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APPLICATION OF ANAEROBICALLY DIGESTED BIOSOLIDS TO DRYLAND WINTER WHEAT 2002-2003 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; (http://www.epa.gov/unix0008/water/). 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 twenty-second 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 can move below the root zone or off-site and contaminate groundwater or surface waters. 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.

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 required by winter wheat. 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} as the most viable land-application rate for similar biosolids nutrient characteristics and crop yields.

The overall objective of our research was 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 pH, EC, total C, inorganic and organic C, total N, and C/N ratio, and (e) soil NO_3-N accumulation.

MATERIALS AND METHODS

The North Bennett experimental plots used in the 2002-03 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.

We applied biosolids (60% 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 26 and 22 July 2002, respectively. The same plots received biosolids and N fertilizer, at the above rates, in August 1994, 1996, 1998, and 2000. 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 and 2002 seasons.

At harvest (20 July 2003), we measured grain yield and protein content. We estimated gross income using prices paid for wheat in March 2004 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 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 2003, we collected soil samples from the 0-8 and 8-24-inch depths from all plots and analyzed them for pH, EC, total C, inorganic C, organic C, total N, and C/N ratio. 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. All plant and soil samples were analyzed using analysis of variance. If significant, a least-significant difference (LSD) was calculated at either the 95 or 99% confidence interval.

This report provides data for the 2002-03 crop year only. The reader is reminded that the 2002-03 North Bennett plots received biosolids at the same application rates in August 1994, 1996, 1998, and 2000. Considering these four prior years and the current application, the recommended 2 dry tons A^{-1} biosolids rate for the 2002-03 growing season represents a cumulative addition of 10 dry tons A^{-1} biosolids for the life (9 years) of the experiment.

RESULTS AND DISCUSSION

Grain Yields, Protein Content, and Estimated Income

North Bennett grain yields were similar to the Adams County average yield (30 bu A^{-1}; 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. These findings were similar to our 2001-02 growing season results, also a drought year.

The biosolids average economic return was similar to the average N fertilizer economic return (Table 2). This finding is different than our 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 lower return (\$114 A^{-1}) as compared to the 40 lbs N fertilizer A^{-1} treatment (\$140 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 a cost to the system.

Biosolids Application Recommendation

To better determine the N equivalency of the biosolids, we compared yields from N fertilizer and biosolids plots at North Bennett. However, we did not find any significant relationships for the biosolids or N fertilizer 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 or straw trace metal concentrations (Tables 3 and 4). Increasing biosolids rate decreased grain and straw Mo concentration and increased straw Cd concentration. Overall, grain and straw from biosolids treated plots had lesser amounts of Mo as compared to N-treated plots. All grain and straw metal concentrations were well below the levels considered harmful to livestock (National Research Council, 1980).

Soil pH and Electrical Conductivity

Increasing N fertilizer rate caused a slight decrease in soil pH and increase in EC in the 8-24-inch depth (Table 5). Increasing biosolids rate had no effect on soil pH, but caused a slight increase in EC in the 8-24-inch depth. No differences were observed between N fertilizer and biosolids.

Soil Total C, Inorganic C, Organic C, Total N, and C/N Ratio

Increasing N fertilizer did not affect total C, inorganic C, organic C, total N, or the soil C/N ratio in the 0-8-inch depth (Table 6). Increasing biosolids rate, however, caused a slight increase in organic C content and a decrease in the C/N ratio. However, even after 5 biosolids applications we did not observe an increase in organic C content as compared to N fertilizer.

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). In addition, this rate did not increase NO_3-N above 2 ppm anywhere in the profile. The 5 dry tons biosolids A^{-1} application rate significantly increased NO_3-N in the 0-8-inch depth. However, this application rate did not produce any soil NO_3-N levels above 6 ppm. This indicates the movement of NO_3-N below the root zone is minimal as compared to the control.

SUMMARY

Increasing the N fertilizer and biosolids land application rates in 2002-2003 produced yields at the North Bennett site similar to 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 similar with biosolids application versus N fertilizer. The recommended 2 dry tons A^{-1} rate produced an economic return less than the 40 lbs N A^{-1} treatment. This trend was different than previous findings which showed the recommended 2 dry tons A^{-1} rate providing a greater economic advantage as compared to the 40 lbs N fertilizer A^{-1} treatment.

Increasing N fertilizer rates did not affect grain or straw trace metal concentrations, while increasing biosolids rates resulted in decreased grain and straw Mo concentrations, and increased straw Cd. The straw Mo concentration was greater with N fertilizer treatment versus biosolids. All metal concentrations in wheat plants were well below those levels considered harmful to livestock.

Increasing N fertilizer rates caused a slight decrease in soil pH and increase in EC in the 8-24-inch soil depth, and did not affect total C, inorganic C, organic C, total N, or the soil C/N ratio. Increasing biosolids rates caused a slight increase in soil EC in the 8-24-inch depth, and a slight increase in organic C and decrease in the soil C/N ratio in the 0-8-inch depth. No differences were observed between N fertilizer and biosolids treatments for soil pH, EC, or C/N dynamics.

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 2 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 the soil 0-8-inch depth. This application rate did not produce any soil NO_3-N levels above 6 ppm. This indicates that NO_3-N movement below the root zone is minimal and that five applications of biosolids, applied every other year over ten years, have not led to significant 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}. 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

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Table 1. Average composition of Littleton/Englewood (L/E) sludge applied in 2002-03 compared to the Grade I and II biosolids limits.

Property	L/E Biosolids Dry Weight Concentrations	Limit	
		Grade I Biosolids[¶]	Grade II Biosolids
Organic N (%)	5.3		
NO_3-N (%)	<0.01		
NH_4-N (%)	1.0		
Solids (%)	60		
P (%)	1.9		
As (mg kg^{-1})[π]	1.6	41	75
Cd "	0.9	39	85
Cr "	9.9	1200	3000
Cu "	326	1500	4300
Pb "	9.8	300	840
Hg "	3.7	17	57
Mo "	16	Not finalized	75
Ni "	7.6	420	420
Se "	6.0	36	100
Zn "	351	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, 2002-03.

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		29	13.5	0	127
20		27	13.9	9	109
40		35	14.6	13	140
60		30	14.2	18	113
80		32	15.0	22	118
100		34	15.0	26	123
Mean[§]		31	14.5	18	117
Sign. N rates		NS[¶]	*		
LSD[§]			1.1		
	0	23	13.0	0	101
	1	32	14.3	0	140
	2	26	14.6	0	114
	3	30	15.1	0	131
	4	26	14.9	0	114
	5	22	15.2	0	96
	Mean[§]	27	14.8	0	118
	Sign. biosolids rates	NS	*		
	LSD		0.7		
	N vs. biosolids[§]	NS	NS		

† Identical biosolids applications were made in 1994, 1996, 1998 2000, and 2002; 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 \$4.37 bu^{-1} for wheat from March 2004.

§ 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, 2002-03.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1} †	Cd	Cr	Cu	Pb	Mo	Ni	Zn
					mg kg^{-1}			
0		0.03	0.32	5.35	0.36	0.88	5.52	23.2
20		0.03	0.15	5.45	0.36	0.79	4.22	20.0
40		0.04	0.32	5.62	0.32	0.74	5.27	23.4
60		0.02	0.19	5.47	0.25	0.88	4.91	22.3
80		0.04	0.17	5.40	0.18	0.69	4.45	24.2
100		0.03	0.16	5.42	0.30	0.72	4.88	22.2
Mean§		0.03	0.20	5.47	0.28	0.76	4.74	22.4
Sign. N rates		NS¶	NS	NS	NS	NS	NS	NS
LSD								
	0	0.03	0.14	5.14	0.31	0.88	4.69	22.7
	1	0.05	0.24	5.44	0.33	0.66	5.21	23.3
	2	0.03	0.20	5.55	0.24	0.57	4.68	27.0
	3	0.04	0.46	5.38	0.25	0.53	6.03	27.6
	4	0.02	0.31	5.92	0.37	0.58	5.77	33.3
	5	0.03	0.19	5.34	0.39	0.50	4.44	28.9
	Mean	0.03	0.28	5.52	0.32	0.57	5.23	28.0
	Sign. biosolids rates	NS	NS	NS	NS	*	NS	NS
	LSD					0.12		
	N vs bio-solids	NS	NS	NS	NS	**	NS	NS

† Identical biosolids applications were made in 1994, 1996, 1998, 2000, and 2002; 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, 2002-03.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1}†	Cd	Cr	Cu	Pb mg kg^{-1}	Mo	Ni	Zn
0		0.06	1.30	2.75	0.38	1.49	0.83	12.9
20		0.06	1.28	2.51	0.39	1.15	0.79	10.2
40		0.08	1.22	2.70	0.32	1.24	0.76	9.27
60		0.07	1.19	2.82	0.49	1.70	0.85	12.4
80		0.08	0.95	3.00	0.43	0.96	0.78	13.7
100		0.08	0.79	2.93	0.50	1.24	0.60	12.4
Mean§		0.07	1.08	2.79	0.44	1.26	0.76	11.6
Sign. N rates		NS¶	NS	NS	NS	NS	NS	NS
LSD								
	0	0.04	1.02	2.73	0.42	1.65	0.71	12.3
	1	0.07	0.94	3.07	0.44	0.99	0.71	14.2
	2	0.08	1.31	2.97	0.40	0.78	0.84	12.9
	3	0.08	1.03	2.94	0.44	0.51	0.74	12.9
	4	0.12	1.03	2.95	0.39	0.87	0.65	12.9
	5	0.13	1.51	2.84	0.30	0.55	0.95	13.0
	Mean	0.08	1.13	2.87	0.42	1.00	0.77	12.4
	Sign. biosolids rates	*	NS	NS	NS	*	NS	NS
	LSD	0.06				0.34		
	N vs bio-solids	NS	NS	NS	NS	**	NS	NS

† Identical biosolids applications were made in 1994, 1996, 1998, 2000, and 2002; 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 5. Effects of N fertilizer and biosolids rates on pH and EC in the 0-8 and 8-24-inch depths at harvest at North Bennett, 2002-03.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1} †	0 to 8 inches pH	EC ($dS\ m^{-1}$)	8 to 24 inches pH	EC ($dS\ m^{-1}$)
0		7.4	0.33	8.2	0.24
20		7.8	0.30	8.4	0.22
40		7.3	0.37	8.1	0.27
60		7.7	0.34	8.3	0.22
80		7.3	0.35	8.0	0.35
100		7.6	0.36	8.2	0.30
Mean§		7.5	0.34	8.2	0.27
Sign. N rates		NS¶	NS	*	*
LSD				0.2	0.08
	0	7.6	0.30	8.1	0.24
	1	7.7	0.33	8.2	0.24
	2	7.6	0.39	8.1	0.34
	3	7.2	0.47	8.1	0.31
	4	7.6	0.38	8.2	0.31
	5	7.3	0.50	8.0	0.38
	Mean	7.5	0.41	8.1	0.32
	Sign. biosolids rates	NS	NS	NS	*
	LSD				0.09
	N vs biosolids	NS	NS	NS	NS

† Identical biosolids applications were made in 1994, 1996, 1998, 2000, and 2002; 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.

Table 6. Total C, inorganic and organic C, total N, and the C/N ratio in the 0-8-inch depth at harvest at North Bennett, 2002-03.

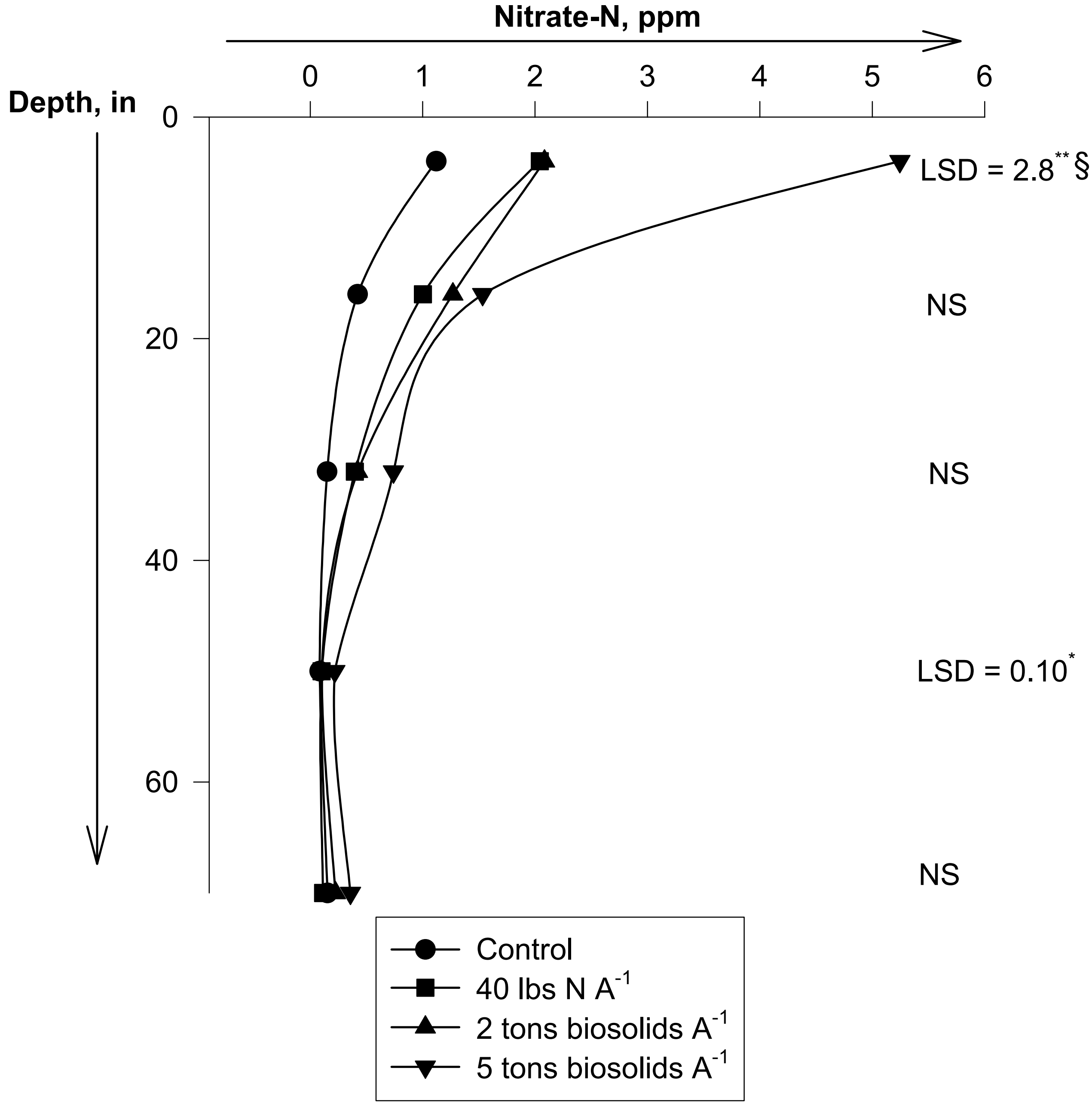
N fert. lbs N A^{-1}	Biosolids dry tons A^{-1} †	Total C %	Inorganic C %	Organic C %	Total N %	C/N Ratio
0		0.81	0.10	0.70	0.05	19.0
20		0.81	0.09	0.72	0.05	37.0
40		0.71	0.01	0.70	0.05	15.6
60		1.02	0.31	0.72	0.06	21.2
80		0.79	0.06	0.73	0.05	18.2
100		0.76	0.08	0.67	0.05	21.2
Mean§		0.82	0.11	0.71	0.05	22.7
Sign. N rates		NS	NS	NS	NS	NS¶
LSD						
	0	0.71	0.08	0.63	0.04	46.0
	1	0.96	0.23	0.74	0.05	20.2
	2	0.89	0.06	0.83	0.07	12.8
	3	0.83	0.01	0.83	0.07	13.1
	4	0.85	0.07	0.78	0.07	13.4
	5	0.88	0.12	0.76	0.07	15.2
	Mean	0.88	0.09	0.79	0.07	14.9
	Sign. bio-solids rates	NS	NS	*	NS	*
	LSD			0.09		6.5
	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 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.

Figure 1. North Bennett Harvest Soil Nitrogen 2002-03.



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