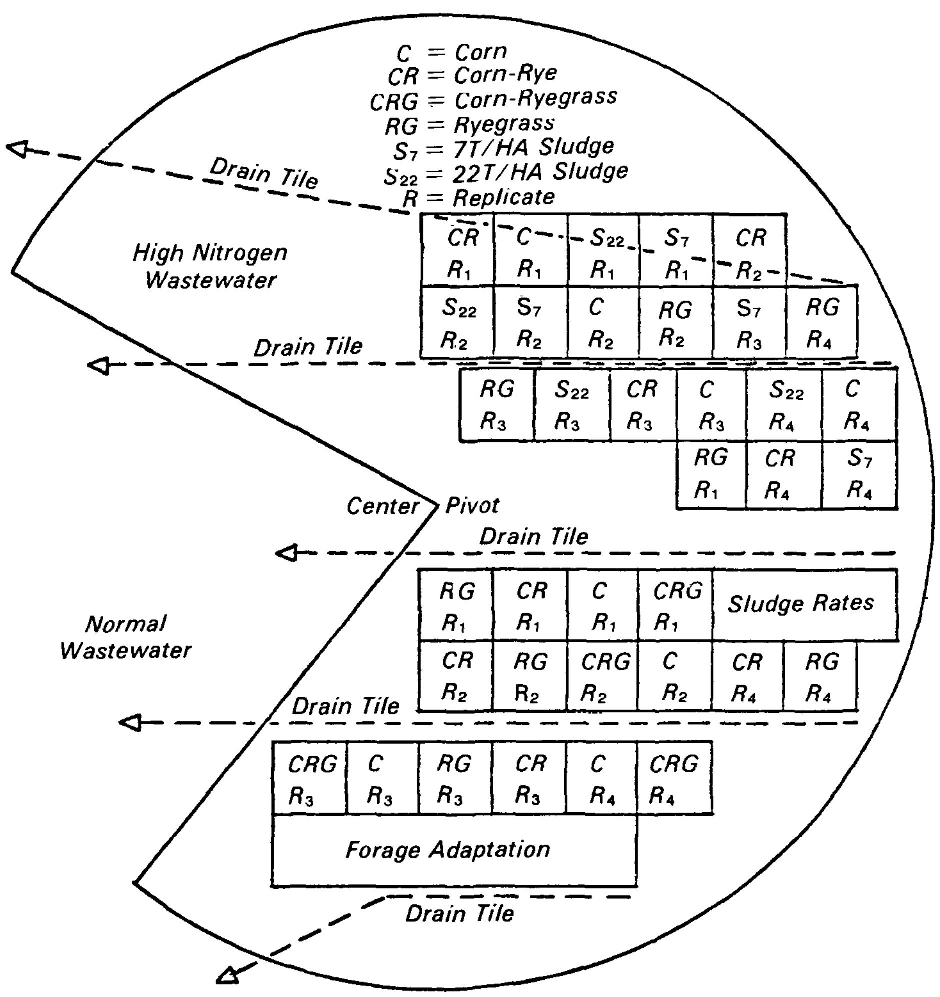

Figure 1. *Plot arrangement for low and high nitrogen N-stripping experiments.*

The objective of a second sludge study, conducted on separate isolated plots, was to evaluate the effect of applying a heavy-metal contaminated sludge to plots where corn is grown and irrigated with municipal wastewater. This particular sludge was highly contaminated with metals from the Grand Rapids, Michigan industries and contained high concentrations copper (Cu), nickel (Ni), cadmiun (Cd), zinc (Zn), lead (Pb), and chromium (Cr). Specific plots were set aside and loaded with this sludge at the rates of 11, 22, 54, and 99 tons per hectare during the first year. The plots were subdivided each succeeding year and retreated with sludge each spring. Therefore, plots receiving the highest metal additions exceeded the suggested maximum by 2 - 3 times for Cd, 13 - 14 times for Ni, 6 - 7 times for Cu, and 12 - 13 times for Zn.

A number of parameters were measured to determine the impact metal-contaminated sludge had on them. These parameters were monitored for the range of sludge loadings and include grain yield, nitrogen uptake by the plant tissue, and dry matter yields. Corn was monitored for uptake of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) both in the plant and in the grain through its growth cycle. Corn was also monitored for heavy-metal uptake in both the plant and grain through its growth cycle. These metals include Cu, Cd, Ni, Pb, Cr, and Hg.

Analyses of groundwater were not part of the original work plan of this study; however, samples were collected in the summer of 1978 under the highest sludge application rate (99 + 81 + 140 T/ha) and under the forage-corn treatment of the nitrogen-stripping plots to compare levels of heavy metals in the groundwater. This allowed comparison of groundwater collected beneath plots where the maximum application of metal-load in sludge was applied to that of groundwater collected some distance from the area, thereby evaluating plots with the highest potential for leaching. The samples were split and half of each sample was sent to the Robert S. Kerr

Environmental Research Laboratory in Ada, Oklahoma and the other retained at Michigan State University for analyses.

Summary of Results

Initially, the wastewater being applied to the fields was sampled at the spray nozzles during the application of wastewater, and by collection vessels placed within the treatment areas. Although the collection vessels gave verification of uniform application rates, the samples tended to become contaminated with dust and insects. Therefore, once comparisons indicated that the better samples were obtained from the spray nozzles, these data were used. While there was considerable variation in the individual measurements, a thorough analysis of the data did not show a consistent variation along the length of the irrigation system. The amount of water applied for the whole 1976 season was 12.4 mm (0.5 in) for each pass of the irrigation rig.

The total wastewater applied during each season is tabulated in Table 1. These values are much lower than the 1780 mm (70 in) per year for which the system was designed. The poorly drained soils, with a less than adequate tile drain system, resulted in application of less than the amounts designed for Circle 26. There was no fall application in 1976 because of the late planting and slow drying of the corn and also the early subfreezing temperatures which occurred before late fall application after harvest. The extremely wet conditions in the fall of 1978 prevented irrigation on the high nitrogen side of Circle 26.

The considerable day-to-day variation in the composition of the wastewater is caused by the method of blending. The most notable variation is during the period of the large nitrogen demand by corn in late June, July, and early August, when nitrogen is injected as part of the crop management by the county. The average nutrient contents, specific conductivities, and pH values of the wastewater are presented in Table 2. The Muskegon wastewater is low in phosphorus and nitrogen due to the large proportion of industrial waters collected by the system. The nitrogen injection for the high-nitrogen studies boosts the average total nitrogen from 16 ppm to 24.4 ppm, which is less than was planned, but there appeared to be a loss by volatilization in spray application.

Evaluation of the effectiveness of the various intercropping experiments for nitrogen extraction from the soil was based on ammonia-nitrogen and nitrate-nitrogen removal by the plants for the entire growing seasons for the years of 1976, 1977, and 1978. As shown in Table 3, during 1976 the various crops were evaluated for the normal wastewater (Low N) used for irrigation; then in 1977 and 1978 the experiment was expanded to evaluate the effect of nitrogen spiked effluent (High N).

The ammonia-nitrogen (NH_4-N) levels were initially low in the soils and remained low through the experiment for application of wastewaters for both low and high nitrogen. In 1976, the values were generally in the 1 to 2 ppm range for the surface soil and lower in deeper horizons, indicating that the ammonia (NH_4) was rapidly being nitrified to nitrate (NO_3) in these well aerated soils. Similar results were found in 1977, except that the last sample in the fall showed an increase in NH_4 in soil layers to a depth of 30 cm, which was attributed to the effect of low temperature inhibiting the nitrifying organisms. These higher values, which were still present in the spring of 1978, also remained higher during the growing seasons than the two previous years as

Table 1. *Amount of Wastewater Applied Each Season*

Year	Season		Amount
			mm
1976	Summer		835
1977	Summer		927
	Fall		114
		Total	1041
1978	Summer		673
	Fall (Low N Only)		343
		Total Low N	1016

Table 2. *Summary of the Chemical Composition, Specific Conductivity and pH of the Applied Wastewater*

Year and N/level	NO_3	NH_4	TKN	TN	Cl	PO_4	TP	K	Ca	Mg	Spec. Cond.	pH
	ppm										μ/mohs	
1976 Low N	5.1	3.13	9.62	14.48	240	2.20	2.30	10.9	65.6	14.4	1070	8.11
Std. Dev.	5.4	2.04	4.96	6.05	54	0.44	0.54	1.6	10.4	1.9	150	0.26
1977 Low N	4.28	6.00	12.58	16.86	280	2.24	2.31	10.9	70.2	19.5	980	7.73
Std. Dev.	6.11	4.09	9.48	15.20	77	0.23	0.41	2.1	8.9	7.9	140	0.26
1977 High N	6.01	8.54	18.54	24.55	271	2.22	2.46	10.7	69.1	20.2	980	7.76
Std. Dev.	6.72	5.77	13.96	20.05	64	0.21	0.75	1.1	9.2	8.8	130	0.27
1978 Low N	3.85	5.84	12.68	16.53	181	1.58	1.68	15.0	86.5	14.7	1080	7.75
Std. Dev.	2.72	6.37	10.83	12.54	19	0.30	0.53	5.0	20.0	1.3	130	0.29
1978 High N	5.80	10.25	18.45	24.25	182	1.70	1.92	16.6	86.8	14.4	1110	7.79
Std. Dev.	2.67	7.79	16.24	17.24	19	0.22	0.36	4.5	23.4	1.5	130	0.19
Low N Avg.	4.41	4.99	11.63	15.96	233.67	2.01	2.10	12.27	74.07	16.2	1043	7.86
High N Avg.	5.90	9.40	18.50	24.40	226.5	1.96	2.19	13.65	77.95	17.3	1045	7.78

a result of the failure of the drainage system on this circle. Data show there were no significant differences between the NH_4 distributions in the soil due to the cropping systems. The well data reflect values less than 1 ppm nitrogen as NH_4 during the three-year study.

The nitrate nitrogen (NO_3-N) in the soils was initially rather low in 1976, when wastewater irrigation began as shown in Table 3. The NO_3-N levels were even lower in the deeper soil layers. This is attributed to plant uptake of NO_3-N which caused the reduction of NO_3-N with depth in the soil. The corn-ryegrass treatment in 1976 was planted as an oats-ryegrass mixture. The oats quickly became established and reduced the NO_3 in the soil to the lowest concentration of the three treatments. The soil under the ryegrass treatment was intermediate in NO_3-N content because the ryegrass developed more slowly. The treatment of corn alone did not reduce soil NO_3-N until after July, when the corn had developed a full canopy and was in its stage of rapid growth. Therefore, corn alone was the poorest treatment for removing NO_3-N from the soil for the entire growing season, but was comparable to other treatments from the 34th to the 39th week. All treatments became less effective in reducing soil NO_3-N after August.

The low N plots of 1976 were continued into 1977 and 1978. During these irrigation seasons, nitrogen-spiked wastewater (high N) experiments also were evaluated for the three cropping systems. By the spring of 1977, the ryegrass in the low N plots had become well established and had the lowest NO_3-N content in the surface soil. In May and June, the corn-rye grass and corn-rye soils had less NO_3-N content in the soil than the corn-alone plots as a result of early nitrogen uptake of the grass in the intercropping practices. However, in August and September, the vigorously growing corn in the plots with corn alone had the same or slightly lower soil NO_3-N content than the intercropped plots. The high nitrogen plots were established in an oats cover crop as in previous experiments to simulate overwintering rye. All plots had an initial content of about 15 ppm nitrogen as NO_3 in the surface soil. The ryegrass grew quickly and reduced NO_3 in the surface soil to about 5 ppm nitrogen in about four weeks, while the corn-oats system was intermediate in reducing the soil NO_3 content. At the 15-30 cm depth, the intercropped corn reduced the NO_3 content of soil beginning in June each year to below that of corn alone. The soil-under-ryegrass plots always had the lowest NO_3 content during both years of the high nitrogen experiments. The corn-oats system was similar to corn alone in July but in August as the oats matured, the corn in both treatments did equally well in reducing NO_3 in the profile.

The most significant changes, as far as the N stripping project is concerned, are the changes in NO_3-N concentration in the leached water. In 1976, the corn-rye treatment in which oats simulated rye the first year, kept the NO_3-N in well water lowest early in the season, reflecting the uptake by the quick growing oats. These low concentrations were continued by the NO_3 stripping of the ryegrass and corn. Initially, the ryegrass plot lost NO_3-N by leaching, but as the grass became established it was very efficient at removing NO_3-N.

The corn-alone plots only stripped NO_3-N for a month which showed up in the low NO_3-N well samples in August. The average NO_3-N concentration in the well water for the first season was 3.7 ppm for the corn-ryegrass with oats, 6.2 ppm for the ryegrass alone and 8.0 ppm for the corn alone.

In 1977, the low N experiments showed the real benefits of the intercropping systems at reducing NO_3-N in the leached water after the initial starting year since all the first-year treatments were not complete. The NO_3-N in the well water below the corn-alone plots was rarely below 5 ppm, and during periods when extra N was being added to increase corn production on the farm, the concentrations rose to above 15 ppm indicating that corn alone is a poor nitrogen stripper. The corn-rye system, which was always better than corn alone, had an average of about half as much NO_3 in the well water; the corn-rye system never allowed a concentration over 10 ppm. The ryegrass had the lowest NO_3 in well water, averaging 2.1 ppm and with only one value above 5 ppm. The corn-ryegrass intercrop system was similar to ryegrass alone; however, this was because the ryegrass was not sufficiently controlled to produce an acceptable corn crop. On the high N side of the experiment, the data indicated the intercropping plots were not significantly different from corn alone.

In 1977 the N stripping sludge plots were established using sludge additions of 7 and 22 T/ha in the area irrigated with high N wastewater. These plots had only corn as the crop and were thus directly comparable to the corn-alone stripping studies. The NO_3 content of the surface layer of soil under the corn alone plots was moderately high early in the season. The 7 T/ha sludge application increased the NO_3 content of the surface soil slightly; this increase persisted for at least three weeks before being reduced to a value near the control. The 22 T/ha sludge application increased the soil NO_3 significantly.

The increased levels of NO_3 in the surface soil are reflected in the 15-30 cm layers. Both sludge applications had higher values of NO_3 in the subsoil for

Table 3. *Nitrate Content of Soils-N-Stripping Experiment*

			Treatment					
			Corn		*Corn-Rye*		*Ryegrass*	
Year	*Sample*		*Low N*	*High N*	*Low N*	*High N*	*Low N*	*High N*
					ppm N as No_3			
1976	*Week 20*	*0-15cm*	*1.9*		*2.5*		*2.2*	
1976	*Week 20*	*15-30cm*	*1.7*		*1.8*		*1.6*	
1976	*Average*	*0-15cm*	*3.5*		*2.2*		*3.1*	
1976	*Average*	*15-30cm*	*2.1*		*1.6*		*1.8*	
1977	*Average*	*0-15cm*	*4.3*	*7.1*	*4.7*	*7.0*	*2.9*	*5.6*
1977	*Average*	*15-30cm*	*3.8*	*3.4*	*1.4*	*3.1*	*0.9*	*2.4*
1977	*Week 47*	*0-15cm*	*2.0*	*2.8*	*2.1*	*4.1*	*0.9*	*2.5*
1977	*Week 47*	*15-30cm*	*0.8*	*1.0*	*1.1*	*1.8*	*0.3*	*1.0*
1978	*Average*	*0-15cm*	*3.7*	*4.4*	*4.0*	*4.0*	*2.7*	*3.1*
1978	*Average*	*15-30cm*	*1.7*	*2.1*	*1.6*	*1.9*	*1.2*	*1.4*
1978	*Week 48*	*0-15cm*	*3.8*	*10.4*	*3.7*	*11.4*	*3.5*	*7.2*
1978	*Week 48*	*15-30cm*	*1.5*	*3.5*	*1.0*	*4.4*	*1.4*	*2.1*

several weeks. In fact, at the 15-30 cm depth the soil NO_3 on the 22 T/ha plots was always higher, except during the mid-July to mid-August period, when the corn on these plots was growing vigorously and reduced the NO_3 levels to the level of the no-sludge corn plots. It can be concluded that immediately after the application of sludge, well aerated conditions prevailed, allowing the readily available nitrogen in the sludge to be converted to NO_3 which is readily leached unless the corn is in its rapid-growth, maximum-demand stage, where it can absorb the NO_3. Sludge, when applied at 22 T/ha, increased the concentration of NO_3-N in the well samples, but the application of 7 T/ha sludge did not increase the nitrate content of well samples. Thus, applications of low amounts of sludge is an acceptable practice.

The yields of corn grain and silage (Table 4) are similar to those obtained on similar soils on the Muskegon Wastewater Treatment Facility farm operation. Corn and corn-rye cropping systems produced the same corn grain and silage yield except on the high N plots in 1977 when oats were used to simulate overwintering rye. This intercropped forage was too competitive for the corn. The ryegrass intercrop significantly reduced corn grain and silage yields except in 1978, when there was an overkill of the ryegrass to the extent that nitrogen stripping was impaired. The addition of sludge beginning in 1977 corrected the infertility of this poor soil and gave excellent yields but did add to the NO_3 leaching. The yield of corn in 1978 was suppressed compared to 1977 which may have been the result of too much water on these soils which have a poor underdrain system particularly on the north half of circle 26. Corn-rye has proven to be an acceptable N-stripping winter crop without reduction in yield; however, corn-ryegrass would need to be better controlled to reduce the forage competition before it could be advocated.

The supplementary forage experiments demonstrated that all of the forages, with the exception of crown vetch, can be grown at the Muskegon Wastewater Facility. The crown vetch had difficulty in germination and never became a well-established stand. All the others were no-till planted to corn in 1978 and their yields are presented in the detailed manuscript. All the legumes, rye, ryegrass, and the natural quackgrass crops were compatible as an intercrop. Reed canary grass, tall fescue and orchard grass would not be suitable in these soils because their dense root system would interfere with the no-till corn planter. If these forages were used they should be tested as to their N stripping abilities.

Table 4. *Yields of Corn and Silage on N-Stripping Experiment*

Crop	*Corn Grain 1976*	*Corn Grain 1977*	*Corn Grain 1978*	*Corn Silage 1976*	*Corn Silage 1977*	*Corn Silage 1978*
		hl/ha			*T/ha*	
Low N Corn	*40.6a**	*68.9b*	*53.4a*	*26.0*	*26.3b*	*29.6a*
Low N Corn in Rye	*42.6a*	*71.5b*	*54.1a*		*25.7b*	*28.5a*
Low N Corn in Ryegrass	*23.5b*	*36.6c*	*49.8ab*	*6.4*	*13.7c*	*25.4ab*
High N Corn		*72.5b*	*35.4abc*		*25.3b*	*23.4ab*
High N Corn in Rye		*42.6c*	*21.7c*		*14.3c*	*14.5b*
7 T/ha Sludge on High N Corn		*92.5a*	*32.8bc*		*35.7a*	*20.9ab*
22 T/ha Sludge on High N Corn		*89.1ab*	*52.7ab*		*34.7a*	*20.9a*
LSD (.05)		*18.8*	*18.5*		*8.2*	*10.6*

**Yields with the same letter are not different from others in the same column.*

An experiment was established to study the influence of metal loading rates from a metal-contaminated sludge upon crop yield and the movement of heavy metals under irrigation. Application of sludge to a wastewater treatment system such as the one at Muskegon is considerably different from applying sludge to agricultural lands in a conventional dry land or irrigated production system. First, the soils at Muskegon are very sandy which will provide maximum opportunity for sludge to be decomposed by microorganisms because of well aerated conditions in the soil. Secondly, the water application rate is much higher than in conventional agricultural systems even where irrigation is practiced. Thus, the Muskegon Wastewater Treatment Site allows for evaluation of metal contaminated sludge application to agricultural lands under conditions in which problems are most likely to occur due to leaching of nutrients and heavy metals into the groundwater.

Sludge from the Grand Rapids, Michigan Municipal Wastewater Treatment Facility was transported to the test site where it was applied by spreading weighed quantities. A randomized block design with five treatments (0, 11, 22, 54, and 99 T/ha) and four replications were used. The experiment was modified by splitting the 11, 22, and 99 T/ha treatments in 1977 and adding yearly sludge applications to one half of each plot.

The concentration of all major plant nutrients (N, P, K, Ca, and Mg) in this sludge would be considered about average for sewage sludges. This sludge was high in Cu, Fe, Ni, Cr, and Zn, above average in Cd and Pb, and average in Mn. The quantity of metals added to the soil by the sludge applications were quite substantial, particularly at the high rates. Maximum metal loadings to agricultural soils have been suggested by a North Central Regional Research Committee. For soils like those in this study, having a cation exchange capacity of less than 5 meg/100g, the maximum lifetime metal loadings suggested in Kg/ha were: Cd - 5.6, Ni - 56, Cu - 140, Zn - 280, and Pb - 560. The total quantity of metals added to plots retreated with the highest sludge rate in 1977 and 1978 was: Cd - 12.6, Ni - 770, Cu - 930, Zn - 3,490, and Pb - 370 Kg/ha. Therefore, plots receiving the highest metal additions (i.e. the "99 + 81 + 140" plots) exceeded the suggested maximum by 2-3 times for Cd, 13-14 times for Ni, 6-7 times for Cu, and 12-13 times for Zn. Only about 2/3 of the suggested maximum Pb loadings was added. While the research committee's expected lifetime loadings for these five metals were considered to be conservative, the impact of metal loadings at levels which are 6-19 times these suggested maximums are largely unknown.

The effects of the above indicated metal loadings on plant yield, plant composition, and metal mobility and movement in the soils were thoroughly investigated. The effects of the range of metal contaminated sludge loading on corn grain yield are given in Table 5. The yield response to the sludge application in the initial year of study was dramatic. Eleven T/ha of sludge increased the yield from 64 to 102 hl/ha (73 to 117 bu/acre). Further yield increases from additional sludge loadings were small and statistically insignificant. Data in Table 5 indicate a gradual decline in

Table 5. *Grain Yields from Metal Contaminated Sludge Study*

Treatment	*Grain Yield 1976*	*1977*	*1978*	*Average*
	-hl/ha#-			
No Sludge	*64.4b*	*77.2c*	*46.4c*	*62.7*
11	*101.7a*	*81.1bc*	*59.4abc*	*80.7*
*11**		*96.8ab*	*70.6ab*	*83.7*
22	*107.7a*	*93.3abc*	*52.0bc*	*84.3*
*22**		*99.9ab*	*73.2a*	*86.6*
54	*111.9a*	*92.0abc*	*68.2ab*	*90.7*
99	*98.5a*	*93.2abc*	*74.0a*	*88.6*
*99**		*100.8a*	*67.6ab*	*84.2*
L.S.D.	*18.9*	*16.2*	*17.6*	

****Annual application (11 + 11 + 11, 22+22+22, and 99+81+140 T/ha, respectively).***
#Numbers followed by the same letter within a column are not significantly different at the 5% level.

nutrient availability with increased sludge loading as the nutrients were utilized by the crop, leached, or fixed by the soil.

The economic benefit of multiple addition of sludge applications in successive years was evaluated based on the value of additional corn produced. There appeared to be an economic benefit from applying some sludge each year. Although the average yield for a single application of 11 T/ha of sludge was 18 hl/ha (20.7 bu/acre), most of the increase came in the first year. The yield increase from residual sludge was 3.9 and 12.0 hl/ha in 1977 and 1978, respectively, compared to untreated plots but an annual application of 11 T/ha sludge gave 19.6 and 21.4 hl/ha increase for the years of 1977 and 1978, respectively. These facts illustrate the economic feasibility of annual sludge loadings. Since it is probable that sludge would be in short supply, the question was posed whether or not it would be more economical to apply low quantities of sludge over a large acreage or apply larger quantities to smaller acreages. Assuming there is a uniform cost per ton of sludge applied, calculations of the return were made for each case. The conclusions were that the maximum economic benefit would be gained by applying a small quantity of sludge to a larger acreage.

Heavy-metal uptake in the corn plants and grain was monitored for all three years of the study. The Fe and Mn content of plant tissue showed appreciable decrease in uptake with years over all treatments. The major decrease in Fe content occurred between the first and second sampling in 1976, while the Mn decrease was approximately linear each year. The authors speculate that this reduction pattern in uptake was probably due to an increase in soil pH caused by the application of wastewater. There was still adequate Fe in the plant in 1978 for good growth but the Mn content became lower than desirable for optimum yield by 1978.

The Cu and Zn uptake patterns in the plant tissue were similar. Data clearly indicate that Cu uptake was increased by sludge application. However, the Cu content of plants grown on the control plots decreased from 1976 to 1978, probably due to the increased pH of the soil. The same effect was observed but was more pronounced for Zn. In 1976, the application of sludge increased the Zn content of plants from about 100 ppm to over 300 ppm. By 1978, the Zn content of plants grown on the control were about 30 ppm and those from the highest sludge rate were down to about 100 ppm. This decrease in uptake from 1976 to 1978 could also be accounted for by changing corn hybrids during each year since hybrids are known to absorb varying quantities of Zn when grown in the same environment.

Zinc was the only heavy metal of those monitored whose content was increased in both the tissue and the grain by sludge application. A nearly linear increase in Zn content of both tissue and grain occurred in 1978. The Zn content of the grain was nearly doubled by the highest sludge application (3,490 Kg Zn/ha). However, this Zn level in the grain would not be considered toxic to either animals or humans. The Zn content of plant tissue from the sludge treated plots in the initial year were very high but not high enough to be toxic to either plants or animals. Although there was an increase in Zn content in the corn grain, the increase was relatively small compared to the increase in the plant tissue. The incorporation of cadmium (Cd) into the food chain through the use of sludge on agricultural land is of major concern. The sludge used in this study had a moderate Cd concentration and 12.6 Kg/ha of Cd were applied to the high sludge loaded plots over a three year period. The Zn application from this sludge was more than 100 times the Cd rate. Nevertheless, some apparent increase in Cd occurred in the young tissue in 1976 but was near the detection limit. No Cd was detected in plant tissue in 1977 and 1978 and no Cd was detected in the grain in any year.

The data indicated that sludge application did not significantly affect the Pb, Ni, Cr, or Hg content of the plant tissue or grain, although an evaluation is difficult since metal concentrations were usually at or below detection limits.

Both DTPA extractable and total heavy metals were followed in the soils throughout the three years of the experiment. Soil analysis for the surface soil (0-15 cm) showed a linear increase in DTPA extractable Zn with Zn applied in the sludge in 1976. About one-sixth of the Zn applied in the sludge was extracted by the DTPA at the end of the season. The next soil layer (15-30 cm) showed an elevated Zn content at the highest Zn application rate but no increase at the lower loading rates. The extractable Zn in the surface layer decreased considerably by the end of 1977 but did not change appreciably in 1978. Analyses indicate that a portion of the Zn migrated into the groundwater while the major portion of that applied over the three year study precipitated in the soil as pH increased with additional sludge and wastewater.

DTPA extractable Cu and Ni both increased linearly in the surface layer with application rate similar to Zn. Even though Cu was more variable than Zn the trends were similar. About 10 percent of the added Cu was DTPA extractable. As with Zn, the Cu level in the subsoil was increased by the highest application of sludge during the first year. However, Cu did not become less soluble with time as did Zn. This is understandable since it is known that Cu will remain available for many years in soils once it has been applied and is not so dependent on soil pH as are other heavy metals. The Ni level in the soil decreased with time particularly at high levels of applied Ni. Data indicated that Ni was leached into the soil profile in a manner similar to Zn. The DTPA extractable levels of other heavy metals were not increased by the addition of sludge which would suggest that they should not be susceptible to leaching or increased plant uptake.

Groundwater samples were collected in the summer of 1978 under the highest sludge application plots (99 + 81 + 140 T/ha) and under the forage-corn treatment of the N stripping plots where no sludge had been applied. Sampling from these separate areas provided a comparison of the levels of heavy metals in the groundwater under the maximum application of sludge to a treatment that was removed from the area assuring that no contamination existed.

Data clearly indicated that Zn, Cu, and Ni all had leached into the groundwater under the highest sludge loaded plots. Zinc values were approaching one ppm and exceeded this value for one month at the end of summer. The level of Zn applied to the plots where groundwater samples were collected was 3,490 Kg/ha, which is clearly an exorbitant quantity of Zn to apply under any circumstance. The results would indicate that an undesirable quantity of Zn reaches the groundwater under such high loading rates.

The Cu increase in the groundwater beneath the high sludge loaded plots was about double that of the control area. Thus, movement was confirmed which agrees with the DTPA extractable soil Cu and Zn values but the quantity of Cu is not excessive even under the high quantity of Cu addition (930 Kg/ha).

Like Cu and Zn, Ni content of the groundwater also increased under sludge application. The quantity of increase appeared to be intermediate between Cu and Zn and again indicated that movement was occurring. No detectable Hg was found in the groundwater at any time. Increases of Cr, Cd, and Pb may have occurred but the great variation between replicate samples made this uncertain since surface contamination is possible.

Conclusions

As a result of this research effort, a number of conclusions can be drawn concerning the fate of nutrients and heavy metals applied to sandy soils at municipal wastewater land treatment sites which are used to grow corn as a major cash crop.

In the nitrogen stripping studies, the nitrogen added in the wastewater was rapidly converted to nitrate nitrogen (NO_3) leaving very low levels of ammonia nitrogen (NH_4) in the soil during two of the three years of study. Even during periods when rainfall combined with wastewater resulted in poor soil aeration, levels of NH_4 rarely exceed 4 ppm in the soil profile.

Corn grown alone was only effective in removing nitrogen during a four-week period during its rapid growth near maturity beginning in late July. At other times the NO_3 levels moving through the soil were near those of the applied water.

Ryegrass forage was the best treatment for removing nitrogen from the wastewater for the entire season. However, during the four week period discussed above there was little difference in cropping systems with respect to the quantity of nitrogen removed.

Intercropping forage with corn reduced the total nitrogen leached considerably when compared to corn alone. The Muskegon system was generally nitrogen deficient leaving a delicate balance where the corn yields were reduced by as much as 50 percent if the forage was too vigorous. When forage was controlled with paraquat the intercropped corn yielded about the same as corn alone.

A management system where rye is strip killed with paraquat and then no-till corn planted will produce a satisfactory management system to effectively strip nitrogen from the water and produce a satisfactory corn yield. The varieties of rye used in this study did not shatter in the field to reseed themselves in late summer. A search for varieties of rye which would shatter when matured could preclude seeding the rye each year.

A study to compare different forages showed that corn intercropped with red clover, alfalfa, birdsfoot trefoil, and ryegrass gave satisfactory yields. Yields were drastically reduced when tall fescue or orchard grass was the forage. Rye, quackgrass, and reed canary grass were intermediate in affecting yield.

When sludge was applied to an area receiving about 24 ppm nitrogen in the sprayed wastewater, a sludge loading rate of 7 metric tons per hectare (T/ha) gave little increase in NO_3 in the soil. However, when sludge was applied at 22 T/ha under the same conditions, NO_3 increased in both the surface and the 15-30 cm layer of soil.

The application of sludge at about 11 T/ha increased the corn yield from 64 to 102 hectoliters per hectare (73 to 117 bu/acre). Rates of sudge application above 11 T/ha did not show an appreciable increase in yield over the 11 T/ha rate. Economically, the returns would favor application of a 11 T/ha rate over a large acreage rather than heavy applications of sludge to small acreages.

Zinc (Zn) was the only metal to be significantly increased in the corn grain by the additions of sludge. Although the level was increased from about 30 to 50 ppm Zn in the grain, this level is quite safe in a food grain. Zinc, Copper (Cu), and Nickel (Ni) were found to move in the soil and to give increased levels in the groundwater under the highest sludge application rate (3,490, 930, and 770 Kg/ha) of Zn, Cu, and Ni, respectively. Zinc content of the groundwater was increased from about 0.1 ppm to about 0.8 ppm, Cu from 0.04 to 0.13 ppm and Ni from 0.03 to 0.07 ppm under the heaviest sludge application as compared to no sludge. Low rates of sludge (less than 54 T/ha) did not appear to be a hazard to either crop or leaching on these sandy soils.

Recommendations

Effective treatment of wastewater by land application must include careful management of the land and crop resources to obtain maximum nutrient removal through high production and simultaneously produce desireable groundwater. Because of the inability of corn to reduce NO_3 in the soil solution during much of the growing season it cannot be recommended as the crop except for a system with very low incoming N levels (i.e. less than 10 ppm N in the water being applied to the land).

Land treatment systems receiving wastewater containing high quantities of N should consider forages or forages intercropped with corn to renovate the wastewater. A management system is suggested where rye is intercropped with corn by killing a strip of the rye with a suitable herbicide at the time that corn is no-till planted. This reduces the competition for nutrients in the corn until it reaches a height sufficient that it will shade the rye and thus reduce the competition. A rye that shatters easily could eliminate the need to reseed the rye each summer; however, the varieties that were used in this study resisted shattering.

Application of sludge is compatible with wastewater treatment systems but the application rate should be kept low. At application rates less than 54 T/ha, movement of heavy metals in the soil profile did not appear to be a problem. Uptake and translocation of heavy metals into the grain were only noted in the case of Zn. The recommendation for a low application of sludge will give the greatest economic returns per ton of available sludge and at the same time lessen the chance of leaching of metals from the sludge.

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The complete report, entitled "Cropping Systems for Treatment and Utilization of Municipal Wastewater Sludge," (Order No. PB 81-187 254; Cost: $17.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
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