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APPLICATION OF ANAEROBICALLY DIGESTED BIOSOLIDS TO DRYLAND WINTER WHEAT 2013-2014 RESULTS

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INTRODUCTION

Over 40% of biosolids are land applied in the U.S. (Brobst, Robert. 2011. USEPA, Personal Communication). Land application 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 thirty third year, has provided information on the effects of continuous biosolids applications to dryland winter wheat (*Triticum aestivum* L.) and on soil properties. Previous research has shown that Littleton/Englewood biosolids are an effective alternative to commercial N fertilizer with respect to grain production and nutrient content of winter wheat (Barbarick et al., 1992). As with other N fertilizers, however, application rates of biosolids exceeding the N needs of the crop result in an accumulation of soil nitrate-N. Excess soil nitrate-N may move below the root zone or runoff to 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 provide a more constant supply of N during the critical grain-filling period versus commercial N fertilizer. They can also furnish significant amounts of plant available P, Zn, and Fe.

For the Littleton/Englewood biosolids, a 2 dry tons biosolids A^{-1} application rate will supply approximately 32 lbs N A^{-1} over the growing season (Barbarick and Ippolito, 2000; Barbarick and Ippolito, 2007), an amount within the typical application range for dryland winter wheat crops in our study area. Other biosolids sources may exhibit a different N fertilizer equivalency. Previous research has shown no detrimental grain trace-metal accumulation with this application rate (Barbarick et al., 1995). Therefore, we continue to recommend a 2 dry tons biosolids A^{-1} rate as the most sustainable land-application rate for biosolids with similar nutrient characteristics and for similar 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 grain production, b) estimated income, c) grain and straw total nutrient and trace-metal content, and d) soil NO_3-N accumulation and movement.

MATERIALS AND METHODS

The North Bennett experimental plots were established in August 1993. The soil is classified as a Weld loam, Aridic Argiustoll. The land is managed with minimum-tillage practices. Precipitation amounts are shown in Table 1.

We applied N fertilizer (46-0-0; urea) at rates of 0, 20, 40, 60, 80, and 100 lbs N A^{-1} and biosolids (93% solids, Table 2) at rates of 0, 1, 2, 3, 4, and 5 dry tons A^{-1} on 29 and 30 July 2013, respectively. The same plots received biosolids and N fertilizer, at the above rates, in July or August 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2009, 2011, and 2013. We did not apply biosolids nor N fertilizer in 2007 since the farmer grew proso millet (*Panicum millaceum*, L.) to help control an infestation of jointed goat grass (*Aegilops cylindrica* Host). 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 2). We uniformly broadcast both biosolids and N fertilizer and the materials were incorporated to a depth of 4 to 6 inches. The North Bennett site was cropped with the winter wheat cultivar 'TAM 107' during the 1993-4, 1995-6, and 1997-8 growing seasons, 'Prairie Red' during the 1999-2006 seasons, 'Ripper' from 2007-12, and 'Prowers99' in 2013 .

At harvest (10 July 2014), we measured grain yield and protein content. We estimated net return to fertilizer application using $7.03 per bushel for wheat (USDA-ERS, 2015b), subtracted the cost for either N fertilizer ($.64 lb^{-1} N; USDA-ERS, 2015a) or biosolids, and considered all other costs equal. The biosolids and its application are currently free. We collected three random 3-foot row samples from each plot on 10 July 2014 to determine biomass and grain yields. Plant P, Cu, Ni, and Zn concentrations were determined in nitric-acid digests (Huang and Schulte, 1985) using an inductively coupled plasma-atomic emission spectrophotometer (ICP-AES; Soltanpour et al., 1996).

Two to three soil samples from 0 to 8 and 8 to 24 inches were taken from each plot and composited. We used ammonium bicarbonate diethylenetriaminepentaacetic acid (ABDTPA) to extract the soils and determine plant-available P, Cu, Ni, and Zn using the ICP-AES (Barbarick and Workman, 1987). 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 2013-2014 crop year only. The reader is reminded that the 2013-2014 North Bennett plots received biosolids at the same application rates in July or August 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2009, 2011, and 2013. Considering these nine prior applications plus the most recent application, the recommended 2 dry tons A^{-1} biosolids rate for the 2013-2014 growing season represents a cumulative addition of 20 dry tons A^{-1} biosolids for the life of the experiment or about 320 lbs. available N A^{-1}.

RESULTS AND DISCUSSION

Grain Yields, Protein and Grain and Straw Elemental Content, and Estimated Income

Commercial N fertilizer rates increase grain Cu but did not impact grain yields and protein and grain and straw P, Ni, and Zn concentrations (Tables 3-5). The L/E biosolids did not affect yields nor protein nor grain and straw P, Cu, Ni, and Zn concentrations but significantly increased protein and straw P and Zn content as application rates increased. Compared to the N fertilizer, the biosolids produced greater grain and straw P and grain Zn concentrations. All grain and straw metal contents were well below the levels considered harmful to livestock (National Research Council, 1980).

Yields (average of about 50 bu A^{-1}) were above the Colorado 2014 average yield of 38 bushels A^{-1} (USDA NASS Colorado Field Office, 2015). Over 16 inches of precipitation in 2013 led to the above average yields (Table 1). Because it was supplied free of charge, the biosolids provided higher income per acre than the N fertilizer (Table 3).

Biosolids Application Recommendation

We compared yields from N and biosolids plots at North Bennett to determine the N equivalency of the biosolids. However, we did not find any significant N equivalency relationships for the biosolids or N-fertilizer treatments (Figure 1). 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; Barbarick and Ippolito, 2007). This approximation is used in planning long-term biosolids applications.

<u>Nutrient Availability and Residual Soil NO_3-N</u>

Biosolids or N fertilizer application did not affect AB-DTPA soil-extractable nutrient levels in the 0-8 or the 8-24 inch soil depths (Tables 6 and 7). Neither the recommended 2 dry tons biosolids A^{-1} nor the 5 dry tons biosolids A^{-1} application rate significantly affected NO_3-N throughout the profile as compared to either the control or the 40 lbs N A^{-1} fertilizer application rate (Figure 2). Soil NO_3-N concentrations at all depths and for all treatments were less than 10 ppm.

SUMMARY

North Bennett grain yields were above the Colorado 2014 average yield of 38 bu A^{-1} (USDA NASS Colorado Field Office, 2015) because of excellent precipitation levels. On average, the estimated net return to biosolids was greater than the N fertilizer application primarily due to the cost-free aspect of biosolids application. This trend was similar to previous findings where biosolids usage provided a greater economic advantage.

The biosolids produced greater grain and straw P and Zn and grain Zn concentrations relative to the N fertilizer. All grain and straw metal concentrations were well below the levels considered harmful to livestock, and all findings were relatively similar to previous years. The 2 and 5 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} fertilizer application rate.

We continue to recommend 2 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} of fertilizer (Barbarick and Ippolito, 2000; Barbarick and Ippolito, 2007). These approximations are used in planning long-term biosolids applications. We recommend that producers use soil testing and, biosolids analyses, and along with appropriate yield goals to select a fertilizer program that will ensure optimum crop yields along with environmental protection.

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Table 1. Monthly precipitation (Precip) in inches at the Bennett research site, 2010-2014. (Precipitation datalogger was installed in May, 2008).

	2010	2011	2012	2013	2014
	Precip., inches				
January	0.1	0.3	0.1	0.3	0.2
February	0.2	0.0	0.4	0.4	0.2
March	0.3	0.2	0.0	0.8	0.5
April	2.5	0.9	1.4	1.3	1.1
May	1.5	3.7	1.2	1.0	2.8
June	1.8	0.7	0.7	1.2	1.7
July	1.4	3.6	1.2	2.8	0.4
August	2.5	1.5	0.1	2.3	
September	0.1	1.0	2.0	6.0	
October	0.8	0.9	1.2	0.5	
November	0.5	0.2	0.4	0.1	
December	0.0	0.1	0.2	0.0	
Total	11.7	13.1	8.9	16.7	6.9

Table 2. Average composition of Littleton/Englewood biosolids applied in 2013-2014 compared to the Grade I and II biosolids limits.

Property	Dry Weight Concentration Littleton/Englewood	lbs. added per ton	Grade I Biosolids Limit[¶]	Grade II Biosolids Limit
Organic N (%)	4.67	93		
NO_3-N (%)	<0.01	---		
NH_4-N (%)	0.25	5		
Solids (%)	89.0	---		
P (%)	3.9	64		
Ag (mg kg^{-1}) [†]	6.8	0.089		
As (mg kg^{-1})	<0.001	<0.000001	41	75
Ba (mg kg^{-1})	306	0.62		
Be (mg kg^{-1})	0.08	0.0002		
Cd (mg kg^{-1})	1.5	0.0030	39	85
Cr (mg kg^{-1})	34.7	0.070	1200	3000
Cu (mg kg^{-1})	442	0.9	1500	4300
Pb (mg kg^{-1})	28.5	0.058	300	840
Hg (mg kg^{-1})	0.010	0.00002	17	57
Mn (mg kg^{-1})	406	0.49		
Mo (mg kg^{-1})	7.7	0.015	Not finalized	75
Ni (mg kg^{-1})	15.5	0.031	420	420
Se (mg kg^{-1})	8.0	0.016	36	100
Zn (mg kg^{-1})	956	1.92	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 3. Effects of N fertilizer and biosolids on wheat yield, and projected income at North Bennett, 2013-2014.

N fert. lbs. A^{-1}	Biosolids† dry tons A^{-1}	Yield bu A^{-1}	Fert. cost‡ \$ A^{-1}	Income - fert. cost \$ A^{-1}
0		52	0	393
20		59	23	423
40		54	36	372
60		49	49	321
80		60	62	392
100		51	75	311
Mean◊		55	49	367
LSD N rate¶		NS		
	0	59	0	446
	1	42	0	318
	2	60	0	469
	3	41	0	310
	4	55	0	416
	5	50	0	378
Mean◊		50	0	378
LSD biosolids rate¶		NS		
N vs. biosolids¶		NS		

† Identical biosolids applications were made in 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2009, 2011, and 2013; therefore, the cumulative amount is 10 times that shown.

‡ The price for urea was considered to be \$.64 lb^{-1} N (USDA-ERS, 2014a) plus \$10.00 A^{-1} application charge. The biosolids and its application are currently free. We used a grain price of \$7.56 bu^{-1} for wheat (USDA-ERS, 2014b).

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

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

Table 4. Effects of N fertilizer and biosolids rates on protein and elemental concentrations of dryland winter wheat grain at North Bennett, 2013-2014.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1} †	Protein %	P g kg^{-1}	Cu --------	Ni mg kg^{-1}	Zn -----------
0		12.0	3.4	3.7	0.38	19
20		13.1	3.5	3.4	0.40	19
40		14.0	3.4	3.7	0.40	18
60		14.6	3.8	3.8	0.42	20
80		13.6	3.4	4.0	0.44	19
100		16.3	3.8	4.9	0.49	23
Mean§		14.3	3.6	4.0	0.43	20
Sign. N rates		NS	NS	**	NS	NS
LSD				0.8		
	0	11.6	3.3	3.5	0.42	17
	1	14.9	3.9	4.1	0.43	23
	2	15.1	3.8	3.6	0.44	22
	3	16.8	4.1	4.5	0.58	28
	4	14.5	3.8	3.3	0.41	22
	5	17.3	4.2	4.3	0.46	26
	Mean	15.7	4.0	4.0	0.46	24
	Sign. biosolids rates	NS	NS	NS	NS	NS
	LSD					
	N vs biosolids	NS	**	NS	NS	**

† Identical biosolids applications were made in 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2009, 2011, and 2013; therefore, the cumulative amount is 10 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 elemental concentrations of dryland winter wheat straw at North Bennett, 2013-2014.

N fert. lbs N A^{-1}	Biosolids dry tons A^{-1}†	P g kg^{-1}	Cu ----------	Ni mg kg^{-1}	Zn -----------
0		1.1	1.8	0.37	6.6
20		1.1	1.4	0.27	5.9
40		1.2	1.7	0.30	6.7
60		1.4	1.7	0.25	7.4
80		1.0	1.3	0.25	6.1
100		1.4	5.2	0.57	11
Mean§		1.2	2.3	0.33	7.5
Sign. N rates		NS	NS	NS	*
LSD					3.9
	0	1.0	2.0	0.30	6.1
	1	1.5	2.0	0.28	7.4
	2	1.1	1.7	0.28	7.4
	3	2.5	3.1	0.42	14
	4	1.7	2.0	0.36	9.6
	5	1.7	2.4	0.32	10
	Mean	1.7	2.2	0.33	9.6
	Sign. biosolids rates	NS	NS	NS	NS
	LSD				
	N vs biosolids	**	NS	NS	NS

† Identical biosolids applications were made in 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2009, 2011, and 2013; therefore, the cumulative amount is 10 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. Soil ABDTPA elemental concentrations for the 0 to 8 inches depth at harvest at North Bennett, 2013-2014.

N fert. lbs N A^{-1}	Biosolids	P	Cu	Ni	Zn
	dry tons A^{-1}†		mg	kg^{-1}	
0		25	0.11	0.056	0.15
20		27	0.09	0.045	0.20
40		22	0.12	0.044	0.20
60		47	0.11	0.046	0.29
80		18	0.08	0.046	0.13
100		25	0.34	0.058	0.20
Mean§		28	0.15	0.048	0.20
Sign. N rates		NS	NS	NS	NS
LSD					
	0	20	0.10	0.043	0.16
	1	33	0.10	0.042	0.20
	2	29	0.10	0.042	0.24
	3	41	0.14	0.040	0.38
	4	23	0.11	0.044	0.43
	5	56	0.12	0.040	0.36
	Mean	36	0.11	0.042	0.32
	Sign. biosolids rates	NS	NS	NS	NS
	LSD				
	N vs biosolids	NS	NS	NS	NS

† Identical biosolids applications were made in 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2009, 2011, and 2013; therefore, the cumulative amount is 10 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 7. Soil ABDTPA elemental concentrations for the 8 to 24 inches depth at harvest at North Bennett, 2013-2014.

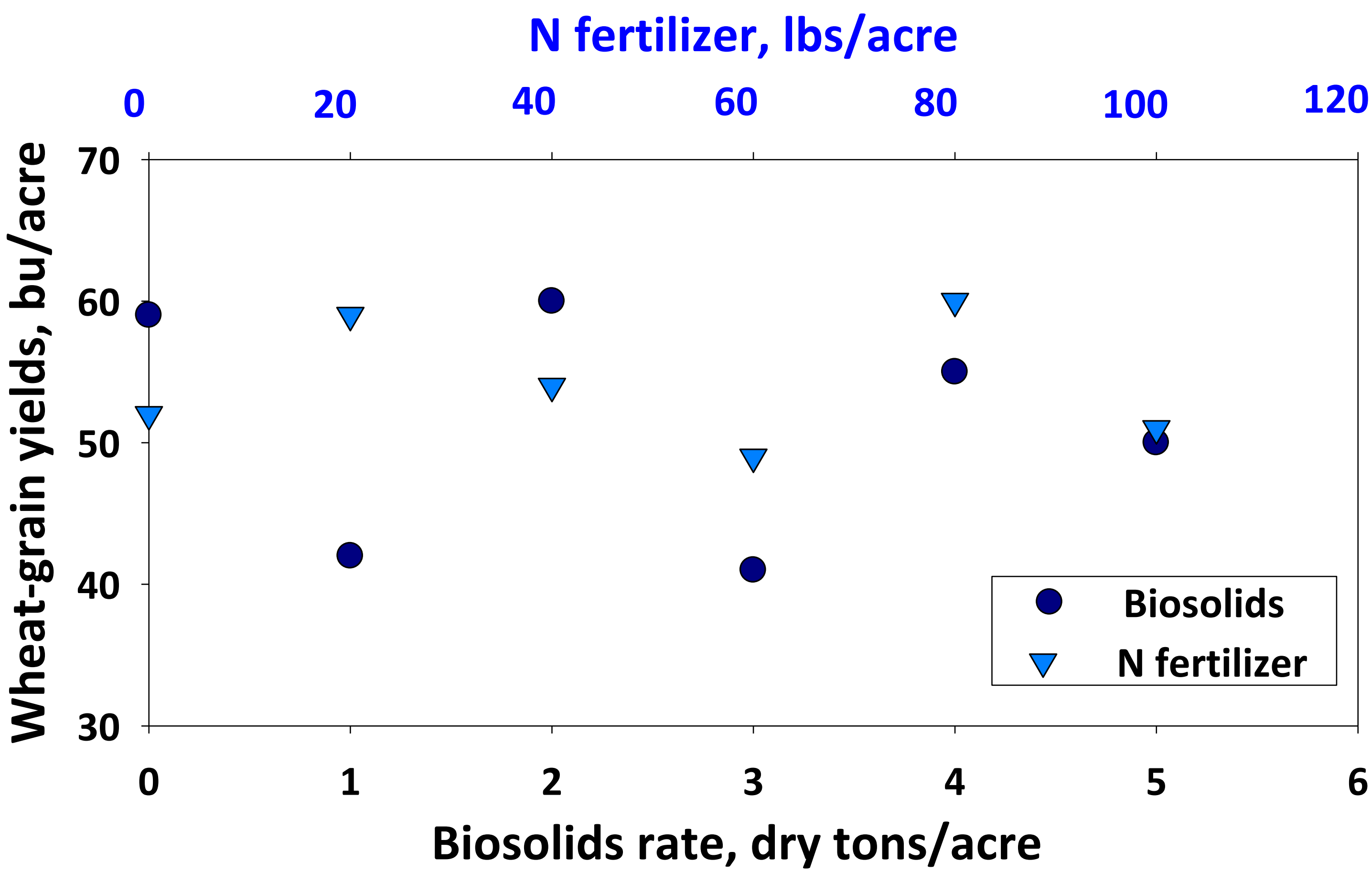
N fert. lbs N A^{-1}	Biosolids	P	Cu	Ni	Zn
	dry tons A^{-1}†		mg	kg^{-1}	
0		1	0.25	0.060	<0.01
20		1	0.62	0.134	<0.01
40		1	0.50	0.131	<0.01
60		1	0.15	0.037	<0.01
80		1	0.67	0.128	<0.01
100		1	0.33	0.062	<0.01
Mean§		1	0.45	0.098	<0.01
Sign. N rates		NS	NS	NS	
LSD					
	0	1	0.28	0.048	<0.01
	1	91	0.31	0.051	<0.01
	2	61	0.33	0.055	<0.01
	3	7	0.21	0.058	<0.01
	4	1	0.24	0.044	<0.01
	5	1	0.26	0.049	<0.01
	Mean	32	0.27	0.051	<0.01
	Sign. biosolids rates	NS	NS	NS	
	LSD				
	N vs biosolids	NS	NS	NS	

† Identical biosolids applications were made in 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2009, 2011, and 2013; therefore, the cumulative amount is 10 times that shown.

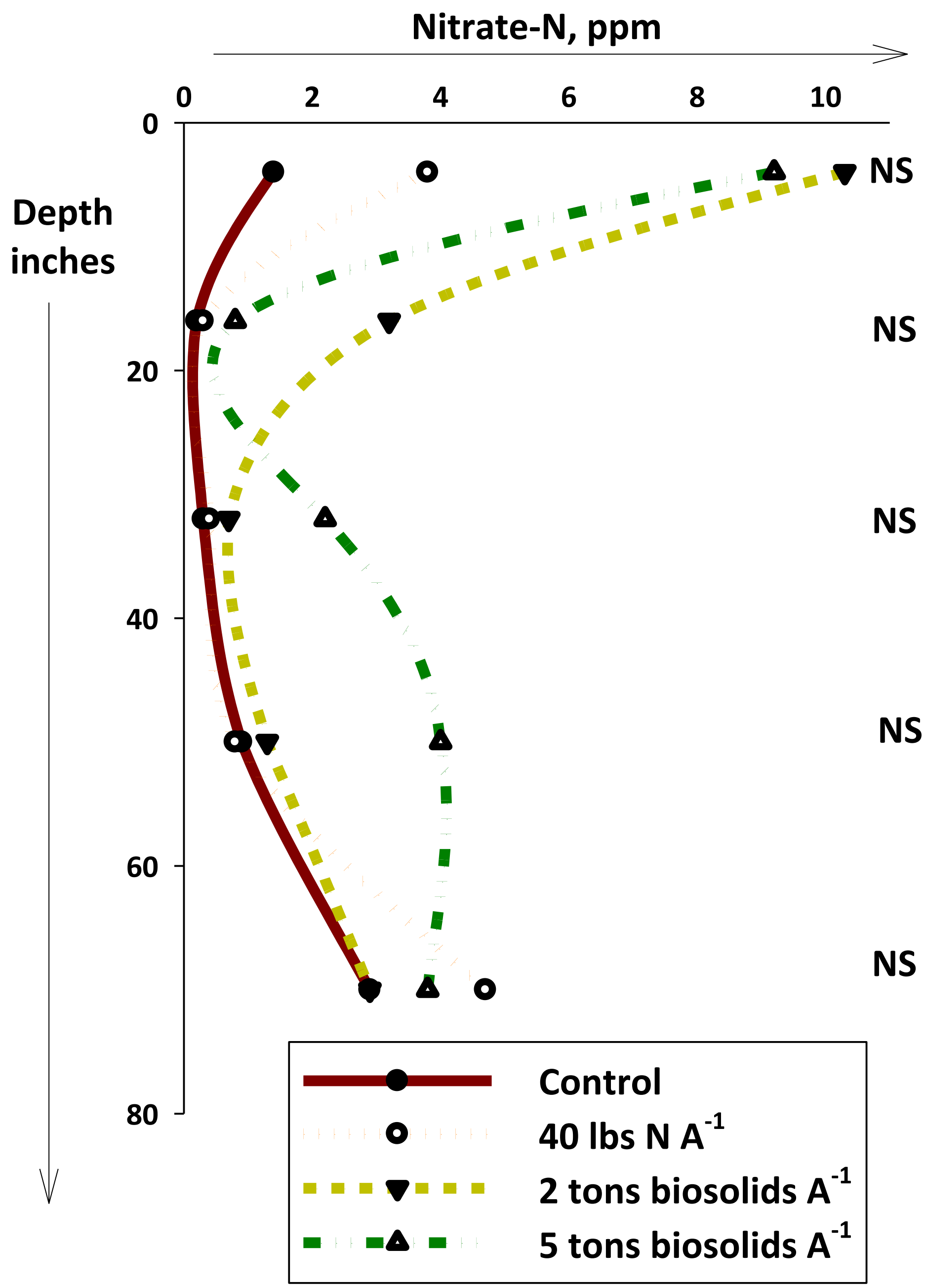
§ Means/LSDs/N vs biosolids do not include the controls (the zero rates).

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

Figure 1. North Bennett wheat yields in 2014 as affected by either N fertilizer or biosolids application.



North Bennett harvest soil nitrate-N, 2013-2014.



NS = non significant.