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Application of Anaerobically Digested Biosolids to Dryland Winter Wheat 2003-2004 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-third 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 they 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.

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 nutrient and trace metal content, (d) soil nutrient and trace metal accumulation, and (e) soil NO_3-N accumulation and movement.

MATERIALS AND METHODS

The North Bennett experimental plots used in the 2003-04 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 28 and 29 July 2003, respectively. The same plots received biosolids and N fertilizer, at the above rates, in August 1993, 1995, 1997, 1999, and 2001. 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 and 2001 seasons.

At harvest (6 July 2004), we measured grain yield and protein content. We estimated net income using prices paid for wheat in March 2004, subtracted the cost for either fertilizer or biosolids, and considered all other costs equal. We applied urea fertilizer, but 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 cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), molybdenum (Mo), nickel (Ni), and zinc (Zn) concentrations.

Following harvest in July 2004, 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 2003-04 crop year only. The reader is reminded that the 2003-04 North Bennett plots received biosolids at the same application rates in August 1993, 1995, 1997, 1999, and 2001. Considering these five prior years and the current application, the recommended 2 dry tons A^{-1} biosolids rate for the 2003-04 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 were greater than the Adams County average yield (30 bu A^{-1}; Table 2). This was attributable to the well-managed crop residue that promoted efficient use of precipitation. We also found that increasing N fertilizer and biosolids rates increased protein content, although there was no difference between N fertilizer and biosolids treatments.

The biosolids average economic return was slightly greater than the average N fertilizer economic return (Table 2). This finding is similar to 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 equal to that of the 40 lbs N fertilizer A^{-1} treatment (\$144 A^{-1}). This trend is different than years past 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 and 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 metal concentrations (Table 3), but did increase straw Cd, Cu, and Zn concentrations, and in general decreased straw Ni concentration (Table 4). Increasing biosolids rate increased grain Cu, Ni, and Zn concentrations (Table 3), increased straw Cu and Zn concentrations, and decreased straw Mo concentration (Table 4). Overall, straw from biosolids treated plots had greater amounts of Mo and 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 caused a slight decrease in soil Ni concentration and increasing biosolids rate increased soil Cu concentration in the 0-8-inch depth (Table 5). As compared with N fertilizer, biosolids application increased Cu and Zn soil concentrations in the 0-8-inch depth. There were no differences within or between treatments in the 8-24-inch soil depth (Table 6). Soil nutrient and trace metal concentrations in both depths are ten to one hundred times lower than those considered hazardous to human health (Chang et al., 1992).

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 1). This rate caused NO_3-N to be slightly above 10 ppm in the 0-8-inch depth, but was below 10 ppm throughout the remainder of the soil profile. Applicators could fertilizer with biosolids if soil NO_3-N concentrations within the top foot of soil are less than 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 throughout the profile. However, this application rate did not produce any soil NO_3-N levels above 10 ppm throughout the remainder of 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 2003-2004 produced yields at the North Bennett site greater than the long-term Adams County average. This was attributable to the well-managed crop residue which promoted efficient precipitation usage. We also found that increasing N fertilizer and biosolids rates increased grain protein content. On average, estimated net income was slightly greater with biosolids application versus N fertilizer applications. 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 was a greater economic advantage.

Increasing N fertilizer rates did not affect grain trace metal concentrations, but did increase straw Cd, Cu, and Zn concentrations, and affected straw Ni concentration. Increasing biosolids rates resulted in increased grain Cu, Ni, and Zn concentrations. Biosolids caused a decrease in straw Mo concentration. Straw Ni and 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.

Increasing N fertilizer rate caused a slight decrease in soil Ni concentration, while increasing biosolids rate increased soil Cu concentration in the 0-8-inch depth. As compared to N fertilizer, biosolids application increased Cu and Zn soil concentrations in the 0-8-inch depth. There were no differences within or between treatments on these metal concentrations in the 8-24-inch soil depth. Soil nutrient and trace metal concentrations in both depths were ten to one hundred times lower in concentration than those considered hazardous to human health by the World Health Organization.

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 12 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 in throughout the soil profile. This application rate did not produce any soil NO_3-N levels above 10 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.

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Table 1. Average composition of Littleton/Englewood biosolids applied in 2003-04 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 (%)	1.9		
NO_3-N (%)	<0.01		
NH_4-N (%)	0.3		
Solids (%)	92		
P (%)	2.4		
As (mg kg^{-1})[π]	1.4	41	75
Cd "	1.7	39	85
Cr "	16.1	1200	3000
Cu "	594	1500	4300
Pb "	15.0	300	840
Hg "	0.10	17	57
Mo "	15.2	Not finalized	75
Ni "	10.9	420	420
Se "	0.15	36	100
Zn "	418	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 estimated income at North Bennett, 2003-04.

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		51	10.4	0	171
20		46	12.6	9	145
40		47	12.3	13	144
60		45	13.8	18	133
80		46	14.5	22	132
100		43	14.8	26	118
Mean[§]		45	14.1	18	133
Sign. N rates		NS[¶]	*		
LSD[§]			2.2		
	0	43	10.7	0	144
	1	45	12.2	0	151
	2	43	13.5	0	144
	3	43	14.8	0	144
	4	42	14.8	0	141
	5	38	15.2	0	127
	Mean[§]	42	14.1	0	141
	Sign. biosolids rates	*	*		
	LSD	6	2.2		
	N vs. biosolids[§]	NS	NS		

† Identical biosolids applications were made in 1993, 1995, 1996, 1999, and 2001; 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 \$3.35 bu^{-1} for wheat from January 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, 2003-04.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1}[†]	Cd -----------	Cr -----------	Cu -----------	Pb mg kg^{-1}	Mo -----------	Ni ----------	Zn -----------
0		0.02	ND[¶]	2.47	ND	0.15	1.02	14.6
20		0.02	ND	3.17	ND	0.16	1.49	18.5
40		0.03	0.03	3.09	ND	0.22	1.09	15.5
60		0.02	ND	3.37	ND	0.19	1.18	17.7
80		0.02	ND	3.57	ND	0.16	1.14	17.5
100		0.03	0.08	3.17	ND	0.13	1.74	17.4
Mean[§]		0.02	0.02	3.27	ND	0.17	1.33	17.3
Sign. N rates		NS		NS		NS	NS	NS
LSD								
	0	0.02	ND	2.94	ND	0.22	0.96	18.4
	1	0.02	ND	3.20	ND	0.19	0.87	19.2
	2	0.02	ND	3.52	ND	0.23	0.97	19.7
	3	0.01	ND	3.70	ND	0.13	1.02	21.5
	4	0.01	ND	4.11	ND	0.18	1.14	23.9
	5	0.02	0.04	3.74	ND	0.15	1.64	24.8
	Mean	0.01		3.65	ND	0.18	1.13	21.8
	Sign. biosolids rates	NS		**		NS	*	**
	LSD			0.57			0.71	4.1
	N vs bio-solids	NS		NS		NS	NS	NS

† Identical biosolids applications were made in 1993, 1995, 1996, 1999, and 2001; 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, 2003-04.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1}[†]	Cd	Cr	Cu	Pb mg kg^{-1}	Mo	Ni	Zn
0		0.06	0.75	1.57	ND	0.31	0.47	3.78
20		0.06	0.71	1.56	ND	0.23	0.43	4.58
40		0.05	0.79	1.70	ND	0.33	0.41	3.87
60		0.06	0.57	1.84	ND	0.33	0.34	4.04
80		0.08	0.52	1.99	ND	0.26	0.37	5.06
100		0.10	0.72	2.17	ND	0.22	0.48	5.90
Mean[§]		0.07	0.66	1.85	ND	0.27	0.41	4.69
Sign. N rates		**[¶]	NS	**		NS	**	*
LSD		0.04		0.53			0.12	1.44
	0	0.05	0.78	1.57	ND	0.27	0.46	4.91
	1	0.05	0.71	1.79	ND	0.34	0.45	4.91
	2	0.08	0.84	2.05	ND	0.41	0.50	5.69
	3	0.06	0.85	2.35	ND	0.26	0.55	6.37
	4	0.06	0.68	2.50	ND	0.29	0.47	7.41
	5	0.06	0.65	2.53	ND	0.20	0.46	7.82
	Mean	0.06	0.75	2.24	ND	0.30	0.49	6.44
	Sign. biosolids rates	NS	NS	**		*	NS	*
	LSD			0.61		0.14		2.70
	N vs bio-solids	NS	NS	NS		NS	*	*

† Identical biosolids applications were made in 1993, 1995, 1996, 1999, and 2001; 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, 2003-04.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1} [†]	Cd -----------	Cr -----------	Cu -----------	Pb mg kg^{-1}	Mo -----------	Ni ----------	Zn -----------
0		ND[¶]	11.3	11.4	2.83	0.004	11.5	60.1
20		ND	12.3	13.3	3.01	0.004	13.2	64.0
40		ND	12.2	12.6	3.09	0.000	12.2	62.6
60		ND	11.7	12.0	2.80	0.000	11.5	61.5
80		ND	12.2	12.7	3.13	0.000	11.9	63.6
100		ND	11.6	11.8	2.77	0.000	11.2	63.2
Mean[§]		ND	12.0	12.5	2.96	0.001	12.0	63.0
Sign. N rates			NS	NS	NS	NS	*	NS
LSD							1.8	
	0	ND	11.9	12.1	3.07	0.004	11.6	61.6
	1	ND	11.9	13.7	2.73	0.000	11.6	64.9
	2	ND	12.5	15.0	3.42	0.005	12.0	67.1
	3	ND	11.8	13.8	3.12	0.000	11.4	67.2
	4	ND	12.3	17.0	3.27	0.004	11.8	70.4
	5	ND	12.4	17.6	3.36	0.005	12.0	69.6
	Mean	ND	12.2	15.4	3.18	0.003	11.8	67.8
	Sign. biosolids rates		NS	**	NS	NS	NS	NS
	LSD			3.2				
	N vs bio-solids		NS	**	NS	NS	NS	**

† Identical biosolids applications were made in 1993, 1995, 1996, 1999, and 2001; 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, 2003-04.

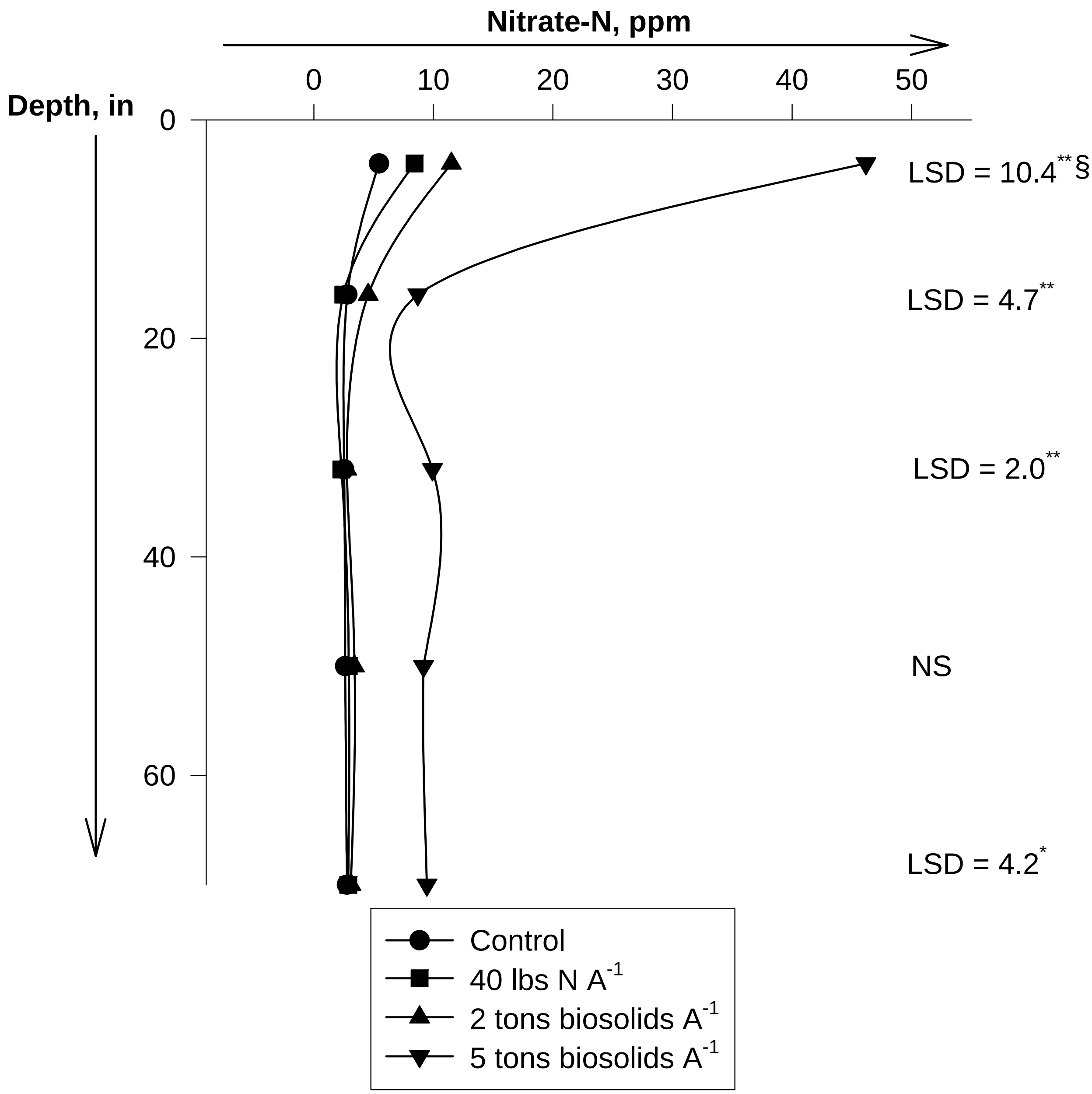
N fert. lbs N A^{-1}	Biosolids dry tons A^{-1}[†]	Cd -----------	Cr -----------	Cu -----------	Pb mg kg^{-1}	Mo -----------	Ni ----------	Zn -----------
0		ND[¶]	8.81	10.2	3.08	ND	9.22	51.2
20		ND	9.18	10.5	3.05	ND	9.49	52.6
40		ND	8.62	10.0	3.01	ND	9.13	51.3
60		ND	8.75	10.2	2.73	ND	9.25	52.4
80		ND	8.90	10.3	2.87	ND	9.29	52.1
100		ND	8.69	10.6	2.61	ND	9.22	51.7
Mean[§]		ND	8.83	10.3	2.85	ND	9.28	52.0
Sign. N rates			NS	NS	NS		NS	NS
LSD								
	0	ND	8.43	10.0	2.58	ND	8.88	51.1
	1	ND	9.39	10.8	3.04	ND	9.65	53.4
	2	ND	8.67	10.2	2.91	ND	9.22	51.3
	3	ND	9.07	10.4	2.96	ND	9.26	52.1
	4	ND	8.96	10.9	2.85	ND	9.38	52.5
	5	ND	8.92	10.2	2.99	ND	9.41	51.2
	Mean	ND	9.00	10.5	2.95	ND	9.38	52.1
	Sign. biosolids rates		NS	NS	NS		NS	NS
	LSD							
	N vs bio-solids		NS	NS	NS		NS	NS

† Identical biosolids applications were made in 1993, 1995, 1996, 1999, and 2001; 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. Nitrate-nitrogen in the soil following wheat harvest at the North Bennett site, 2003-04.



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