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Application of Anaerobically Digested Biosolids to Dryland Winter Wheat 2005-2006 Results

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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 disposal method can greatly benefit municipalities and farmers by recycling plant nutrients in an environmentally sound manner (Barbarick et al., 1992).

Our long-term biosolids project, now in its twenty-fifth year, has provided valuable information on the effects of continuous biosolids applications 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-nitrogen (NO_3-N). Excess soil NO_3-N may move below the root zone or off-site and contaminate groundwater or surface waters. The potential benefit of biosolids is that they contain organic N, which can act like a slow-release N source and provides a more constant supply of N during the critical grain-filling period versus pre-plant applied commercial N fertilizer.

A 2 to 3 dry tons biosolids A^{-1} application rate will supply approximately 40 lbs N A^{-1} over the growing season, the amount typically required by dryland winter wheat crops in our study area. Previous research has shown no detrimental grain trace metal accumulation with this application rate. Therefore, we continue to recommend a 2 to 3 dry tons biosolids A^{-1} rate 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 total nutrient and trace metal content; d) soil nutrient and total trace metal accumulation; and e) soil NO_3-N accumulation and movement.

MATERIALS AND METHODS

The North Bennett experimental plots used in the 2005-06 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 N fertilizer (46-0-0; urea) at rates of 0, 20, 40, 60, 80, and 100 lbs N A^{-1} and biosolids (92% solids, Table 1) at rates of 0, 1, 2, 3, 4, and 5 dry tons A^{-1} on 25 and 26 July 2005, respectively. The same plots received biosolids and N fertilizer, at the above rates, in August 1993, 1994, 1997, 1999, 2001, and 2003. 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, 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 seasons, and ‘Prairie Red’ during the 1999, 2001, and 2003 seasons.

At harvest (7 July 2006), we measured grain yield and protein content. We estimated net income using $4.65 per bushel for wheat, subtracted the cost for either fertilizer or biosolids, and considered all other costs equal. Although we applied urea fertilizer, we based our estimated gross income calculations on the cost of anhydrous ammonia, since this is the most common 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 total cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), molybdenum (Mo), nickel (Ni), and zinc (Zn) concentrations.

Following harvest in July 2006, we collected soil samples from the 0-8 and 8-24-inch depths from all plots and analyzed them for total Cd, Cr, Cu, Pb, Mo, Ni, and Zn concentrations. We also 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 2005-06 crop year only. The reader is reminded that the 2005-06 North Bennett plots received biosolids at the same application rates in August 1993, 1995, 1997, 1999, 2001, 2003, and July 2005. Considering these six prior years and the current application, the recommended 2 dry tons A^{-1} biosolids rate for the 2005-06 growing season represents a cumulative addition of 14 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 were slightly below the Adams County average yield of 30 bu A^{-1} (Table 2). Increasing biosolids or N rates did not affect grain production (Figure 1), unlike previous years where grain yields increased with increasing biosolids application rate. Nutrient application, whether as N fertilizer or biosolids, probably caused rapid water usage during spring 2006. Coupled with continuing droughty conditions, there was not sufficient water for most treatments to maintain at least average yields. The decrease in yield was reflected in greater grain protein content, similar to recent drought years.

The biosolids average economic return was greater than the average N fertilizer economic return (Table 2). This finding was similar to our previous observations at this site that showed biosolids produced a greater estimated net income versus that from the N-treated plots. The recommended rate of 2 dry tons biosolids A^{-1} produced a return greater than that of the 40 lbs N fertilizer A^{-1} treatment ($126 versus $117 A^{-1}, respectively). This trend was also similar to previous years where economic return differences resulted from the fact that the biosolids were free and N fertilizer was an input cost.

Biosolids Application Recommendation

To better determine the N equivalency of the biosolids, we compared yields from N and biosolids plots at North Bennett. However, we did not find any significant N equivalency relationships for the biosolids or N treatments. During past growing seasons we have estimated that 1 dry ton of biosolids would supply the equivalent of 16 lbs of fertilizer N (Barbarick and Ippolito, 2000). This approximation could help in planning long-term biosolids applications.

Grain and Straw Nutrients and Trace Metals

Increasing N fertilizer had no effect on grain or straw metal concentrations (Tables 3 and 4). Increasing biosolids rate increased grain Zn content but did not affect straw metal concentrations. Overall, grain from biosolids treated plots had greater amounts of Zn as compared to those on N-treated plots. The increase in grain Zn content due to increasing biosolids application can be viewed as positive since this soil is Zn deficient. All metal concentrations in grain and straw were well below the levels considered harmful to livestock (National Research Council, 1980).

Soil Nutrients and Trace Metals

Increasing N fertilizer rate affected Zn concentration in the 0-8-inch soil depth; differences were not observed in the 8-24-inch soil depth (Tables 5 and 6). Increasing biosolids rate increased soil Cu, Pb, and Zn concentrations in the 0-8-inch soil depth, and Pb content in the 8-24-inch soil depth. As compared with N fertilizer, biosolids application increased Cu and Zn concentrations in the 0-8-inch soil depth. Soil nutrient and trace metal concentrations in both depths in all treatments were about ten times lower than those considered hazardous to human health (Chang et al., 2002).

Residual Soil NO_3-N

The recommended 2 dry tons biosolids A^{-1} application rate did not significantly affect NO_3-N throughout the profile as compared to either the control or the 40 lbs N A^{-1} rate (Figure 2). This rate resulted in approximately 20 mg kg^{-1} NO_3-N in the 0-8-inch soil depth, and below 10 mg kg^{-1} throughout the remainder of the soil profile. The excess 0-8-inch NO_3-N was most likely caused by several years of drought, yield reduction, and thus less NO_3-N removed from the ecosystem. Applicators could fertilize with biosolids if soil NO_3-N concentrations within the top foot of soil are less than approximately 15 mg kg^{-1}, according to Colorado State University fertilizer recommendation guidelines.

As compared with other treatments, the 5 dry tons biosolids A^{-1} application rate significantly increased NO_3-N in the 24-40 and 60-80-inch soil depths. This continuous application rate produced soil NO_3-N levels above 20 mg kg^{-1} in the soil surface and between 10 and 20 mg kg^{-1} throughout the remainder of the soil profile. The NO_3-N is moving into the root zone and possibly below the root zone as compared to the control. The cumulative NO_3-N load is above the agronomic rate and would constitute a leaching risk in a wet year, especially following a crop failure.

SUMMARY

North Bennett grain yields were slightly below the Adams County average yield of 30 bu A^{-1}. Increasing biosolids or N rates did not affect grain production, unlike previous years where grain yields increased with increasing biosolids application rate. Nutrient application, whether as N fertilizer or biosolids, probably caused rapid water usage during the 2005-2006 growing season. Coupled with drought conditions, for most treatments there was insufficient water to maintain at least average yields.

On the average, the estimated net return to biosolids was greater than N fertilizer application. The recommended 2 dry tons A^{-1} rate produced an economic return greater than that of the 40 lbs N A^{-1} treatment. This trend was similar to previous findings where biosolids usage provided a greater economic advantage.

Increasing N fertilizer rates did not affect grain or straw trace metal concentrations. Increasing biosolids rates resulted in increased grain Zn but did not affect straw metal concentrations. Biosolids caused an increase in grain Zn concentration as compared to N fertilizer treatments. The increase in grain Zn content due to increasing biosolids application can be viewed as positive since this soil is Zn deficient. All grain and straw metal concentrations were well below the levels considered harmful to livestock, and all findings were relatively similar to previous years.

Increasing N fertilizer affected soil Zn concentration in the 0-8-inch depth, but did not affect trace metals in the 8-24-inch soil. Increasing biosolids rate increased soil Cu, Pb, and Zn concentrations in the 0-8-inch depth, and soil Pb concentration in the 8-24-inch depth. As compared to N fertilizer, biosolids application increased soil Cu and Zn concentrations in the 0-

8-inch depth. Soil nutrient and trace metal concentrations in both depths were approximately ten times lower in concentration than those considered hazardous to human health by the World Health Organization (Chang et al., 2002).

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. This rate increased NO_3-N above 20 mg kg^{-1} in the 0-8-inch soil depth, most likely caused by several years of drought, yield reduction, and thus less NO_3-N removed from the ecosystem. Application of 5 dry tons biosolids A^{-1} at the North Bennett site resulted in increased NO_3-N throughout the soil profile. The NO_3-N associated with the 5 dry tons biosolids A^{-1} has moved into the root zone and has the potential for movement below the root zone. The cumulative NO_3-N load is above the agronomic rate and would constitute a leaching risk in a wet year, especially following a crop failure.

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, Zn, and other beneficial nutrients. We continue to recommend a 2 to 3 dry tons biosolids application A^{-1}. Previous growing season results show that 1 dry ton biosolids A^{-1} is equivalent to 16 lbs N A^{-1} (Barbarick and Ippolito, 2000). 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., and J.A. Ippolito. 2000. Nitrogen fertilizer equivalency of sewage biosolids applied to dryland winter wheat. J. Environ. Qual. 29:1345-1351.

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.

Chang, A.C., G. Pan, A.L. Page, and T. Asano. 2002. Developing Human Health-Related Chemical Guidelines for Reclaimed Waste and Sewage Sludge Applications in Agriculture. World Health Organization, Geneva, Switzerland. Available at: http://www.envisci.ucr.edu/downloads/chang/WHO_report.pdf (verified 27 February 2006).

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 5 November 2003; verified 1 April 2004).

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 biosolids applied in 2005-06 compared to the Grade I and II biosolids limits.

Property	Dry Weight Concentration Littleton/Englewood	Grade I Biosolids Limit[¶]	Grade II Biosolids Limit
Organic N (%)	3.0		
NO_3-N (%)	<0.01		
NH_4-N (%)	0.36		
Solids (%)	93		
P (%)	1.4		
As (mg kg^{-1})[π]	0.11	41	75
Cd "	0.59	39	85
Cr "	5.2	1200	3000
Cu "	234	1500	4300
Pb "	4.45	300	840
Hg "	0.13	17	57
Mo "	3.6	Not finalized	75
Ni "	4.7	420	420
Se "	0.22	36	100
Zn "	206	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.

Table 2. Effects of N fertilizer and biosolids on wheat yield, protein, and projected income at North Bennett, 2005-06.

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		25	13.9	0	116
20		28	15.2	9	121
40		28	15.6	13	117
60		27	15.5	18	108
80		27	16.5	22	104
100		27	16.0	26	100
Mean§		27	15.8	18	108
LSD N rate§		NS ¶	1.7**		
	0	28	14.6	0	130
	1	30	15.1	0	140
	2	27	16.5	0	126
	3	28	16.7	0	130
	4	28	17.3	0	130
	5	29	17.6	0	135
Mean§		28	16.7	0	130
LSD biosolids rate		NS	NS		
N vs. biosolids§		NS	NS		

† Identical biosolids applications were made in 1993, 1995, 1997, 1999, 2001, and 2003; therefore, the cumulative amount is 7 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 \$4.65 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, 2005-06.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1} †	Cd	Cr	Cu	Pb mg kg^{-1}	Mo	Ni	Zn
0		ND	ND	2.75	ND	0.051	1.1	15.4
20		ND	ND	2.52	ND	0.035	0.98	14.2
40		ND	ND	2.98	ND	0.033	1.28	14.0
60		ND	ND	2.59	ND	0.054	0.99	13.7
80		ND	ND	2.71	ND	0.028	0.85	14.5
100		ND	ND	2.61	ND	0.011	1.23	14.6
Mean§				2.68		0.032	1.06	14.2
Sign. N rates				NS		NS	NS	NS
LSD								
	0	0.006	ND	2.71	ND	0.025	0.87	13.9
	1	ND	ND	3.32	ND	0.048	1.01	15.4
	2	ND	ND	2.76	ND	0.015	1.00	17.0
	3	ND	ND	2.97	ND	0.017	1.23	18.0
	4	ND	ND	2.71	ND	ND	1.00	19.1
	5	ND	ND	3.12	ND	ND	2.26	20.5
	Mean			2.98		0.022	1.30	18.0
	Sign. biosolids rates			NS		NS	NS	**
	LSD							2.7
	N vs bio-solids			NS		NS	NS	*

† Identical biosolids applications were made in 1993, 1995, 1997, 1999, 2001, and 2003; therefore, the cumulative amount is 7 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, 2005-06.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1}[†]	Cd	Cr	Cu	Pb mg kg^{-1}	Mo	Ni	Zn
0		0.026	0.29	1.62	ND	0.568	0.17	2.34
20		0.024	0.38	2.04	ND	0.528	0.07	2.62
40		0.010	0.39	1.94	ND	0.520	0.14	2.88
60		0.036	0.50	1.98	ND	0.530	0.15	2.27
80		0.023	0.39	2.00	ND	0.424	0.22	2.75
100		0.027	0.44	1.99	ND	0.475	0.16	2.76
Mean[§]		0.024	0.42	2.25		0.792	0.15	2.66
Sign. N rates		NS[¶]	NS	NS		NS	NS	NS
LSD								
	0	0.012	0.34	2.02	ND	0.413	0.07	2.79
	1	0.012	0.33	1.94	ND	0.315	ND	2.67
	2	0.010	0.45	2.30	ND	0.500	0.18	3.90
	3	0.015	0.50	2.03	ND	0.642	0.18	3.80
	4	0.008	0.34	2.17	ND	0.416	0.31	3.57
	5	0.022	0.41	2.21	ND	0.326	0.07	3.81
	Mean	0.013	0.41	2.13		0.440	0.15	3.55
	Sign. biosolids rates	NS	NS	NS		NS	NS	NS
	LSD							
	N vs bio-solids	NS	NS	NS		NS	NS	NS

† Identical biosolids applications were made in 1993, 1995, 1997, 1999, 2001, and 2003; therefore, the cumulative amount is 7 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 5. Effects of N fertilizer and biosolids rates on soil elemental concentrations in the 0-8" depth at North Bennett, 2005-06.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1} †	Cd	Cr	Cu	Pb	Mo	Ni	Zn
		-----------	-----------	-----------	mg kg^{-1}	-----------	----------	-----------
0		ND¶	12.3	9.93	3.09	ND	13.2	59.0
20		ND	10.7	9.68	3.11	0.001	8.87	57.5
40		ND	12.2	9.71	2.98	ND	10.6	59.1
60		ND	12.3	10.8	3.19	ND	10.2	59.4
80		ND	12.5	10.4	3.35	ND	10.3	59.5
100		ND	12.0	9.74	3.17	ND	10.9	57.7
Mean§			11.9	10.1	3.16		10.2	58.6
Sign. N rates			NS	NS	NS		NS	*
LSD								2.2
	0	ND	12.2	10.2	2.92	0.004	10.5	58.9
	1	ND	12.1	10.5	2.86	ND	10.6	59.8
	2	ND	12.3	13.3	3.14	0.001	10.0	63.0
	3	ND	12.7	14.1	3.47	0.003	10.3	64.9
	4	ND	12.6	13.9	3.27	0.001	10.1	65.6
	5	ND	13.0	15.0	3.31	ND	10.6	66.3
	Mean		12.6	13.4	3.21	0.001	10.3	63.9
	Sign. biosolids rates		NS	**	*		NS	**
	LSD			2.9	0.42			5.2
	N vs bio-solids		NS	*	NS		NS	*

† Identical biosolids applications were made in 1993, 1995, 1997, 1999, 2001, and 2003; therefore, the cumulative amount is 7 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 6. Effects of N fertilizer and biosolids rates on soil elemental concentrations in the 8-24" depth at North Bennett, 2005-06.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1} †	Cd	Cr	Cu	Pb mg kg^{-1}	Mo	Ni	Zn
0		ND[¶]	9.09	7.41	2.54	ND	8.67	50.6
20		ND	8.40	8.01	3.08	0.005	8.03	51.0
40		ND	9.36	8.23	2.72	ND	8.84	50.6
60		ND	9.52	7.79	2.79	ND	9.01	50.8
80		ND	9.43	7.64	2.50	ND	8.86	50.4
100		ND	9.90	8.75	2.80	ND	9.19	52.0
Mean[§]		ND	9.32	8.08	2.78		8.79	51.0
Sign. N rates			NS	NS	NS		NS	NS
LSD								
	0	ND	10.2	8.92	2.93	ND	9.41	53.0
	1	ND	9.76	8.24	3.09	ND	9.65	52.3
	2	ND	9.34	7.68	2.83	ND	8.81	51.0
	3	ND	9.80	8.02	2.89	ND	9.10	51.6
	4	ND	9.52	8.06	2.77	ND	9.11	53.9
	5	ND	9.36	8.11	3.26	ND	9.01	53.1
	Mean	ND	9.56	8.02	2.97		9.14	52.4
	Sign. biosolids rates		NS	NS	*		NS	NS
	LSD				0.43			
	N vs bio-solids		NS	NS	NS		NS	NS

† Identical biosolids applications were made in 1993, 1995, 1997, 1999, 2001, and 2003; therefore, the cumulative amount is 7 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. 2005-2006 North Bennett wheat yields as affected by either N fertilizer or biosolids application.

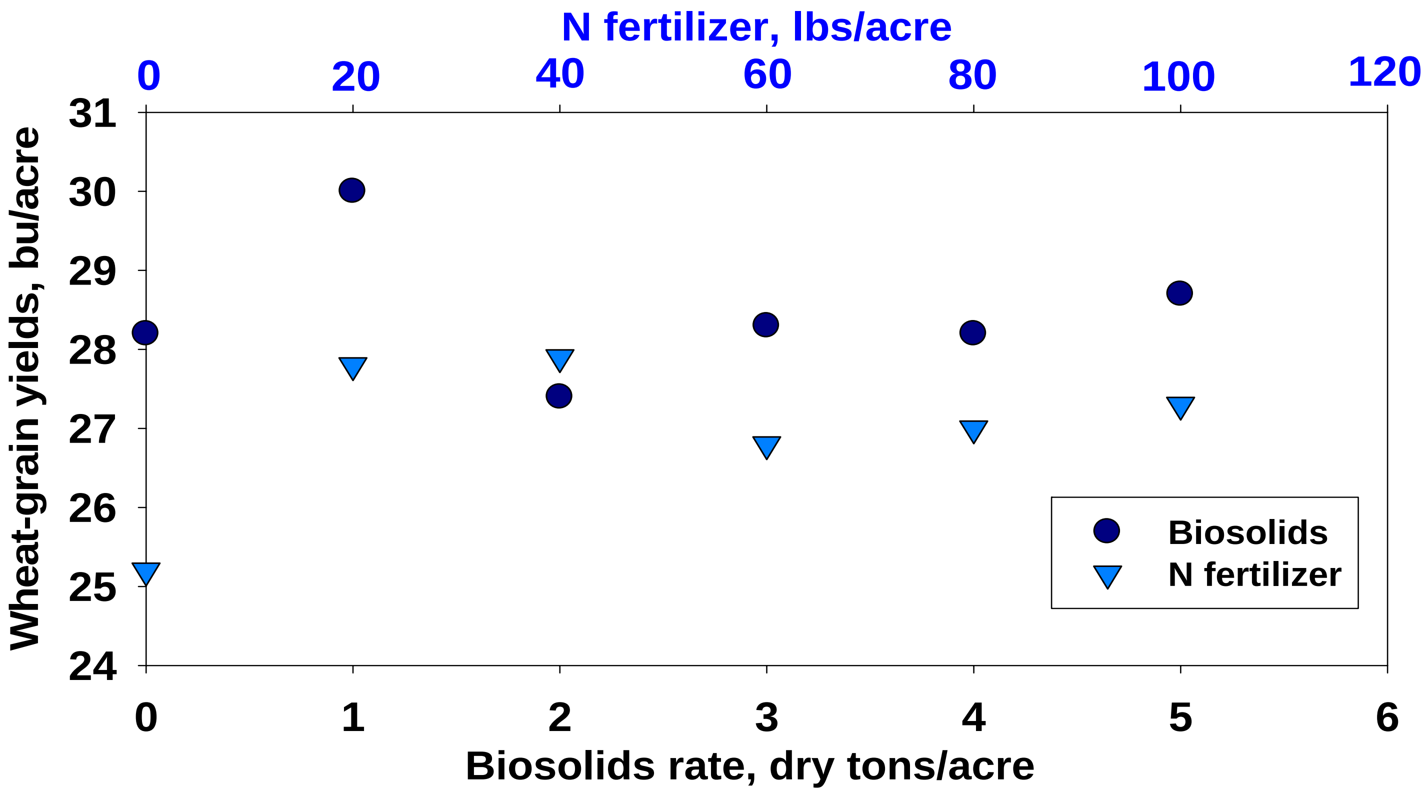
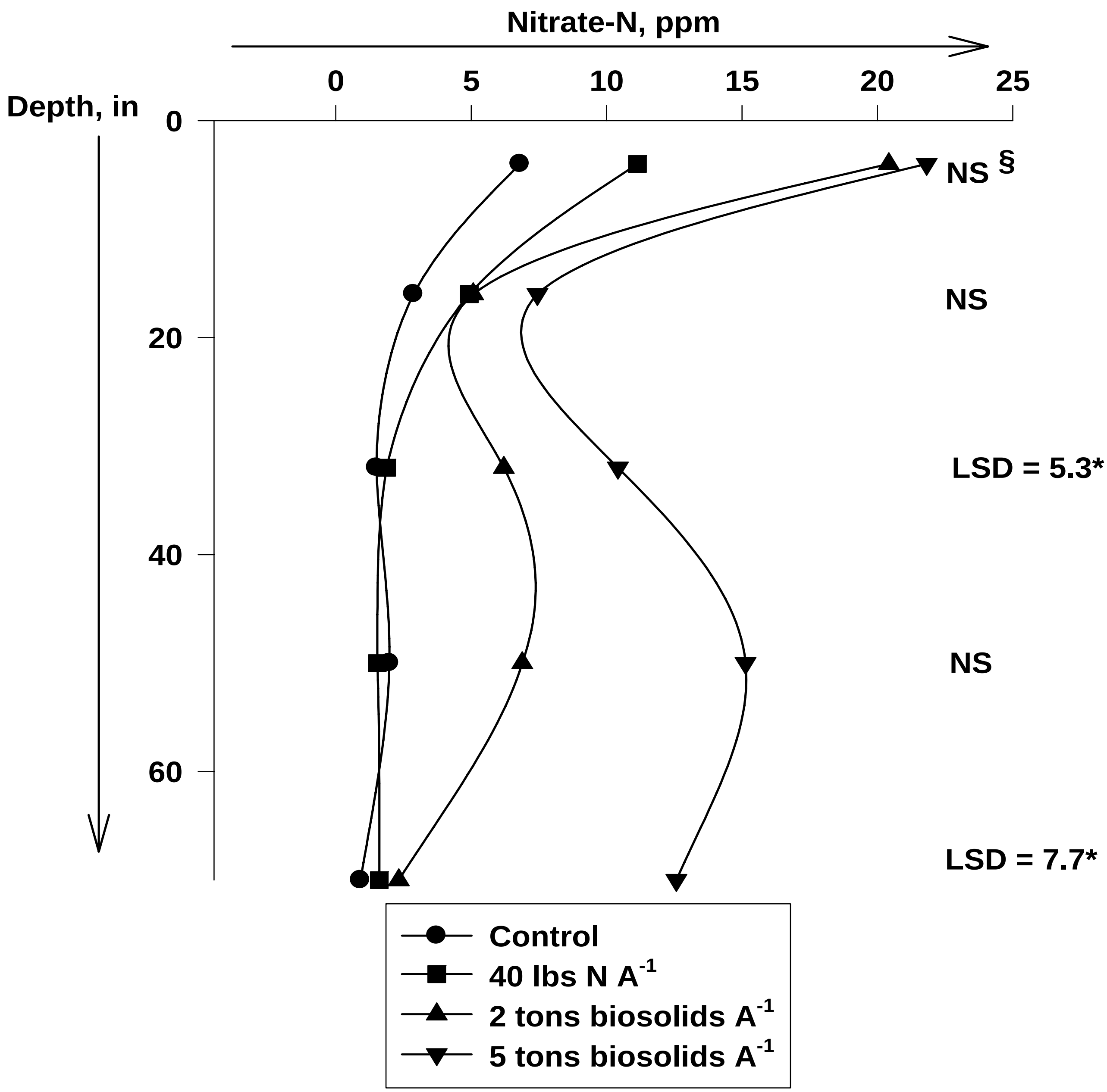


Figure 2. North Bennett Harvest Soil Nitrogen 2005-06.



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