Exhibit 1A

Sustainable Rates of Sewage Sludge for Dryland Winter Wheat Production I. Soil Nitrogen and Heavy Metals

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The application of sewage sludge to agricultural land has become the major method of sludge disposal in the USA. Therefore, the long-term impact of sludge application to the soil environment must be investigated in order that proper loading rates are employed. Thus, a field study was initiated in 1982 in Adams County, Colorado, with the goal of evaluating the effects of the Littleton/Englewood, CO, sewage sludge on soil N, Zn, Cu, Cd, Ni, and Pb levels in a dryland hard red winter wheat (*Triticum aestivum* L., 'Vona')—fallow management system compared to commercial NH_4NO_3 fertilizer. This report covers soil data for the last three years of this 5-yr study where sludge rates ranged from 0 to 18 dry ton/acre, and N fertilizer rates ranged from 0 to 120 lb N/acre. Sewage sludge application resulted in increased soil NO_3-N levels at harvest compared with the N fertilizer for all depths sampled and each year reported. Mean NO_3-N levels of the surface 8 in. for the sludge and N fertilizer treatments ranged from 10 to 32 ppm and from 2 to 9 ppm, respectively. The soil NO_3-N in the root zone (considered to be about 6 ft for wheat) data showed that three sludge applications, of 12 ton/acre resulted in significantly higher NO_3-N levels throughout the root zone compared with the control or 50 lb N/acre. A loading rate of 3 ton/acre resulted in significantly greater NO_3-N than the control at the 0 to 8 in. and 24 to 35 in. depths. Sludge application, at all loading rates tested, resulted in significantly increased NH_4HCO_3-diethylenetriaminepentaaceticacid (AB-DTPA) extractable concentrations of Zn, Cu, Cd, Ni, and Pb compared to the control in the surface 8 in. of the soil. Because of the potential for NO_3-contamination of groundwater (and metal build-up in the soil) by the higher sludge loading rates, a loading rate of 3 ton/acre is recommended as the maximum safe loading rate for his dryland wheat system.

THE APPLICATION of sewage sludge to agricultural land has become the major method of sludge disposal in this country. (USEPA, 1983). Land application of sludge provides a feasible disposal alternative to many municipalities plus the environmental benefit of nutrient recycling. As available land for landfills decreases and air quality restrictions prevent incineration as an alternative to disposal, widespread employment of land application of sludges is imminent in the USA. However, there are possible detrimental effects to the environment which must be considered. The major considerations are accumulation of heavy metals in soils, contamination of groundwater by NO_3-N, pathogenic organisms, and toxic organics (Sommers and Barbarick, 1986).

The potential for contamination of groundwater due to NO_3^- leaching as a result of land application of sludge has been studied by several researchers (Brown, 1975; Higgins, 1984; Hinesly et al., 1974), and sludge loading rate estimates have been developed (USEPA, 1977) to minimize the contamination of groundwater. Specific loading rates should be based on proper monitoring of NO_3-N levels in the groundwater and soil which will be dependent on a number of site specific parameters such as N content of the sludge, soil texture, depth to groundwater, climate, crop demand for N, and management practices employed (Higgins, 1984). Higgins (1984) found that 10 dry ton/acre was the maximum loading rate that would ensure groundwater quality (i.e., not in excess of 10 ppm NO_3-N, USEPA, 1976) for a sandy loam soil in which the average depth to groundwater was 79 in. The study by Hinesly et al. (1974) was in agreement with the results found by Higgins (1984) in which low loading rates of 1.8 to 2.7 dry ton/acre of sludge did not result in groundwater contamination by NO_3-N.

The accumulation and movement of heavy metals in soils as a result of sludge application has been extensive-

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ly studied (Baxter et al., 1983; Emmerich et al., 1982; Higgins, 1984; Lerch, 1987; Sommers et al., 1979). Also, guidelines for the maximum cumulative addition of Cd, Cu, Ni, Pb, and Zn, based on the cation exchange capacity (CEC) of the soil, have been established by the USEPA (1977). Higgins (1984) demonstrated increased total Zn and Cu in the surface 12 in. of a sandy loam soil after 4 yr of sludge addition at a loading rate of 20 dry ton/acre. Baxter et al. (1983) showed increases in total soil Zn, Cu, Ni, Cd, Pb, and Hg after a cumulative sludge addition of 58 dry ton/acre. Also, AB-DTPA extractable levels of Zn, Cu, Cd, and Pb were increased in the surface 8 in. of a loam soil after 2 yr of sludge application at loading rates of 3 to 18 dry ton/acre (Lerch, 1987). Soil column studies (Emmerich et al., 1982; Sommers et al., 1979) and a field study (Higgins, 1984) have shown that most surface soil horizons have sufficient capacity to retain metals which accumulate from sludge addition. Therefore, heavy metal contamination of groundwater due to land application of sludge does not appear to be a major environmental concern.

Given the substantial amount of information concerning the potential adverse effects of sludge application, municipalities need information which will allow them to apply sludge, on a long-term basis, at loading rates which maximize the agricultural benefits to a crop and minimize the deterimental effects to the environment. Thus, a long-term field project was established to determine a sustainable sewage sludge rate (or range of rates) for a dryland winter wheat-fallow system in eastern Colorado. The primary objectives of the study were to determine (i) the levels of NO_3-N and NH_4-N in the soil due to sludge and N fertilizer application, (ii) the accumulation of heavy metals in the plow layer from sludge application, and (iii) the recommendation of a maximum long-term sludge loading rate for dryland winter wheat.

MATERIALS AND METHODS

A long-term field study was initiated in August 1982 near Bennett, CO, in Adams County. Hard red winter wheat was grown in a dryland summer fallow rotation system. This report will present data pertinent to the soil N and heavy metals over the last three years of this five year study. Further details of the first two years are provided by Utschig (1985) and Utschig et al. (1986).

The field site was established on a Weld loam soil (fine, montmorillonitic, Mesic Aridic Paleustolls). Due to the wheat-fallow rotation, the site has two separate sets of plots or locations (Table 1) so that a wheat crop is present each year of the rotation. The 1984–85 and 1986–87 data are from location A with plot dimensions of 12 ft by 56 ft, and the 1985–86 data are from location B with plot dimensions of 9 ft by 56 ft. Because of the wheat-fallow rotation, this report covers two years of sludge and commercial N fertilizer application to the 1985–86 and the 1984–85 plots and three years to the 1986–87 plots (Table 1). The data tables presented in the results and discussion section indicate only the current years' sludge and N fertilizer application. Sludge and N fertilizer treatments were applied in August of 1984, 1985, and 1986 for each of the three growing seasons. Sewage sludge, obtained from the Littleton/Englewood, CO, waste treatment facility, was applied at rates of 0, 3, 6, and 12 dry ton/acre in 1984 and at rates of 0, 3, 6, 12, and 18 dry ton/acre in 1985 and 1986. The 18 ton/acre rate was included in the statistics for location A beginning in 1986. Nitrogen fertilizer (NH_4NO_3) was applied at rates of 0, 25, 50, and 100 lb N/acre in 1984 and 1986 and at rates of 0, 30, 60, 90, and 120 lb N/acre in 1985. The sludge was applied by evenly spreading the solid sludge over the plots followed by hand raking to improve the uniformity of application. The sludge was incorporated to a depth of about 4 to 6 in. using a tractor mounted roto-tiller. The NH_4NO_3 was uniformly spread by hand over the plots and incorporated by roto-tilling.

Table 1. Crop rotation, sewage sludge, and N fertilizer application history at each experimental location.

Location	1982–83	1983–84	1984–85	1985–86	1986–87
A	S-W†	F	S-W	F	S-W
B	F	S-W	F	S-W	F

† F = Fallow; S-W = sludge or N fertilizer applied 30-60 d prior to planting wheat.

The experimental design of the plots was randomized complete block with the treatments arranged in a nested split plot design. The sludge and N fertilizer were the main plots and the treatments (rates) within each main plot were subplots (Steele and Torrie, 1980). Each subplot was replicated four times. Trend analysis of the effect of N or sludge treatments on a given parameter were performed by partitioning the treatment sum of squares. Only the linear and quadratic trends are reported since the physical and biological significance of higher order equations are difficult to interpret. In the design of the experiment, the sludge rates used were not intended to be equivalent to the N rates, but instead, each set of treatments was designed to cover the entire range of available soil N, from deficient to excessive. Therefore, a rate × N source interaction of the data was not performend.

Baseline soil samples were collected prior to treatment from 0 to 6 in. depth in August 1982 and 1983. All soil samples were air dried and ground to pass a 0.08 in. sieve. The soil samples were analyzed by the Colorado Soil Testing Lab., Coloardo State University. The NO_3-N content of the samples was determined in 2M KCl extracts (Keeney and Nelson, 1982) by the Lachat flow injection analyzer system (Soltanpour and Workman, 1981). The pH and electrical conductivity of the samples were measured on saturated pastes, and organic matter content was determined by the colorimetric dichromate procedure (Walkley, 1947). The available elemental content of the samples was determined by AB-DTPA extracts (Barbarick and Workman, 1987; Soltanpour, 1985, Soltanpour et al., 1982) which were analyzed by the Inductively Coupled Plasma-Atomic Emission Spectrophotometer (ICP-AES) (Table 2).

The harvest soil samples were taken at depths of 0 to 8 and 8 to 24 in. for all three years, and, in addition, for 1986–87, soil samples were obtained from 24 to 40 in. Analysis for the NO_3-N and NH_4-N concentrations were performed on samples at all three depths, and analysis

Table 2. Selected chemical properties of the Weld loam soil, 0–6 in., prior to sludge application.

Location	pH	Electrical conductivity	Organic matter	NO_3-N	AB-DTPA extract P	K	Zn	Cu	Fe	Mn
	paste	mmhos/cm	%	ppm						
A	6.7	0.1	0.9	3	11	375	0.7	2.1	13.2	13.6
B	6.6	0.3	1.0	4	11	383	0.9	2.6	10.6	27.4

of the soil metal concentrations were performed for the 0 to 8 in. samples, only. The NO_3-N concentration was determined with a $CuSO_4/Ag_2SO_4$ extracting solution followed by analysis using the NAS-Szechrome colorimetric procedure with a Spectronic 20 (based on a procedure developed by Szekely, 1968). The NH_4-N content of the samples was determined by extraction with 2M KCl (Keeney and Nelson, 1982) followed by analysis using a Technicon Autoanalyzer (Technicon, 1977). The soil Zn, Pb, Cu, Ni, and Cd were extracted with AB-DTPA, and the concentrations of the metals were analyzed using the ICP-AES. Extraction of the metals with AB-DTPA was chosen because this method has been shown to significantly correlate with the total metal added, and for some elements, it can provide an indication of plant availability (Barbarick and Workman, 1987).

In order to evaluate the extent of NO_3-N leaching through the soil profile, additional soil samples were obtained two years after sludge application in early August, 1987 (at location B) and 1988 (at location A). Composited soil samples were obtained from 0 to 8, 8 to 24, 24 to 35, 35 to 47, and 47 to 71 in. At location A, the control, 50 lb N/acre, and the 3 and 12 ton/acre sludge rates were sampled, and at location B, the control, 60 lb N/acre, and the 3 and 12 ton/acre sludge rates were sampled. The 50 and 60 lb N/acre were selected because these treatments are typical N rates applied in eastern Colorado for dryland winter wheat production. The NO_3-N analysis was performed by the same method previously described for the harvest samples. The treatment differences were statistically analyzed by a oneway analysis of variance (AOV), and the means were graphed at the midpoint of each depth sampled (Figs. 1 and 2). Mean separation values (F-LSD) were calculated for cases in which the p-values (from the AOV) were less than 0.01.

Sludge samples for each year were collected at the time of application, and the elemental compositions (Table 3) were determined by using a HNO_3-$HClO_4$ digest (Havlin and Soltanpour, 1980). The sludge applied in the 1984–85 and 1986–87 growing seasons would be classified as Grade I by the Colorado Department of Health (1985). Grade I sludge can be applied to any land for beneficial use after dewatering and storage for one year. The sludge applied in the 1985–86 growing season would be classified as a Grade II because of the higher Cu and Zn concentrations. Grade II sludge can be applied to agricultural and disturbed lands, only.

RESULTS AND DISCUSSION

Harvest Soil Nitrogen

Soil NH_4-N and NO_3-N were measured at harvest to evaluate the plant available N status of the soil at the end of the growing season and to evaluate the potential for NO_3-N leaching through the profile. Soil NH_4-N content of the top 8 in. increased linearly with increasing sludge application rate in two out of three years while the N fertilizer treatments had no significant affect on soil NH_4-N in any of the years (Table 4 and 5). The mean soil

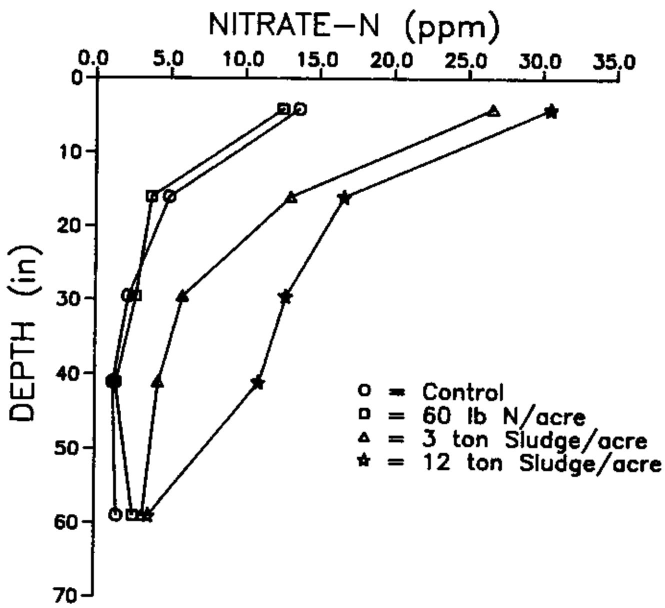

Fig. 1. The effect of two applications of sludge and N fertilizer application on root zone NO_3-N, Location B, 1987.

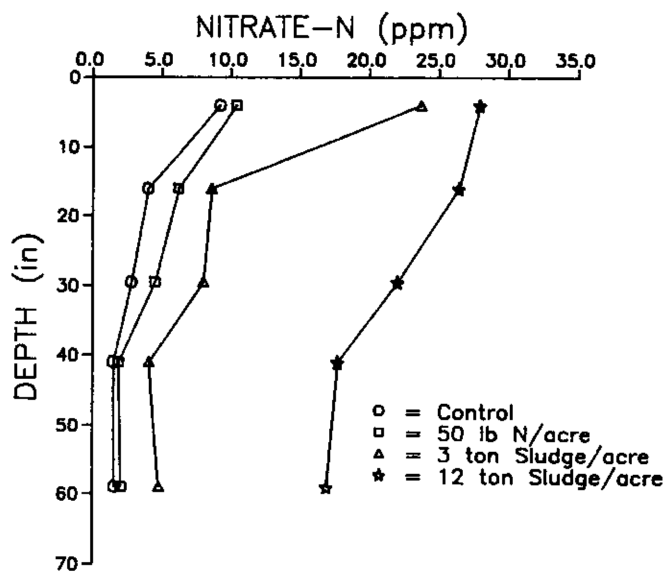

Fig. 2. The effect of three applications of sludge and N fertilizer application on root zone NO_3-N, Location A, 1988.

Table 3. Average composition of the sewage sludge used for the 1984-85, 1985-86, and 1986-87 growing seasons.

Element/ constituent	Crop year 1984-85	1985-86	1986-87	Health standard† Grade I	Grade II
Solid, %	53	68	85	None	Specified
Total N, %	2.9	2.2	1.0	–	–
NO_3-N, ppm	14	712	7.4	–	–
NH_4-N, %	0.8	0.2	0.2	–	–
P, %	1.1	2.7	0.8	–	–
K, %	0.3	0.3	0.2	–	–
Ca, %	1.4	3.2	1.4	–	–
Mg, %	0.3	0.4	0.2	–	–
Na, %	0.12	0.06	0.05	–	–
Fe, %	1.0	1.8	0.9	–	–
Cd, ppm	8	11	10	25	70
Cr, ppm	175	356	131	None	Specified
Cu, ppm	462	1159	359	625	1650
Mn, ppm	122	204	–	None	Specified
Mo, ppm	12	38	7	None	Specified
Ni, ppm	56	91	47	250	650
Pb, ppm	531	322	206	1000	2500
Zn, ppm	751	2538	618	1250	3325

† Grade I sludge which has been dewatered and stored for one year prior to application may be applied to any land for any beneficial use. Grade II sludge can be used for beneficial use on agricultural and disturbed lands only (Colorado Department of Health, 1985).

NH_4-N content of the sludge treatments also was significantly higher than the N fertilizer treatments in two out of three years. Depending on soil moisture prior to sampling, the levels of NH_4-N vs. NO_3-N in the soil show considerable variation. In 1984-85 and 1985-86, NH_4-N was as high or higher than NO_3-N, while in 1986-87 NO_3-N was much greater than NH_4-N (Tables 4 and 5). Soil NH_4-N levels in the subsoil (8-24 in. and 24-40 in.) were generally unaffected by either sludge or N fertilizer application over all three years (Tables 4 and 5).

Soil NO_3-N levels of the 0 to 8 and 8 to 24 in. depths showed linear increases with increasing sludge rate over the three years while N fertilizer application did not affect the NO_3-N levels except in the 1986-87 growing season (Tables 4 and 5). Mean soil NO_3-N levels from the sludge treatments were significantly greater than those from the N fertilizer treatments for the top two depth increments as well. Over the three years, the mean soil NO_3-N levels of the top 8 in. for the sludge treatments ranged from 2.7 to 6.6 times greater than the mean soil NO_3-N levels of the N fertilizer treatments. At the 8 to 24 in. depth, mean soil NO_3-N content of the sludge treatments ranged from 2.1 to 7.6 times greater than the mean soil NO_3-N levels of the N fertilizer treatments. In all three years, soil NO_3-N levels from the 3 ton/acre rate were not significantly greater than the control (F-LSD values not shown), and they were always significantly less than the highest sludge rate applied (12 ton/acre in 1984-85 and 18 ton/acre in 1985-86 and 1986-87).

An additional depth increment of 24 to 40 in. was samples in the 1986-87 growing season. At the 24-40 in. depth, both sludge and N fertilizer treatments resulted in linear increases in soil NO_3-N with increasing application rate (Table 4). Mean soil NO_3-N content of the sludge treatments was significantly higher than that from the N fertilizer treatments.

Root Zone Nitrate

Due to the greater soil NO_3-N content of the sludge

Table 4. Effects of N fertilizer and sewage sludge rates on the concentration of NH_4-N and NO_3-N in the soil at harvest, Location A, 1984-85 and 1986-87.

N fertilizer	Sewage sludge	1984-85 NH_4-N	1984-85 NO_3-N	1986-87 NH_4-N	1986-87 NO_3-N
lb N/acre	dry ton/acre	ppm			
		Depth, 0-8 in.			
0	–	16	3	2	7
25	–	16	3	1	7
50	–	15	4	1	8
100	–	16	5	2	13
Mean		16	4	1	9
Linear		NS	NS	NS	**
Quadratic		NS	NS	NS	NS
–	0	15	3	2	7
–	3	19	6	1	19
–	6	17	12	2	19
–	12	22	21	3	53
	18	–	–	5	64
Mean		18	10	2	32
Linear		NS	**	**	**
Quadratic		NS	NS	*	NS
N fertilizer vs. sludge		*	**	*	**
		Depth, 8-24 in.			
0	–	13	2	2	2
25	–	13	1	2	2
50	–	13	2	2	2
100	–	13	2	3	4
Mean		13	2	2	2
Linear		NS	NS	*	*
Quadratic		NS	NS	NS	NS
–	0	13	1	2	2
–	3	14	3	2	7
–	6	11	4	3	9
–	12	14	7	2	25
	18	–	–	3	41
Mean		13	4	2	17
Linear		NS	**	NS	**
Quadratic		NS	NS	NS	**
N fertilizer vs. sludge		NS	**	NS	**
		Depth, 24-40 in.			
0	–			1	2
25	–			1	2
50	–			1	3
100	–			2	4
Mean				1	3
Linear				NS	*
Quadratic				NS	NS
–	0			1	2
–	3			1	7
–	6			3	10
–	12			3	15
–	18			2	20
Mean				2	11
Linear				NS	**
Quadratic				NS	NS
N fertilizer vs. sludge				NS	**

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

treatments and the environmental concerns of NO_3^- leaching into groundwater, samples were acquired for the entire root zone (about 6 ft for winter wheat) two years after sludge application (Figs. 1 and 2). The data plotted in Figs. 1 and 2 represent the NO_3-N status of the root zone two years after the second (location B) and third (location A) sludge and N fertilizer applications, respectively.

At both locations, application of fertilizer at 50 or 60 lb N/acre resulted in NO_3-N levels throughout the root zone which were not significantly different (F-LSD)

Table 5. Effects of N fertilizer and sewage sludge rates on the concentration of NH_4-N and NO_3-N in the soil at harvest, Location B, 1985–86.

N fertilizer	Sewage sludge	NH_4-N	NO_3-N
lb N/acre	dry ton/acre	ppm	
	Depth, 0–8 in.		
0	–	18	2
30	–	11	2
60	–	12	1
90	–	14	2
120	–	16	2
Mean		14	2
Linear		NS	NS
Quadratic		NS	NS
–	0	12	2
–	3	18	11
–	6	19	10
–	12	20	9
–	18	55	27
Mean		25	12
Linear		*	**
Quadratic		NS	NS
N fertilizer vs. sludge		NS	*
	Depth, 8–24 in.		
0	–	9	1
30	–	11	4
60	–	12	2
90	–	12	11
120	–	10	3
Mean		11	4
Linear		NS	NS
Quadratic		NS	NS
–	0	12	1
–	3	12	13
–	6	10	25
–	12	15	22
–	18	14	36
Mean		13	19
Linear		NS	**
Quadratic		NS	NS
N fertilizer vs. sludge		NS	*

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

values not shown) from the control. The 3 ton/acre sludge rate resulted in significantly greater NO_3-N levels than the control at 0 to 8 and 24 to 35 in. depths at both locations, but there were no significant differences compared with the control at the 8 to 24, 35 to 47, and 47 to 71 in. depths. The 12 ton/acre rate at location B lead to significantly greater soil NO_3-N levels than the control and 60 lb N/acre rates at all depths, except the 47 to 71 in. depth, and it had significantly greater soil NO_3-N compared to the 3 ton/acre rate at 24 to 35 and 35 to 47 in. depths (Fig. 1). At location A, the 12 ton/acre rate produced significantly greater soil NO_3-N than the three other treatments at all depths, except at the 0 to 8 in. depth for the 3 ton/acre rate (Fig. 2).

The effect of previous sludge application on the NO_3-N levels in the root zone is evident from the higher soil NO_3-N—particularly at the 0 to 8 in. depth—of the sludge treatments compared with the control, and the 50 and 60 lb N/acre rates. Furthermore, the effect of the third application of 12 ton sludge/acre at location A (Fig. 2) can be seen from the high levels of NO_3-N throughout the root zone, even at the 47 to 71 in. depth.

Other researchers have shown the potential for NO_3-N contamination of groundwater due to sludge application to land (Higgins, 1984; Brown, 1975; Hinesly et al., 1974).

Table 6. Ranges of loading rates of Zn, Cu, Cd, Ni, and Pb from sludge addition for 3 to 12 or 18 tons/acre, 1984–1987.

Zn	Cu	Cd	Ni	Pb
		lb/acre		
		1984–85		
4.5–27	2.7–17	0.05–0.3	0.3–2.0	3.2–19
		1985–86		
15–90	7.0–42	0.07–0.4	0.5–3.3	1.9–12
		1986–87		
3.7–22	2.2–13	0.06–0.4	0.3–1.7	1.2–7.4

In the study by Higgins (1984), a sludge loading rate of 10 ton/acre was recommended as an upper limit to ensure protection of groundwater quality. The soil NO_3-N data from this study strongly points to the 3 ton/acre rate as the maximum sludge loading rate for a dryland winter wheat-fallow management system, which is in agreement with Higgins (1984). This lower loading rate results in adequate plant N and grain protein levels (Lerch, 1987; Utschig, 1985; Utschig et al., 1986) without the high potential for NO_3-N contamination of the groundwater and soil heavy metal accumulation with the higher loading rates.

Heavy Metal Accumulation

The loading rates of heavy metals for the three years of the study indicate that Zn and Cu have been added to the soil in the greatest quantities (Table 6) as a result of sludge application. The loading rate of Cu represents the greatest limitation to land application of this sludge since its accumulation most rapidly approaches the federal and state maximum cumulative additions of 125–500 lb/acre (Colorado Department of Health, 1985; USEPA, 1977). At the 3 ton/acre sludge rate, however, it would take from 72 to 228 yr before the maximum cumulative addition of Cu would be reached (assuming that sludge is applied every year that a wheat crop is planted, and that the CEC of the soil in this study is from 5 to 16 meq/100 g).

The AB-DTPA extractable levels of Zn, Cu, Cd, Ni, and Pb at 0 to 8 in. were all linearly increased with increasing sludge rate for all three years (Table 7), and the quadratic trend analyses were all nonsignificant. As would be expected, the N fertilizer treatments had no effect on AB-DTPA extractable levels of the heavy metals, and the mean metal levels of the N fertilizer treatments were significantly less than the mean levels of the sludge treatments for all three years. Sludge application, at any loading rate generally increased the content of all five metals compared with the control for every year reported (F-LSD values not shown). The 3 ton/acre rate, however, generally had significantly less AB-DTPA extractable heavy metals than the 12 and 18 ton/acre rates.

Barbarick and Workman (1987) found that AB-DTPA extractable Zn, Cu, Cd, and Pb significantly correlated with the total amount of each element added for 3 yr of this field study (from 1983-86). They also found that AB-DTPA extractable levels of Zn and Pb significantly correlated with grain Zn and Pb, and it was concluded that

Table 7. The effect of sludge application on the AB-DTPA extractable heavy metals in the soil, 0–8 in.

Sewage sludge	Zn	Cu	Cd	Ni	Pb
dry ton/acre			ppm		
			1984–85		
0	1.2	3.5	0.13	1.2	2.0
3	2.8	5.5	0.15	1.5	2.5
6	3.8	6.8	0.17	1.6	2.7
12	5.8	8.6	0.22	2.1	3.1
Mean	3.4	6.1	0.17	1.6	2.6
Linear	**	**	**	**	**
			1985–86		
0	1.8	4.1	0.13	1.2	1.4
3	6.8	8.8	0.19	1.5	1.7
6	5.6	8.0	0.18	1.5	1.8
12	6.3	8.8	0.18	2.1	1.9
18	16.8	12.2	0.27	2.1	2.2
Mean	7.5	8.4	0.19	1.7	1.8
Linear	**	**	**	**	**
			1986–87		
0	0.7	2.4	0.12	1.4	1.4
3	2.9	4.9	0.16	1.8	2.2
6	4.0	6.2	0.19	1.9	4.2
12	6.6	8.5	0.23	2.2	3.0
18	8.1	10.0	0.25	2.4	3.5
Mean	5.6	6.4	0.19	1.9	2.9
Linear	**	**	**	**	*

*,** Significant at the 0.05 and 0.01 probability levels respectively.

AB-DTPA extraction of heavy metals from sludge-amended soils was a simple, routine method for monitoring the accumulation of heavy metals in the soil.

On the basis of the data presented, the 3 ton/acre sludge loading rate is recommended as the maximum safe loading rate of N for a dryland winter wheat management system. This, or lower loading rates, offers the advantage of increasing soil available N levels over the control without the high potential for groundwater contamination by NO_3-N; and it offers considerably less limitation with respect to heavy metal accumulation in the soil than higher loading rates.

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