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Biosolids Application to No-Till Dryland Rotations: 2005 Results

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Dryland Crop Rotations: 2005 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) found that continuous application of biosolids from the Littleton/Englewood, CO wastewater treatment plant to dryland winter wheat-fallow rotation provides 16 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).
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 25 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 (see Tables 1 and 2 for 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 plot was 100 feet wide by approximately 0.5 mile 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 and sunflowers in December 2003. We experienced corn and sunflower crop failures in 2002 and a corn failure in 2003 and 2005 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. We determined the yield for each area and then took a subsample from each cutting for subsequent grain analyses for protein or N, P, Zn, and Cu content (Ippolito and Barbarick, 2000).

Following each harvest, we collected soil samples using a Giddings hydraulic probe. For AB-DTPA extractable P, Zn, and Cu (Barbarick and Workman, 1987) and EC, 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 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 did collect samples from the WCSFW (wheat-corn-sunflowers-fallow-wheat) rotation due to crop failure.

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 since 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, and 10 inches in 2004 and 2005. 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, and 3.5 inches of precipitation in July and August 2000, 2001, 2002, 2003, 2004, and 2005, respectively.

2005 Crop Grain Data

No treatment or rotation affected grain yields (Figure 1), protein (Figure 2), P (Figure 3), Zn (Figure 4), and Cu (Figure 5). All wheat grain yields were less than 10 bushels/acre due to droughty conditions.

Due to lack of July-August precipitation (Table 1), we experienced a corn crop failure in 2005.

2005 Soil Data

As shown in Figure 6 through 10, treatment or rotation did not affect AB-DTPA-extractable P, Zn, and Cu, salinity (EC) or NO_3-N levels 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. However, the residual NO_3-N in the top 36 inches also indicates that future biosolids and fertilizer applications 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).

For the corn rotations, (Table 5), biosolids affected AB-DTPA P, Zn, and Cu, and EC and NO_3-N compared to N fertilizer. Most of the differences were found in the 0-2 and 2-4-inch soil depths. Again, lack of significant crop production over the last 5 years has reduced N removal from the soil. Biosolids and N fertilizer applications will not be reapplied until the residual levels of these nutrients reaches a point where fertilizer applications would be recommended (15 mg kg^{-1} (ppm) NO_3-N in the top foot; Davis et al., 2005).

CONCLUSIONS

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

1. Application of biosolids has produced the same wheat yields as those of commercial N fertilizer per lb of available N.
2. 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.
3. We found that biosolids application increased AB-DTPA P, Zn, Cu, and soil salinity (EC) and the soil accumulation of NO_3-N in the corn plots as compared to N fertilizer applications.

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Table 1. Monthly mean maximum (Max) and minimum (Min) temperatures and precipitation (Precip) in inches at the Byers research site, 2000-2005. (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		
	Max °F	Min °F	Precip inches
January	43.9	21.5	0.1
February	49.4	24.5	0.0
March	53.0	27.2	0.2
April	59.0	34.0	1.1
May	72.0	44.6	0.8
June	80.1	50.4	2.4
July	94.2	61.1	1.3
August	84.6	56.7	2.2
September	83.3	51.9	0.1
October	65.1	39.1	1.3
November	56.5	29.7	0.5
December	41.6	17.5	0.0
Total			10.0

† 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

Table 3. Biosolids and fertilizer applications and crop varieties used at the Byers research site, 1999-2005.

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

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. Soil characteristics for the corn rotation (CFW) at the Byers research site for 2005. ***Highlighted parameters*** are significant at the 10% probability level.

Parameter, units	Depth, inches	Biosolids	Nitrogen	Probability level
AB-DTPA P, mg kg^{-1}	***0-2***	***49.6***	***12.8***	***0.001***
	2-4	***10.2***	***5.1***	***0.057***
	4-8	2.9	2.6	0.453
	8-12	2.4	1.5	0.227
AB-DTPA Zn, mg kg^{-1}	***0-2***	***7.16***	***1.14***	***<0.001***
	2-4	***1.10***	***0.42***	***<0.001***
	4-8	***0.32***	***0.16***	***<0.001***
	8-12	0.37	0.11	0.134
AB-DTPA Cu, mg kg^{-1}	***0-2***	***11.5***	***1.8***	***<0.001***
	2-4	***4.0***	***2.4***	***0.026***
	4-8	4.1	3.8	0.449
	8-12	***3.4***	***2.8***	***0.078***
ECe, dS m^{-1}	0-2	1.2	0.7	0.273
	2-4	***1.2***	***0.5***	***0.081***
	4-8	***1.6***	***0.6***	***0.070***
	8-12	***1.3***	***0.6***	***0.097***
NO_3-N, mg kg^{-1}	0-2	49.1	41.2	0.190
	2-4	***44.1***	***14.9***	***0.040***
	4-8	***69.5***	***19.5***	***0.051***
	8-12	***60.6***	***21.6***	***0.079***
	12-24	***44.4***	***14.7***	***0.081***
	24-36	17.5	8.6	0.277
	36-48	7.7	4.0	0.449
	48-60	2.6	2.6	0.961
	60-72	4.7	2.8	0.438

Figure 1. Wheat grain yields for 2005 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences. (WF = wheat-fallow and WCF = wheat-corn-fallow rotations).

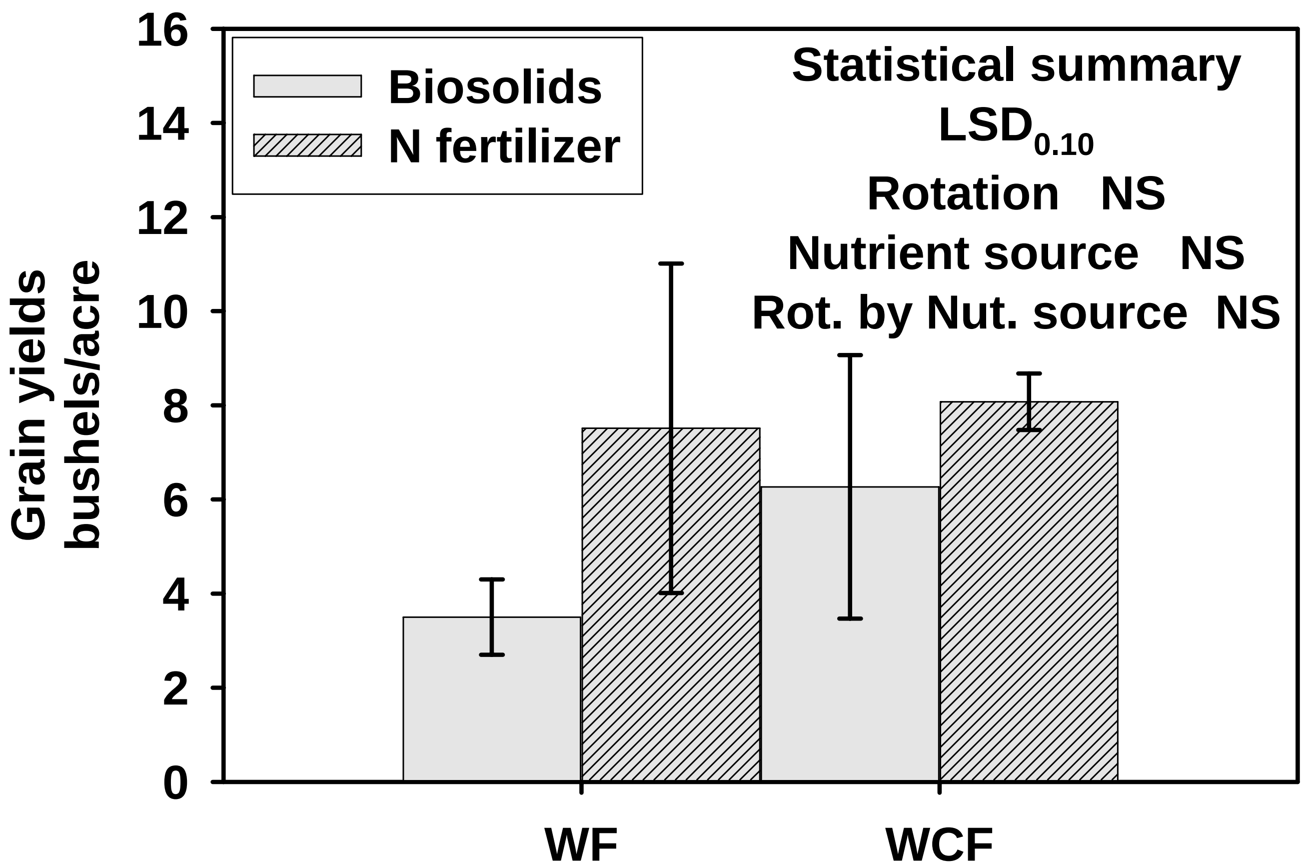


Figure 2. Wheat grain protein concentrations for 2005 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences. (WF = wheat-fallow and WCF = wheat-corn-fallow rotations).

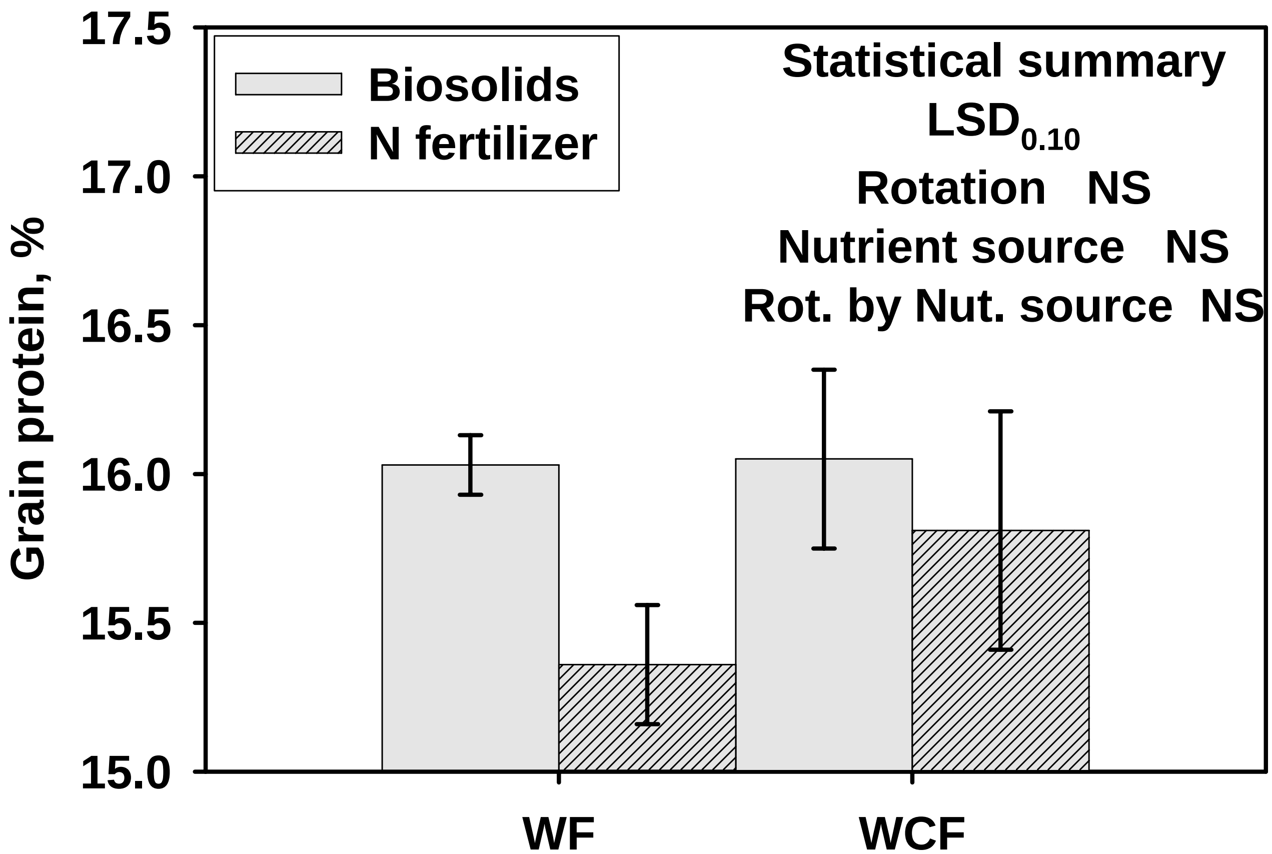


Figure 3. Wheat grain P concentrations for 2005 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences. (WF = wheat-fallow and WCF = wheat-corn-fallow rotations).

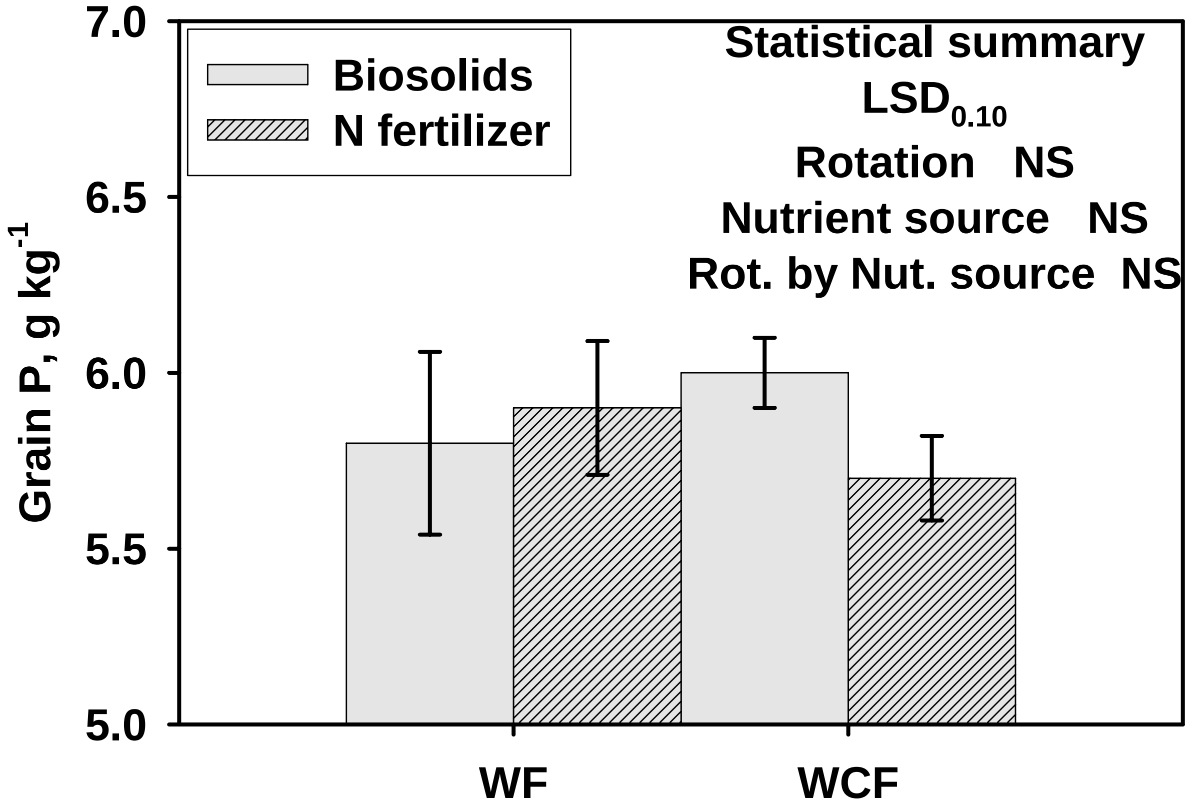


Figure 4. Wheat grain Zn concentrations for 2005 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences. (WF = wheat-fallow and WCF = wheat-corn-fallow rotations).

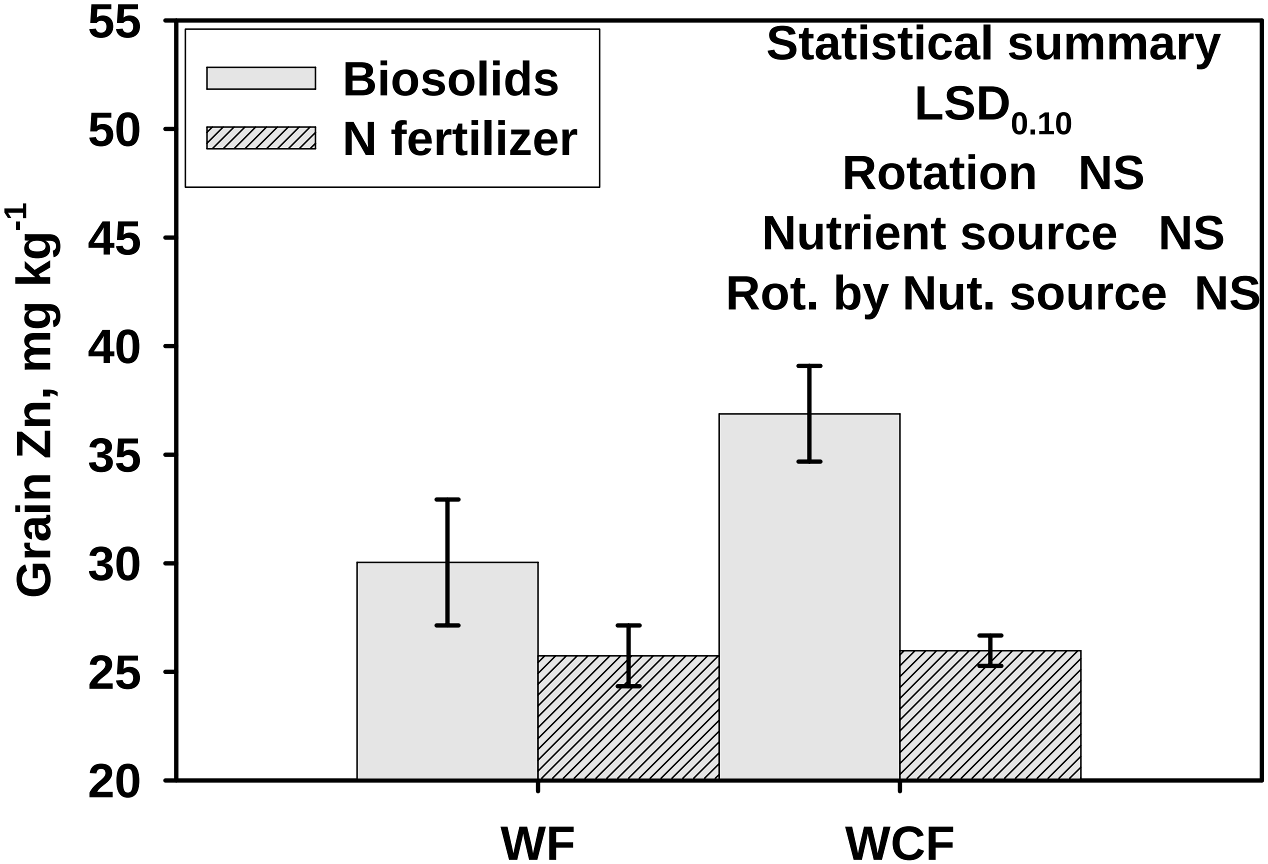


Figure 5. Wheat grain Cu concentrations for 2005 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences. (WF = wheat-fallow and WCF = wheat-corn-fallow rotations).

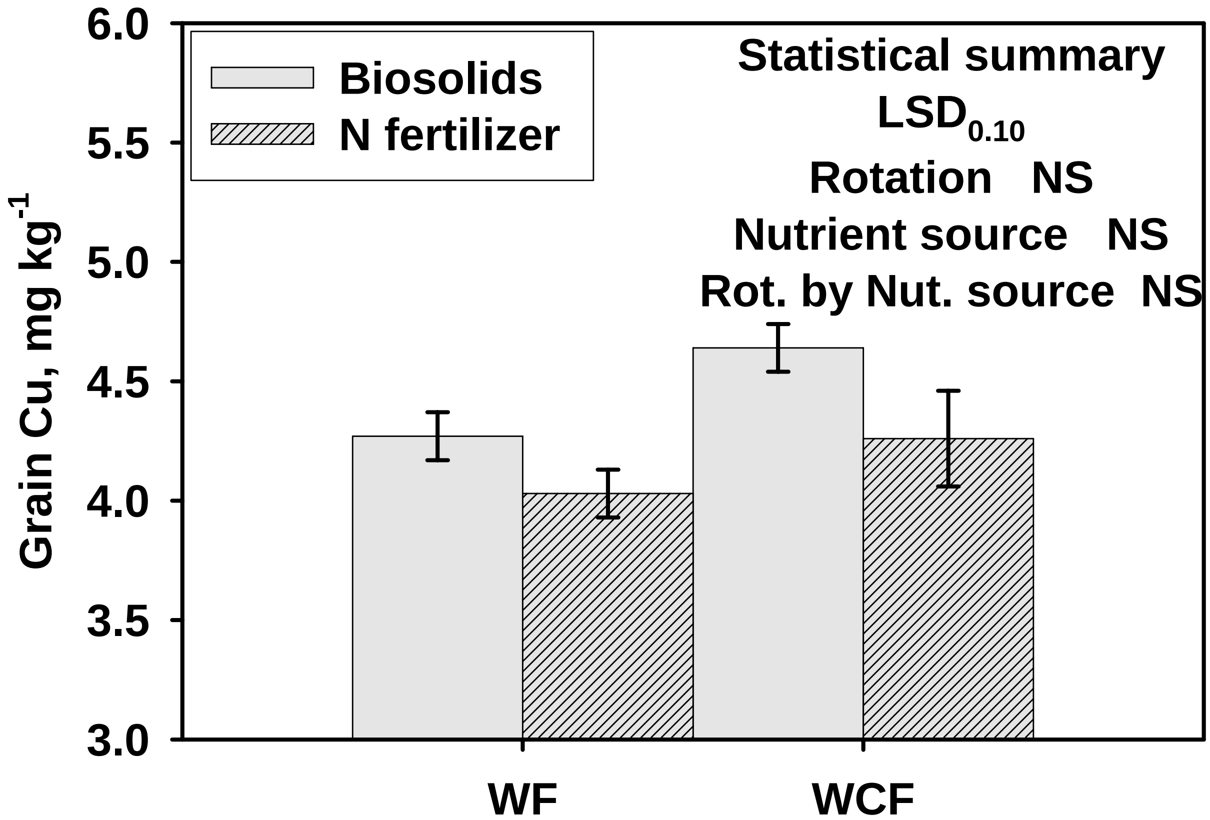
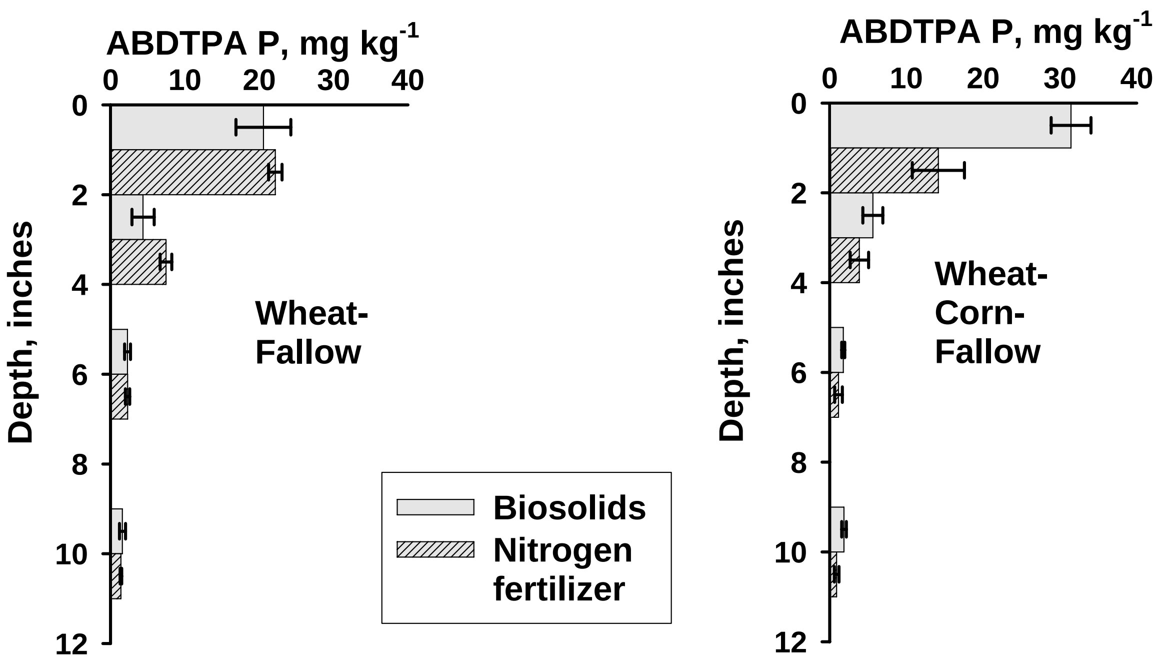


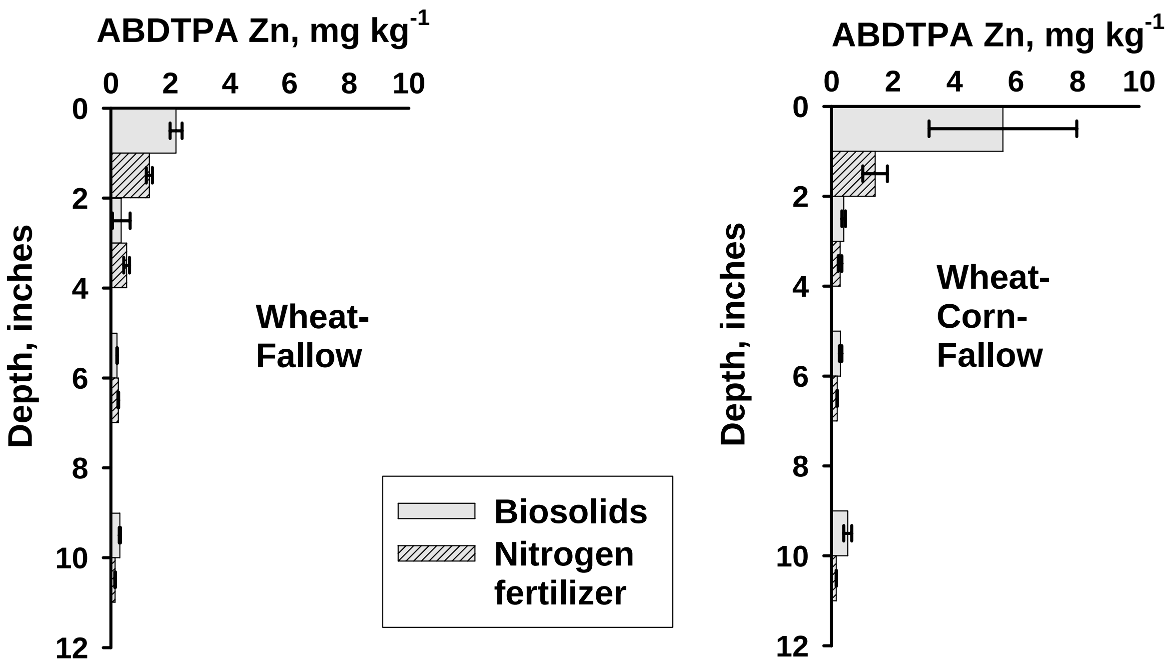
Figure 6. Soil AB-DTPA-extractable P concentration following 2005 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant 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

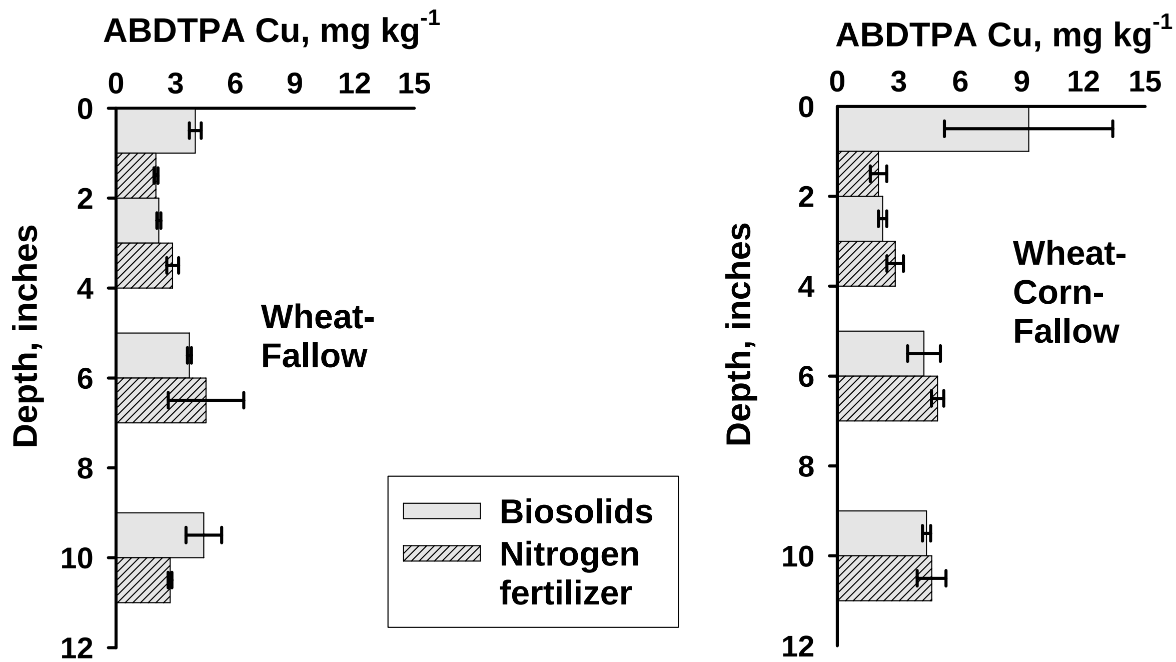
Figure 7. Soil AB-DTPA-extractable Zn concentration following 2005 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant 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

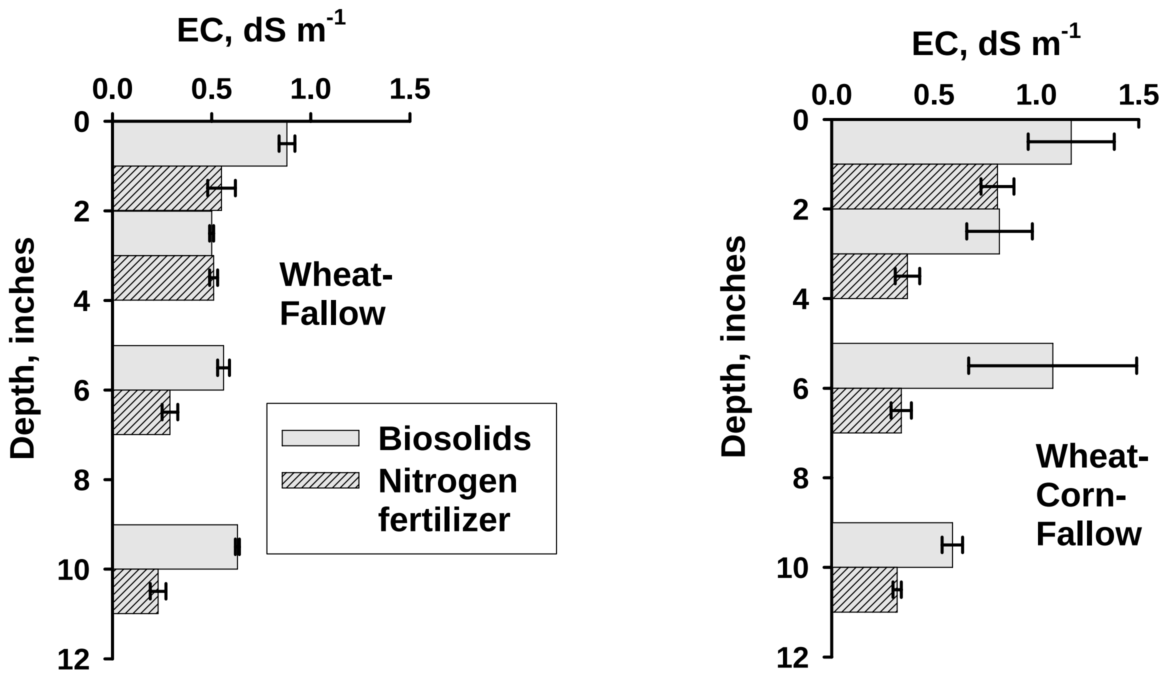
Figure 8. Soil AB-DTPA-extractable Cu concentration following 2005 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant 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

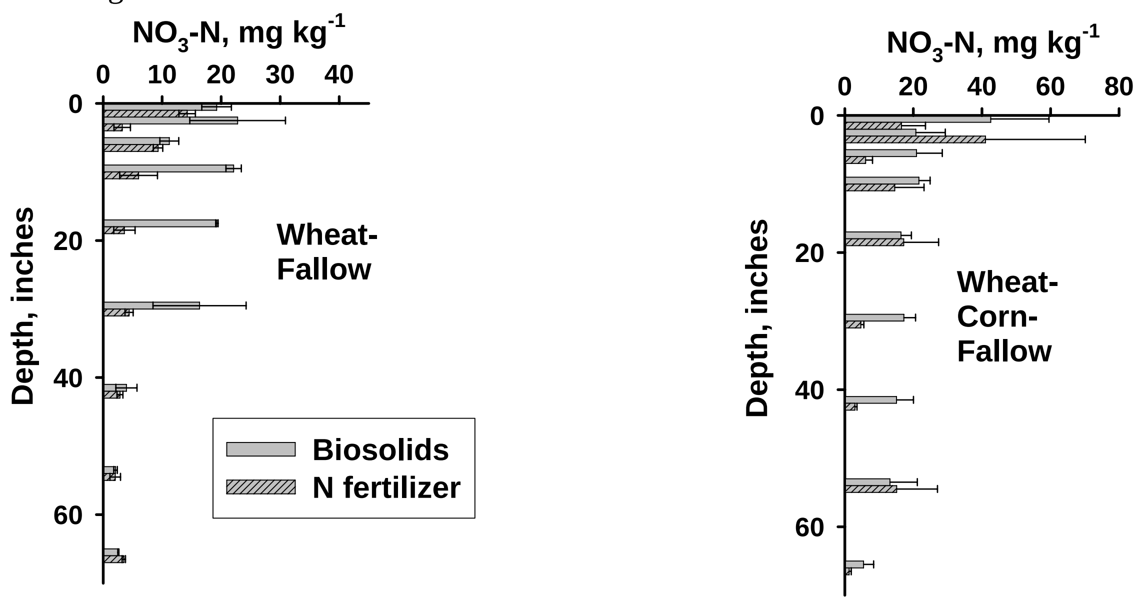
Figure 9. Soil saturated paste extract electrical conductivity (EC) following 2005 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and 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 10. Soil NO_3-N following 2005 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 10% probability level and NS indicates non-significant differences.



Statistical summary by soil depth:

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

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

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

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

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

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

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

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

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