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Application of Anaerobically Digested Biosolids to Dryland Winter Wheat

J.A. Ippolito
K.A. Barbarick
T. Gourd

Colorado State University

Knowledge to Go Places

APPLICATION OF ANAEROBICALLY DIGESTED BIOSOLIDS TO DRYLAND WINTER WHEAT[π]

2000-01 Technical Report

J.A. Ippolito, K.A. Barbarick, and T. Gourd[§]

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[§] Research Associate and Professor, Department of Soil and Crop Sciences, and Cooperative Extension Agent, Adams County, respectively.

INTRODUCTION

The application of biosolids to lands in EPA Region 8 (includes Colorado) is the major method of biosolids disposal, with 80% of the material being land applied (National Biosolids Partnership, 1999). This recycling method can greatly benefit municipalities by recycling plant nutrients in an environmentally sound manner (Barbarick et al., 1992).

Our long-term biosolids project, now in its twentieth year, has provided valuable information on the effects of continuous biosolids application to dryland winter wheat. Previous research has shown that Littleton/Englewood (L/E) biosolids is an effective alternative to commercial nitrogen (N) fertilizer with respect to grain production and nutrient content of winter wheat (Barbarick et al., 1992). However, as with other N fertilizers, application rates exceeding the N needs of the crop result in an accumulation of soil nitrate. Biosolids contain organic N, which acts as a slow release N source and provides a more constant supply of N during the critical grain-filling period versus commercial nitrogen fertilizer. We continue to recommend a 2 to 3 dry tons biosolids A^{-1} as the most viable land-application rate for similar biosolids nutrient characteristics and crop yields. Our recommended biosolids rates are based on crop N requirements and biosolids-borne N mineralization release rates.

The overall objective of our research is to compare the effect of L/E biosolids and commercial N fertilizer rates on: (a) dryland winter wheat (Triticum aestivum L., 'Prairie Red') grain production, (b) estimated income, (c) grain and straw elemental content, (d) soil pH and electrical conductivity (EC; salt content), (e) ammonium bicarbonate-diethylenetriaminepentaacetic acid (AB-DTPA) extractable soil elements, and (f) soil NO_3-N accumulation.

MATERIALS AND METHODS

We established the West Bennett experimental site in Adams County, Colorado in August 1982 on the farm owned by the Hazlet family. The soil is classified as a Platner loam, Abruptic Aridic Paleustoll. The land is farmed using conventional tillage practices.

In late July/early August 2000 we applied air-dried biosolids (76% solids; Table 1), supplied by the L/E wastewater treatment plant, at rates equivalent to 0, 3, 6, and 12 dry tons A^{-1}. According to the Colorado Department of Public Health and Environment Biosolids Regulations (1996), L/E biosolids are classified as Grade I and are suitable for application to agricultural and disturbed lands (Table 1). Urea fertilizer was applied to non-biosolids plots at rates of 0, 25, 50, and 100 lbs N A^{-1}. These same plots received biosolids and N fertilizer applications (at the same rates shown above) in August 1982, 1984, 1986, 1988, 1990, 1992, 1994, 1996, and 1998. We planted the winter wheat cultivar 'Vona' for the first eight years of the study, 'TAM 107' in years 9 to 18, and 'Prairie Red' (_Triticum_ _aestivum_ L., 'Prairie Red') in years 19 and 20.

In order to better determine the N equivalency of the biosolids, we initiated a new study site in 1994 on the John Sauter farm in Adams County, Colorado, designated North Bennett in this report. The soil is classified as a Weld loam, Aridic Argiustoll. The land is farmed using minimum-tillage practices. We applied biosolids at rates of 0, 1, 2, 3, 4, and 5 dry tons A^{-1} and N fertilizer at rates of 0, 20, 40, 60, 80, and 100 lbs N A^{-1} in late July/early August 2000. The same application rates were applied in 1994, 1996, and 1998. The North Bennett site was cropped with the winter wheat cultivar 'TAM 107' during the 1994, 1996, and 1998 growing seasons. During the 2000-01 growing season the winter wheat cultivar 'Prairie Red' was grown.

At both sites we uniformly applied both the biosolids and the N fertilizer and incorporated with a rototiller to a depth of 4 to 6 inches. We discontinued the West Bennett 18 dry tons biosolids A^{-1} application rate after five applications (last application was in 1990), but have continued cropping with winter wheat to observe the recovery of these plots as compared to the other biosolids treated plots. It has been 10 years since biosolids application was discontinued on the 18 dry tons biosolids A^{-1} application plots.

A crop failure occurred at both sites due to hail damage in June 2001. Therefore, we did not obtain measurements pertaining to grain production, estimated income, or grain and straw elemental content. In July and August 2001 we collected soil samples from the 0-8 and 8-24-inch depth increments from all plots at both locations and analyzed them for pH, EC, and AB-DTPA extractable soil elements. We also collected soil samples from the 0-8, 8-24, 24-40, 40-60, and 60-80-inch depth increments in the control, 50 lbs N A^{-1}, and 3 and 12 dry tons biosolids A^{-1} treatments at West Bennett and the control, 40 lbs N A^{-1}, and 2 and 5 dry tons biosolids A^{-1} treatments at North Bennett. These soils were analyzed for NO_3-N accumulation.

This report provides data for the 2000-01 crop year only. The reader is reminded that the 2000-01 West and North Bennett plots received biosolids at the same application rates in nine and three previous years, respectively. Considering these prior years and the current application, the recommended 3 dry tons A^{-1} biosolids rate at West Bennett represents a cumulative addition of 30 dry tons A^{-1} biosolids and the recommended 2 dry tons A^{-1} biosolids rate at North Bennett represents a cumulative addition of 8 dry tons A^{-1} biosolids.

RESULTS AND DISCUSSION

Grain Yields, Protein Content, Estimated Income, Grain and Straw Nutrients and Trace Metals

Due to a crop failure associated with severe hail damage in June 2001, we did not obtain measurements pertaining to grain production, protein content, estimated income, or grain and straw nutrient and trace metal content.

Soil pH and Electrical Conductivity

West Bennett:

West Bennett harvest soil pH and EC are presented in Table 2. Increasing N fertilizer did not affect pH or EC in the 0-8-inch depth, while increasing biosolids application caused an increase in EC. Increased EC in the biosolids plots was likely due to the amount of soluble salts added via biosolids application. Biosolids plots, on average, had a slightly higher EC as compared to the N plots in the 0-8-inch depth.

Increasing N fertilizer and biosolids applications affected both pH and EC in the 8-24-inch depth. The biosolids plots, on average, had a lower pH and a higher EC in the 8-24-inch depth. Increased EC in the 100 # N fertilizer plot has historically been higher than the other N-treated plots. We cannot explain the difference. An EC > 2 dS m^{-1}, as associated with the 12 dry tons biosolids A^{-1} rate, may be detrimental to plants. A decrease in pH associated with increased biosolids application may have been due to biosolids-borne ammonia (NH_3) volatilization or nitrification of biosolids-borne ammonium (NH_4^+).

The discontinued 18 dry tons biosolids A^{-1} application rate had the lowest pH in both the 0-8 and 8-24-inch depths. The EC in the 0-8-inch depth was similar to the 3 dry tons biosolids

A^{-1} application rate, whereas the EC in the 8-24-inch depth was similar to the 6 dry tons biosolids A^{-1} application rate.

North Bennett:

Increasing N fertilizer and biosolids application had no affect on pH or EC in the 0-8-inch depth, and there were no differences between N and biosolids plots (Table 3).

Increasing N fertilizer application affected only pH in the 8-24-inch depth, while increasing biosolids application had no affect on pH or EC. Also, there were no differences between N and biosolids plots. The slight increase in pH associated with the 80# N fertilizer application may be due to urea application. A marked rise in soil pH within close proximity of the urea fertilizer is typically observed (Tisdale et al., 1985).

AB-DTPA extractable soil elements

Barbarick and Workman (1987) and Barbarick et al. (1997) reported that AB-DTPA soil extractions can provide some information about element availability to plants and an even better indication of elemental loading rates in biosolids-amended soils. The fact that the biosolids adds a number of elements when applied to soils is reflected by the data in Tables 4 through 7.

West Bennett:

Increasing N fertilizer application rate did not influence AB-DTPA extractable elements in the 0-8-inch depth (Table 4). However, increasing biosolids application increased AB-DTPA extractable Zn, Cu, and Ni concentrations. On average, biosolids plots had greater AB-DTPA extractable Zn, Cu, Ni, Cd, and Pb concentrations in the 0-8-inch depth as compared to the N fertilizer plots. Increased element concentrations was due to increased element addition associated with increasing biosolids application rate.

Increasing N fertilizer rate had no affect on AB-DTPA extractable elements in the 8-24-inch depth, whereas increasing biosolids application caused an increase in P, Zn, Cu, and Ni concentrations (Table 5). No differences existed between N fertilizer plots and biosolids plots in the 8-24-inch depth.

The AB-DTPA extractable elements from the 0-8-inch depth in the discontinued 18 dry tons biosolids A^{-1} application rate fell between the 6 and 12 dry tons biosolids A^{-1} application rates. However, the AB-DTPA extractable elements from the 8-24-inch depth were still elevated above the 12 dry tons biosolids A^{-1} application rate even after 10 years of discontinued biosolids application.

North Bennett:

Increasing N fertilizer application rate did not affect AB-DTPA extractable elements in the 0-8-inch depth, whereas increasing biosolids application rate caused an increase in P, Zn, and Cu (Table 6). On average, biosolids plots had higher AB-DTPA extractable P, Zn, and Cu concentrations as compared to the N fertilizer plots. Again, increases in element concentrations was due to increased element addition associated with increasing biosolids application rate.

Increasing N fertilizer and biosolids application did not impact AB-DTPA extractable elements in the 8-24-inch depth, and there were no differences between the two sets of plots (Table 7).

Residual Soil NO_3-N

We recommend applying biosolids based on crop N requirements as well as biosolids N mineralization rates. We have bracketed our biosolids application rates accordingly. Therefore, we recommend applying 3 and 2 dry tons biosolids A^{-1} at the West and North Bennett sites, respectively.

West Bennett:

The recommended 3 dry tons biosolids A^{-1} application rate had similar residual soil NO_3-N throughout the profile as compared to the control or the 50 lbs N A^{-1} rate (Figure 1). There was, however, residual NO_3-N (>20 ppm NO_3-N) throughout the top 8 inches associated with the 3 dry tons biosolids A^{-1} application rate. We have chosen 20 ppm soil NO_3-N as a reference point because this concentration translates to 40 lbs N A^{-1}, a typical N requirement for dryland winter wheat.

There also was residual NO_3-N throughout the top 40 inches of soil depth associated with the 12-dry tons biosolids A^{-1} rate. The residual NO_3-N can be attributed to the large amounts of available N (291 lbs N A^{-1}) from the first biosolids application in 1982, which was in liquid form (4.2% solids; Utschig et al., 1986). Liquid biosolids contains three to four times the amount of nitrogen as compared to dried biosolids. The last nine applications were dried (greater than 50% solids) prior to addition, resulting in lower total applied N levels (Utschig et al., 1986; Lerch et al., 1990). These nitrate levels are relatively high, but the potential for groundwater contamination is negligible because the water table depth at this site is over 100 feet and the cropping system is under dryland wheat production.

North Bennett:

The recommended 2 dry tons biosolids A^{-1} application rate did not affect NO_3-N throughout the profile as compared to the control or the 40 lbs N A^{-1} rate (Figure 2). In addition, this rate did not increase NO_3-N above 5 ppm anywhere in the profile.

The 5 dry tons biosolids A^{-1} application rate significantly increased NO_3-N within the top 24 inches of soil as compared to the control, 40 lbs N A^{-1}, and 2 dry tons biosolids A^{-1} application rate. However, the 5 dry tons biosolids A^{-1} application rate did not produce any NO_3-N levels above 20 ppm.

SUMMARY

Due to a crop failure associated with severe hail damage in June 2001, we did not obtain measurements pertaining to grain production, protein content, estimated income, or grain and straw nutrient and trace metal content.

Long-term application of increasing biosolids caused an increase in EC in the 0-8-inch soil depth at West Bennett. Increased EC in the biosolids plots was likely due to the amount of soluble salts added via biosolids application. Increasing N fertilizer affected the pH and increased the EC, and biosolids decreased and increased pH and EC, respectively, within the 8-24-inch depth at West Bennett. Elevated EC values associated with the 100# fertilizer application have been historically observed at the West Bennett site. However, we cannot explain the reason for the elevated levels. Biosolids application compared to N fertilizer, on average, increased the 0-8-inch soil EC, decreased the 8-24-inch soil pH, and increased the 8-24-inch EC. At North Bennett, pH in the 8-24-inch depth was increased by increasing N fertilizer rate. This increase may be associated with urea fertilizer application. A decrease in pH associated with increased biosolids application may have been due to biosolids-borne ammonia (NH_3) volatilization or nitrification of biosolids-borne ammonium (NH_4^+).

Increasing N fertilizer rate did not affect soil AB-DTPA extractable elements in the 0-8 or 8-24-inch depth at West Bennett. Increasing biosolids application rate, however, caused an increase in AB-DTPA extractable Zn, Cu, and Ni concentrations in the 0-8-inch depth and P, Zn, Cu, and Ni concentrations in the 8-24-inch depth. Increased element concentrations was due to increased element addition associated with increasing biosolids application rate. On average, biosolids plots had higher AB-DTPA extractable Zn, Cu, Ni, Cd, and Pb in the 0-8-inch depth as compared to N fertilizer.

Increasing N fertilizer rate did not impact soil AB-DTPA extractable elements in the 0-8 or 8-24-inch depth at North Bennett. Increasing biosolids application rate, however, caused an increase in AB-DTPA extractable P, Zn, and Cu concentrations in the 0-8-inch depth. On average, biosolids plots had higher AB-DTPA extractable P, Zn, and Cu in the 0-8-inch depth as compared to N fertilizer.

The discontinued West Bennett 18 dry tons biosolids A^{-1} application rate (the last application was in 1990) had the lowest soil pH values as compared to the other biosolids treatments. A decrease in pH associated with increased biosolids application may have been due to biosolids-borne ammonia (NH_3) volatilization or nitrification of biosolids-borne ammonium (NH_4^+). The EC was similar to the 3 and 6 dry tons biosolids A^{-1} application rates in the 0-8 and 8-24-inch depths, respectively. The AB-DTPA extractable elements in the discontinued 18 dry tons biosolids A^{-1} application rate fell between the 6 and 12 dry tons biosolids A^{-1} application rates in the 0-8-inch depth, and they were still the highest, as compared to the other biosolids treatments, in the 8-24-inch depth.

Our recommended application rate of 3 dry tons biosolids A^{-1} resulted in soil NO_3-N accumulations comparable to the control or 50 lbs N A^{-1} rate at West Bennett. The 3 dry tons biosolids A^{-1} also resulted in residual soil NO_3-N (>20 ppm NO_3-N) accumulation throughout the top 8 inches of soil. We have chosen 20 ppm soil NO_3-N as a reference point because this concentration translates to 40 lbs N A^{-1}, a typical N requirement for dryland winter wheat. There was residual NO_3-N throughout top 40 inches of soil depth associated with the 12-dry tons biosolids A^{-1} rate. This residual NO_3-N can be attributed to the large amounts of available N from the first sludge application in 1982, which was in liquid form. Liquid biosolids contains three to four times the amount of nitrogen as compared to dry biosolids. These nitrate levels are relatively high, but the potential for groundwater contamination is negligible because the water table depth at this site is over 100 feet and the cropping system is under dryland wheat production.

Our recommended application rate of 2 dry tons biosolids A^{-1} resulted in soil NO_3-N accumulations comparable to the control or 40 lbs N A^{-1} rate at North Bennett. Application of 5 dry tons biosolids A^{-1} resulted in a greater NO_3-N accumulation within the top 24 inches of soil as compared to the control, 40 lbs N A^{-1}, and 2 dry tons biosolids A^{-1} application rate. However, the NO_3-N concentration did not exceed 20 ppm throughout the profile. Four applications of biosolids have not led to soil NO_3-N accumulation.

Even though we did not harvest wheat during the 2000-01 growing season, we would have expected increases in grain yield and protein content when we applied biosolids or N fertilizer at recommended rates on N-deficient soils. Biosolids supplies slow-release N, P, and Zn as beneficial nutrients during the growing season. We continue to recommend a 2 to 3 dry tons biosolids application A^{-1} based on biosolids-N equivalency. Our 1999-00 growing season results showed that 1 dry ton biosolids A^{-1} was equivalent to 19 lbs N A^{-1}. In both 1995 and 1999 we found one dry ton biosolids A^{-1} to be equivalent to 18 lbs N A^{-1}. These values could help in planning long-term biosolids applications. We recommend that soil testing, biosolids analyses, and setting appropriate yield goals must be used with any fertilizer program to ensure optimum crop yields along with environmental protection.

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Table 1. Average composition of Littleton/Englewood sludge applied in 2000-01 compared to the Grade I and II biosolids limits.

Property	Dry Weight Concentration Littleton/Englewood	Limit Grade I Biosolids[¶]	Limit Grade II Biosolids
Organic N (%)	1.85		
NO_3-N (%)	<0.01		
NH_4-N (%)	0.59		
Solids (%)	76		
P (%)	3.60		
As (mg kg^{-1})[π]	2.6	41	75
Cd "	2.4	39	85
Cr "	17	1200	3000
Cu "	352	1500	4300
Pb "	22.9	300	840
Hg "	0.34	17	57
Mo "	6.4	Not finalized	75
Ni "	1.1	420	420
Se "	6.4	36	100
Zn "	370	2800	7500

[¶] Grade I and II biosolids are suitable for land application (Colorado Department of Public Health and Environment, 1996).

[π] mg kg^{-1} = parts per million (ppm).

Table 2. Effects of N fertilizer and biosolids rates on soil pH and EC in the 0-8 and 8-24-inch at harvest at West Bennett, 2000-01.

N fert.	Biosolids	0 to	8 inch	8 to	24 inch
lbs. N A^{-1}	dry tons A^{-1} [†]	pH	EC (dS m^{-1})	pH	EC (dS m^{-1})
0		6.8	0.51	7.7	0.42
25		6.8	0.58	7.6	0.44
50		6.8	0.59	7.7	0.44
100		6.7	0.58	7.4	0.90
Mean[§]		6.8	0.58	7.6	0.59
Sign. N rates		NS[¶]	NS	*	**
LSD				0.2	0.37
	0	6.8	0.48	7.6	0.44
	3	6.6	0.79	7.6	0.70
	6	6.7	0.89	7.4	1.14
	12	6.4	1.05	7.3	2.97
	18[β]	6.3	0.61	7.3	1.44
	Mean	6.5	0.83	7.4	1.56
	Sign. biosolids rates	NS	**	**	**
	LSD		0.40	0.2	0.98
	N vs biosolids	NS	**	*	**

[†] Identical biosolids applications were made in 1982, 1984, 1986, 1988, 1990, 1992, 1994, 1996, and 1998; therefore, the cumulative amount is 10 times that shown (except for the 18 dry tons A^{-1} rate).

[§] Means/LSDs/N vs biosolids do not include the controls (the zero rates).

[¶] NS = not significant, * = significance at 5% probability level, ** = significance at 1% probability level.

[β] The 18 dry tons A^{-1} biosolids rate was discontinued in 1992-93.

Table 3. Effects of N fertilizer and biosolids rates on pH and EC in the 0-8 and 8-24-inch depths at harvest at North Bennett, 2000-01.

		0 to 8 inch		8 to 24 inch	
N fert. lbs N A^{-1}	Biosolids dry tons A^{-1} [†]	pH	EC (dS m^{-1})	pH	EC (dS m^{-1})
0		6.8	0.40	7.6	0.32
20		7.0	0.42	7.6	0.39
40		6.9	0.44	7.6	0.33
60		7.2	0.41	7.7	0.30
80		7.0	0.38	7.8	0.34
100		6.9	0.42	7.6	0.34
Mean[§]		7.0	0.42	7.7	0.34
Sign. N rates		NS[¶]	NS	*	NS
LSD				0.1	
	0	7.1	0.46	7.7	0.33
	1	7.2	0.42	7.8	0.36
	2	6.8	0.48	7.7	0.37
	3	6.9	0.44	7.7	0.39
	4	7.2	0.52	7.7	0.40
	5	6.8	0.48	7.7	0.47
	Mean	7.0	0.47	7.7	0.40
	Sign. biosolids rates	NS	NS	NS	NS
	LSD				
	N vs biosolids	NS	NS	NS	NS

[†] Identical biosolids applications were made in 1994, 1996, and 1998; therefore, the cumulative amount is 4 times that shown.

[§] Means/LSDs/N vs biosolids do not include the controls (the zero rates).

[¶] NS = not significant, * = significance at 5% probability level, ** = significance at 1% probability level, ND = non-detectable.

Table 4. Effects of N fertilizer and biosolids rates on the AB-DTPA extractable element concentrations in the 0-8-inch soil depth at West Bennett, 2000-01.

N fert. lbs A^{-1}	Biosolids dry tons A^{-1} [†]	P	Zn	Cu	Ni	Cd	Pb
		--------	--------	--------	mg kg^{-1}	--------	--------
0		12.4	1.5	3.6	1.3	0.10	2.10
25		11.2	1.1	3.1	1.3	0.10	2.06
50		11.5	0.9	2.9	1.4	0.10	2.04
100		16.0	2.0	4.3	1.5	0.12	2.20
Mean[§]		12.9	1.3	3.4	1.4	0.11	2.10
Sign. N rates[§]		NS[¶]	NS	NS	NS	NS	NS
LSD							
	0	13.5	1.2	3.3	1.3	0.10	1.96
	3	25.5	6.9	10.7	1.9	0.18	2.72
	6	23.6	7.1	11.3	1.8	0.19	2.50
	12	25.5	13.9	20.5	2.6	0.24	2.83
	18[β]	21.3	10.1	15.0	2.3	0.21	2.74
	Mean	24.0	9.5	14.4	2.1	0.20	2.70
	Sign. biosolids rates	NS	*	*	*	NS	NS
	LSD		4.7	5.6	0.4		
	N vs. biosolids[§]	NS	**	**	**	**	*

[†] Identical biosolids applications were made in 1982, 1984, 1986, 1988, 1990, 1992, 1994, 1996, and 1998; therefore, the cumulative amount is 10 times that shown (except for the 18 dry tons A^{-1} rate).

[§] Means/LSDs/N vs biosolids do not include the controls (the zero rates).

[¶] NS = not significant, * = significance at 5% probability level, ** = significance at 1% probability level.

[β] The 18 dry tons A^{-1} biosolids rate was discontinued in 1992-93.

Table 5. Effects of N fertilizer and biosolids rates on the AB-DTPA extractable element concentrations in the 8-24-inch soil depth at West Bennett, 2000-01.

N fert. lbs A^{-1}	Biosolids dry tons A^{-1} [†]	P	Zn	Cu	Ni	Cd	Pb
		--------	---------	---------	mg kg^{-1}	---------	--------
0		2.6	0.2	2.2	0.6	0.02	0.88
25		2.9	0.2	2.3	0.6	0.03	0.86
50		2.7	0.2	2.2	0.6	0.03	0.94
100		3.7	0.3	2.3	0.6	0.02	0.91
Mean[§]		3.1	0.2	2.2	0.6	0.02	0.90
Sign. N rates[§]		NS[¶]	NS	NS	NS	NS	NS
LSD							
	0	3.6	0.2	2.4	0.6	0.03	1.07
	3	3.0	0.2	2.2	0.5	0.02	0.91
	6	5.3	0.7	2.7	0.6	0.03	0.91
	12	5.8	0.8	3.1	0.8	0.04	0.94
	18[β]	8.9	1.6	3.8	0.8	0.05	1.10
	Mean	5.7	0.8	3.0	0.7	0.04	0.96
	Sign. biosolids rates	*	*	*	**	NS	NS
	LSD	4.8	1.0	1.3	0.3		
	N vs. biosolids[§]	NS	NS	NS	NS	NS	NS

[†] Identical biosolids applications were made in 1982, 1984, 1986, 1988, 1990, 1992, 1994, 1996, and 1998; therefore, the cumulative amount is 10 times that shown (except for the 18 dry tons A^{-1} rate).

[§] Means/LSDs/N vs biosolids do not include the controls (the zero rates).

[¶] NS = not significant, * = significance at 5% probability level, ** = significance at 1% probability level.

[β] The 18 dry tons A^{-1} biosolids rate was discontinued in 1992-93.

Table 6. Effects of N fertilizer and biosolids rates on the AB-DTPA extractable element concentrations in the 0-8-inch soil depth at North Bennett, 2000-01.

N fert. lbs A^{-1}	Biosolids dry tons A^{-1} [†]	P	Zn	Cu	Ni	Cd	Pb
		--------	---------	---------	mg kg^{-1}	---------	--------
0		6.6	0.5	2.8	1.1	0.08	1.98
20		6.6	0.6	3.0	1.3	0.07	2.00
40		7.3	0.6	3.1	1.3	0.07	2.04
60		6.5	0.6	3.3	1.2	0.07	1.95
80		6.5	0.5	3.2	1.3	0.08	2.12
100		6.8	0.6	3.3	1.4	0.08	2.06
Mean[§]		6.6	0.6	3.2	1.3	0.07	2.03
Sign. N rates[§]		NS[¶]	NS	NS	NS	NS	NS
LSD							
	0	7.5	0.6	3.2	1.4	0.08	2.14
	1	7.3	0.9	3.6	1.3	0.08	2.10
	2	9.6	1.0	3.5	1.3	0.09	2.21
	3	9.5	1.1	3.7	1.5	0.09	2.27
	4	10.2	1.3	4.1	1.2	0.07	1.90
	5	15.4	1.8	4.6	1.3	0.10	2.17
	Mean	10.4	1.2	3.9	2.1	0.08	2.13
	Sign. biosolids rates	**	**	**	NS	NS	NS
	LSD	4.8	0.7	1.1			
	N vs. biosolids[§]	*	**	*	NS	NS	NS

[†] Identical biosolids applications were made in 1994, 1996, and 1998; therefore, the cumulative amount is 4 times that shown.

[§] Means/LSDs/N vs biosolids do not include the controls (the zero rates).

[¶] NS = not significant, * = significance at 5% probability level, ** = significance at 1% probability level, ND = non-detectable.

Table 7. Effects of N fertilizer and biosolids rates on the AB-DTPA extractable element concentrations in the 8-24-inch soil depth at North Bennett, 2000-01.

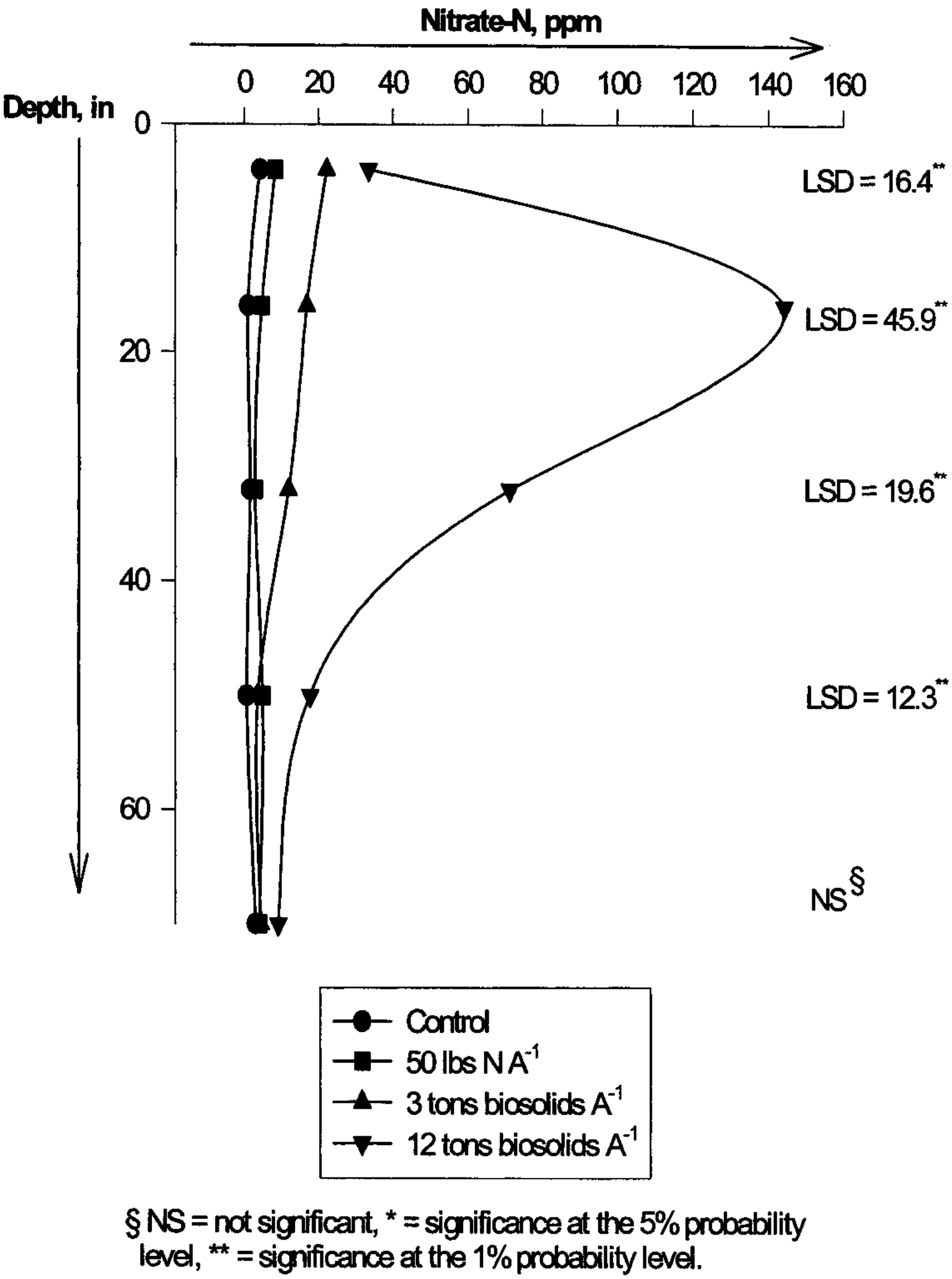
N fert. lbs A^{-1}	Biosolids dry tons A^{-1} [†]	P	Zn	Cu	Ni	Cd	Pb
		--------	---------	---------	mg kg^{-1}	---------	--------
0		2.0	0.14	2.4	0.60	ND	0.78
20		2.1	0.16	2.3	0.54	ND	0.75
40		2.5	0.16	2.3	0.62	ND	0.86
60		2.2	0.15	2.1	0.49	ND	0.79
80		2.0	0.15	2.2	0.48	ND	0.75
100		2.1	0.69	2.4	0.50	ND	0.72
Mean[§]		2.2	0.26	2.3	0.53		0.78
Sign. N rates[§]		NS[¶]	NS	NS	NS		NS
LSD							
	0	2.1	0.13	2.2	0.50	ND	0.67
	1	2.0	0.19	2.1	0.49	ND	0.70
	2	2.0	0.15	2.4	0.58	ND	0.73
	3	2.3	0.17	2.3	0.50	ND	0.70
	4	2.1	0.14	2.2	0.49	ND	0.62
	5	2.3	0.16	2.2	0.56	ND	0.71
	Mean	2.1	0.16	2.2	0.52		0.69
	Sign. biosolids rates	NS	NS	NS	NS		NS
	LSD						
	N vs. biosolids[§]	NS	NS	NS	NS		NS

[†] Identical biosolids applications were made in 1994, 1996, and 1998; therefore, the cumulative amount is 4 times that shown.

[§] Means/LSDs/N vs biosolids do not include the controls (the zero rates).

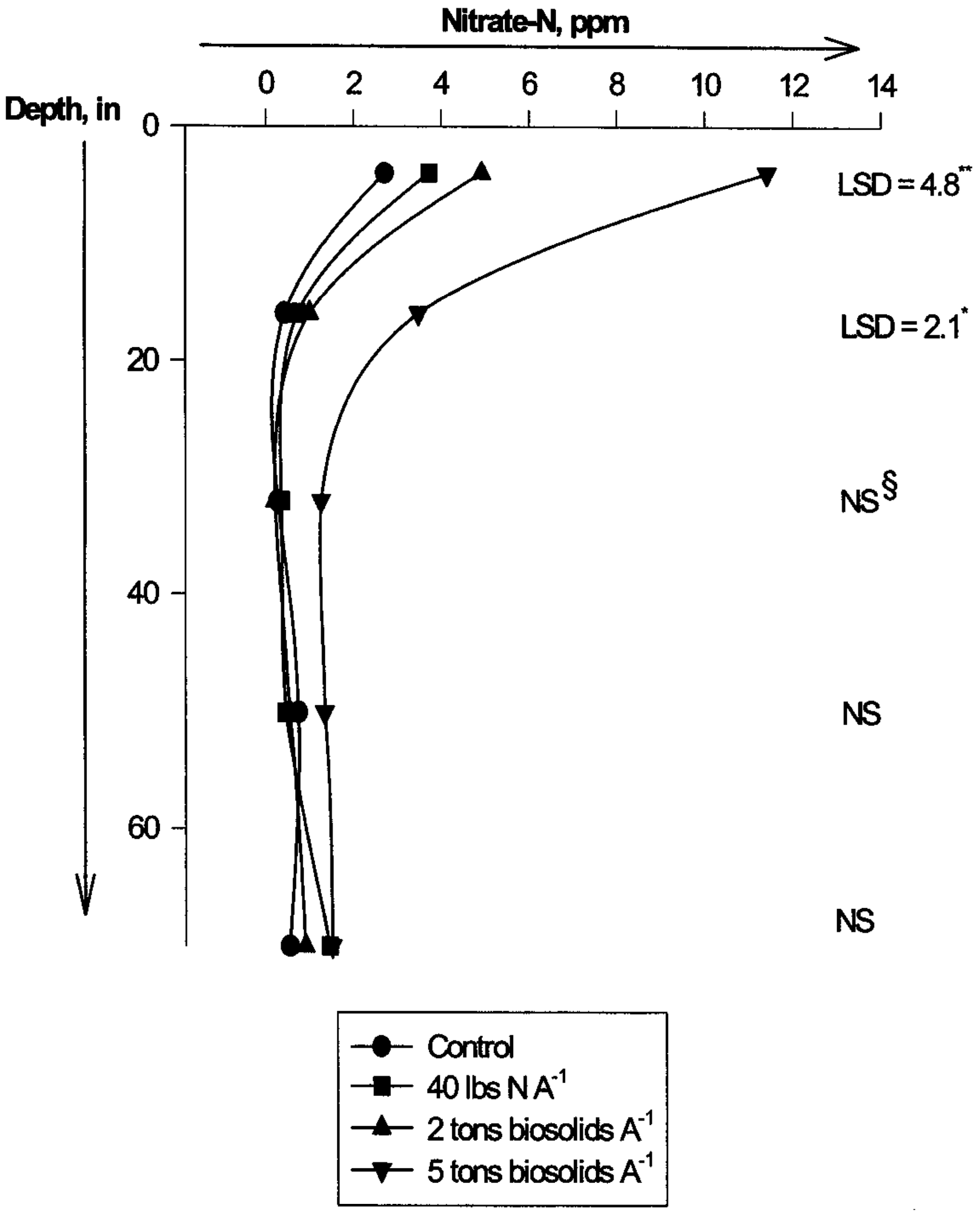
[¶] NS = not significant, * = significance at 5% probability level, ** = significance at 1% probability level, ND = non-detectable.

Figure 1. West Bennett Harvest Soil Nitrogen 2000-01.



§ NS = not significant, * = significance at the 5% probability level, ** = significance at the 1% probability level.

Figure 2. North Bennett Harvest Soil Nitrogen 2000-01.



§ NS = not significant, * = significance at the 5% probability level, ** = significance at the 1% probability level.