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

1997-98 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 seventeenth 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 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} application as the most viable land disposal rate for similar biosolids nutrient characteristics and crop yields.

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) estimated income, (c) grain and straw elemental content, and (d) soil NO_3-N accumulation.

MATERIALS AND METHODS

The West Bennett experimental plot used in the 1997-98 growing season was originally established in August 1983; it was reestablished for the eighth time on June 4, 1997 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 in 1983 through 1989, followed by TAM 107 (*Triticum aestivum* L., 'TAM 107') in the successive years.

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 or N fertilizer to the West Bennett plots during the 1995-96 growing season due to continuous cropping. We also did not apply air-dried biosolids to the West Bennett plots during the 1997-98 growing season due to potential land development. However, we did apply N fertilizer during the 1997-98 growing season. Biosolids treatments (0, 3, 6, and 12 dry tons biosolids A^{-1}) and N fertilizer applications (either 34-0-0 or 46-0-0)(0, 30, 60, 90, and 120 lbs N A^{-1}) were made in August 1983, 1985, 1987, 1989, 1991, and 1993, and N fertilizer alone in 1997. From 1983 to 1989 biosolids were also applied at an 18 dry tons A^{-1} application rate. This application rate was discontinued in 1991 due to excessive accumulation of soil NO_3-N. We continue to study the 18 dry tons biosolids A^{-1}

plots to determine 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. The soil is classified as a Weld loam, Abruptic Aridic Paleustoll. The land is farmed using minimum-tillage practices. We applied biosolids (53% 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 1997. The same plots received biosolids and N fertilizer (46-0-0), at the above rates, in August 1993 and 1995. The North Bennett site has been cropped with the winter wheat cultivar TAM 107.

According to the 1996 Colorado Department of Public Health and Environment Biosolids Regulations, 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. 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 February 1999 and subtracted the cost for either fertilizer or biosolids. We applied urea fertilizer, but based our estimated gross income calculations on the cost of anhydrous ammonia, since this is the main N fertilizer used in Eastern Colorado. The biosolids and its application are currently free.

Following harvest in July 1998, we analyzed soil samples collected from the 0-8, 8-24, 24-40, 40-60, and 60-80-inch depths 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 1997-98 crop year only. The reader is reminded that the 1997-98 West Bennett plots received biosolids application rates in August 1983, 1985, 1987, 1989, 1991, and 1993. Considering these six prior years, the 3 dry tons A^{-1} biosolids rate for the 1997-98 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 treatments.

The reader also is reminded that the 1997-98 North Bennett plots received biosolids application rates in August 1993, 1995, and 1997. The biosolids application rate of 2 dry tons A^{-1} for the 1997-98 growing season represents a cumulative addition of 6 dry tons A^{-1} biosolids for the life of the experiment.

RESULTS AND DISCUSSION

Grain Yields, Protein Content, and Estimated Income

West Bennett :

Grain yields within the N and biosolids treated plots averaged 16 and 14 bu A^{-1}, respectively (Table 2). The Adams County long-term average is 30 bu A^{-1}. Overall, the N plots yielded more bu A^{-1} as compared to the biosolids plots. Protein content was not affected by N fertilizer or biosolids treatment at West Bennett, and there was no significant difference in yield between the two fertilizer sources (Table 2). The protein content of all treatments appeared elevated. This, in conjunction with poor yields, indicates stressed conditions.

Estimated income was higher, overall, for the biosolids plots than the N fertilizer plots. This was true even when comparing the 60 lbs N A^{-1} rate versus the 3 dry tons A^{-1} rate.

North Bennett :

Grain yields averaged higher than the long-term Adams County average (30 bu A^{-1}) on both N fertilizer (49 bu A^{-1}) and biosolids (50 bu A^{-1}) treated plots (Table 3). This is mostly 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 \$21 A^{-1} greater estimated income versus the N-treated plots. The recommended rate of 2 dry tons A^{-1} produced a \$19 A^{-1} greater return compared to the 40 lbs N A^{-1} treatment.

Biosolids Application Recommendation

To better determine the N equivalency of the biosolids, we compared yields from N and biosolids plots at North Bennett. The 1998 data indicates no difference in yield between the N and biosolids treated plots (Table 3), and so 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}. These values supply biosolids applicators with a biosolids N fertilizer equivalency.

Plant Nutrients and Trace Metals

Grain :

West Bennett :

Increasing N fertilizer or biosolids rates did not increase grain trace metals (Table 4). Compared with N fertilizer, biosolids application did result in a higher grain Zn concentration due to greater addition of Zn to the soil by the biosolids application.

North Bennett :

Increasing N fertilizer rate increased the grain N concentration, while increasing biosolids rate increased grain Zn and N concentrations (Table 5). Compared with N fertilizer, biosolids resulted in a higher grain Zn concentration. Again, this is due to a greater addition of Zn to the soil by the biosolids application.

Straw :

West Bennett :

Increasing N fertilizer increased straw Pb and N concentrations, while increasing biosolids did not affect straw trace metals (Table 6). Compared with N fertilizer, biosolids resulted in higher straw Zn concentration.

North Bennett :

Increasing N fertilizer rate increased straw Pb, while increasing biosolids rate increased straw P concentration (Table 7). Compared with N fertilizer, biosolids resulted in slightly higher straw P, Zn, and N concentrations.

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 in the 0-8-inch soil depth as compared to the control, the 60 lbs N A^{-1}, or 12 dry tons biosolids A^{-1} (Figure 1). However, the 12 dry tons biosolids A^{-1} rate increased residual NO_3-N accumulation throughout the top 60 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) and from lack of N use by crops during low yielding years. The potential for leaching from the 12-dry tons A^{-1} rate is minimal because NO_3-N concentrations are low below the 60 inch soil depth. 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-fallow production.

The NO_3-N in the discontinued 18 dry tons biosolids A^{-1} rate is not different from the other treatments in the 0 to 8 inch depth (Table 8). However, after 7 years the discontinued 18 dry tons biosolids A^{-1} rate is similar to the 0, 3, and 6 dry tons biosolids A^{-1} rates in the 8 to 24 inch depth.

<u>North Bennett :</u>

The 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 (three applications to date) significantly increased NO_3-N to a depth of 80 inches. This occurred even in light of the fact that wheat yields on this site have exceeded the county average. However, the NO_3-N concentration did not exceed 10 ppm in any depth increment.

SUMMARY

In 1998 the West Bennett site produced lower yields than long-term Adams County average yields and higher grain protein content than average. This may have been due to stressed conditions. North Bennett N fertilizer and biosolids application rates produced higher yields than the long-term Adams County average yields. This may be attributable to residue management allowing for more efficient soil storage of precipitation. Estimated income was

higher, on average, with biosolids application versus N fertilizer, and the 2 dry tons A^{-1} rate produced a higher return as compared to the 40 lbs N fertilizer A^{-1} treatment.

Increasing biosolids rate did not affect grain or straw trace metal concentrations at West Bennett. Also, we could not distinguish the 18 dry tons biosolids A^{-1} treatment (five years since discontinuance) from the other biosolids treatments. As compared to N fertilizer, increasing biosolids rate increased grain and straw Zn concentration.

Increasing biosolids rate resulted in increased grain Zn and N concentrations, and increased straw P concentration at North Bennett. Compared to N fertilizer, biosolids application increased grain Zn concentration and straw P, Zn, and N concentrations. Biosolids may aid Zn availability on the Zn-deficient soils at both 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 straw Cd concentration for N fertilizer and biosolids at West Bennett were 1.13 and 1.17 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 60 inches of soil at West Bennett. Most of the residual can be attributed to the 1983 liquid application. In addition, the discontinued 18 dry tons biosolids A^{-1} rate has soil NO_3-N concentrations that fall between the 0 and 6 dry tons biosolids A^{-1} rates in the 8-24-inch soil depth. The risk of groundwater contamination due to NO_3-N leaching is minimal at West Bennett due to the depth of the water table and low amount of average precipitation.

Application of 5 dry tons biosolids A^{-1} at the North Bennett site resulted in a greater NO_3-N accumulation throughout the profile as compared to the other treatments. However, the NO_3-N concentration did not exceed 10 ppm at any depth throughout the profile. Three applications of all biosolids treatments 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 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 a 2 to 3 dry tons biosolids application A^{-1}. Soil testing, biosolids analyses, and setting appropriate yield goals must be conducted with any fertilizer program to ensure optimum crop yields along with environmental protection.

REFERENCES

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Table 1. Average composition of Littleton/Englewood sludge applied in 1997-98 compared to the Grade I and II biosolids limits.

Property	Dry Weight Concentration Littleton/Englewood	Limit Grade I Biosolids[¶]	Grade II Biosolids
Organic N (%)	3.44	"	"
NO_3-N (%)	<0.01	"	"
NH_4-N (%)	0.06	"	"
Solids (%)	53	"	"
P (%)	3.59	"	"
As (mg kg^{-1})[p]	2.56	41	75
Cd "	2.9	39	85
Cr "	40	1200	3000
Cu "	459	1500	4300
Pb "	39.0	300	840
Hg "	0.78	17	57
Mo "	8.0	Not finalized	75
Ni "	34.7	420	420
Se "	6.2	36	100
Zn "	422	2800	7500

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

[p] mg kg^{-1} = parts per million.

Table 2. Effects of N fertilizer and biosolids on wheat yield, protein, and projected income at West Bennett, 1997-98.

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		20	17.0	0	56
30		18	18.0	11	38
60		17	18.2	18	29
90		15	18.2	24	19
120		15	17.6	31	10
Mean[§]		16	18.0	21	24
LSD N rate		NS[¶]	NS		
	0	15	18.4	0	42
	3	12	19.0	0	33
	6	13	18.4	0	35
	12	16	18.6	0	44
	18	13	18.7	0	37
Mean[§]		14	18.7	0	37
LSD biosolids rate		NS	NS		
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).

[‡] 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 \$2.76 bu^{-1}. No protein premium was paid in February 1999.

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

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

[ß] 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, 1997-98.

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		44	11.5	0	122
20		47	12.5	9	120
40		49	11.6	13	122
60		48	12.6	18	116
80		48	13.0	22	110
100		52	12.4	26	119
Mean§		49	12.4	18	117
LSD N rate§		NS¶	NS		
	0	48	11.7	0	132
	1	49	12.0	0	135
	2	51	13.0	0	141
	3	48	13.2	0	134
	4	50	13.2	0	139
	5	51	13.2	0	142
	Mean	50	12.9	0	138
	LSD biosolids rate	NS	NS		
	N vs. biosolids§	NS	NS		

† Identical biosolids applications were made in 1993, 1995 and 1997; therefore, the cumulative amount is 3 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 \$2.76 bu^{-1}. No protein premium was paid in February 1999.

§ 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, 1997-98.

N fert. lbs N A^{-1}	Bio-solids dry tons A^{-1} [†]	P	Zn	Cu	Ni	Cd	Pb	N
		g kg^{-1}			mg kg^{-1}			%
0		5.3	49	16.2	75	0.60	2.3	3.23
30		5.3	43	9.3	28	0.40	1.4	3.39
60		5.7	42	8.8	20	0.43	1.4	3.36
90		5.3	44	9.4	27	0.43	1.5	3.36
120		5.2	42	8.0	15	0.37	1.1	3.24
Mean[§]		5.4	43	8.9	23	0.41	1.3	3.34
Sign. N rates		NS[¶]	NS	NS	NS	NS	NS	NS
LSD								
	0	5.4	55	10.9	35	0.46	1.2	3.41
	3	5.6	57	10.5	32	0.43	1.5	3.52
	6	5.7	57	13.2	48	0.53	1.8	3.43
	12	5.4	54	10.3	32	0.46	1.4	3.37
	18[ß]	5.7	55	9.0	20	0.43	1.2	3.41
	Mean	5.6	56	10.7	33	0.46	1.5	3.43
	Sign. bio-solids rates	NS	NS	NS	NS	NS	NS	NS
	LSD							
	N vs bio-solids	NS	*	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.

[ß] 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, 1997-98.

N fert. lbs N A^{-1}	Bio-solids dry tons A^{-1} †	P	Zn	Cu	Ni	Cd	Pb	N
		g kg^{-1}			mg kg^{-1}			%
0		3.5	19	5.2	2.19	0.19	0.72	2.21
20		3.3	19	5.4	2.42	0.20	0.59	2.41
40		3.1	16	5.5	3.27	0.19	0.54	2.31
60		3.3	21	5.2	2.29	0.23	0.62	2.45
80		3.2	20	4.9	2.06	0.22	0.54	2.56
100		3.2	19	5.7	2.44	0.22	0.67	2.50
Mean§		3.2	19	5.3	2.50	0.21	0.59	2.45
Sign. N rates		NS¶	NS	NS	NS	NS	NS	*
LSD								0.19
	0	3.6	19	5.5	2.49	0.23	0.67	2.29
	1	3.6	20	4.7	2.23	0.19	0.63	2.39
	2	3.0	21	4.7	3.43	0.22	0.65	2.58
	3	3.3	22	6.3	2.18	0.23	0.79	2.59
	4	3.4	24	5.2	2.34	0.23	0.79	2.67
	5	3.4	23	4.6	2.49	0.22	0.55	2.60
	Mean	3.3	22	5.1	2.53	0.22	0.68	2.57
	Sign. bio-solids rates	NS	*	NS	NS	NS	NS	*
	LSD		3					0.20
	N vs bio-solids	NS	*	NS	NS	NS	NS	NS

† Identical biosolids applications were made in 1993, 1995, and 1997; therefore, the cumulative amount is 3 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, 1997-98.

N fert. lbs N A^{-1}	Bio-solids dry tons A^{-1} †	P	Zn	Cu	Ni	Cd	Pb	N
		$g\ kg^{-1}$			$mg\ kg^{-1}$			%
0		1.2	13	5.8	2.07	0.83	4.42	1.11
30		1.5	16	7.4	2.15	0.96	4.80	1.33
60		1.4	16	7.1	2.46	1.08	5.49	1.37
90		1.5	19	8.1	2.32	1.05	6.75	1.50
120		1.7	19	7.4	2.92	1.43	7.33	1.51
Mean§		1.5	18	7.5	2.46	1.13	6.10	1.43
Sign. N rates		NS¶	NS	NS	NS	NS	*	**
LSD							2.38	0.19
	0	1.4	22	8.8	2.24	0.99	5.07	1.39
	3	1.9	28	9.1	2.78	1.32	6.18	1.60
	6	1.7	25	8.1	2.57	1.27	6.18	1.59
	12	1.7	29	8.2	2.48	1.12	5.54	1.54
	18ß	1.8	27	9.2	2.15	0.96	4.99	1.65
	Mean	1.8	28	8.6	2.49	1.17	5.72	1.59
	Sign. bio-solids rates	NS	NS	NS	NS	NS	NS	NS
	LSD							
	N vs bio-solids	NS	**	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.

ß 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, 1997-98.

N fert. lbs N A^{-1}	Bio-solids dry tons A^{-1}	P	Zn	Cu	Ni	Cd	Pb	N
		g kg^{-1}			mg kg^{-1}			%
0		0.26	2.8	2.6	1.12	0.21	1.36	0.44
20		0.24	2.7	2.8	1.17	0.28	1.57	0.46
40		0.24	2.4	2.5	1.15	0.30	1.57	0.44
60		0.21	2.4	2.1	1.02	0.21	1.27	0.47
80		0.21	2.5	2.5	0.93	0.21	1.21	0.46
100		0.24	2.9	3.1	1.04	0.26	1.57	0.51
Mean[§]		0.23	2.6	2.6	1.06	0.25	1.44	0.47
Sign. N rates		NS[¶]	NS	NS	NS	NS	*	NS
LSD							0.32	
	0	0.25	3.6	3.0	1.07	0.28	1.48	0.44
	1	0.23	3.3	3.4	1.21	0.26	1.48	0.44
	2	0.23	2.5	2.4	1.01	0.21	1.05	0.56
	3	0.28	3.6	3.6	0.88	0.20	1.11	0.51
	4	0.24	2.7	2.3	1.01	0.18	1.11	0.52
	5	0.33	4.3	3.1	1.07	0.26	1.38	0.65
	Mean	0.26	3.3	2.9	1.04	0.22	1.23	0.53
	Sign. bio-solids rates	*	NS	NS	NS	NS	NS	NS
	LSD	0.09						
	N vs bio-solids	*	*	NS	NS	NS	NS	**

[†] Identical biosolids applications were made in 1993, 1995, and 1997; therefore, the cumulative amount is 3 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 8. Effects of N fertilizer and biosolids rates on NO_3-N and NH_4-N in the 0-20 and 20-60-cm depths at harvest at West Bennett, 1997-98.

Biosolids dry tons A^{-1} †	0 to 8 inch		8 to 24 inch	
	NO_3-N	NH_4-N	NO_3-N	NH_4-N
	---------	------ mg	kg^{-1} -----	--------
0	9.5	3.4	14.1	2.9
3	11.5	3.5	25.2	3.3
6	19.4	3.8	48.5	2.1
12	41.3	3.7	112.8	3.4
18[ß]	9.8	3.6	31.3	3.0
Mean	20.5	3.7	54.4	3.0
Sign. biosolids rates	NS	NS	**	NS
LSD			47.1	

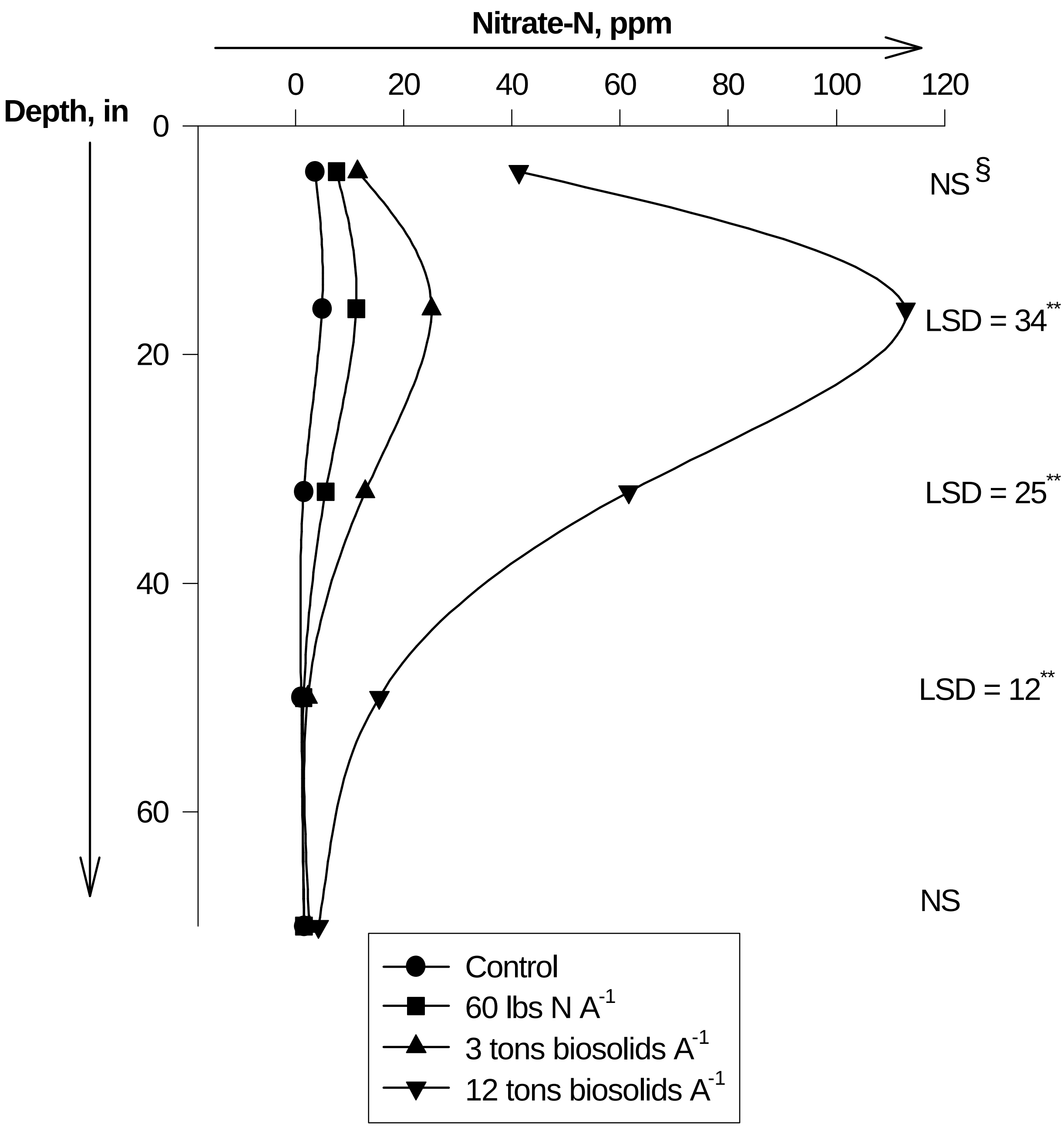
† Identical biosolids applications were made in 1983, 1985, 1987, 1989, 1991, and 1993; therefore, the cumulative amount is 6 times that shown (except for the 18 dry tons A^{-1} rate).

§ Means/LSDs do not include the controls (the zero rates).

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

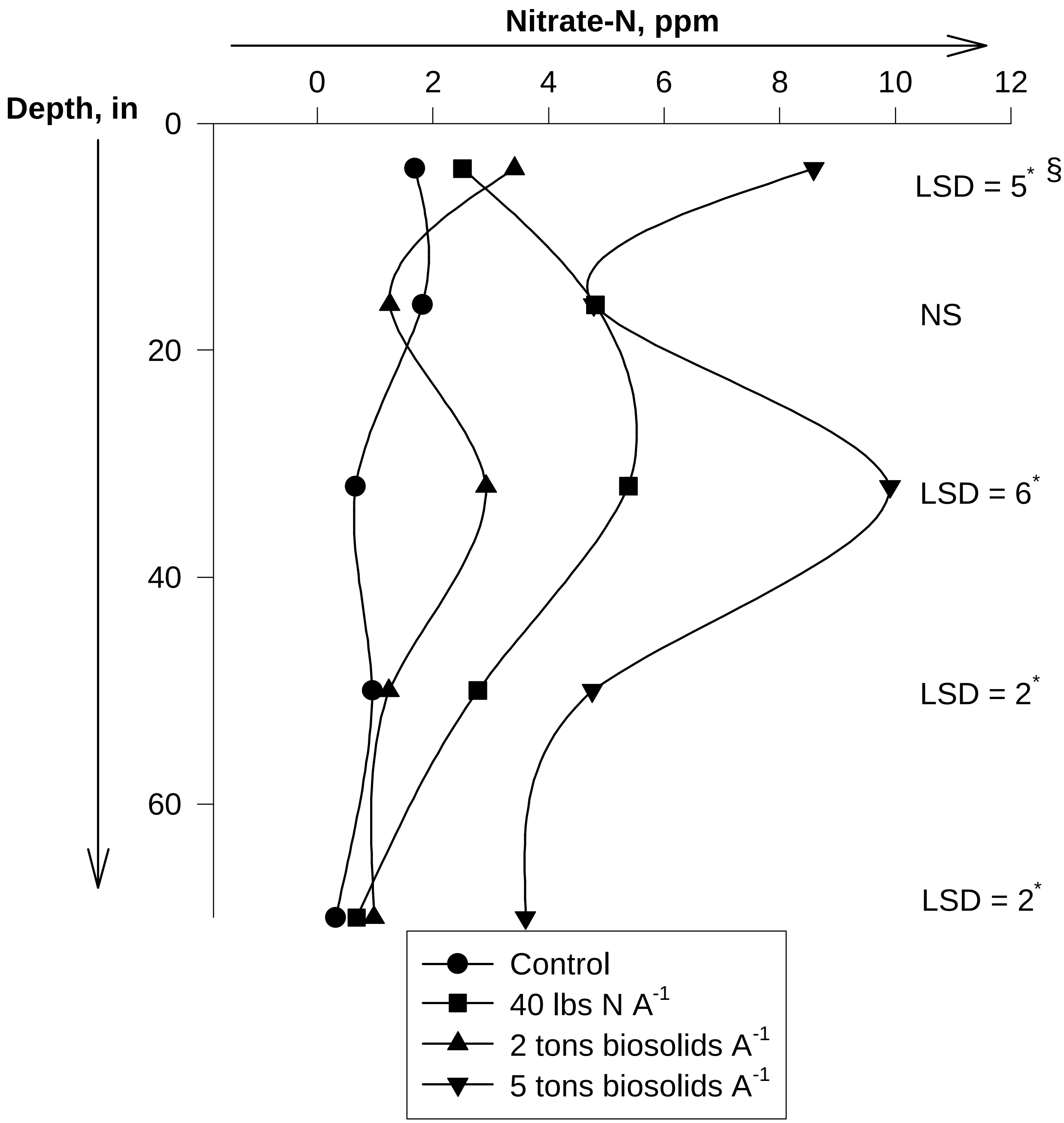
ß The 18 dry tons A^{-1} biosolids rate was discontinued in 1991-92.

Figure 1. West Bennett Harvest Soil Nitrogen 97-98.



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

Figure 2. North Bennett Harvest Soil Nitrogen 97-98.



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