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

2001-02 Technical Report

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INTRODUCTION

The application of biosolids to lands in EPA Region 8 (includes Colorado) is the major method of biosolids disposal, with 85% of the material being reused (USEPA, 2003). 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 twenty-first 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 of biosolids 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 N 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.

The overall objective of our research is to compare the effects of Littleton/Englewood (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, and (d) soil NO_3-N accumulation.

MATERIALS AND METHODS

The North Bennett experimental plots used in the 2001-02 growing season were established in August 1993. The soil is classified as a Weld loam, Aridic Argiustoll. The land is farmed using minimum-tillage practices.

We applied biosolids (75% solids, Table 1) at rates of 0, 1, 2, 3, 4, and 5 dry tons A^{-1} and N fertilizer (46-0-0; urea) at rates of 0, 20, 40, 60, 80, and 100 lbs N A^{-1} on 31 and 30 July 2001, respectively. The same plots received biosolids and N fertilizer, at the above rates, in August 1993, 1995, 1997, and 1999. 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 and incorporated with a rototiller to a depth of 4 to 6 inches. The North Bennett site was cropped with the winter wheat cultivar ‘TAM 107' during the 1993, 1995, and 1997 growing season. During the 1999-00 and 2001-02 growing season the site was cropped with the winter wheat cultivar ‘Prairie Red’.

At harvest (3 July 2002), we measured grain yield and protein content. We estimated gross income using prices paid for wheat in January 2003 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 by wheat-fallow farmers in Eastern Colorado. The biosolids and its application are currently free. Grain and straw were additionally analyzed for nitrogen (N), phosphorus (P), cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) concentrations.

Following harvest in July 2002, we collected soil samples from the 0-8, 8-24, 24-40, 40-60, and 60-80-inch depths in the control, 40 lbs N A^{-1}, and 2 and 5 dry tons biosolids A^{-1} treatments and analyzed them for NO_3-N accumulation.

This report provides data for the 2001-02 crop year only. The reader is reminded that the 2001-02 North Bennett plots received biosolids at the same application rates in August 1993, 1995, 1997, and 1999. Considering these four prior years and the current application, the recommended 2 dry tons A^{-1} biosolids rate for the 2001-02 growing season represents a cumulative addition of 10 dry tons A^{-1} biosolids for the life of the experiment.

RESULTS AND DISCUSSION

Grain Yields, Protein Content, and Estimated Income

North Bennett grain yields exceeded the Adams County average yield (30 bu A^{-1}) in every treatment except the controls (Table 2). This was attributable to the well-managed crop residue which promoted efficient use of precipitation even during a drought year. We also found that increasing N fertilizer and biosolids rates increased protein content, although there was no difference between N fertilizer and biosolids.

The biosolids average economic return exceeded the average N fertilizer economic return by \$35 A^{-1} (Table 2). This finding is similar to all previous observations at this site which showed that biosolids produced a greater estimated income versus the N-treated plots. The recommended rate of 2 dry tons biosolids A^{-1} produced a greater return (\$166 A^{-1}) as compared to the 40 lbs N fertilizer A^{-1} treatment (\$128 A^{-1}). This trend was similar to our 1997-98 results. The difference in return resulted from the fact that the biosolids were free and N fertilizer was a cost to the system.

Biosolids Application Recommendation

To better determine the N equivalency of the biosolids, we compared yields from N and biosolids plots at North Bennett (Figure 1). Using the linear regression equations (shown in the figure legend for each material) and assuming the intercepts for both curves are equal, we can estimate that 1 ton of biosolids would supply an equivalent of about 18 lbs of fertilizer N. In both 1995 and 1999 we also found one dry ton biosolids A^{-1} to be equivalent to 18 lbs N A^{-1}. These approximations could help in planning long-term biosolids applications.

Grain and Straw Nutrients and Trace Metals

Increasing N fertilizer caused a decrease in grain P and an increase in grain N concentrations (Table 3). Increasing biosolids rate increased grain Zn, Cu, and N concentrations. There were no observed differences between grain from the N fertilized and biosolids plots.

Increasing N fertilizer and biosolids rate both increased straw Cu and N concentrations (Table 4). Again, there were no observed differences between grain from the N fertilized and biosolids plots.

All grain and straw metal concentrations were well below the levels considered harmful to livestock (National Research Council, 1980).

Residual Soil NO_3-N

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

The 5 dry tons biosolids A^{-1} application rate significantly increased NO_3-N throughout the soil profile. However, this application rate did not produce any NO_3-N levels above 5 ppm. This indicates the movement of NO_3-N below the root zone is minimal.

SUMMARY

Increasing the N fertilizer and biosolids land application rates produced higher yields at the 2001-2002 North Bennett site than the long-term Adams County average. This was attributable to the well-managed crop residue which promoted efficient precipitation usage even during a drought year. We also found that increasing N fertilizer and biosolids rates increased grain protein content. On average, estimated income was higher with biosolids application versus N fertilizer. The recommended 2 dry tons A^{-1} rate produced an economic return greater than the 40 lbs N fertilizer A^{-1} treatment because the cost of biosolids is zero. This trend was similar to previous findings.

Increasing N fertilizer rates decreased grain P concentration, increased grain N concentration, and increased straw Cu and N concentrations. Increasing biosolids rates resulted in increased grain Zn, Cu, and N concentrations, and increased straw Cu and N concentrations. There were no differences between N fertilizer and biosolids application in the grain or straw elemental concentrations. All metal concentrations in wheat plants were below those levels considered harmful to livestock.

The recommended 2 dry tons biosolids A^{-1} application rate did not affect NO_3-N throughout the profile as compared to either the control or the 40 lbs N A^{-1} rate. In addition, this rate did not increase NO_3-N above 1 ppm anywhere in the profile. Application of 5 dry tons biosolids A^{-1} at the North Bennett site resulted in significantly increased NO_3-N throughout the soil profile. However, this application rate did not produce any NO_3-N levels above 5 ppm. This indicates the movement of NO_3-N below the root zone is minimal and that five applications of biosolids have not led to NO_3-N accumulations in the soil.

We expect increases in grain yield and protein content when we apply biosolids or N fertilizer at recommended rates on N-deficient soils. During most growing seasons biosolids could supply slow-release N, P, and Zn as beneficial nutrients. We continue to recommend a 2 to 3 dry tons biosolids application A^{-1}. The 2001-2002 growing season results show that 1 dry ton biosolids A^{-1} is equivalent to 18 lbs N A^{-1}. In both 1995 and 1999 we also found one dry ton biosolids A^{-1} to be equivalent to 18 lbs N A^{-1}. These approximations 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.

REFERENCES

Barbarick, K.A., R.N. Lerch, J.M. Utschig, D.G. Westfall, R.H. Follett, J.A. Ippolito, R. Jepson, and T.M. McBride. 1992. Eight years of application of biosolids to dryland winter wheat. Colorado Agricultural Experiment Station Technical Bulletin TB92-1.

Colorado Department of Public Health and Environment. 1996. Revised Biosolids Regulation 4.9.0. Denver, CO.

U.S. Environmental Protection Agency. 2003. Region 8 Biosolids Management Program. Available at http://www.epa.gov/region08/water/wastewater/biohome/biohome.html (posted 24 March 2003; verified 21 April 2003).

National Research Council. 1980. Mineral Tolerance of Domestic Animals. National Academy of Sciences, Washington, D.C. 577 pp.

Table 1. Average composition of Littleton/Englewood sludge applied in 2001-02 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 (%)	2.08		
NO_3-N (%)	<0.01		
NH_4-N (%)	0.40		
Solids (%)	75		
P (%)	1.99		
As (mg kg^{-1})[B]	1.8	41	75
Cd "	0.6	39	85
Cr "	12	1200	3000
Cu "	398	1500	4300
Pb "	7.6	300	840
Hg "	2.97	17	57
Mo "	13	Not finalized	75
Ni "	8.0	420	420
Se "	5.8	36	100
Zn "	428	2800	7500

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

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

Table 2. Effects of N fertilizer and biosolids on wheat yield, protein, and estimated income at North Bennett, 2001-02.

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		22	9.9	0	91
20		31	10.6	9	119
40		34	10.4	13	128
60		35	11.8	18	127
80		38	12.9	22	135
100		42	12.7	26	148
Mean[§]		36	11.7	18	131
LSD N rate[§]		11** [¶]	2.0**		
	0	26	10.3	0	108
	1	34	10.8	0	141
	2	40	12.0	0	166
	3	42	12.7	0	174
	4	44	13.2	0	182
	5	41	13.8	0	170
Mean[§]		40	12.5	0	166
LSD biosolids rate		8*	1.9**		
N vs. biosolids[§]		NS	NS		

† Identical biosolids applications were made in 1993, 1995, 1997, 1999, and 2001; therefore, the cumulative amount is 5 times that shown.

‡ The price for anhydrous NH_3 was considered to be \$0.22 lb^{-1} N plus \$4.50 A^{-1} application charge. The biosolids and its application are currently free. We used a grain price of \$4.14 bu^{-1} for wheat.

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

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

Table 3. Effects of N fertilizer and biosolids rates on elemental concentrations of dryland winter wheat grain at North Bennett, 2001-02.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1}†	P g kg^{-1}	Zn	Cu	Ni mg kg^{-1}	Cd	Pb	N %
0		2.43	11	1.6	1.7	0.04	ND	1.71
20		2.34	11	1.7	1.0	0.03	ND	1.79
40		2.33	11	1.9	0.7	0.02	ND	1.78
60		2.07	10	2.0	2.3	0.02	ND	2.03
80		2.12	12	2.6	0.8	0.01	ND	2.25
100		2.10	11	2.3	0.8	0.02	ND	2.14
Mean§		2.19	11	2.1	1.1	0.02	ND	2.00
Sign. N rates		**¶	NS	NS	NS	NS		**
LSD		0.28						0.37
	0	2.54	12	1.7	0.8	0.02	ND	1.72
	1	2.29	11	1.8	0.6	0.02	ND	1.83
	2	2.28	12	2.1	0.8	0.01	ND	2.02
	3	2.40	14	2.2	1.0	0.02	ND	2.22
	4	2.28	14	2.3	1.2	0.02	ND	2.28
	5	2.18	14	2.2	0.7	0.02	ND	2.33
	Mean	2.29	13	2.1	0.8	0.02	ND	2.14
	Sign. biosolids rates	NS	**	**	NS	NS		**
	LSD		2	0.4				0.43
	N vs bio-solids	NS	NS	NS	NS	NS		NS

† Identical biosolids applications were made in 1993, 1995, 1997, 1999, and 2001; therefore, the cumulative amount is 5 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 elemental concentrations of dryland winter wheat straw at North Bennett, 2001-02.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1}†	P g kg^{-1}	Zn	Cu	Ni mg kg^{-1}	Cd	Pb	N %
0		0.33	1.9	2.1	ND	0.05	0.38	0.41
20		0.28	2.3	2.4	ND	0.05	0.35	0.46
40		0.24	2.6	2.4	0.15	0.05	0.44	0.49
60		0.24	2.7	2.8	0.16	0.05	0.46	0.54
80		0.28	1.9	2.7	0.03	0.03	0.40	0.63
100		0.22	2.4	3.6	ND	0.04	0.41	0.61
Mean§		0.25	2.4	2.8	ND	0.04	0.41	0.55
Sign. N rates		NS¶	NS	*		NS	NS	**
LSD				0.9				0.18
	0	0.33	2.3	2.7	ND	0.09	0.41	0.48
	1	0.32	2.3	2.2	0.05	0.03	0.40	0.46
	2	0.34	2.7	2.5	ND	0.05	0.40	0.56
	3	0.31	3.0	2.9	0.04	0.05	0.42	0.65
	4	0.27	2.5	2.7	0.11	0.03	0.28	0.66
	5	0.25	3.6	2.9	ND	0.05	0.36	0.70
	Mean	0.30	2.8	2.6	ND	0.04	0.37	0.60
	Sign. bio-solids rates	NS	NS	**		NS	NS	**
	LSD			0.7				0.19
	N vs bio-solids	NS	NS	NS		NS	NS	NS

† Identical biosolids applications were made in 1993, 1995, 1997, 1999, and 2001; therefore, the cumulative amount is 5 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. North Bennett wheat yields in 2002 as affected by either N fertilizer or biosolids application.

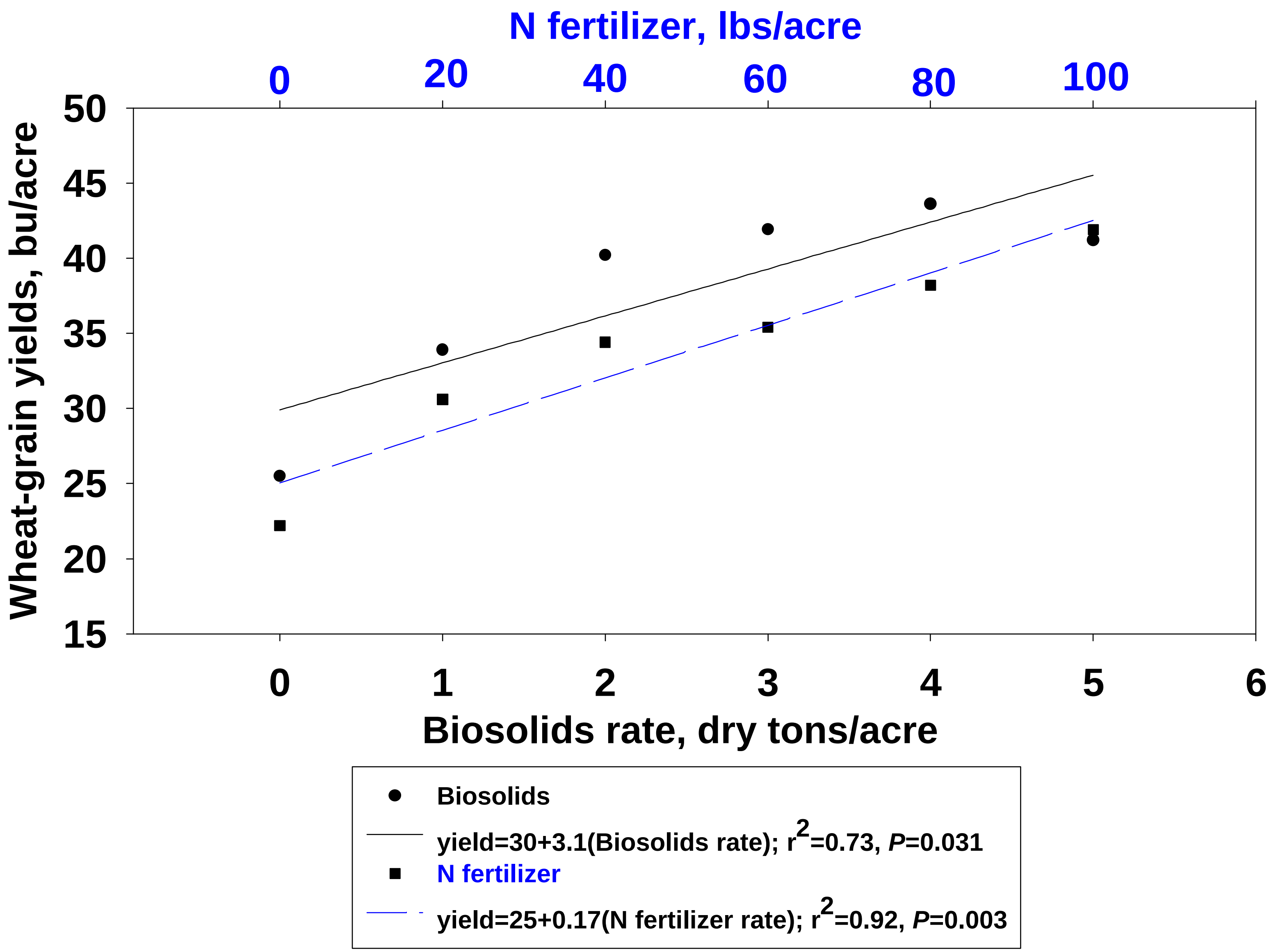
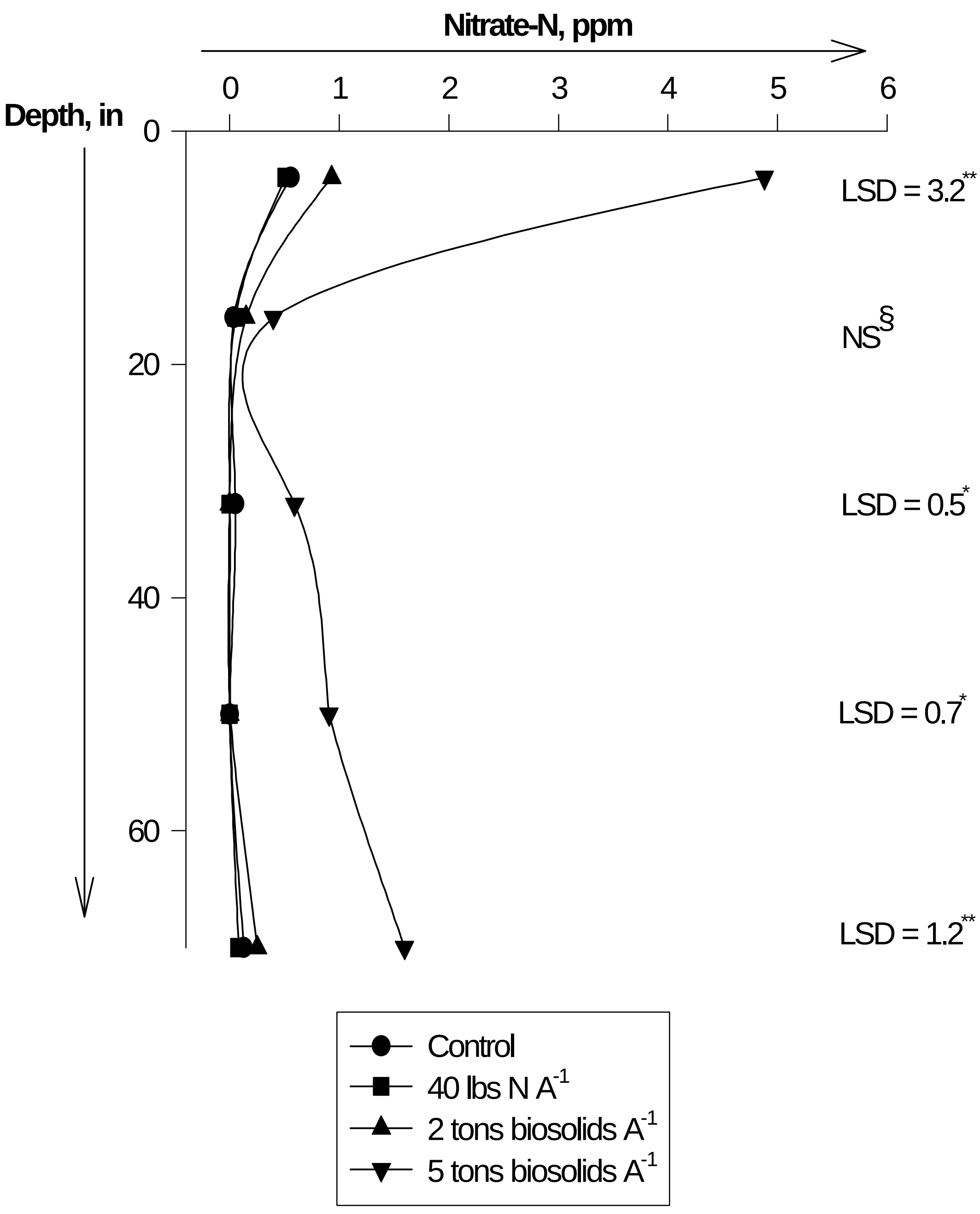


Figure 2. North Bennett Soil Nitrate-N at Harvest in 2001-02.



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