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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[¤]

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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 method of disposal can be cost effective for municipalities by recycling plant nutrients in an environmentally sound manner (Barbarick et al., 1992).

Our long-term biosolids project, now in its sixteenth 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). Biosolids contain organic N compounds, which perform as slow-release N sources and provide a more constant supply of N during the grain-filling period as compared to commercial N fertilizer. However, application rates exceeding the N needs of the crop result in an accumulation of soil nitrate-N (NO_3-N). Excess soil N could result in leaching below the root zone. We continue to recommend 2 to 3 dry tons biosolids A^{-1} application per crop year as the most viable dryland application rate for the L/E biosolids and other biosolids of similar characteristics. We base this recommendation on the amount of N released from biosolids over the growing season being similar to that of a typical N fertilizer application.

The overall objective of our research is to compare the effect of Littleton/Englewood biosolids and commercial N fertilizer 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

We established the West Bennett experimental site in Adams County, Colorado in August 1982 on the farm owned by the Hazlet family. The land is farmed using conventional tillage practices. We planted the winter wheat cultivar 'Vona' for the first eight years of the study, followed by 'TAM 107' (Triticum aestivum L., 'TAM 107') in years 9 to 16.

In August 1996 we applied air-dried biosolids (73% solids; Table 1), supplied by the Littleton/Englewood (L/E) wastewater treatment plant, at rates equivalent to 0, 3, 6, and 12 dry tons A^{-1}. According to the 1996 Colorado Department of Health Biosolids Regulations, L/E biosolids are classified as Grade I and are suitable for application to agricultural and disturbed lands (Table 1). Ammonium nitrate 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, and 1994.

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 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 long-term removal of residual NO_3-N.

In order to better determine the N equivalency of the biosolids, we started a new study site in 1993 on the John Sauter farm, designated North Bennett in this report. The land is farmed using minimum-tillage practices. We uniformly applied and incorporated biosolids (73% solids; Table 1) 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 August 1996. The North Bennett site also was cropped with 'TAM 107'. The same application rates were applied in 1994. We will focus on the 2 dry tons A^{-1} application rate as the recommended rate at North Bennett.

At harvest, we measured grain yield and protein content. We analyzed the grain and straw for nitrogen (N), phosphorus (P), cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) concentrations. We estimated gross income using prices paid for winter wheat in December 1997 and subtracted the cost for either fertilizer or biosolids. We applied urea fertilizer, but based our estimated gross income calculations on anhydrous ammonia cost, since this is the main N fertilizer used in Eastern Colorado. Following harvest in July 1997, we analyzed NO_3-N in soil samples collected from all plots at depths of 0-8 and 8-24 inches. Also, we measured soil NO_3-N levels down to a depth of 7 feet for selected plots : the control (receiving no biosolids or N fertilizer), 50 lbs N A^{-1}, and 3 and 12 dry tons biosolids A^{-1}

treatments at West Bennett; 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 1996-97 crop year only. The reader is reminded that the 1996-97 West and North Bennett plots received the same biosolids application rates in seven and one previous cropping cycles, respectively. Results reflect a history of applications, which is especially true for the biosolids treatments.

RESULTS AND DISCUSSION

Grain Yields, Protein Content and Estimated Income

West Bennett :

Grain yields within the N and biosolids treated plots both averaged 13 bu A^{-1} (Table 2). The Adams County long-term average is 30 bu A^{-1}. There were yield differences between the N fertilizer treatments. There were no differences between biosolids treatments or biosolids versus N fertilizer treatments.

The protein content was above 12% for both biosolids and N fertilizer treated units. This may be attributable to low yields, thus concentrating the protein. Although protein content did not increase with increasing N fertilizer rates, increasing biosolids rates did increase protein content. There were no significant protein differences between N fertilizer and biosolids rates. Seven years after discontinuance, the protein content in the 18 dry tons biosolids A^{-1} treatment (16.3%) was about the same as the 6 and 12 dry tons biosolids A^{-1} rates

(16.7%). Apparently, the wheat is removing the residual NO_3-N in the 18 dry tons A^{-1} treatment (received a total of 90 dry tons A^{-1} from 1982 to 1990).

Estimated income was higher for the biosolids plots than the N fertilizer plots. This was true even when comparing the 50 lbs N A^{-1} rate versus the 3 dry tons A^{-1} rate. The 3 dry tons A^{-1} rate also produced a higher economic return as compared to the other biosolids rates because this form of N was free and came at no cost to the producer.

North Bennett :

Grain yields averaged higher than the long-term Adams County average (Table 3). This may be attributable to residue management allowing for more efficient use of precipitation. Increasing biosolids rates increased yield. There were no yield differences between N fertilizer and biosolids rates.

Although protein content was similar for both N fertilizer and biosolids plots, estimated income was somewhat higher in biosolids treated plots versus N plots. This was true even when comparing the 40 lbs N A^{-1} rate versus the 2 dry tons A^{-1} rate. This can be attributed to the free application cost of biosolids.

Biosolids Application Recommendation

To better determine the N equivalency of the biosolids, we compared yields from N and biosolids plots at North Bennett. The 1997 data indicates no difference in yield between the N and biosolids treated plots (Table 3), and thus no comparison between these plots can be made. The same was true for the 1996 data.

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}.

Plant Nutrients and Trace Metals

Grain :

West Bennett :

Increasing N fertilizer rate increased grain Cu (Table 5), but did not affect grain P (Table 4), Zn, Ni, Cd, or Pb (Table 5). Increasing biosolids rate did not affect grain elemental concentrations. Differences between N fertilizer and biosolids applications were noted for grain Zn and Cd concentrations. Seven years after discontinuance, the 18 dry tons biosolids A^{-1} rate had grain nutrient and trace metal concentrations similar to the 6 to 12 dry tons A^{-1} rates.

North Bennett :

Increasing N fertilizer or biosolids rate did not affect grain P (Table 6) or Ni (Table 7). Increasing N fertilizer rate increased grain Zn, Cu, Cd, but decreased Pb, while increasing biosolids rate only increased Zn concentration (Table 7). Overall, biosolids application resulted in a higher grain Zn concentration as compared to N fertilizer.

Straw :

West Bennett :

Increasing N fertilizer rate increased straw Cd (Table 8), but did not affect straw N, P (Table 4), Zn, Cu, Ni, or Pb

(Table 8). Increasing biosolids rate increased straw N and P concentrations. Compared with N fertilizer, biosolids resulted in higher straw P, Zn, Cu, Ni, and Cd concentrations. The 18 dry tons A^{-1} biosolids treatment had straw elemental concentrations intermediate between the 3 and 12 dry tons A^{-1} rates.

North Bennett :

Increasing N fertilizer rates did not affect micronutrients and trace metals (Tables 6 and 9). Increasing biosolids rates increased straw N, P, and Zn. Compared with N fertilizer, biosolids resulted in higher straw Zn and Cu concentrations.

Grain micronutrient and trace metal concentrations at either site were not above the levels considered hazardous for livestock consumption (Logan and Chaney, 1983; NRC, 1980). However, for the 100 lbs N A^{-1} and all biosolids treatments at West Bennett, the straw Cd concentration was above the 0.5 mg kg^{-1} maximum tolerable level for domestic animals. We believe this is due to the abnormally low yields during this year, thus concentrating straw Cd.

Residual Soil NO_3-N

West Bennett :

Biosolids applications at the 12-dry tons A^{-1} rate increased NO_3-N accumulation to the 30 inch depth as compared to the control, 50 lbs N A^{-1}, and 3 dry tons biosolids A^{-1} rate (Figure 1). The 3-dry tons biosolids A^{-1} rate (the recommended application rate) did not increase soil NO_3-N as compared to the control or 50 lbs N A^{-1}.

There was residual NO_3-N (>10 ppm NO_3-N) throughout top 70 inch soil depth for the 3 and 12-dry tons biosolids A^{-1} rates. The residual NO_3-N can be attributed to the large amounts of available N (291 lbs N A^{-1}) from the first sludge application in 1982, which was in liquid form (4.2% solids, Utschig et al., 1986). The last seven 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 :

Biosolids applications at the 5-dry tons A^{-1} rate increased NO_3-N accumulation to the 15 inch depth, and at the 70 inch depth, as compared to the control, 40 lbs N A^{-1}, and 2 dry tons biosolids A^{-1} rate (Figure 2). All NO_3-N levels were below those considered residual except the 5-dry tons A^{-1} rate at the surface; all others were less than 5 ppm NO_3-N. Note the difference in the NO_3-N scales between Figure 1 and Figure 2. The scale for Figure 1 (West Bennett) is over 10 times that for Figure 2 (North Bennett).

SUMMARY

West Bennett N fertilizer and biosolids application rates produced yields lower than the long-term Adams County yields. In contrast, N fertilizer and biosolids application at the North Bennett site resulted in above average yields. Yields above the county average can be attributed to residue management, allowing for more efficient use of the precipitation at the North Bennett site. The 18 dry tons biosolids A^{-1} (seven years since discontinuance) treatment at West Bennett produced yields and protein contents that were similar to the 0 and 6 dry tons biosolids A^{-1} treatments, respectively. The residual N in this discontinued treatment apparently is approaching that of the lower biosolids treatments.

On average, biosolids gave a higher economic return compared to N fertilizer at West and North Bennett. Recommended rates at both West and North Bennett (3 and 2 dry tons biosolids A^{-1}, respectively) produced higher economic returns as compared to their N fertilizer counterparts (50 and 40 lbs N A^{-1}, respectively). The economic advantage of biosolids over N fertilizer is cost; the biosolids and their application are essentially free, although application costs may be charged in the future.

There were no differences in grain micronutrient concentrations between biosolids and N fertilizer at the West Bennett site. Compared with N fertilizer, biosolids resulted in higher grain Zn concentrations at the North Bennett site.

Differences were observed between biosolids and N fertilizer straw P, Zn, Cu, Ni, and Cd concentrations at West Bennett. Straw Zn and Cu were also higher with biosolids application as compared to N fertilizer application at North Bennett. All trace metal levels in the grain were below those considered to be a health hazard and harmful to livestock. However, the West Bennett straw Cd concentration was slightly above the 0.5 mg kg^{-1} maximum tolerable level for domestic animals for the 100 lbs N A^{-1} and all biosolids treatments. We believe this is due to lower than county yields, thus concentrating straw Cd.

Repeated applications of 12-dry tons biosolids A^{-1} resulted in significant residual soil NO_3-N accumulation in the top 70 inches at West Bennett. Most of the residual may be attributed to the 1982 liquid application. Although the amount of NO_3-N available for leaching is high, the risk of groundwater contamination would be minimal due to the depth of the water table, low precipitation received at the sites, and cropping system.

There was minimal NO_3-N accumulation with the 5-dry ton biosolids A^{-1} rate at North Bennett. Most concentrations did not exceed 5 ppm for any treatment or depth in the soil profile.

During most growing seasons biosolids will supply slow-release N, P, and Zn. We expect substantial increases in grain yield and protein content when we apply biosolids or N fertilizer at recommended rates on N-deficient soils. Soil testing and biosolids analyses must be conducted with any fertilizer program to ensure optimum crop yields along with environmental protection. Research will continue towards refining recommended biosolids applications rates for dryland wheat production.

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Table 1. Average composition of Littleton/Englewood sludge applied in 1996-97 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 (%)	1.24	none specified	none specified
NO_3-N (%)	<0.01	"	"
NH_4-N (%)	0.86	"	"
Solids (%)	73	"	"
P (%)	2.30	"	"
K (%)	0.292	"	"
Cd (mg kg^{-1})[π]	6.1	39	85
Cu (mg kg^{-1})	657	1500	4300
Ni (mg kg^{-1})	51.7	420	420
Mo (mg kg^{-1})	24.4	75	75
Pb (mg kg^{-1})	27.0	300	840
Zn (mg kg^{-1})	652	2800	7500
Cr (mg kg^{-1})	59	3000	3000
As (mg kg^{-1})	4.3	41	75
Se (mg kg^{-1})	9.0	100	100

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

π mg kg^{-1} = parts per million.

Table 2. Effects of N fertilizer and biosolids on wheat yield, protein, and projected income at West Bennett, 1996-97.

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		13	14.9	0	39
25		8	16.0	10	14
50		13	16.3	16	23
100		19	16.8	26	31
Mean§		13	16.4	13	26
LSD N rate§		8**¶	NS		
	0	12	14.8	0	36
	3	15	17.0	0	45
	6	11	16.7	0	33
	12	11	16.7	0	33
	18β	13	16.3	0	39
Mean§		13	16.7	0	39
LSD biosolids rate		NS	0.6**		
N vs. biosolids§		NS	NS		

† Identical biosolids applications were made in 1982, 1984, 1986, 1988, 1990, 1992, and 1994; therefore, the cumulative amount is 8 times that shown (except for the 18 dry tons A^{-1} rate).

‡ The price for anhydrous NH_3 was \$.22 lb^{-1} N plus \$4.50 A^{-1} application charge. The biosolids and its application are currently free. The grain price was \$3.00 bu^{-1}. No protein premium was paid in December 1997.

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

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

β The 18 dry tons A^{-1} rate was discontinued in 1990-91.

Table 3. Effects of N fertilizer and biosolids on wheat yield, protein, and projected income at North Bennett, 1996-97.

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		46	10.6	0	138
20		48	10.8	9	135
40		51	10.9	13	140
60		51	11.1	18	135
80		58	12.6	22	152
100		50	11.4	26	124
Mean[§]		52	11.4	18	138
LSD N rate[§]		NS[¶]	NS		
	0	48	10.7	0	144
	1	46	10.8	0	138
	2	53	12.3	0	159
	3	53	11.6	0	159
	4	54	11.1	0	162
	5	55	12.0	0	165
Mean[§]		52	11.6	0	156
LSD biosolids rate		6*	NS		
N vs. biosolids[§]		NS	NS		

† Identical biosolids applications were made in 1994; therefore, the cumulative amount is 2 times that shown.

‡ The price for anhydrous NH_3 was \$.22 lb^{-1} N plus \$4.50 A^{-1} application charge. The biosolids and its application are currently free. The grain price was \$3.00 bu^{-1}. No protein premium was paid in December 1997.

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

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

Table 4. Effects of N fertilizer and biosolids rates on N and P contents in wheat grain and straw at West Bennett, 1996-97.

N Fert. lbs N A^{-1}	Biosolids[†] dry tons A^{-1}	Straw N	Straw P g kg^{-1}	Grain P
0		9.4	1.49	4.1
25		10.6	1.36	4.1
50		11.9	1.26	4.1
100		14.0	1.32	4.2
Mean[§]		12.2	1.31	4.1
LSD N rate[§]		NS[¶]	NS	NS
	0	8.4	1.29	4.2
	3	15.6	3.09	4.4
	6	14.4	2.56	4.3
	12	12.9	2.14	4.4
	18[β]	13.5	3.21	4.2
	Mean	12.3	2.30	4.3
	LSD biosolids rate	0.2*	1.14**	NS
	N vs biosolids[§]	NS	**	NS

[†] Identical biosolids applications were made in 1982, 1984, 1986, 1988, 1990, 1992, and 1994; therefore, the cumulative amount is 8 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.

[β] The 18 dry tons A^{-1} rate was discontinued in 1990-91.

Table 5. Effects of N fertilizer and biosolids rates on the concentrations of micronutrients and trace metals in wheat grain at West Bennett, 1996-97.

N fert. lbs A^{-1}	Biosolids dry tons A^{-1} †	Zn	Cu	Ni	Cd	Pb
		---------	---------	mg kg^{-1}	---------	--------
0		43	6.6	12.7	0.32	0.74
25		47	6.4	9.0	0.34	0.79
50		48	6.6	8.1	0.30	0.72
100		53	7.1	10.6	0.35	0.79
Mean§		49	6.7	9.2	0.33	0.77
Sign. N rates§		NS¶	**	NS	NS	NS
LSD			0.6			
	0	42	6.1	7.1	0.29	0.79
	3	60	7.3	5.9	0.36	0.79
	6	55	6.8	7.1	0.36	0.95
	12	55	7.9	12.4	0.37	0.92
	18β	55	7.2	7.6	0.40	0.92
	Mean	52	7.0	8.6	0.35	0.89
	Sign. bio-solids rates	NS	NS	NS	NS	NS
	LSD					
	N vs. biosolids§	*	NS	NS	*	NS

† Identical biosolids applications were made in 1982, 1984, 1986, 1988, 1990, 1992, and 1994; therefore, the cumulative amount is 8 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.

β The 18 dry tons A^{-1} rate was discontinued in 1990-91.

Table 6. Effects of N fertilizer and biosolids rates on N and P contents in wheat grain and straw at North Bennett, 1996-97.

N fert. lbs A^{-1}	Biosolids dry tons A^{-1} †	Straw N	Straw P	Grain P
		--------	g kg^{-1}	----------
0		3.96	0.31	3.2
20		4.02	0.34	3.0
40		4.33	0.34	3.2
60		4.01	0.35	3.4
80		4.76	0.33	3.0
100		5.00	0.33	3.3
Mean§		4.42	0.34	3.2
Sign. N rates§		NS¶	NS	NS
LSD				
	0	3.56	0.36	3.1
	1	3.75	0.32	3.2
	2	5.16	0.36	3.2
	3	4.97	0.36	3.3
	4	5.08	0.34	3.3
	5	5.90	0.39	3.3
	Mean§	4.97	0.35	3.3
	Sign. bio-solids rates	*	*	NS
	LSD	1.40	0.06	
	N vs. biosolids§	NS	NS	NS

† Identical biosolids applications were made in 1994; therefore, the cumulative amount is 2 times that shown.

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

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

Table 7. Effects of N fertilizer and biosolids rates on the concentrations of micronutrients and trace metals in wheat grain at North Bennett, 1996-97.

N fert. lbs A^{-1}	Biosolids dry tons A^{-1}[†]	Zn	Cu	Ni	Cd	Pb
		--------	---------	mg kg^{-1}	---------	--------
0		19	4.8	2.1	0.21	0.40
20		17	4.7	2.1	0.18	0.56
40		20	5.1	2.1	0.15	0.16
60		21	5.1	2.2	0.17	0.18
80		20	5.0	2.0	0.18	0.22
100		22	5.5	2.5	0.24	0.31
Mean[§]		20	5.1	2.2	0.18	0.28
Sign. N rates[§]		*[¶]	**	NS	**	*
LSD		4	0.6		0.06	0.34
	0	19	5.0	2.3	0.19	0.34
	1	19	4.8	2.3	0.19	0.34
	2	22	5.1	2.5	0.19	0.32
	3	22	5.0	2.3	0.18	0.20
	4	22	5.1	2.1	0.21	0.38
	5	24	5.2	2.3	0.19	0.25
	Mean	22	5.0	2.3	0.19	0.30
	Sign. bio-solids rates	*	NS	NS	NS	NS
	LSD	3				
	N vs biosolids[§]	*	NS	NS	NS	NS

[†] Identical biosolids applications were made in 1994; therefore, the cumulative amount is 2 times that shown.

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

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

Table 8. Effects of N fertilizer and biosolids rates on the concentrations of micronutrients and trace metals in wheat straw at West Bennett, 1996-97.

N fert. lbs A^{-1}	Biosolids dry tons A^{-1} [†]	Zn	Cu	Ni	Cd	Pb
		---------	---------	mg kg^{-1}	---------	--------
0		13	2.9	0.6	0.26	0.24
25		15	3.1	0.7	0.37	0.09
50		14	3.2	0.7	0.38	0.40
100		20	3.7	0.9	0.58	0.45
Mean[§]		16	3.3	0.8	0.44	0.31
Sign. N rates[§]		NS[¶]	NS	NS	*	NS
LSD					0.19	
	0	11	2.6	0.7	0.33	0.41
	3	43	5.4	1.1	0.67	0.43
	6	37	4.8	1.2	0.63	0.38
	12	38	5.1	2.1	0.63	0.30
	18[β]	50	5.1	1.3	0.80	0.40
	Mean	34	4.4	1.3	0.60	0.37
	Sign. bio-solids rates	NS	NS	NS	NS	NS
	LSD					
	N vs. biosolids[§]	**	*	*	**	NS

[†] Identical biosolids applications were made in 1982, 1984, 1986, 1988, 1990, 1992, and 1994; therefore, the cumulative amount is 8 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.

[β] The 18 dry tons A^{-1} rate was discontinued in 1990-91.

Table 9. Effects of N fertilizer and biosolids rates on the concentrations of micronutrients and trace metals in wheat straw at North Bennett, 1996-97.

N fert. lbs A^{-1}	Biosolids dry tons A^{-1}[†]	Zn	Cu	Ni	Cd	Pb
		------	------	mg kg^{-1}	-------	-------
0		3.3	1.8	0.6	0.13	0.11
20		3.3	1.8	0.5	0.12	0.02
40		3.2	2.1	0.7	0.13	0.13
60		2.8	1.7	0.5	0.08	0.06
80		3.3	2.1	0.5	0.12	0.08
100		3.1	2.1	0.6	0.12	0.04
Mean[§]		3.2	2.0	0.6	0.11	0.06
Sign. N rates[§]		NS[¶]	NS	NS	NS	NS
LSD						
	0	3.3	1.6	0.5	0.12	0.17
	1	3.2	1.8	0.5	0.10	0.09
	2	3.8	2.2	0.6	0.13	0.08
	3	4.0	2.0	0.6	0.12	0.04
	4	3.4	2.2	0.6	0.14	0.19
	5	4.6	2.2	0.6	0.12	0.11
	Mean	3.8	2.1	0.6	0.12	0.10
	Sign. biosolids rates	*	NS	NS	NS	NS
	LSD	0.9				
	N vs biosolids[§]	**	*	NS	NS	NS

[†] Identical biosolids applications were made in 1994; therefore, the cumulative amount is 2 times that shown.

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

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

Figure 1. West Bennett Harvest Soil Nitrogen 96-97

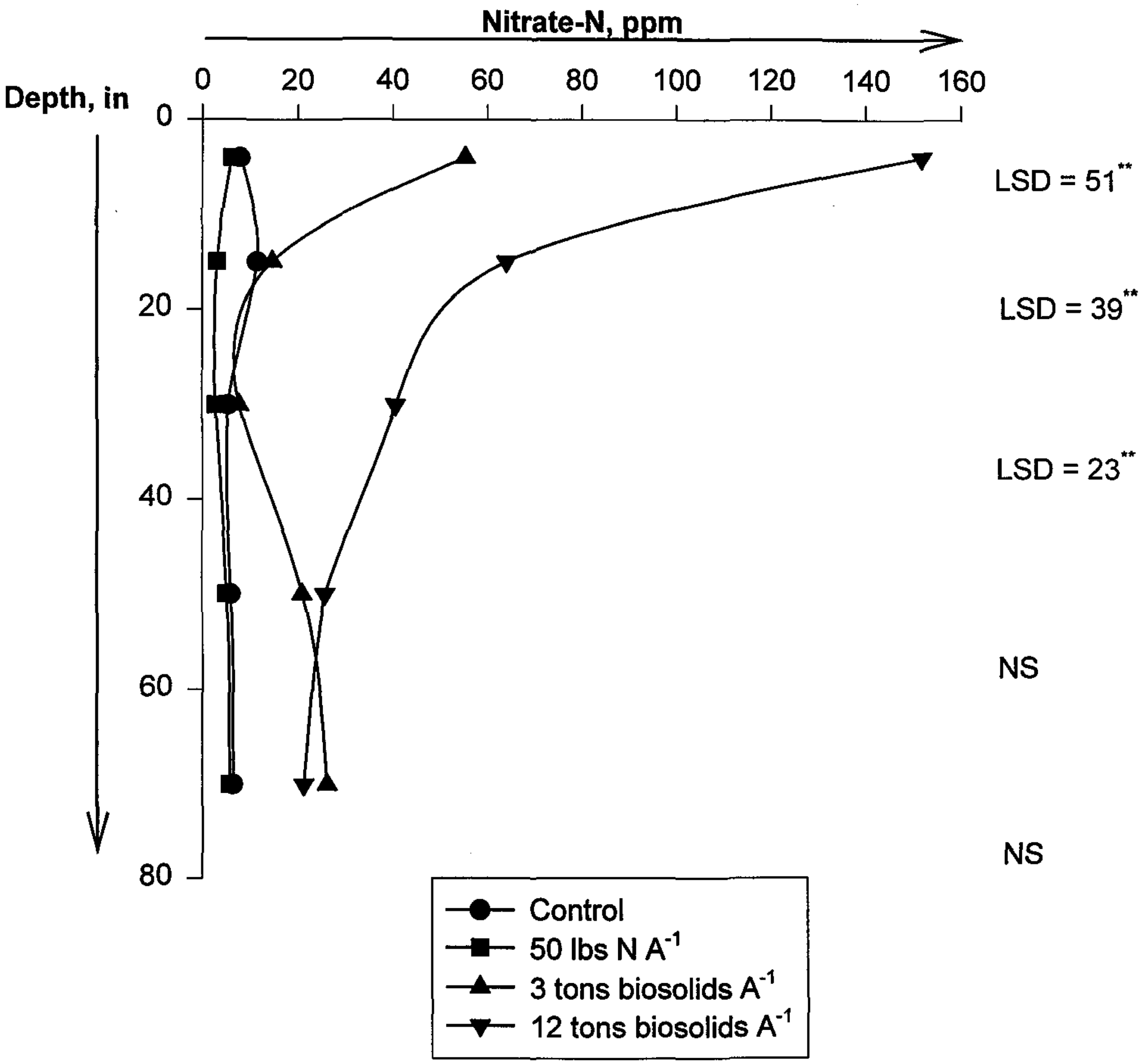

Figure 2. North Bennett Harvest Soil Nitrogen 96-97