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Application of Anaerobically Digested Biosolids to Dryland Winter Wheat

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

1995-96 Technical Report

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INTRODUCTION

The application of biosolids to agricultural land is the major method of biosolids disposal in the USA (USEPA, 1983). This disposal 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 fifteenth year, has provided valuable information on the effects of continuous biosolids application to dryland winter wheat. Previous research has shown that Littleton/Englewood biosolids is an effective alternative to commercial N fertilizer with respect to grain production and nutrient content of winter wheat (Barbarick et al., 1992). However, 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 3 dry tons biosolids A^{-1} application as the most viable land disposal rate.

The overall objective of our research is to compare the effect of Littleton/Englewood biosolids and commercial N fertilizer rates on: (a) dryland winter wheat (Triticum aestivum L., 'TAM 107') grain production, (b) grain and straw elemental content, (c) estimated income, and (d) soil NO_3-N accumulation.

MATERIALS AND METHODS

The West Bennett experimental plot used this year was originally established in August 1983; it was reestablished for the seventh time on June 22, 1995 when we acquired the baseline soil samples. The West Bennett site is on a Platner loam soil, classified as an Abruptic Aridic Paleustoll. We planted the winter wheat cultivar 'Vona' at the West Bennett location for the first eight years of the study, followed by TAM 107 (Triticum aestivum L., 'TAM 107') in years 9 to 15.

The plot is farmed as a wheat-fallow rotation. During the years 1994-96, however, the site was continuously cropped. We chose to harvest the volunteer wheat population in 1995, a designated fallow year. We did not apply air-dried biosolids to the West Bennett plots during the 1995-96 growing season. Biosolids treatments (0, 3, 6, and 12 dry tons biosolids A^{-1}) and N fertilizer applications (34-0-0) (0, 30, 60, 90, and 120 lbs N A^{1}) we made in August 1983, 1985, 1987, 1989, 1991, and

1993. In the past, biosolids were also applied at an 18 dry tons A^{-1} application rate, but in 1991-92 we discontinued this application rate due to the high accumulation of soil NO_3-N. Our study of the 18 dry tons biosolids A^{-1} will focus on the time required to remove the excess soil NO_3-N via winter wheat production.

To better determine the N equivalency of the biosolids, we created a new and separate study site noted as North Bennett throughout this report. We applied biosolids (60% solids; Table 1) at rates of 0, 1, 2, 3, 4, and 5 dry tons A^{-1} and N fertilizer (urea) at rates of 0, 20, 40, 60, 80, and 100 lbs N A^{-1} in August 1995. The same plots received biosolids and N fertilizer (34-0-0), at the above rates, in August 1993. The North Bennett site was cropped with the winter wheat cultivar TAM 107.

According to the 1996 Colorado Department of Public Health and Environment Biosolids Regulations, the L/E biosolids are classified as Grade I and are suitable for application to agricultural and disturbed lands (Table 1). We uniformly applied both biosolids and N fertilizer, at both sites, and incorporated with a rototiller to a depth of 4 to 6 inches.

We measured grain yield and protein content at harvest. The grain and straw were analyzed for N, phosphorus (P), cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) concentrations. We estimated gross income using prices paid for wheat in December 1996 and subtracted the cost for either fertilizer or biosolids. Urea fertilizer was applied, but based our estimated gross income calculations on the cost of anhydrous ammonia, since this is the main N fertilizer used in Eastern Colorado. Following harvest in July 1996, we analyzed soil samples collected from all plots at depths of 0-8 and 8-24 inches for NO_3-N. We also measured soil NO_3-N levels to a depth of 7 feet for the following plots : 1) the control (receiving no biosolids or N fertilizer), 60 lb N A^{-1}, and 3 and 12 dry tons biosolids A^{-1} treatments at West Bennett; 2) the control, 40 lbs N A^{-1}, and 2 and 5 dry tons biosolids A^{-1} at North Bennett.

This report provides data for the 1995-96 crop year only. The reader is reminded that the 1995-96 West Bennett plots received biosolids application rates in August 1983, 1985, 1987, 1989, 1991, and 1993. Considering these six prior years, the biosolids application rate of 3 dry tons A^{-1} for the 1995-96 growing season represents a cumulative addition of 18 dry tons A^{-1} biosolids for the life of the experiment. The biosolids application history at the West Bennett site must be kept in mind when interpreting the data, especially for the biosolids treatment.

The reader also is reminded that the 1995-96 North Bennett plots first received biosolids application rates in August 1993. The biosolids application rate of 2 dry tons A^{-1} for the 1995-96 growing season represents a cumulative addition of 4 dry tons A^{-1} biosolids for the life of the experiment.

RESULTS AND DISCUSSION

Grain Yields, Protein Content, and Estimated Income

West Bennett :

Due to poor stand establishment, we harvested the West Bennett plots by hand rather than with a combine, and grain yields and estimated income were not determined. Protein content was not affected by N fertilizer or biosolids treatment at West Bennett, and there was no difference between the two fertilizer sources (Table 2).

North Bennett :

Grain yields averaged higher than the long-term Adams County average (30 bu A^{-1}) on both N fertilizer and biosolids treated plots (Table 3). This is partially attributable to the well-managed crop stubble residue, which allowed for efficient storage of precipitation. There were no yield or protein differences between N fertilizer and biosolids treatments. On average, the biosolids treated plots produced a \$9 A^{-1} greater estimated income versus the N treated plots. The recommended rate of 2 dry tons A^{-1} produced a \$5 A^{-1} greater return compared to the 40 lbs N A^{-1} treatment. No protein premium was paid in December of 1996.

<u>Biosolids Application Recommendation</u>

To better determine the N equivalency of the biosolids, we compared yields from N and biosolids plots at North Bennett. The 1996 data indicates no difference in yield between the N and biosolids treated plots (Table 3), and no comparison between these plots can be made. However, in 1995 we found an equivalency of one dry ton biosolids A^{-1} to 25 lbs N A^{-1}; in 1994 we found an equivalency of one dry ton biosolids A^{-1} to 40 lbs N A^{-1}.

<u>Plant Nutrients and Trace Metals</u>

<u>Grain :</u>

<u>West Bennett :</u>

Increasing N fertilizer increased grain Cu, while increasing biosolids increased grain Zn, Cu, and Ni (Table 4). Since the Pb content of all samples were below detection limits, we could not perform statistical analysis. Compared with N fertilizer, biosolids resulted in a higher grain Zn concentration. This is due to a greater addition of Zn to the soil by the biosolids application. The discontinued 18 dry tons biosolids A^{-1} rate closely resembles elemental concentrations between the 3 and 6 dry tons A^{-1} rates.

North Bennett :

Increasing N fertilizer did not affect grain trace metal concentration, while increasing biosolids increased grain P, Zn, and Cu concentrations (Table 5). Compared with N fertilizer, biosolids resulted in a higher grain Zn concentration.

Straw :

West Bennett :

Increasing N fertilizer did not affect straw trace metal concentration, while increasing biosolids increased straw Cd concentration (Table 6). Compared with N fertilizer, biosolids resulted in higher straw Zn and Cu concentrations. The discontinued 18 dry tons biosolids A^{-1} rate closely resembles elemental concentrations between the 3 and 6 dry tons A^{-1} rates.

North Bennett :

Increasing N fertilizer increased straw P and Cd concentrations, while increasing biosolids increased straw P, Zn, Cu, Cd, Pb, and N concentrations (Table 7). There were no differences between N fertilizer and biosolids applications.

Residual Soil NO_3-N

West Bennett :

The 3 dry tons biosolids A^{-1} rate (the recommended application rate) did not increase soil NO_3-N compared to the control or 60 lbs N A^{-1}, but exceeded 10 ppm NO_3-N in the 8-24 and 24-40-inch depth increment (Figure 1). The leaching potential for this NO_3-N is low due to the low NO_3-N concentrations at lower depths.

The 12 dry tons biosolids A^{-1} rate increased residual NO_3-N accumulation throughout the top 40 inches of the profile. This can be attributed to the large amounts of available N from the first sludge application in 1983, which was in liquid form (Utschig et al., 1986). The potential for leaching from the 12-dry tons A^{-1} rate is minimal because the NO_3-N concentrations are low at deeper depths. Also, the potential for groundwater contamination is negligible because water table depths at this site are generally over 100 feet deep and the cropping system is dryland wheat production.

North Bennett :

The 2 dry tons biosolids A^{-1} application rate did not affect NO_3-N throughout the profile as compared to the control or 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 (two applications to date) significantly increased NO_3-N to a depth of 24 inches. This rate also was significantly different than the control and the 40 lbs N A^{-1} rate at the 24-40-inch depth, but the NO_3-N concentration did not exceed 10 ppm.

SUMMARY

Yields were not measured at West Bennett due to poor stands. North Bennett N fertilizer and biosolids application rates produced yields slightly higher than long-term Adams County average yields. This may be attributable to residue management allowing for more efficient soil storage of precipitation. Grain protein content also increased with increasing biosolids application, but no differences between biosolids and N fertilizer treatments were apparent. Estimated income was higher, on average, with biosolids application versus N fertilizer, and the recommended rate of 2 dry tons A^{-1} produced a higher return as compared to the 40 lbs N fertilizer A^{-1} treatment.

Increasing biosolids rate resulted in increased grain Zn, Cu, and Ni concentrations, and higher straw Cd concentrations at West Bennett. The 18 dry tons biosolids A^{-1} treatment (five years since discontinuance) is now affecting micronutrient uptake similar to that of six years of 3 to 6 dry tons A^{-1} biosolids rates. As compared to N fertilizer, increasing biosolids rate increased grain Zn concentration, and straw Zn and Cu concentrations.

Increasing biosolids rate resulted in increased grain P, Zn, and Cu concentrations, and increased straw P, Zn, Cu, Cd, Pb, and N concentrations at North Bennett. Compared to N fertilizer, biosolids application increased grain Zn concentration, but did not affect straw micronutrient concentrations. Biosolids appear to aid Zn availability on the Zn-deficient soils at West and North Bennett.

All metal concentrations in wheat plants were below the levels considered harmful to livestock, except Cd in the wheat-straw at West Bennett (NRC, 1980). The maximum tolerable Cd concentration for most domestic animals is 0.5 mg kg^{-1}. The average Cd concentration for N fertilizer and biosolids at West Bennett were 0.81 and 0.87 mg kg^{-1}, respectively. We believe that due to lower moisture availability during the growing season at West Bennett, Cd concentrated within the wheat-straw. Consequently, climatic conditions, and not the N fertilizer or biosolids treatments, were primarily responsible for the elevated concentration in the plant tissue.

Repeated applications of 12 dry tons biosolids A^{-1} resulted in residual NO_3-N (>10 ppm) accumulation in the top 80 inches of soil at West Bennett. Most of the residual can be attributed to the 1983 liquid application. Although the potential for NO_3-N leaching is high, the risk of groundwater contamination is minimal due to the depth of the water table and low amount of average precipitation.

Application of 5 dry tons biosolids A^{-1} resulted in residual NO_3-N accumulation in the top 40 inches of soil at North Bennett. The potential for NO_3-N leaching is high, but the risk of groundwater contamination is minimal due to the depth of the water table and low amount of average precipitation. Two applications of 2 dry tons biosolids A^{-1} has not led to soil NO_3-N accumulation.

During most growing seasons biosolids could supply slow-release N, P, and Zn as beneficial nutrients. We expect substantial increases in grain yield and protein content when we apply biosolids or N fertilizer at recommended rates on N-deficient soils. We continue to recommend 3 dry tons biosolids application A^{-1}. Soil testing and biosolids analyses must be conducted 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 1995-96 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 (%)	2.54	"	"
NO_3-N (%)	<0.01	"	"
NH_4-N (%)	0.50	"	"
Solids (%)	60	"	"
P (%)	1.74	"	"
Cd (mg kg^{-1})	4.0	39	85

Cu (mg kg^{-1})	458	1500	4300
Ni (mg kg^{-1})	42.3	420	420
Pb (mg kg^{-1})	83.5	300	840
Zn (mg kg^{-1})	816	2800	7500

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

R Determined via saturated extract.

B mg kg^{-1} = parts per million.

Table 2. Effects of N fertilizer and biosolids on wheat protein at West Bennett, 1995-96.

Nitrogen Fertilizer lbs A^{-1}	Biosolids Dry tons A^{-1}†	Protein %
0		14.8
30		17.2
60		17.4
90		15.6
120		16.3

Mean[§]		16.6
Sign. N rates		NS[¶]
LSD		
	0	16.4
	3	16.8
	6	16.7
	12	17.2
	18[$]	16.4
	Mean	16.8
	Sign. biosolids rates	NS
	LSD	
	N vs biosolids	NS

[†] Identical biosolids applications were made in 1983, 1985, 1987, 1989, 1991, and 1993; therefore, the cumulative amount is 6 times that shown (except for the 18 dry tons A^{-1} rate).

[§] Means/LSD/N vs biosolids do not include the controls.

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

[$] The 18 dry tons A^{-1} rate was discontinued in 1991-92.

Table 3. Effects of N fertilizer and biosolids on wheat yield, protein, and projected income at North Bennett, 1995-96.

N fert. lbs A^{-1}	Biosolids dry tons A^{-1}[†]	Yield bu A^{-1}	Protein %	Fert. cost[‡] \$ A^{-1}	Income - fert. cost \$ A^{-1}
0		37	10.6	0	154

20		40	11.6	9	157
40		39	12.0	13	149
60		42	12.3	18	157
80		37	12.8	22	132
100		44	12.9	26	157
Mean§		40	12.3	18	150
LSD N rate§		NS¶	1.4*		
	0	36	10.6	0	150
	1	42	11.3	0	175
	2	37	13.0	0	154
	3	40	13.1	0	166
	4	36	13.3	0	150
	5	36	13.6	0	150
	Mean	38	12.8	0	159
	LSD biosolids rate	5*	0.9**		
	N vs. biosolids§	NS	NS		

† Identical biosolids applications were made in 1993; therefore, the cumulative amount is 2 times that shown.

‡ The price for anhydrous NH_3 was considered to be \$.22 lb^{-1} N plus \$4.50 A^{-1} application charge. The biosolids and its application are currently free. The grain price was \$4.16 bu^{-1}. No protein premium was paid in December 1996.

§ 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.

Table 4. Effects of N fertilizer and biosolids rates on elemental concentrations of dryland winter wheat grain at West Bennett, 1995-96.

N fert. lbs N A^{-1}	Bio-solids dry tons A^{-1}†	P g kg^{-1}	Zn	Cu	Ni mg kg^{-1}	Cd	Pb	N %
0		4.9	48	6.8	1.51	0.08	ND	2.70

30		5.1	44	7.2	1.41	0.12	ND	2.86
60		5.1	39	6.9	1.46	0.08	ND	2.75
90		5.0	35	6.3	1.23	0.12	ND	2.81
120		5.0	38	7.2	1.41	0.16	ND	2.84
Mean[§]		5.0	39	6.9	1.38	0.12		2.82
Sign. N rates		NS[¶]	NS	*	NS	NS		NS
LSD				0.8				
	0	4.9	46	6.9	1.38	0.12	ND	2.87
	3	4.7	42	7.0	1.40	0.14	ND	2.95
	6	4.9	51	7.3	1.40	0.12	ND	3.01
	12	5.1	58	8.6	1.50	0.18	ND	2.87
	18[$]	4.9	49	7.3	1.28	0.12	ND	2.77
	Mean	4.9	50	7.5	1.40	0.14		2.90
	Sign. bio-solids rates	NS	**	*	**	NS		NS
	LSD		11	0.9	0.47			
	N vs bio-solids	NS	**	NS	NS	NS		NS

† Identical biosolids applications were made in 1983, 1984, 1987, 1989, 1991, and 1993; therefore, the cumulative amount is 6 times that shown (except for the 18 dry tons A^{-1} rate).

§ Means/LSD/N vs biosolids do not include the controls.

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

$ The 18 dry tons A^{-1} rate was discontinued in 1991-92.

Table 5. Effects of N fertilizer and biosolids rates on elemental concentrations of dryland winter wheat grain at North Bennett, 1995-96.

N fert. lbs N A^{-1}	Bio-solids dry tons A^{-1}[†]	P g kg^{-1}	Zn	Cu	Ni mg kg^{-1}	Cd	Pb	N %
0		3.5	19	4.2	1.01	0.07	0.28	2.24
20		3.3	20	4.1	0.93	0.05	0.20	2.46
40		3.2	16	4.4	1.09	0.05	0.20	2.57

60		3.0	20	4.1	0.86	0.06	0.24	2.59
80		3.4	22	4.5	1.09	0.05	0.24	2.67
100		3.1	19	4.3	0.95	0.08	0.28	2.33
Mean§		3.2	19	4.3	0.98	0.06	0.23	2.46
Sign. N rates		NS¶	NS	NS	NS	NS	NS	NS
LSD								
	0	3.6	19	3.9	1.06	0.05	0.32	2.28
	1	3.1	20	3.8	0.91	0.06	0.20	2.46
	2	3.4	25	4.7	1.24	0.12	0.16	2.57
	3	3.5	26	4.9	1.20	0.04	0.24	2.59
	4	3.4	28	4.7	1.11	0.07	0.40	2.67
	5	3.6	31	5.1	1.06	0.03	0.08	2.33
	Mean	3.4	26	4.6	1.10	0.06	0.22	2.53
	Sign. bio-solids rates	*	**	**	NS	NS	NS	NS
	LSD	0.4	5	0.7				
	N vs bio-solids	NS	*	NS	NS	NS	NS	NS

† Identical biosolids applications were made in 1993; therefore, the cumulative amount is 2 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.

Table 6. Effects of N fertilizer and biosolids rates on elemental concentrations of dryland winter wheat straw at West Bennett, 1995-96.

N fert. lbs N A^{-1}	Bio-solids dry tons A^{-1}†	P g kg^{-1}	Zn	Cu	Ni mg kg^{-1}	Cd	Pb	N %
0		1.7	18	2.7	1.59	0.72	3.24	0.79
30		1.5	15	3.2	1.64	0.84	3.46	0.95

60		1.4	13	2.6	1.61	0.82	3.84	0.95
90		1.3	10	2.5	1.44	0.80	2.48	0.87
120		1.2	12	3.0	1.51	0.91	3.16	1.13
Mean§		1.3	14	2.8	1.55	0.81	3.24	0.97
Sign. N rates		NS¶	NS	NS	NS	NS	NS	NS
LSD								
	0	1.4	19	3.7	1.63	0.78	3.39	1.01
	3	1.2	16	3.9	1.62	0.79	2.79	1.01
	6	1.2	22	4.2	1.64	0.83	3.31	1.02
	12	1.3	27	5.8	2.12	1.13	5.12	1.08
	18$	1.1	18	3.9	1.58	0.79	3.09	0.92
	Mean	1.2	20	4.4	1.71	0.87	3.47	1.01
	Sign. bio-solids rates	NS	NS	NS	NS	*	NS	NS
	LSD					0.15		
	N vs bio-solids	NS	*	*	NS	NS	NS	NS

† Identical biosolids applications were made in 1983, 1985, 1987, 1989, 1991, and 1993; therefore, the cumulative amount is 6 times that shown (except for the 18 dry tons A^{-1} rate).

§ Means/LSD/N vs biosolids do not include the controls.

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

$ The 18 dry tons A^{-1} rate was discontinued in 1991-92.

Table 7. Effects of N fertilizer and biosolids rates on elemental concentrations of dryland winter wheat straw at North Bennett, 1995-96.

N fert. lbs N A^{-1}	Bio-solids dry tons A^{-1}	P g kg^{-1}	Zn	Cu	Ni mg kg^{-1}	Cd	Pb	N %
0		0.4	4	2.0	1.09	0.47	2.45	0.45
20		0.3	3	1.8	0.69	0.21	0.91	0.48
40		0.3	3	1.6	0.77	0.19	0.88	0.51
60		0.3	4	1.7	0.73	0.17	0.76	0.55
80		0.4	4	2.0	0.77	0.19	0.92	0.62

100		0.3	4	1.9	0.81	0.24	0.80	0.57
Mean[§]		0.3	4	1.8	0.75	0.20	0.85	0.55
Sign. N rates		*[¶]	NS	NS	NS	*	NS	NS
LSD		0.1				0.06		
	0	0.3	3	1.4	0.72	0.17	1.00	0.46
	1	0.3	3	1.3	0.69	0.12	0.60	0.48
	2	0.4	4	1.9	0.96	0.41	1.24	0.51
	3	0.5	5	2.4	0.93	0.43	1.42	0.64
	4	0.4	6	2.4	1.02	0.47	1.73	0.66
	5	0.5	7	2.8	0.93	0.59	2.18	0.74
	Mean	0.4	5	2.1	0.91	0.40	1.43	0.61
	Sign. bio-solids rates	**	**	**	NS	*	*	**
	LSD	0.2	2	1.1		0.41	1.41	0.19
	N vs bio-solids	NS	NS	NS	NS	NS	NS	NS

[†] Identical biosolids applications were made in 1993; therefore, the cumulative amount is 2 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.

Figure 1. West Bennett Harvest Soil Nitrogen 96-97

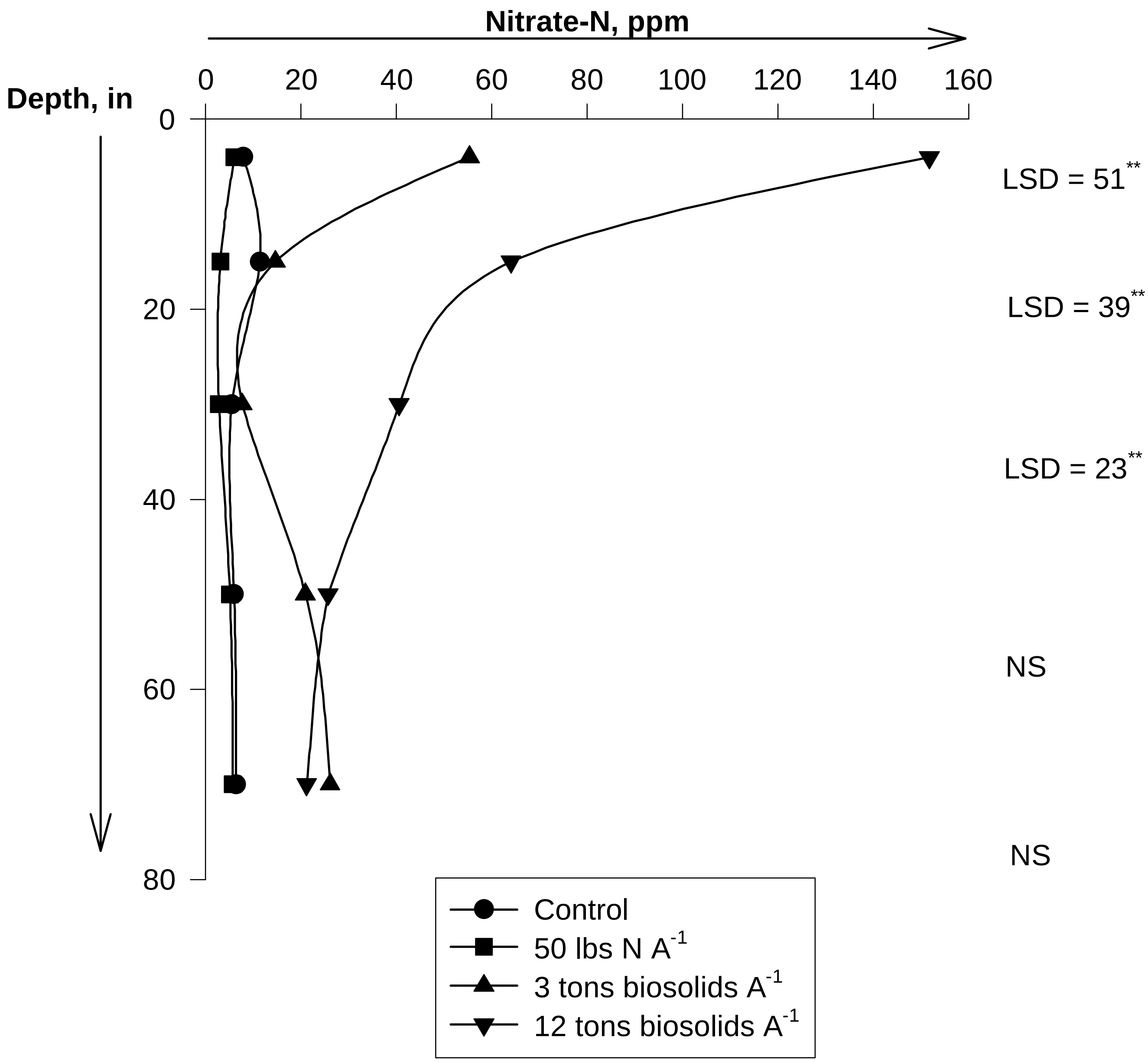

Figure 2. North Bennett Harvest Soil Nitrogen 96-97