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Knowledge to Go Places

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APPLICATION OF ANAEROBICALLY DIGESTED BIOSOLIDS TO DRYLAND WINTER WHEAT
2004-2005 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-fourth 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. Excess soil nitrate-nitrogen 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 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 2004-05 growing season were established in August 1994. The soil is classified as a Weld loam, Aridic Argiustoll. The land is farmed using minimum-tillage practices. Previous reports included results from West Bennett experimental plots. These plots were lost during the 2004-05 growing season due to building site development.

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 26 and 28 July 2004, respectively. The same plots received biosolids and N fertilizer, at the above rates, in August 1994, 1996, 1998, 2000, and 2002. 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 1994, 1996, and 1998 growing seasons, and ‘Prairie Red’ during the 2000, 2002, and 2004 seasons.

At harvest (7 July 2005), we measured grain yield and protein content. We estimated net income using prices paid for wheat in December 2005, 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 2005, 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 2004-05 crop year only. The reader is reminded that the 2004-05 North Bennett plots received biosolids at the same application rates in August 1994, 1996, 1998, 2000, and 2002, and July 2004. Considering these five prior years and the current application, the recommended 2 dry tons A^{-1} biosolids rate for the 2004-05 growing season represents a cumulative addition of 12 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 the untreated controls and the 20 lbs. N A^{-1} treatment (Table 2). However, increasing biosolids rate decreased grain production to below the county average yield (Figure 1), unlike previous years where grain yields increased with increasing biosolids application rate. Nutrient application, whether as N fertilizer or biosolids, caused rapid water usage in May 2005. The water depletion was accompanied by record-breaking high temperature. Consequently, for most treatments, there was not sufficient water to maintain at least average yields. The decrease in yield was evident by an increase in grain protein content as compared to past years.

The biosolids average economic return was equal to the average N fertilizer economic return (Table 2), most likely due to insufficient water during the critical grain filling period for both nutrient sources. This finding was different than our previous observations at this site that showed biosolids producing 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 approximately equal to that of the 40 lbs N fertilizer A^{-1} treatment ($69 versus $66 A^{-1}, respectively). This trend was different from previous years where economic return differences resulted from the fact that the biosolids were free and N fertilizer was an input cost.

<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. 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.

<u>Grain and Straw Nutrients and Trace Metals</u>

Increasing N fertilizer had no affect on grain metal concentrations (Table 3), but did increase straw Cu concentration (Table 4). Increasing biosolids rate increased grain Cu, Zn, and affected grain Mo concentration (Table 3), and increased straw Cu and Zn concentrations (Table 4), similar to past findings. Overall, grain and straw from biosolids treated plots had greater amounts of Zn as compared to those on N-treated plots. All grain and straw metal concentrations were well below the levels considered harmful to livestock (National Research Council, 1980).

Soil Nutrients and Trace Metals

Increasing N fertilizer rate did not effect trace metal concentrations in either the 0-8 or 8-24-inch depth (Tables 5 and 6). Increasing biosolids rate only increased soil Cu in the 0-8-inch depth. As compared with N fertilizer, biosolids application increased Cu concentration in the 0-8-inch depth. Soil nutrient and trace metal concentrations in both depths are 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 caused NO_3-N to be approximately 10 ppm in the 0-8-inch depth, and below 10 ppm throughout the remainder of the soil profile. 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.

The 5 dry tons biosolids A^{-1} application rate significantly increased NO_3-N in the top 30 inches. However, this application rate did not produce any soil NO_3-N levels above 20 ppm throughout the soil profile. The NO_3-N may be moving into the root zone, but movement was minimal below the root zone as compared to the control. However, 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

Increasing the N fertilizer and biosolids land application rates in 2004-2005 produced yields at the North Bennett site which were generally smaller than the long-term Adams County average. Nutrient application, whether as N fertilizer or biosolids, caused rapid water usage in May 2005. The water depletion was accompanied by record-breaking high temperature. Consequently, for most treatments, there was not sufficient water to maintain at least average yields. The decrease in yield was evident by an increase in grain protein content as compared to past years.

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

Increasing N fertilizer rates did not affect grain trace metal concentrations, but did increase straw Cu concentration. Increasing biosolids rates resulted in increased grain Cu and Zn, and affected grain Mo concentration. Biosolids caused an increase in straw Cu and Zn concentrations. Grain and straw Zn concentrations were greater with biosolids versus N fertilizer treatments. All metal concentrations in wheat grain were well below those levels considered harmful to livestock, and all findings were relatively similar to previous years.

Increasing N fertilizer did not affect trace elements in either the 0-8 or 8-24-inch soil depth. Increasing biosolids rate increased soil Cu concentration in the 0-8-inch depth. As compared to N fertilizer, biosolids application also increased soil Cu concentration 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. In addition, this rate did not increase NO_3-N above 10 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 within to top 30 inches of soil. This application rate did not produce any soil NO_3-N levels above 15 ppm below 8 inches in the soil. This indicates that NO_3-N movement below the root zone is minimal. However, 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.

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

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).

Table 1. Average composition of Littleton/Englewood biosolids applied in 2004-05 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 (%)	4.1		
NO_3-N (%)	<0.01		
NH_4-N (%)	1.0		
Solids (%)	55		
P (%)	3.0		
As (mg kg^{-1}) †	<0.05	41	75
Cd "	2.5	39	85
Cr "	16.8	1200	3000
Cu "	652	1500	4300
Pb "	19.6	300	840
Hg "	<0.005	17	57
Mo "	18.2	Not finalized	75
Ni "	13.9	420	420
Se "	0.13	36	100
Zn "	767	2800	7500

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

† mg kg^{-1} = parts per million.

Table 2. Effects of N fertilizer and biosolids on wheat yield, protein, and estimated income at North Bennett, 2004-05.

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		31	12.9	0	107
20		32	13.3	9	101
40		23	14.8	13	66
60		27	14.0	18	75
80		22	15.8	22	54
100		29	15.4	26	74
Mean§		27	14.7	18	75
LSD N rate§		NS ¶	NS		
	0	35	11.7	0	121
	1	29	15.4	0	100
	2	20	16.6	0	69
	3	23	15.8	0	79
	4	19	15.7	0	66
	5	17	16.3	0	59
Mean§		22	15.8	0	76
LSD biosolids rate		NS	NS		
N vs. biosolids§		NS	*		

† Identical biosolids applications were made in 1994, 1996, 1997, 2000, and 2002; therefore, the cumulative amount is 6 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 \$3.40 bu^{-1} for wheat from December 2005.

§ 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, 2004-05.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1} †	Cd	Cr	Cu	Pb	Mo	Ni	Zn
		-----------	-----------	-----------	mg kg^{-1}	-----------	----------	-----------
0		0.006	ND	2.81	0.064	0.188	0.57	16.05
20		ND	ND	2.70	0.039	0.115	0.52	17.50
40		ND	ND	2.97	0.049	0.094	0.62	18.94
60		0.010	0.73	3.16	0.052	0.381	2.23	20.11
80		0.008	ND	3.37	0.044	0.133	0.71	22.90
100		0.020	ND	3.29	0.005	0.163	0.71	21.17
Mean§				3.05	0.042	0.179	0.89	19.45
Sign. N rates				NS	NS	NS	NS	NS
LSD								
	0	0.010	0.89	3.00	0.032	0.339	2.12	17.22
	1	ND	ND	2.76	0.024	0.045	0.60	20.54
	2	ND	ND	3.13	0.025	0.068	0.67	26.33
	3	ND	ND	2.92	0.012	0.018	0.61	25.40
	4	0.006	0.61	4.04	0.018	0.397	2.02	27.02
	5	ND	ND	3.70	0.086	0.196	0.69	29.75
	Mean			3.26	0.033	0.177	1.12	24.38
	Sign. biosolids rates			*	NS	*	NS	*
	LSD			0.94		0.281		7.46
	N vs bio-solids			NS	NS	NS	NS	*

† Identical biosolids applications were made in 1994, 1996, 1997, 2000, and 2002; therefore, the cumulative amount is 6 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, 2004-05.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1}[†]	Cd	Cr	Cu	Pb mg kg^{-1}	Mo	Ni	Zn
0		0.054	0.24	1.98	ND	0.733	ND	5.87
20		0.019	0.20	1.71	ND	0.599	ND	5.37
40		0.048	ND	2.21	ND	0.756	ND	6.09
60		0.037	ND	2.04	ND	1.124	ND	6.78
80		0.078	ND	2.64	ND	0.710	ND	8.42
100		0.053	ND	2.63	ND	0.773	ND	6.37
Mean[§]		0.047		2.25	ND	0.792		6.61
Sign. N rates		NS[¶]		*		NS		NS
LSD				0.79				
	0	0.023	0.08	1.52	ND	0.568	ND	4.50
	1	0.029	0.07	1.85	ND	0.494	ND	6.19
	2	0.051	0.07	2.54	ND	0.801	0.07	8.74
	3	0.033	ND	2.19	ND	0.332	ND	8.93
	4	0.059	ND	2.82	ND	0.679	ND	11.22
	5	0.053	0.07	2.84	ND	0.745	ND	11.08
	Mean	0.045	0.04	2.45	ND	0.610		9.23
	Sign. biosolids rates	NS		*		NS		*
	LSD			0.83				4.34
	N vs bio-solids	NS		NS		NS		**

† Identical biosolids applications were made in 1994, 1996, 1998, 2000, and 2002; therefore, the cumulative amount is 6 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, 2004-05.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1}[†]	Cd	Cr	Cu	Pb mg kg^{-1}	Mo	Ni	Zn
0		ND[¶]	9.25	8.58	2.916	ND	10.48	52.69
20		ND	8.98	8.64	2.802	ND	10.31	51.74
40		ND	9.17	9.88	3.224	0.004	10.00	52.58
60		ND	8.54	10.55	3.026	ND	9.58	54.40
80		ND	9.80	10.92	2.943	ND	10.76	56.65
100		ND	9.36	10.42	3.254	ND	10.41	53.95
Mean[§]			9.17	10.08	3.050		10.21	53.86
Sign. N rates			NS	NS	NS		NS	NS
LSD								
	0	ND	8.43	10.49	2.958	0.006	9.58	54.28
	1	ND	8.87	11.25	3.355	ND	10.12	54.92
	2	ND	8.67	11.02	2.535	0.004	9.53	52.97
	3	ND	9.18	12.95	3.326	ND	10.18	55.47
	4	ND	8.97	13.65	3.434	ND	10.35	57.13
	5	ND	9.01	14.98	2.882	ND	9.66	58.49
	Mean		8.94	12.77	3.106		9.97	55.79
	Sign. biosolids rates		NS	*	NS		NS	NS
	LSD			3.40				
	N vs bio-solids		NS	*	NS		NS	NS

† Identical biosolids applications were made in 1994, 1996, 1998, 2000, and 2002; therefore, the cumulative amount is 6 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, 2004-05.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1}†	Cd	Cr	Cu	Pb mg kg^{-1}	Mo	Ni	Zn
0		ND¶	7.13	9.86	4.001	0.004	8.99	49.09
20		ND	6.65	9.66	4.023	ND	8.79	48.25
40		ND	6.97	9.80	3.715	0.005	9.13	49.48
60		ND	7.82	9.45	4.008	ND	9.81	48.91
80		ND	6.66	9.60	3.556	0.005	8.64	49.28
100		ND	8.33	9.63	3.813	ND	10.10	50.84
Mean§		ND	7.29	9.63	3.822		9.29	49.35
Sign. N rates			NS	NS	NS		NS	NS
LSD								
	0	ND	8.54	9.01	3.841	ND	10.42	51.33
	1	ND	6.98	9.79	4.055	ND	9.03	50.31
	2	ND	7.89	9.54	3.889	ND	9.83	48.43
	3	ND	6.89	9.36	3.285	ND	8.76	49.50
	4	ND	6.95	9.42	3.382	ND	8.68	49.30
	5	ND	8.48	10.10	3.804	ND	10.49	51.12
	Mean	ND	7.44	9.64	3.682		9.36	49.73
	Sign. biosolids rates		NS	NS	NS		NS	NS
	LSD							
	N vs bio-solids		NS	NS	NS		NS	NS

† Identical biosolids applications were made in 1994, 1996, 1998, 2000, and 2002; therefore, the cumulative amount is 6 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 2005 as affected by either N fertilizer or biosolids application.

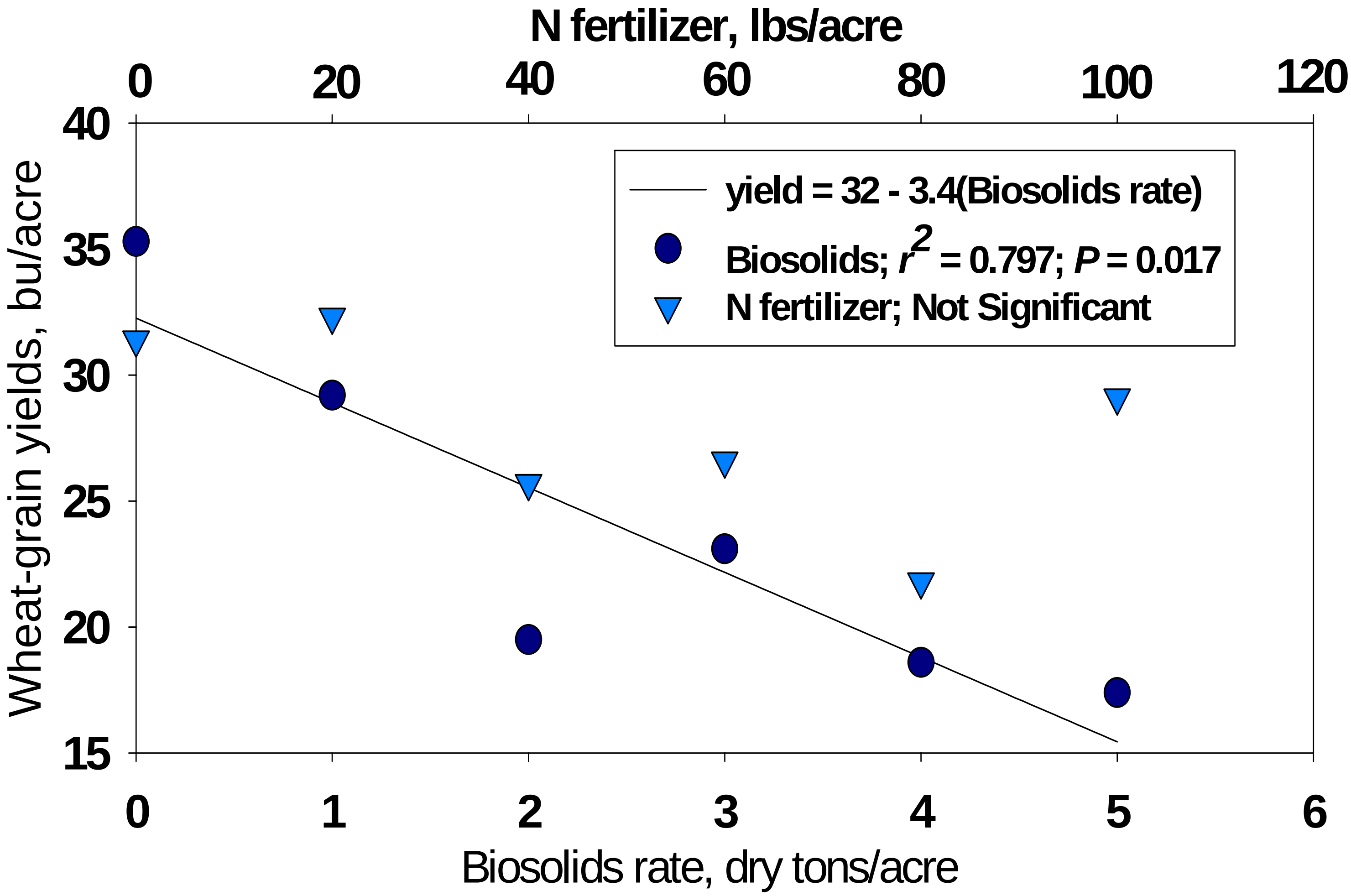
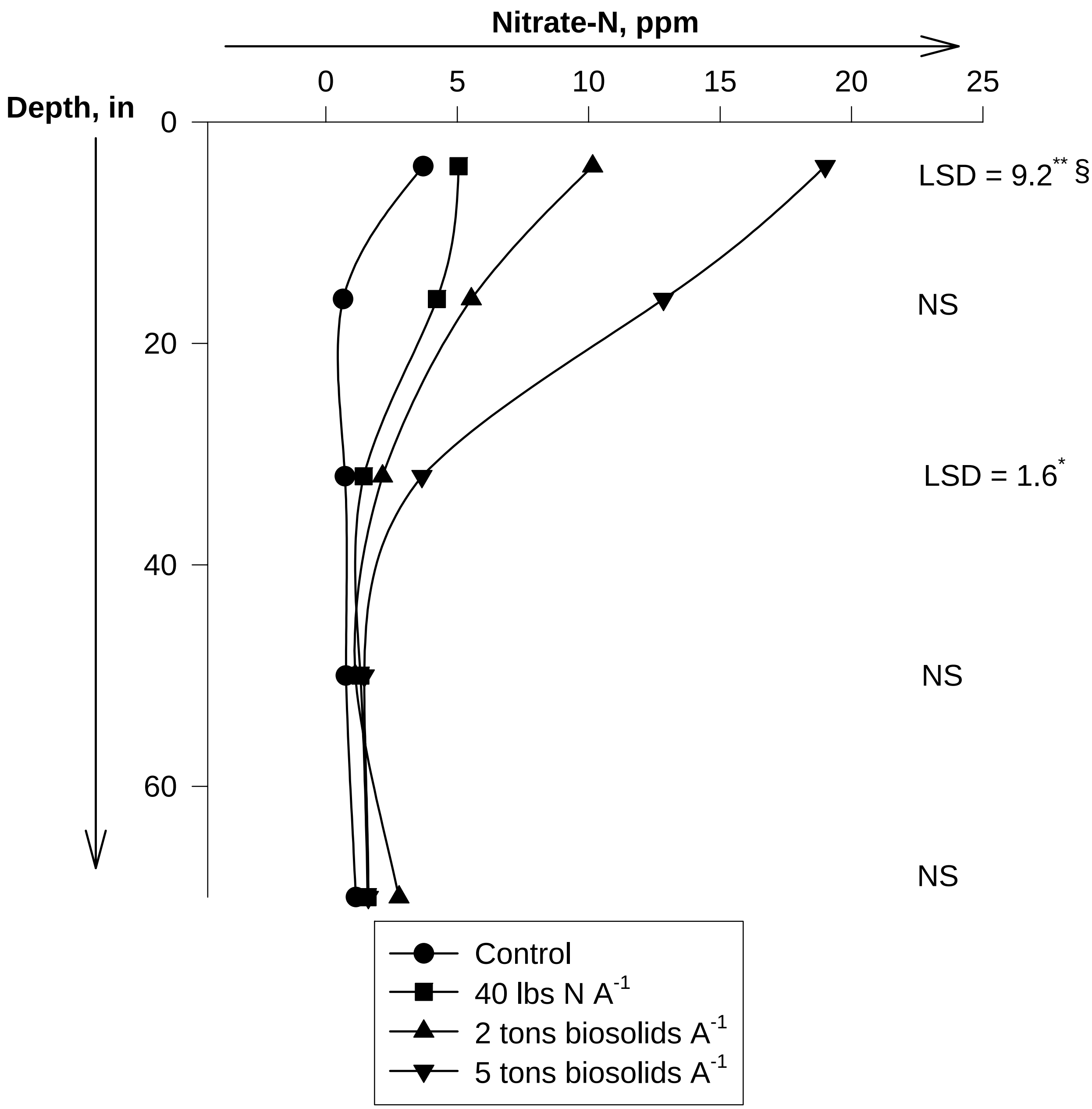


Figure 2. North Bennett Harvest Soil Nitrogen 2004-05.



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