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APPLICATION OF ANAEROBICALLY DIGESTED BIOSOLIDS TO DRYLAND WINTER WHEAT[B]

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INTRODUCTION

The application of biosolids to agricultural land is the major method of biosolids disposal in the USA (USEPA, 1983). This method of disposal can be cost effective for municipalities by recycling plant nutrients in an environmentally sound manner (Barbarick et al., 1992).

Our long-term biosolids project, now in its fourteenth year, has provided valuable information on the effects of continuous biosolids application to dryland winter wheat. Previous research has shown that Littleton/Englewood biosolids is an effective alternative to commercial nitrogen fertilizer with respect to grain production and nutrient content of winter wheat (Barbarick et al., 1992). Biosolids contain organic N compounds, which perform as slow-release N sources and provide a more constant supply of N during the grain-filling period as compared to commercial N fertilizer. However, application rates exceeding the N needs of the crop result in an accumulation of soil nitrate-N (NO_3-N). Excess soil N could result in leaching below the root zone. We continue to recommend 3 dry tons biosolids A^{-1} application per crop year as the most viable dryland application rate for the L/E biosolids and other biosolids of similar characteristics. We base this recommendation on the amount of N released from biosolids over the growing season being similar to that of a typical N fertilizer application.

The overall objective of our research is to compare the effect of Littleton/Englewood biosolids and commercial N fertilizer on (a) dryland winter wheat (Triticum aestivum L., 'TAM 107') grain production, (b) grain and straw elemental content, (c) estimated income, and (d) soil NO_3-N accumulation.

MATERIALS AND METHODS

We established the West Bennett experimental site in Adams County, Colorado in August 1982 on the farm owned by the Hazlet family. The land is farmed using conventional tillage practices. We planted the winter wheat cultivar 'Vona' for the first eight years of the study, followed by 'TAM 107' (Triticum aestivum L., 'TAM 107') in years 9 to 14.

In August 1994 we applied air-dried biosolids (88% solids; Table 1), supplied by the Littleton/Englewood (L/E) wastewater treatment plant, at rates equivalent to 0, 3, 6, and 12 dry tons A^{-1}. According to the 1996 Colorado Department of Health Biosolids Regulations, L/E biosolids are classified as Grade I and are suitable for application to agricultural and disturbed lands (Table 1). Ammonium nitrate fertilizer was applied to non-biosolids plots at rates of 0, 25, 50, and 100 lbs N A^{-1}. These same plots received biosolids and N fertilizer applications (at the same rates shown above) in August 1982, 1984, 1986, 1988, 1990, and 1992.

We uniformly applied both the biosolids and the N fertilizer and incorporated with a rototiller to a depth of 4 to 6 inches. We discontinued the 18 dry tons biosolids A^{-1} application rate after five applications (last application was in 1990), but continued cropping with winter wheat to observe the long-term removal of residual NO_3-N.

In order to better determine the N equivalency of the biosolids, we started a new study site in 1993 on the John Sauter farm, designated North Bennett in this report. The land is farmed using minimum-tillage practices. We uniformly applied and incorporated biosolids (88% solids; Table 1) at rates of 0, 1, 2, 3, 4, and 5 dry tons A^{-1} and N fertilizer at rates of 0, 20, 40, 60, 80, and 100 lbs N A^{-1} in August 1994. The North Bennett site also was cropped with 'TAM 107'.

At harvest, we measured grain yield and protein content. We analyzed the grain and straw for nitrogen (N), phosphorus (P), cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) concentrations. We estimated gross income using prices paid for winter wheat in December 1995 and subtracted the cost for either fertilizer or biosolids. We applied ammonium nitrate fertilizer, but based our estimated gross income calculations on anhydrous ammonia cost since this is the main N fertilizer used in Eastern Colorado. Following harvest in July 1995, we analyzed NO_3-N in soil samples collected from all plots at depths of 0-8 and 8-24 inches. Also, we measured soil NO_3-N levels down to a depth of 7 feet for selected plots : the control (receiving no biosolids or N fertilizer), 50 lbs N A^{-1}, and 3 and 12 dry tons biosolids A^{-1} treatments at West Bennett; the control, 40 lbs N A^{-1}, and 2 and 5 dry tons biosolids A^{-1} at North Bennett.

This report provides data for the 1994-95 crop year only. The reader is reminded that the 1994-95 West Bennett plots also received the same biosolids application rates in six previous cropping cycles. Results for the West Bennett site reflect a history of applications, which is especially true for the biosolids treatments.

RESULTS AND DISCUSSION

Biosolids Application Recommendation

In order to better determine the N equivalency of the biosolids, we compared yields from N and biosolids plots at North Bennett. We performed separate regression analyses of the N fertilizer and biosolids yields, and both responded linearly (Figure 1). If we assume 45 bu A^{-1} as a basis for comparison (average yield for both treatments; see Table 3), then the intersection of that yield with the curves indicates about 2.9 dry tons A^{-1} is equivalent to 71 lbs N A^{-1}. Consequently, we found that 1.0 dry ton biosolids A^{-1} is roughly equivalent to 25 lbs N A^{-1}. This is only an estimate at this point, since we have only two years of data; therefore, the information must be considered tentative. In 1994 we found an equivalency of 40 lbs N A^{-1} for each dry ton of biosolids A^{-1}. Our statistical analyses showed a higher level of significance in 1995 than in 1994. Consequently, we feel the equivalency of a 1 dry ton biosolids A^{-1} addition is closer to 25 lbs N A^{-1} rather than 40 lbs N A^{-1}.

Grain Yields, Protein Content and Estimated Income

West Bennett :

Grain yields within the N-treated plots averaged 35 bu A^{-1}, while yields within the biosolids treated plots averaged 22 bu A^{-1} (Table 2). The Adams County long-term average is 30 bu A^{-1}. During mid-spring of 1995 the biosolids treated wheat may have been delayed in maturity compared to the nitrogen treated wheat. Subsequently, frost damage in May 1995 may have caused some yield reductions in the biosolids treated plots. The 0, 3, 6, and 18 dry tons biosolids A^{-1} application rates all out-yielded the 12 dry tons biosolids A^{-1} rate. Also, the yields in 18 dry tons biosolids A^{-1} rate are now, after 5 years since discontinuance, similar to the 6 dry tons biosolids A^{-1} treatment.

The protein content was above 12% for both biosolids and N fertilizer treated units. This may be attributable to low to average yields, thus concentrating the protein. Although protein content did not increase with increasing N fertilizer rates, increasing biosolids rates did increase protein content. There were no significant protein differences between N fertilizer and biosolids rates. Five years after discontinuance, the protein content in the 18 dry tons biosolids A^{-1} treatment (15.6%) is about the same as the 3 dry tons biosolids A^{-1} rate (15.8%). Apparently, the wheat is removing the residual NO_3-N in the 18 dry tons A^{-1} treatment (received a total of 90 dry tons A^{-1} from 1982 to 1990).

Estimated income was higher for the N fertilizer plots than the biosolids plots. This was true even when comparing the 50 lbs N A^{-1} rate versus the 3 dry tons A^{-1} rate. This occurred because the biosolids treatments had depressed yields relative to the N fertilizer treatments, which decreased gross income for the biosolids treatments.

<u>North Bennett :</u>

Grain yields averaged higher than the long-term Adams County average (Table 3). This may be attributable to residue management allowing for more efficient use of precipitation. There were no yield differences between N fertilizer and biosolids rates.

Although protein content was similar for both N fertilizer and biosolids plots, estimated income was somewhat higher in biosolids treated plots versus N plots. This may be attributed to the free application cost of biosolids.

Plant Nutrients and Trace Metals

Grain :

West Bennett :

Increasing N fertilizer or biosolids rate did not affect grain P (Table 4), Zn, Cu, Ni, or Cd (Table 5). Since the Pb content of many samples were below detection limits, we could not do a statistical analysis. Compared with N fertilizer, biosolids resulted in higher grain Cu and Ni concentrations.

North Bennett :

Increasing N fertilizer or biosolids rate did not affect grain P (Table 6), Zn, Cu, Ni, or Cd (Table 7). Again, since Pb content of most samples were below detection limits, we could not do a statistical analysis. There was no difference in micronutrient and trace metal concentration between N fertilizer and biosolids treatments.

Straw :

West Bennett :

Increasing N fertilizer rate increased straw N (Table 4), Cu, Ni, and Cd (Table 8), but did not affect straw P, Zn, or Pb. Increasing biosolids rate did not affect micronutrient or trace metal concentrations. Compared with N fertilizer, biosolids resulted in higher straw N, P, Zn, Cu, Ni, and Cd concentrations.

North Bennett :

Increasing N fertilizer or biosolids rates did not affect micronutrients and trace metals (Tables 6 and 9). Compared with biosolids, N fertilizer resulted in a higher concentration of Pb.

Neither grain nor straw micronutrient and trace metal concentrations at either site were above the levels considered hazardous for livestock consumption (Logan and Chaney, 1983; NRC, 1980).

Residual Soil NO_3-N

West Bennett :

Biosolids applications at the 12-dry tons A^{-1} rate increased NO_3-N accumulation throughout the soil profile compared to the control, 50 lbs N A^{-1}, and 3 dry tons biosolids A^{-1} rate (Figure 2). The 3-dry tons biosolids A^{-1} rate (the recommended application rate) did not increase soil NO_3-N compared to the control or 50 lbs N A^{-1}.

There was residual NO_3-N (>10 ppm NO_3-N) throughout top 70 inch soil depth for the 12-dry tons biosolids A^{-1} rate. The residual NO_3-N can be attributed to the large amounts of available N (291 lbs N A^{-1}) from the first sludge application in 1982, which was in liquid form (4.2% solids, Utschig et al., 1986). The last six applications were dried (greater than 50% solids) prior to addition, resulting in lower total applied N levels (Utschig et al., 1986; Lerch et al., 1990). The potential for leaching in the 12-dry tons A^{-1} rate may seem high, but the potential for groundwater contamination is negligible because the water table depth at this site is over 100 feet and the cropping system is under dryland wheat production.

North Bennett :

Neither N fertilizer nor biosolids application rates affected soil NO_3-N (Figure 3). All NO_3-N levels were below those considered residual (all were less than 5 ppm NO_3-N). Note the difference in the NO_3-N scales between Figure 2 and Figure 3.

The scale for Figure 2 (West Bennett) is over 10 times that for Figure 3 (North Bennett).

SUMMARY

West Bennett nitrogen fertilizer and biosolids application rates produced yields similar to the long-term Adams County yields. In contrast, N fertilizer and biosolids application at the North Bennett site resulted in above average yields. Yields above the county average at both sites can be attributed to higher than average rainfall during the critical grain filling period. Residue management allowed for more efficient use of the precipitation at the North Bennett site. The 18 dry tons biosolids A^{-1} (five years since discontinuance) treatment at West Bennett produced yields and protein contents that were similar to the 6 and 3 dry tons biosolids A^{-1} treatments, respectively. The residual N in this discontinued treatment apparently is approaching that of the lower biosolids treatments.

On average, N fertilizer gave a higher economic return compared to biosolids at West Bennett. At North Bennett the biosolids gave a higher average economic return than the N fertilizer. The economic advantage of biosolids over N fertilizer is cost; the biosolids and their application are

essentially free, although application costs may be charged in the future.

Biosolids resulted in higher grain Cu and Ni concentrations, and higher straw N, P, Zn, Cu, Ni, and Cd compared to N fertilizer at the West Bennett site. There were no differences in grain micronutrient concentrations between biosolids and N fertilizer at the North Bennett site. Compared with biosolids, N fertilizer resulted in higher straw Pb concentrations at the North Bennett site. All trace metal levels in the grain and straw were below those considered to be a health hazard and harmful to livestock.

Repeated applications of 12-dry tons biosolids A^{-1} resulted in significant residual soil NO_3-N accumulation in the top 70 inches at West Bennett. Most of the residual may be attributed to the 1982 liquid application. Although the potential for NO_3-N leaching is high, the risk of groundwater contamination would be minimal due to the depth of the water table and cropping system.

There was no significant NO_3-N accumulation with the 2 or 5-dry tons biosolids A^{-1} rate at North Bennett. In fact, concentrations did not exceed 5 ppm for any treatment or depth in the soil profile.

During most growing seasons biosolids could supply slow-release N, P, and Zn. We would expect substantial increases in grain yield and protein content when we apply biosolids or N fertilizer at recommended rates on N-deficient soils. Soil testing and biosolids analyses must be conducted with any fertilizer program to ensure optimum crop yields along with environmental protection.

REFERENCES

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.

Colorado Department of Health. 1996. Revised Biosolids Regulation 4.9.0. Denver, CO.

Lerch, R., K.A. Barbarick, D.G. Westfall, R.H. Follett, T.M. McBride, and W.F. Owen. 1990. Sustainable rates of biosolids for dryland winter wheat production. I. Soil nitrogen and heavy metals. J. Prod. Agric. 3:66-71.

Logan, T.J., and R.L. Chaney. 1983. Utilization of wastewater and biosolids on land - metals. pp.235-323. In A.L. Page (ed.). Proc. of the 1983 Workshop on Utilization of Municipal Wastewater and Biosolids on Land. Univ. of California-Riverside.

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

U.S. Environmental Protection Agency. 1983. Land application of municipal biosolids. EPA 625/1-83-016. Office of Research and Development, Municipal Environmental Research Laboratory. Cincinnati, OH.

Utschig, J.M., K.A. Barbarick, D.G. Westfall, R.H. Follett, and T.M. McBride. 1986. Evaluating crop response: Liquid biosolids vs. nitrogen fertilizer. Biocycle 27(7):30-33.

Table 1. Average composition of Littleton/Englewood sludge applied in 1994-95 compared to the Grade I and II biosolids limits.

Property	Dry Weight Concentration Littleton/Englewood	Limit Grade I Biosolids¶	Limit Grade II Biosolids¶
Organic N (%)	2.67	none specified	none specified
NO_3-N (%)	<0.01	"	"
NH_4-N (%)	0.55	"	"
Solids (%)	88	"	"
P (%)	1.66	"	"
K (%)	0.271	"	"
Cd (mg kg^{-1})[B]	6.7	39	85
Cu (mg kg^{-1})	493	1500	4300
Ni (mg kg^{-1})	65.3	420	420
Mo (mg kg^{-1})	22.4	75	75

Pb (mg kg^{-1})	81.4	300	840
Zn (mg kg^{-1})	816	2800	7500
Cr (mg kg^{-1})	80	3000	3000
As (mg kg^{-1})	2.7	41	75
Se (mg kg^{-1})	1.2	100	100

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

B mg kg^{-1} = parts per million.

Table 2. Effects of N fertilizer and biosolids on wheat yield, protein, and projected income at West Bennett, 1994-95.

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		30	12.3	0	152
25		37	12.6	11	176
50		38	13.8	17	186
100		29	16.1	28	139
Mean[§]		35	14.2	19	167
LSD N rate[§]		NS[¶]	NS		
	0	31	10.8	0	157
	3	26	15.8	0	146
	6	25	16.0	0	141

	12	15	17.0	0	87
	18$	23	15.6	0	130
Mean§		22	16.1	0	126
LSD biosolids rate		5*	2.1*		
N vs. biosolids§		*	NS		

† Identical biosolids applications were made in 1982, 1984, 1986, 1988, 1990, 1992, and 1994; therefore, the cumulative amount is 7 times that shown (except for the 18 dry tons A^{-1} rate).

‡ The price for anhydrous NH_3 was considered to be \$.24 lb^{-1} N plus \$4.50 A^{-1} application charge. The biosolids and its application are currently free. The grain price was \$5.05 bu^{-1}. A protein premium of \$0.04 bu^{-1} for each 0.25% above 12.25% was paid in December 1995.

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

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

$ The 18 dry tons A^{-1} rate was discontinued in 1990-91.

Table 3. Effects of N fertilizer and biosolids on wheat yield, protein, and projected income at North Bennett, 1994-95.

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		37	9.8	0	187
20		41	10.4	9	198
40		45	10.5	14	213
60		47	10.2	18	219
80		44	11.5	23	199

100		46	10.7	28	204
Mean[§]		45	10.7	18	207
LSD N rate[§]		NS[¶]	NS		
	0	38	10.3	0	192
	1	44	10.9	0	222
	2	43	11.1	0	217
	3	44	10.4	0	222
	4	50	10.4	0	252
	5	46	11.2	0	232
Mean[§]		45	10.8	0	229
LSD biosolids rate		NS	NS		
N vs. biosolids[§]		NS	NS		

‡ The price for anhydrous NH_3 was considered to be \$.24 lb^{-1} N plus \$4.50 A^{-1} application charge. The biosolids and its application are currently free. The grain price was \$5.05 bu^{-1}. A protein premium of \$0.04 bu^{-1} for each 0.25% above 12.25% was paid in December 1995.

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

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

Table 4. Effects of N fertilizer and biosolids rates on N and P contents in wheat grain and straw at West Bennett, 1994-95.

N Fert. lbs N A^{-1}	Biosolids[†] dry tons A^{-1}	Straw N	Straw P	Grain P
		-----------	g kg^{-1}	----------
0		5.2	0.88	4.9
25		5.0	0.62	4.9

50		5.1	0.50	4.8
100		8.2	0.75	4.8
Mean[§]		6.1	0.62	4.8
LSD N rate[§]		** 2.6[¶]	NS	NS
	0	3.9	0.62	4.9
	3	11.0	1.38	5.2
	6	12.1	1.88	5.2
	12	16.0	2.88	5.5
	18[$]	13.6	2.12	5.2
	Mean	13.2	2.00	5.4
	LSD biosolids rate	NS	NS	NS
	N vs biosolids[§]	*	**	NS

[†] Identical biosolids applications were made in 1982, 1984, 1986, 1988, 1990, 1992, and 1994; therefore, the cumulative amount is 7 times that shown (except for the 18 dry tons A^{-1} rate).

[§] Means/LSD/N vs biosolids do not include the controls.

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

[$] The 18 dry tons A^{-1} rate was discontinued in 1990-91.

Table 5. Effects of N fertilizer and biosolids rates on the concentrations of micronutrients and trace metals in wheat grain at West Bennett, 1994-95.

N fert. lbs A^{-1}	Biosolids dry tons A^{-1} †	Zn	Cu	Ni	Cd	Pb
		---------	---------	mg kg^{-1}	---------	--------
0		33	5.4	1.9	0.34	ND[B]
25		27	4.8	1.8	0.40	0.03
50		30	5.1	1.9	0.32	ND
100		36	5.4	1.6	0.37	ND
Mean§		31	5.1	1.8	0.36	
LSD N rate§		NS¶	NS	NS	NS	
	0	30	5.5	2.0	0.31	0.03
	3	44	5.9	2.3	0.41	0.06
	6	46	6.0	2.8	0.39	0.06
	12	63	8.4	4.3	0.38	ND
	18$	46	7.2	2.8	0.38	ND
	Mean	50	6.9	3.1	0.39	
	LSD biosolids rate	NS	NS	NS	NS	
	N vs. biosolids§	NS	*	*	NS	

† Identical biosolids applications were made in 1982, 1984, 1986, 1988, 1990, 1992, and 1994; therefore, the cumulative amount is 7 times that shown (except for the 18 dry tons A^{-1} rate).

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

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

B ND = Non-detectable

$ The 18 dry tons A^{-1} rate was discontinued in 1990-91.

Table 6. Effects of N fertilizer and biosolids rates on N and P contents in wheat grain and straw at North Bennett, 1994-95.

N fert. lbs A^{-1}	Biosolids dry tons A^{-1}	Straw N	Straw P	Grain P
		-----------	g kg^{-1}	----------

0		3.49	0.62	4.2
20		3.21	0.50	4.2
40		3.97	0.50	4.2
60		3.44	0.62	4.2
80		3.85	0.50	4.4
100		4.04	0.38	4.4
Mean[§]		3.70	0.50	4.2
LSD N rate[§]		NS[¶]	NS	NS
	0	3.53	0.50	4.0
	1	4.32	0.38	4.2
	2	3.56	0.50	4.2
	3	4.06	0.50	4.4
	4	4.11	0.50	4.0
	5	3.41	0.50	4.4
	Mean[§]	3.90	0.50	4.2
	LSD biosolids rate	NS	NS	NS
	N vs. biosolids[§]	NS	NS	NS

[§] Means/LSD/N vs biosolids do not include the controls.

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

Table 7. Effects of N fertilizer and biosolids rates on the concentrations of micronutrients and trace metals in wheat grain at North Bennett, 1994-95.

N fert. lbs A^{-1}	Biosolids dry tons A^{-1}	Zn	Cu	Ni	Cd	Pb
		---------	---------	mg kg^{-1}	---------	--------
0		26	4.7	1.6	0.39	ND[B]
20		22	4.9	1.8	0.37	0.05
40		27	5.4	2.0	0.38	ND
60		30	4.9	2.4	0.34	ND
80		23	5.3	2.2	0.52	0.26
100		22	6.3	1.8	0.30	0.06
Mean[§]		25	5.4	2.0	0.38	
LSD N rate[§]		NS[¶]	NS	NS	NS	
	0	21	5.2	2.5	0.50	ND
	1	23	5.6	1.9	0.29	ND
	2	23	5.1	1.7	0.49	ND
	3	23	5.0	1.6	0.26	ND
	4	22	4.7	1.6	0.25	0.02
	5	25	5.0	1.8	0.26	0.02
	Mean	23	5.1	1.7	0.31	
	LSD biosolids rate	NS	NS	NS	NS	
	N vs biosolids[§]	NS	NS	NS	NS	

[§] Means/LSD/N vs biosolids do not include the controls.

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

[B] ND = Non-detectable

Table 8. Effects of N fertilizer and biosolids rates on the concentrations of micronutrients and trace metals in wheat straw at West Bennett, 1994-95.

N fert. lbs A^{-1}	Biosolids dry tons A^{-1} †	Zn	Cu	Ni	Cd	Pb
		---------	---------	mg kg^{-1}	---------	--------
0		6.2	2.0	0.6	0.07	0.11
25		4.6	1.9	0.6	0.13	0.08
50		4.1	1.9	0.6	0.11	0.08
100		20.7	2.5	0.7	0.26	0.17
Mean§		9.8	2.1	0.6	0.17	0.11
LSD N rate§		NS¶	** 0.1	* 0.1	* 0.14	NS
	0	4.6	1.5	0.6	0.05	ND[B]
	3	14.9	3.1	0.6	0.33	0.29
	6	24.6	4.0	1.2	0.41	0.39
	12	42.3	5.3	2.0	0.57	0.39
	18$	24.6	4.0	1.4	0.44	0.24
	Mean	26.6	4.1	1.4	0.44	0.33
	LSD biosolids rate	NS	NS	NS	NS	NS
	N vs. biosolids§	*	*	*	*	NS

† Identical biosolids applications were made in 1982, 1984, 1986, 1988, 1990, 1992, and 1994; therefore, the cumulative amount is 7 times that shown (except for the 18 dry tons A^{-1} rate).

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

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

B ND = Non-detectable

$ The 18 dry tons A^{-1} rate was discontinued in 1990-91.

Table 9. Effects of N fertilizer and biosolids rates on the concentrations of micronutrients and trace metals in wheat straw at North Bennett, 1994-95.

N fert. lbs A^{-1}	Biosolids dry tons A^{-1}	Zn	Cu	Ni	Cd	Pb
		------	------	mg kg^{-1}	-------	-------
0		3.2	1.6	0.28	0.08	0.19
20		3.3	1.6	0.35	0.07	0.14
40		2.9	1.5	0.29	0.08	0.11
60		3.6	1.6	0.24	0.06	0.11
80		3.3	1.6	0.32	0.08	0.25
100		3.3	2.0	0.31	0.09	0.30
Mean§		3.3	1.7	0.30	0.08	0.18
LSD N rate§		NS¶	NS	NS	NS	NS
	0	3.0	1.4	0.29	0.07	0.14
	1	3.1	1.9	0.29	0.13	0.06
	2	2.9	1.6	0.30	0.06	0.19
	3	3.2	1.7	0.31	0.10	0.08
	4	3.2	1.8	0.33	0.08	0.11
	5	3.5	1.5	0.21	0.05	0.11
	Mean	3.2	1.7	0.29	0.08	0.11
	LSD biosolids rate	NS	NS	NS	NS	NS
	N vs biosolids§	NS	NS	NS	NS	*

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

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