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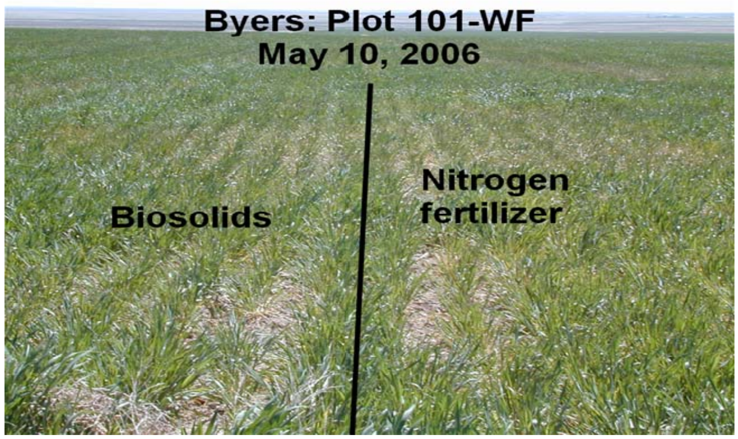
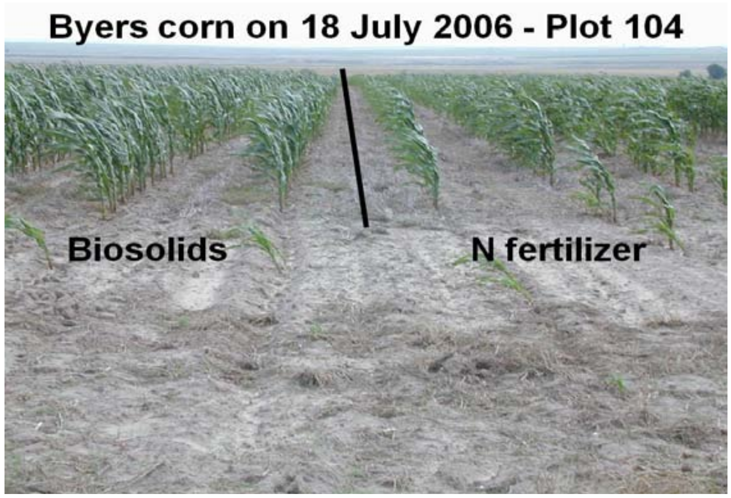
Extension

Biosolids Application to No-Till Dryland Rotations: 2006 Results





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Biosolids Application to No-Till Dryland Crop Rotations: 2006 Results

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INTRODUCTION

Biosolids recycling on dryland winter wheat (*Triticum aestivum*, L.) can supply a reliable, slow-release source of nitrogen (N) and organic material (Barbarick et al., 1992). Barbarick and Ippolito (2000, 2007) found that continuous application of biosolids from the Littleton/Englewood, CO wastewater treatment facility to dryland winter wheat-fallow rotation provides 16 to 18 lbs N per dry ton. This research involved tilling the biosolids into the top 8 inches of soil. A new question related to soil management in a biosolids beneficial-use program is: How much N would be available if the biosolids were surface-applied in a no-till dryland agroecosystem with winter wheat-fallow (WF) and winter wheat-corn (*Zea mays*, L.)-fallow (WCF) crop rotations?

Our objective was to compare agronomic rates of commercial N fertilizer to an equivalent rate of biosolids in combination with WF and WCF crop rotations. Our hypotheses were that biosolids addition, compared to N fertilizer, will:

1. Produce similar crop yields;
2. Not differ in grain P, Zn, and Cu levels (Ippolito and Barbarick, 2000) or soil P, Zn, and Cu AB-DTPA extractable concentrations, a measure of plant availability (Barbarick and Workman, 1987); and
3. Not affect soil salinity (electrical conductivity of saturated soil-paste extract, EC) or soil accumulation of nitrate-N (NO_3-N).

MATERIALS AND METHODS

In 1999, we established our research on land owned by the Cities of Littleton and Englewood (L/E) in eastern Adams County, approximately 28 miles east of Byers, CO. The Linnebur family manages the farming operations for L/E. Soils belong to the Adena-Colby association where the Adena soil is classified as an Ustollic Paleargid and Colby is classified as an Ustic Torriorthent. No-till management is used in conjunction with crop rotations of WF and WCF. We originally also used a wheat-wheat-corn-sunflower (*Helianthus annuus*, L.)-fallow rotation. After the 2004 growing season, we abandoned this rotation because of persistent droughty conditions that restricted sunflower production. We installed a Campbell Scientific weather station at the site in April 2000; Tables 1 and 2 present mean temperature and precipitation data, and growing season precipitation, respectively.

With biosolids application in August 1999, we initiated the study. Planting sequences are given in Table 3. We used two replications of each rotation (20 plots total) and we completely randomized each replicated block. Each phase of each rotation was present every year. Each plot was 100 feet wide by approximately 0.5 mile (2640 feet) long. The width was split so that one 50-foot wide section received commercial N fertilizer applied with the seed and sidedressed after plant establishment

(Table 3), and the second 50-foot wide section received biosolids applied by L/E with a manure spreader. We randomly selected which strip in each rotation received N fertilizer or biosolids. Characteristics of the L/E biosolids are provided in Table 4. We based the N fertilizer and biosolids applications on soil test recommendations determined on each plot before planting each crop. The Cities of L/E completed biosolids application for the summer crops in March 2000, 2001, 2002, 2003, 2004, and 2005. We planted the first corn crop in May 2000. We also established wheat rotations in September 2000, 2001, 2002, and 2003, corn rotations in May 2001, 2002, 2003, and 2004, and sunflower plantings in June 2001, 2002, and 2003. Soil moisture was inadequate in June 2004 to plant sunflowers (see Table 1).

We completed wheat harvests in July 2000, 2001, 2002, 2003, 2004, and 2005, and corn and sunflowers in October 2000 and 2001, sunflowers in December 2003, and corn in 2004 and 2006. We experienced corn and sunflower crop failures in 2002, a corn crop failure in 2003 and 2005, and a wheat-crop failure in 2006 due to lack and proper timing of precipitation (Table 1). For each harvest, we cut grain from four areas of 5 feet by approximately 100 feet within each subplot. We determined the yield for each area and then took a subsample from each cutting for subsequent grain protein or N, P, Zn, and Cu analyses (Huang and Schulte, 1985).

Following each harvest, we collected soil samples using a Giddings hydraulic probe. For AB-DTPA extractable Cu, P, and Zn (Barbarick and Workman, 1987) and EC (Rhoades, 1996) and pH (Thomas, 1996), we sampled to one foot and separated the samples into 0-2, 2-4, 4-8, and 8-12 inch depth increments. For soil NO_3-N (Mulvaney, 1996) analyses, we sampled to 6 feet and separated the samples into 0-2, 2-4, 4-8, 8-12, 12-24, 24-36, 36-48, 48-60, and 60-72 inch depth increments. We inadvertently forgot to sample the corn plots following the 2006 harvest.

For the wheat rotations, the experimental design was a split-plot design where type of rotation was the main plot and type of nutrient addition (commercial N fertilizer versus L/E biosolids) was the subplot. For crop yields and soil-sample analyses, main plot effects, subplot effects, and interactions were tested for significance using least significant difference (LSD) at the 0.10 probability level. Since we only had one corn rotation, we could only compare the commercial N versus L/E biosolids using a “t” test at the 0.10 probability level.

RESULTS AND DISCUSSION

Precipitation Data

Table 1 presents the monthly precipitation records from the time we established the weather station at the Byers research site. The plots received more than 11 inches of total annual rainfall in 2000 and 2001, only 5 inches in 2002, about 12 inches in 2003, 10 inches in 2004 and 2005, and 9 inches in 2006. The critical precipitation months for corn are July and August (Nielsen et al., 1996). The Byers site received 6.0, 3.8, 1.3, 2.6, 2.5, 3.5, and 4.5 inches of precipitation in July and August 2000, 2001, 2002, 2003, 2004, 2005, and 2006, respectively.

2006 Crop Grain Data

Since only 3.8 inches of moisture was received between wheat planting and the reproductive stage of growth (Table 2), we experienced a wheat crop failure in 2006. Corn yields were 12 and 15 bushels/acre for the biosolids and N fertilizer treatments, respectively. These yields were not significantly different but were either comparable or lower than yields observed in previous years. Grain Cu, P, and Zn concentrations were not affected by biosolids additions (Table 5).

2006 Soil Data

As shown in Figure 1 through 3, rotation or treatment did not affect AB-DTPA-extractable Cu, P, and Zn in the wheat plots. The AB-DTPA-extractable P concentration in the 0-2-inch depth is considered medium or high according to the Colorado P Index Risk Assessment (Sharkoff et al., 2003). Overall, this site would most likely have a "medium" risk assessment in terms of the potential for off-site P movement. Interpreted, biosolids land application can still follow crop N requirements.

The salinity level (EC; Figure 4) was increased by biosolids application in the 4 to 8 and 8 to 12 inch soil depths. Soil pH (Figure 5) was not affected by crop rotation or nutrient source.

The residual NO_3-N in the top 36 inches (Figure 6) also indicates that future biosolids and fertilizer applications to both wheat and corn should be ceased until the soil levels are reduced to below 15 mg kg^{-1} (ppm). Nitrogen additions to winter wheat are needed when soil NO_3-N concentrations are less than 15 mg kg^{-1} (ppm) in the top foot (Davis et al., 2005). Nitrogen additions to dryland corn are needed when soil NO_3-N concentrations are less than 12 mg kg^{-1} (ppm) in the top foot (Mortvedt et al., 1996)...

CONCLUSIONS

Relative to our hypotheses listed on page 2, we have found the following trends:

1. In the wheat plots, we observed similar concentrations of P, Zn, and Cu in wheat grain and surface-soil levels following biosolids or N fertilizer application. We found no differences in soil NO_3-N concentrations at depths to 6 feet.

2. We found that biosolids application increased soil salinity (EC) at depths of 4 to 8 and 8 to 12 inches in the wheat plots as compared to N fertilizer applications.

3. Previous biosolids and N fertilizer applications, based on soil test N and crop N requirements, have caused an accumulation of NO_3-N in the soil profile. Therefore, near-future biosolids and N fertilizer applications will be ceased until soil NO_3-N is reduced by wheat and corn removal.

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., and J.A. Ippolito. 2007. Nutrient assessment of a dryland wheat agroecosystem after 12 years of biosolids application. Agron. J. 99:715-722.

Barbarick, K.A., R.N. Lerch, J.M. Utschig, D.G. Westfall, R.H. Follett, J. Ippolito, R. Jepson, and T. McBride. 1992. Eight years of sewage sludge addition to dryland winter wheat. Colo. Agric. Exp. Stn. Bulletin. TB92-1.

Barbarick, K. A., and S. M. Workman. l987. NH_4HCO_3-DTPA and DTPA extractions of sludge-amended soils. J. Environ. Qual. l6:l25-l30.

Davis, J.G., D.G. Westfall, J.J. Mortvedt, and J.F. Shanahan. 2005. Fertilizing winter wheat. Colorado State University Cooperative Extension Fact Sheet no. 0.544.

Huang, C.L., and E.E. Schulte. 1985. Digestion of plant tissue for analysis by ICP emission spectroscopy. Comm. Soil Sci. Plant Anal. 16:943-958.

Mortvedt, J.J., D.G. Westfall, and R.L. Croissant. 1996. Fertilizing corn. Colorado State University Cooperative Extension Fact Sheet no. 0.538.

Mulvaney, R.L. 1996. Nitrogen - inorganic forms. pp. 1123-1184. *In* D.L. Sparks (ed.). Methods of Soil Analysis, Part 3 - Chemical Methods. Soil Science Society of America. Madison, WI.

Nielsen, D., G. Peterson, R. Anderson, V. Ferreira, W. Shawcroft, K. Remington. 1996. Estimating corn yields from precipitation records. Conservation Tillage Fact Sheet #2-96. USDA-ARS, USDA-NRCS, and Colorado Conservation Tillage Association.

Rhoades, J.D. 1996. Salinity: Electrical conductivity and total dissolved solids. pp. 417-435. *In* D.L. Sparks (ed.). Methods of Soil Analysis, Part 3 - Chemical Methods. Soil Science Society of America. Madison, WI.

Sharkoff, J.L., R.M. Waskom, and J.G. Davis. 2003. Colorado phosphorus index risk assessment – version 3.0. Colorado USDA-NRCS Technical Note No. 95.

Thomas, G.W. 1996. Soil pH and soil acidity. pp. 475-490. *In* D.L. Sparks (ed.). Methods of Soil Analysis, Part 3 - Chemical Methods. Soil Science Society of America. Madison, WI.

Table 1. Monthly mean maximum (Max) and minimum (Min) temperatures and precipitation (Precip) in inches at the Byers research site, 2000-2006. (Weather station was installed in April, 2000).

Month	2000			2001			2002			2003			2004		
	Max °F	Min °F	Precip inches	Max °F	Min °F	Precip inches	Max °F	Min °F	Precip inches	Max °F	Min °F	Precip inches	Max °F	Min °F	Precip inches
January	†	†	†	41.0	20.7	0.2	44.1	17.0	0.1	50.4	23.3	0.0	44.9	20.2	0.0
February	†	†	†	42.1	19.0	0.1	48.2	19.7	0.2	39.9	17.1	0.1	42.6	20.4	0.1
March	†	†	†	49.9	27.5	0.2	46.5	17.7	0.2	55.0	29.6	1.0	61.2	31.3	0.1
April	68.9	38.4	0.6	64.2	36.4	1.5	65.8	35.2	0.3	65.0	37.5	1.5	61.9	35.6	0.9
May	78.4	47.0	0.9	70.0	43.7	2.4	73.5	41.8	0.7	71.3	45.3	1.8	75.8	44.8	1.4
June	80.4	49.3	0.9	85.9	53.5	2.4	89.0	56.9	1.2	76.8	51.1	4.7	78.3	51.1	4.1
July	91.9	61.0	2.5	92.2	61.1	1.9	93.3	62.2	0.2	97.4	62.1	0.2	86.9	57.6	1.0
August	90.8	60.2	3.5	88.8	59.0	1.9	88.2	57.0	1.1	91.0	60.5	2.4	85.2	54.6	1.5
September	80.6	49.8	0.8	82.0	51.6	0.8	78.1	50.5	0.7	76.2	45.6	0.1	80.8	50.7	0.6
October	65.9	38.7	1.6	68.0	37.2	0.2	58.6	33.0	0.2	72.3	41.2	0.1	67.3	38.6	0.4
November	40.8	20.0	0.3	56.2	28.9	0.8	50.2	27.1	0.1	51.3	24.3	0.0	48.0	26.6	0.3
December	41.7	17.0	0.3	45.4	21.4	0.0	47.1	22.8	0.0	47.2	20.8	0.0	46.4	22.4	0.1
Total			11.4			12.4			5.0			11.9			10.5

Month	2005			2006		
	Max °F	Min °F	Precip inches	Max °F	Min °F	Precip inches
January	43.9	21.5	0.1	52.2	24.6	0.0
February	49.4	24.5	0.0	41.2	15.3	0.0
March	53.0	27.2	0.2	52.9	25.5	0.6
April	59.0	34.0	1.1	65.0	34.5	0.4
May	72.0	44.6	0.8	76.5	44.6	0.7
June	80.1	50.4	2.4	86.5	54.2	0.2
July	94.2	61.1	1.3	90.6	61.8	1.9
August	84.6	56.7	2.2	86.1	59.0	2.6
September	83.3	51.9	0.1	69.5	43.3	1.4
October	65.1	39.1	1.3	62.5	35.9	1.1
November	56.5	29.7	0.5	53.3	26.9	0.0
December	41.6	17.5	0.0	42.2	21.1	0.1
Total			10.0			9.0

† We installed the weather station in mid-April, 2000.

Table 2. Growing season precipitation.

Stage	Dates	Precipitation, inches
Wheat vegetative	September 2000 - March 2001	3.3
Wheat reproductive	April 2001 - June 2001	6.3
Corn/Sunflowers preplant	July 2000 – April 2001	9.5
Corn/Sunflowers growing season	May 2001 – October 2001	9.6
Wheat vegetative	September 2001 - March 2002	2.1
Wheat reproductive	April 2002 - June 2002	2.2
Corn/Sunflowers preplant	July 2001 – April 2002	6.1
Corn/Sunflowers growing season	May 2002 – October 2002	3.9
Wheat vegetative	September 2002 - March 2003	1.1
Wheat reproductive	April 2003 - June 2003	3.3
Corn/Sunflowers preplant	July 2002 – April 2003	3.4
Corn/Sunflowers growing season	May 2003 – October 2003	9.2
Wheat vegetative	September 2003 - March 2004	0.3
Wheat reproductive	April 2004 - June 2004	2.3
Corn/Sunflowers preplant	July 2003 – April 2004	3.0
Corn/Sunflowers growing season	May 2004 – October 2004	8.6
Wheat vegetative	September 2004 - March 2005	1.7
Wheat reproductive	April 2005 - June 2005	4.3
Corn preplant	July 2004 – April 2005	5.3
Corn growing season	May 2005 – October 2005	8.6
Wheat vegetative	September 2005 - March 2006	2.5
Wheat reproductive	April 2006 - June 2006	1.3
Corn preplant	July 2005 – April 2006	6.4
Corn growing season	May 2006 – October 2006	7.9

Table 3. Biosolids and fertilizer applications and crop varieties used at the Byers research site, 1999-2006.

Year Planted	Date Planted	Crop	Variety	Biosolids Biosolids tons/acre	Treatment Bio/N equiv. lbs	Nitrogen N lbs/acre with seed	Fertilizer N lbs/acre after planting	Treatment Total N lbs/acre	P_2O_5 lbs/acre	Zn lbs/acre
1999	Early Oct.	Wheat	Halt	2.4	38.4	5	40	45	20	0
2000	May	Corn	Pioneer 3752	4	64	5	40	45	15	5
2000	June	Sunflowers	Triumph 765, 766 (confection type)	2	32	5	40	45	15	5
2000	9/25/00	Wheat	Prairie Red	0	0	4	0	4	20	0
2001	5/11/01	Corn	DK493 Round Ready	5.5	88	5	40	45	15	5
2001	6/20/01	Sunflowers	Triumph 765C	2	32	5	40	45	15	5
2001	09/17/01	Wheat	Prairie Red	Variable	Variable	5	Variable	Variable	20	0
2002		Corn	Pioneer 37M81	Variable	Variable	5	Variable	Variable	15	5
2002		Sunflowers	Triumph 545A	0	0	5	0	0	15	5
2002		Wheat	Stanton	Variable	Variable	5	Variable	Variable	20	0
2003	05/21/03	Corn	Pioneer K06							
2003	06/28/03	Sunflowers	Unknown							
2003		Wheat	Stanton	Variable	Variable	5	Variable	Variable	20	0
2004		Corn	Triumph 9066 Roundup Ready	Variable	Variable	5	Variable	Variable	15	5
2004		Sunflowers	Triumph 765 (confection type)	0	0	5	0	0	15	5
2004	09/17/04	Wheat	Yumar	3	54	0	50	50	15	5
2005	05/10/05	Corn	Pioneer J99	4	72	0	75	75	15	5
2005	Sept.	Wheat	Yumar	0	0	0	0	0	0	0
2006	May	Corn	Pioneer J99	0	0	0	0	0	0	0

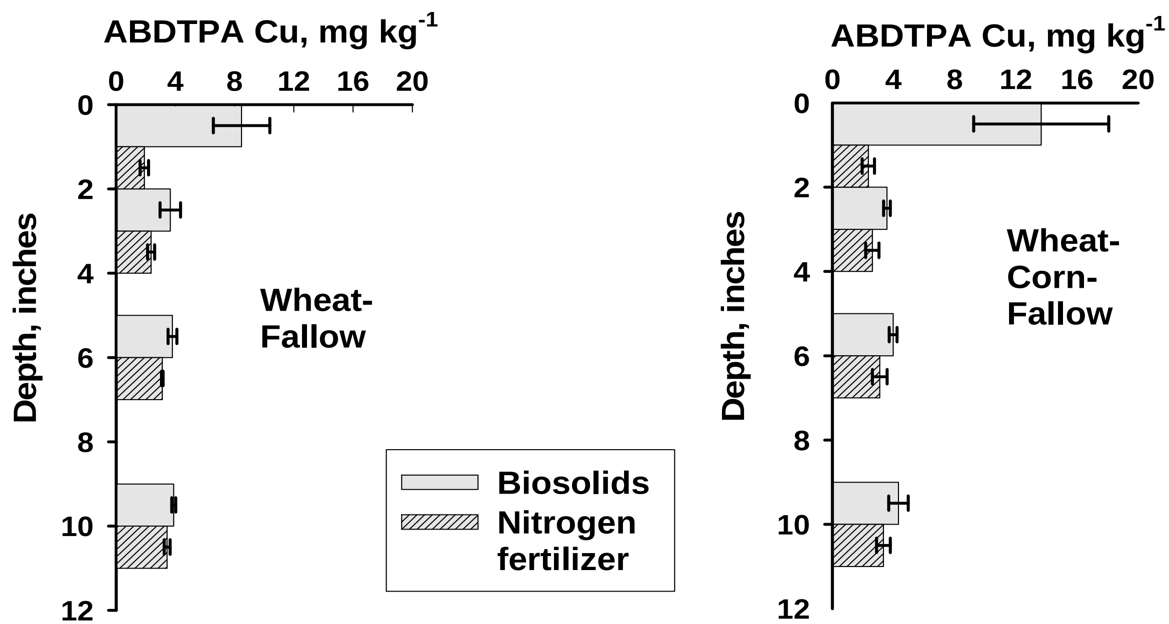
Table 4. Littleton/Englewood biosolids used at the Byers Research site, 1999-2005.

Parameter	1999 Wheat	2000 Corn, Sunflowers	2001 Corn, Sunflowers	2001 Wheat	2003 Corn, sunflowers	2003 Wheat	2004 Wheat	2005 Corn	Avg.	Range
Solids, g kg^{-1}	217	---	210	220	254	192	197	211	214	192-254
pH	7.6	7.8	8.4	8.1	8.5	8.2	8.8	8.2	8.2	7.6-8.8
EC, dS m^{-1}	6.2	11.2	10.6	8.7	7.6	7.4	4.5	5.1	7.7	4.5-11.2
Org. N, g kg^{-1}	50	47	58	39	54	46	43	38	47	38-58
NH_4-N, g kg^{-1}	12	7	14	16	9	13	14	14	12	7-16
NO_3-N, g kg^{-1}	0.023	0.068	0.020	0.021	0.027	0.016	0.010	0	0.023	0-0.068
K, g kg^{-1}	5.1	2.6	1.6	1.9	2.2	2.6	2.1	1.7	2.5	1.6-5.1
P, g kg^{-1}	29	18	34	32	26	28	29	13	26	13-34
Al, g kg^{-1}	28	18	15	18	14	15	17	10	17	10-28
Fe, g kg^{-1}	31	22	34	33	23	24	20	20	26	20-34
Cu, mg kg^{-1}	560	820	650	750	596	689	696	611	672	560-820
Zn, mg kg^{-1}	410	543	710	770	506	629	676	716	620	410-770
Ni, mg kg^{-1}	22	6	11	9	11	12	16	4	11	4-22
Mo, mg kg^{-1}	19	22	36	17	21	34	21	13	23	13-36
Cd, mg kg^{-1}	6.2	2.6	1.6	1.5	1.5	2.2	4.2	2.0	2.7	1.5-6.2
Cr, mg kg^{-1}	44	17	17	13	9	14	18	14	18	9-44
Pb, mg kg^{-1}	43	17	16	18	15	21	26	16	22	15-43
As, mg kg^{-1}	5.5	2.6	1.4	3.8	1.4	1.6	0.5	0.05	2.1	0.05-5.5
Se, mg kg^{-1}	20	16	7	6	17	1	3	0.07	8.8	0.07-20
Hg, mg kg^{-1}	3.4	0.5	2.6	2.0	1.1	0.4	0.9	0.1	1.4	0.1-3.4
Ag, mg kg^{-1}	---	---	---	---	15	7	0.5	1.2	5.9	0.5-15
Ba, mg kg^{-1}	---	---	---	---	---	---	533	7	270	7-533
Be, mg kg^{-1}	---	---	---	---	---	---	0.05	<0.001	0.05	<0.001-0.05
Mn, mg kg^{-1}	---	---	---	---	---	---	239	199	219	199-239

Table 5. Corn grain characteristics for the corn rotation (CFW) at the Byers research site for 2006. ***Highlighted parameters*** are significant at the 0.10 probability level.

Parameter, units	Biosolids	Nitrogen	Probability level
Yield, bushels/acre	12	15	0.346
Cu, mg/kg	31	36	0.171
P, g/kg	75	72	0.389
Zn, mg/kg	244	244	0.545

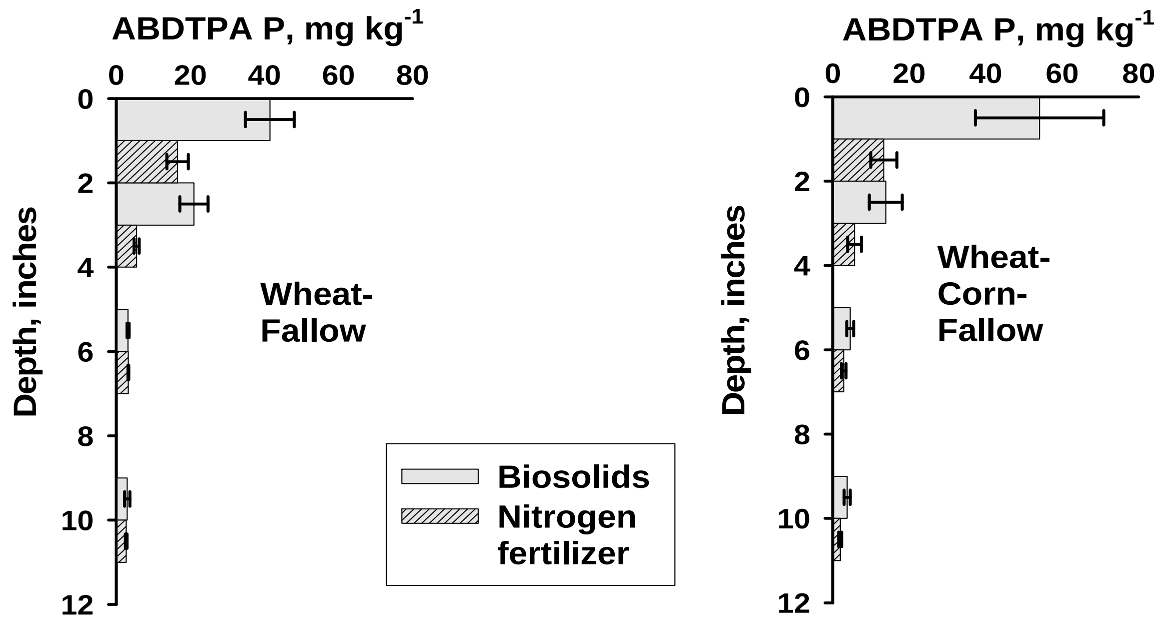
Figure 1. Soil AB-DTPA-extractable Cu concentration following 2006 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 0.10 probability level and NS indicates non-significant differences.



Statistical summary by soil depth:

<u>0-2 inches</u>	<u>2-4 inches</u>	<u>4-8 inches</u>	<u>8-12 inches</u>
$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$
Rotations NS	Rotations NS	Rotations NS	Rotations NS
Treatment NS	Treatment NS	Treatment NS	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

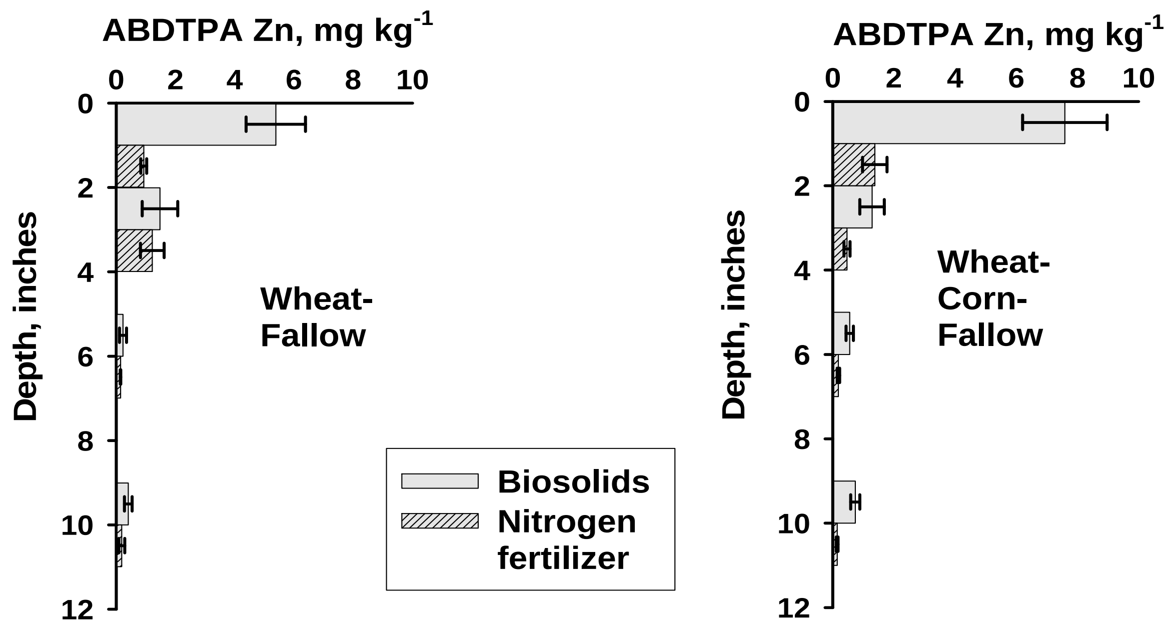
Figure 2. Soil AB-DTPA-extractable P concentration following 2006 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 0.10 probability level and NS indicates non-significant differences.



Statistical summary by soil depth:

0-2 inches	2-4 inches	4-8 inches	8-12 inches
$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$
Rotations NS	Rotations NS	Rotations NS	Rotations NS
Treatment NS	Treatment NS	Treatment NS	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

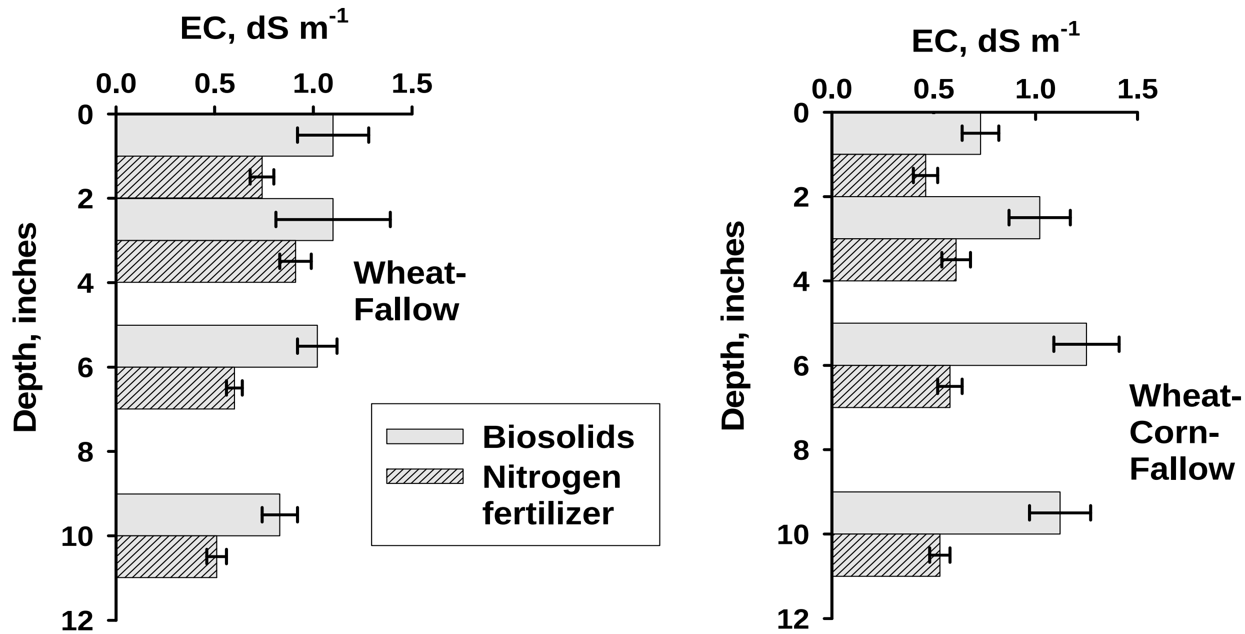
Figure 3. Soil AB-DTPA-extractable Zn concentration following 2006 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 0.10 probability level and NS indicates non-significant differences.



Statistical summary by soil depth:

0-2 inches	2-4 inches	4-8 inches	8-12 inches
$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$
Rotations NS	Rotations NS	Rotations NS	Rotations NS
Treatment NS	Treatment NS	Treatment NS	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

Figure 4. Soil saturated-paste electrical conductivity (EC) following 2006 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 0.10 probability level and NS indicates non-significant differences.



Statistical summary by soil depth:

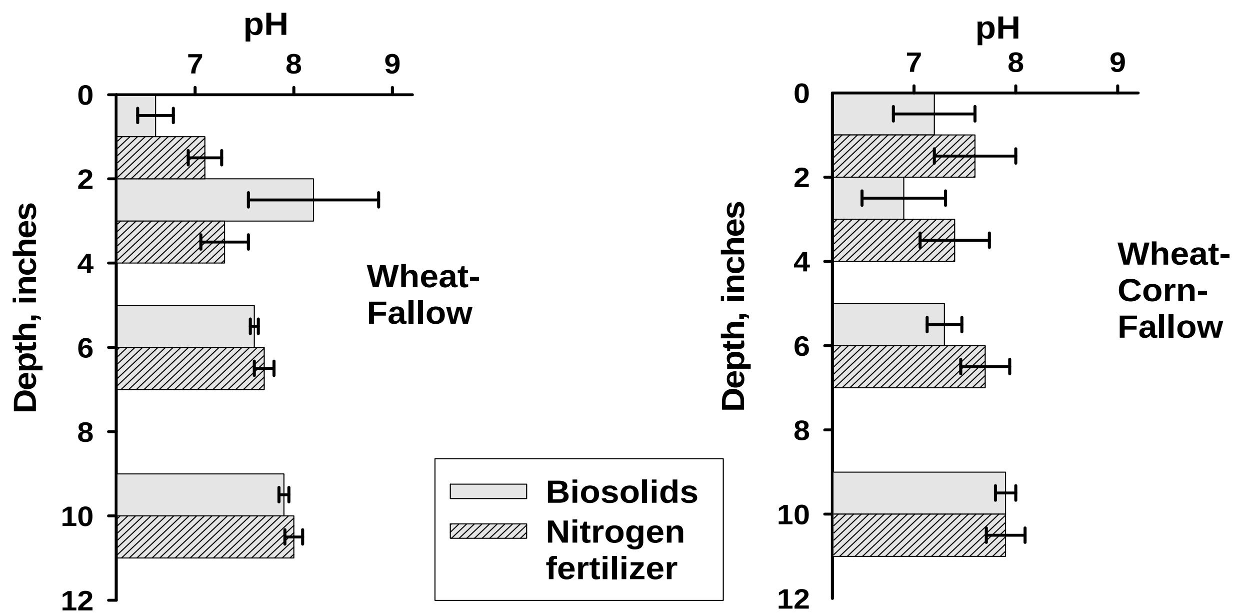
<u>0-2 inches</u>
$LSD_{0.10}$
Rotations NS
Treatment NS
Rot. X Treat. NS

<u>2-4 inches</u>
$LSD_{0.10}$
Rotations NS
Treatment NS
Rot. X Treat. NS

<u>4-8 inches</u>
$LSD_{0.10}$
Rotations NS
Treatment 0.06
Rot. X Treat. NS

<u>8-12 inches</u>
$LSD_{0.10}$
Rotations NS
Treatment 0.05
Rot. X Treat. NS

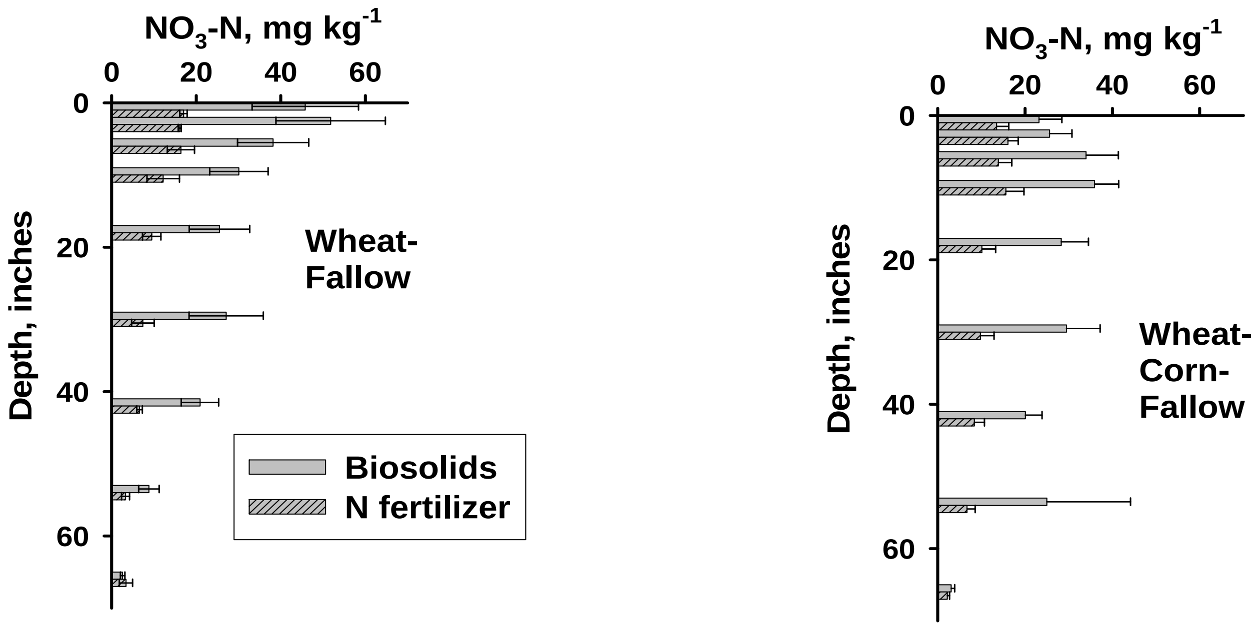
Figure 5. Soil saturated-paste pH following 2006 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 0.10 probability level and NS indicates non-significant differences.



Statistical summary by soil depth:

0-2 inches	2-4 inches	4-8 inches	8-12 inches
$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$
Rotations NS	Rotations NS	Rotations NS	Rotations NS
Treatment NS	Treatment NS	Treatment NS	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

Figure 6. Soil NO_3-N concentrations following 2006 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 0.10 probability level and NS indicates non-significant differences.



Statistical summary by soil depth:

<u>0-2 inches</u>
$LSD_{0.10}$
Rotations NS
Treatment NS
Rot. X Treat. NS

<u>2-4 inches</u>
$LSD_{0.10}$
Rotations NS
Treatment NS
Rot. X Treat. NS

<u>4-8 inches</u>
$LSD_{0.10}$
Rotations NS
Treatment NS
Rot. X Treat. NS

<u>8-12 inches</u>
$LSD_{0.10}$
Rotations NS
Treatment NS
Rot. X Treat. NS

<u>12-24 inches</u>
$LSD_{0.10}$
Rotations NS
Treatment NS
Rot. X Treat. NS

<u>24-36 inches</u>
$LSD_{0.10}$
Rotations NS
Treatment NS
Rot. X Treat. NS

<u>36-48 inches</u>
$LSD_{0.10}$
Rotations NS
Treatment NS
Rot. X Treat. NS

<u>48-60 inches</u>
$LSD_{0.10}$
Rotations NS
Treatment NS
Rot. X Treat. NS

<u>60-72 inches</u>
$LSD_{0.10}$
Rotations NS
Treatment NS
Rot. X Treat. NS