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Biosolids Application to No-Till Dryland Rotations: 2004 Results

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Dryland Crop Rotations:
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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 several crop rotations?

Our objective was to compare agronomic rates of commercial N fertilizer to an equivalent rate of biosolids in combination with winter wheat-fallow (WF), winter wheat-corn (*Zea mays*, L.)-fallow (WCF), and winter wheat-winter wheat-corn-sunflowers (*Helianthus annuus*, L.)-fallow (WWCSF) crop rotations. Our hypotheses are that biosolids addition compared to N fertilizer:

1. Will produce similar crop yields.
2. Will 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. Will not affect soil salinity (electrical conductivity of saturated soil-paste extract, EC) or soil accumulation of nitrate-N (NO_3-N).

MATERIALS AND METHODS

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, WCF, and WWCSF. 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. Wheat planting occurred in early October 1999 (see Table 3). We designed the experiment so that every phase of each rotation is present during each year (10 plots total /replication). 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 section received commercial N fertilizer (applied with the seed and sidedressed after plant establishment; Table 3) and the second 50-foot section received biosolids (applied by L/E with manure spreader). We randomly selected which strip in each rotation received N fertilizer or biosolids. We provide the characteristics of the L/E biosolids 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, and 2004. We planted the first corn crop in May 2000 and the first sunflower crop in June 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, and 2004 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 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 were not able to collect samples from the WCSFW (wheat-corn-sunflowers-fallow-wheat) rotation due to crop failure.

For the wheat and corn 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 sunflower 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. 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, and 3.5 inches of precipitation in July and August 2000, 2001, 2002, 2003, and 2004, respectively. A problem we experienced in 2004 was the timing of precipitation. Even though we received 3.5 inches in July-August 2004, only 0.11 inches of rain fell from June 26th through July 23rd, leading to the corn-crop failure.

2004 Wheat Grain Data

The biosolids-amended WF rotation produced significantly greater wheat yields than all other rotations, while the WWCSF rotation had the lowest yields (Figure 1). No treatment or rotation affected grain protein (Figure 2).

Biosolids addition produced greater wheat-grain P, Zn, and Cu (Figures 3, 4, 5). The highest grain concentrations of these three nutrients were found in the WWCSF rotation (Figures 3, 4, 5). Lower yields in this rotation (Figure 1) probably lead to a "concentrating" effect. Typically, when plant yields are limited, higher elemental or nutrient concentrations result since less biomass is produced.

Due to lack of July-August precipitation (Table 1), we experienced a corn crop failure in 2004.

2004 Soil Data

As shown in Figure 6 through 8, biosolids addition produced the greatest surface AB-DTPA-extractable P, Zn, and Cu. This accumulation in the top 2 inches occurred since the biosolids were not incorporated and since crop production over the last three growing seasons has not allowed for significant removal of these elements in the harvested grain. The residual P levels in the top 2 inches of the biosolids plots indicate potential limitations on future biosolids or fertilizer applications as indicated by risk analysis using the Colorado Phosphorus Index (Sharkoff et al., 2005). The WWCSF rotation had greater soil-extractable concentrations of these three nutrients since it has received more biosolids applications (Table 3) than the WF or WCF rotations. Biosolids addition actually resulted in elevated EC (salt content) in the 0-2 and 4-8 inch soil depths (Figure 9) and the WWCSF rotation had the highest EC values in the top three soil depths. Greater NO_3-N concentrations in the biosolids treatments than those found in the commercial N fertilizer plots were observed in the top three soil depths (Figure 10), and the WWCSF rotation had the largest NO_3-N levels at 4-8 inches. The residual NO_3-N also indicates that future biosolids and fertilizer applications should be ceased until the soil levels are reduced to 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, biosolids application resulted in greater AB-DTPA-extractable P, Zn, and Cu concentrations in the soil surface (Figures 11, 12, 13). Type of rotation or nutrient source did not affect the EC (Figure 14). We did not observe consistent trends in the changes in soil NO_3-N (Figure 15). Again, lack of crop production over the last 3 years has reduced P and N removal from the soil. Biosolids and 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 and 7 mg kg^{-1} (ppm) AB-DTPA P in the top foot; Davis et al., 2005).

As shown in Table 5, we found greater ABDTPA-extractable P from 4-12 inches and NO_3-N at 24-36 inches in the sunflower plots that had previously received commercial N fertilizer as compared to the biosolids plots. We are not sure what created these differences.

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 increasing concentrations of P, Zn, and Cu in wheat grain and surface-soil levels following biosolids application. These accumulations will restrict future biosolids application until the nutrients are depleted to a level where fertilizer additions would be recommended.
3. We found that biosolids increased soil salinity (EC) or the soil accumulation of NO_3-N in the surface 8 inches of soil of the wheat plots.

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Table 1. Monthly mean maximum (Max) and minimum (Min) temperatures and precipitation (Precip) in inches at the Byers research site, 2000-2004. (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

† 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

Table 3. Biosolids and fertilizer applications and crop varieties used at the Byers research site, 1999-2004.

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

Table 4. Littleton/Englewood biosolids used at the Byers Research site, 1999-2004.

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 sunflower rotation (SFWWC) at the Byers research site for 2004. ***Highlighted parameters*** are significant at the 10% probability level.

Parameter, units	Depth, inches	Nitrogen	Biosolids	Probability level
AB-DTPA P, mg kg^{-1}	0-2	46.0	16.8	0.227
	2-4	11.4	4.6	0.125
	4-8	***2.9***	***1.7***	***0.078***
	8-12	***1.4***	***1.1***	***0.032***
AB-DTPA Zn, mg kg^{-1}	0-2	3.2	0.7	0.300
	2-4	1.2	0.4	0.330
	4-8	0.2	0.1	0.365
	8-12	0.1	0.2	0.393
AB-DTPA Cu, mg kg^{-1}	0-2	6.5	2.4	0.314
	2-4	3.6	2.3	0.484
	4-8	3.4	3.6	0.451
	8-12	3.1	3.6	0.681
ECe, dS m^{-1}	0-2	0.7	0.4	0.344
	2-4	0.7	0.3	0.405
	4-8	1.1	0.4	0.316
	8-12	1.1	0.5	0.276
NO_3-N, mg kg^{-1}	0-2	16	6	0.139
	2-4	17	6	0.423
	4-8	25	11	0.543
	8-12	26	27	0.977
	12-24	31	15	0.417
	24-36	***37***	***16***	***0.016***
	36-48	6	7	0.712
	48-60	8	2	0.475
	60-72	1	0	0.384

Figure 1. Wheat grain yields for 2004 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.

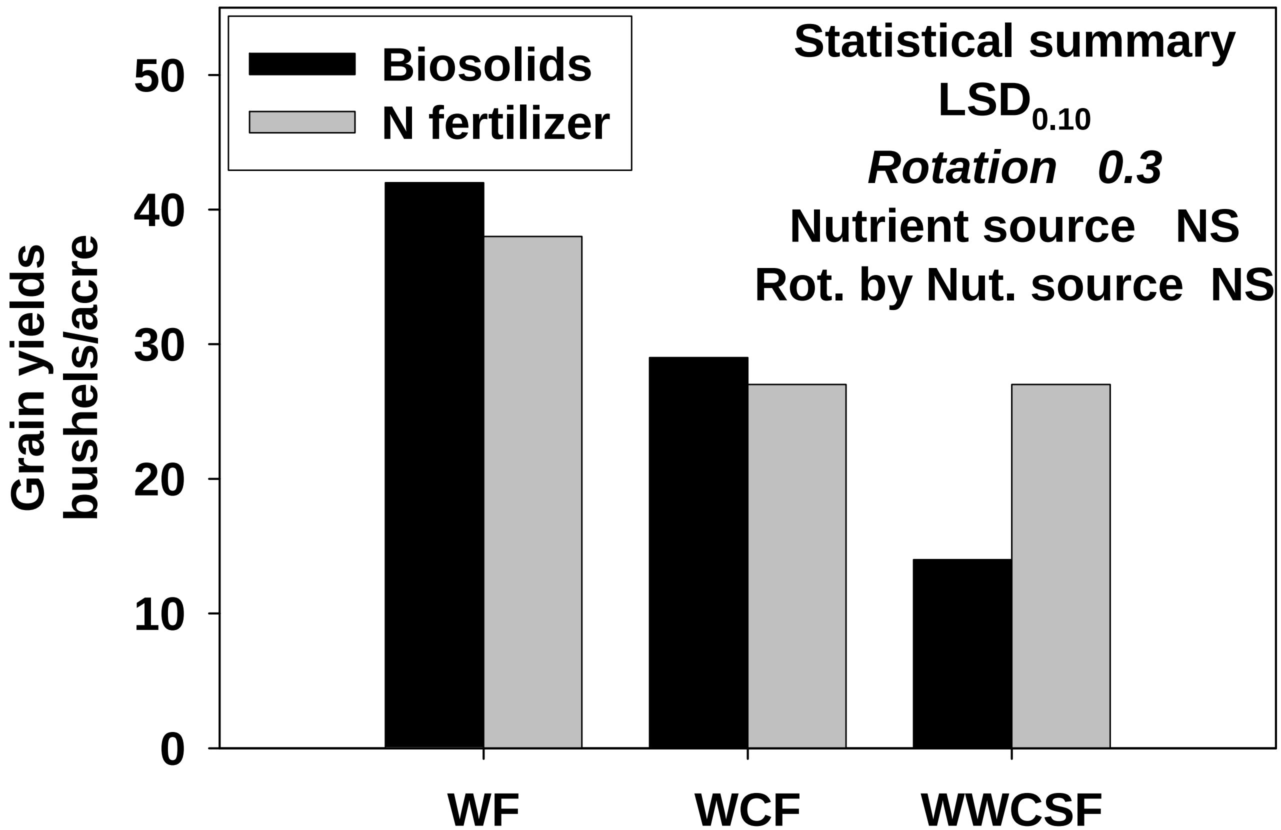


Figure 2. Wheat grain protein concentrations for 2004 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences.

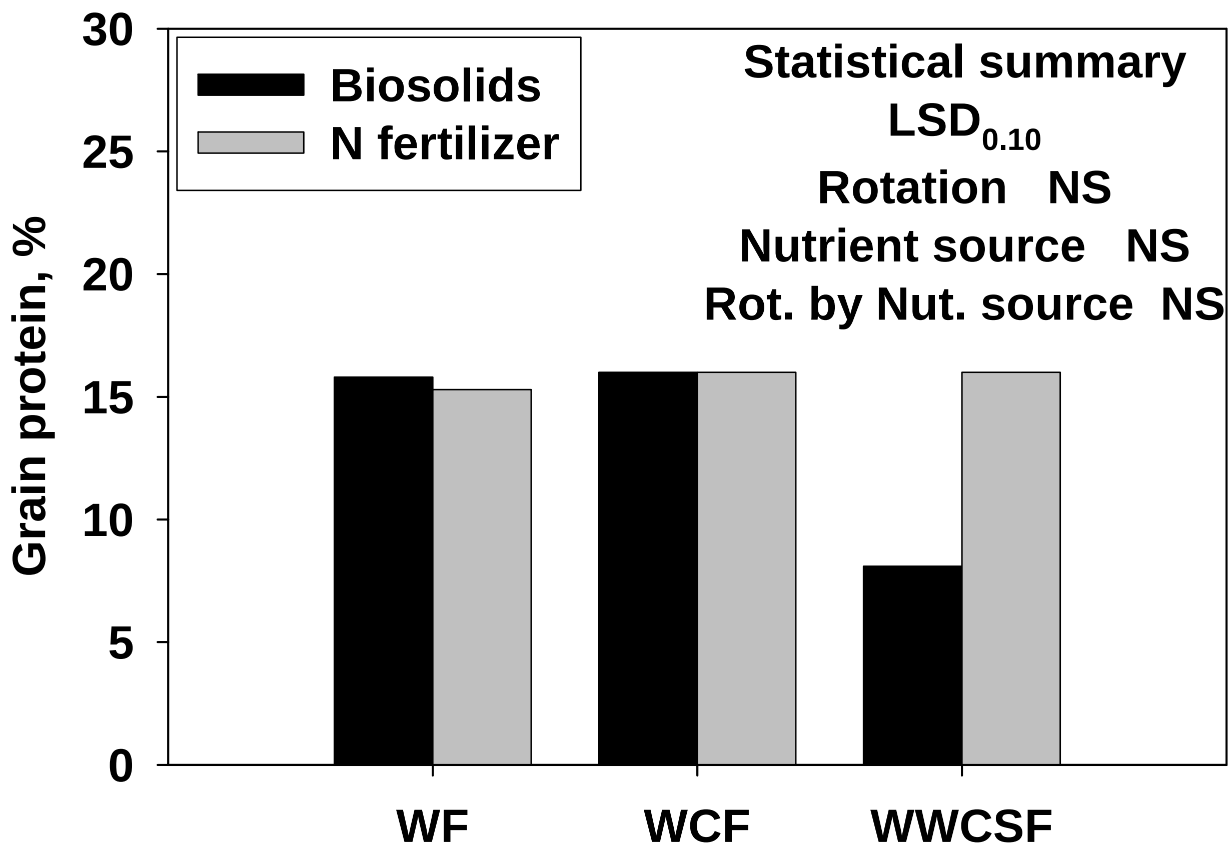


Figure 3. Wheat grain P concentrations for 2004 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences.

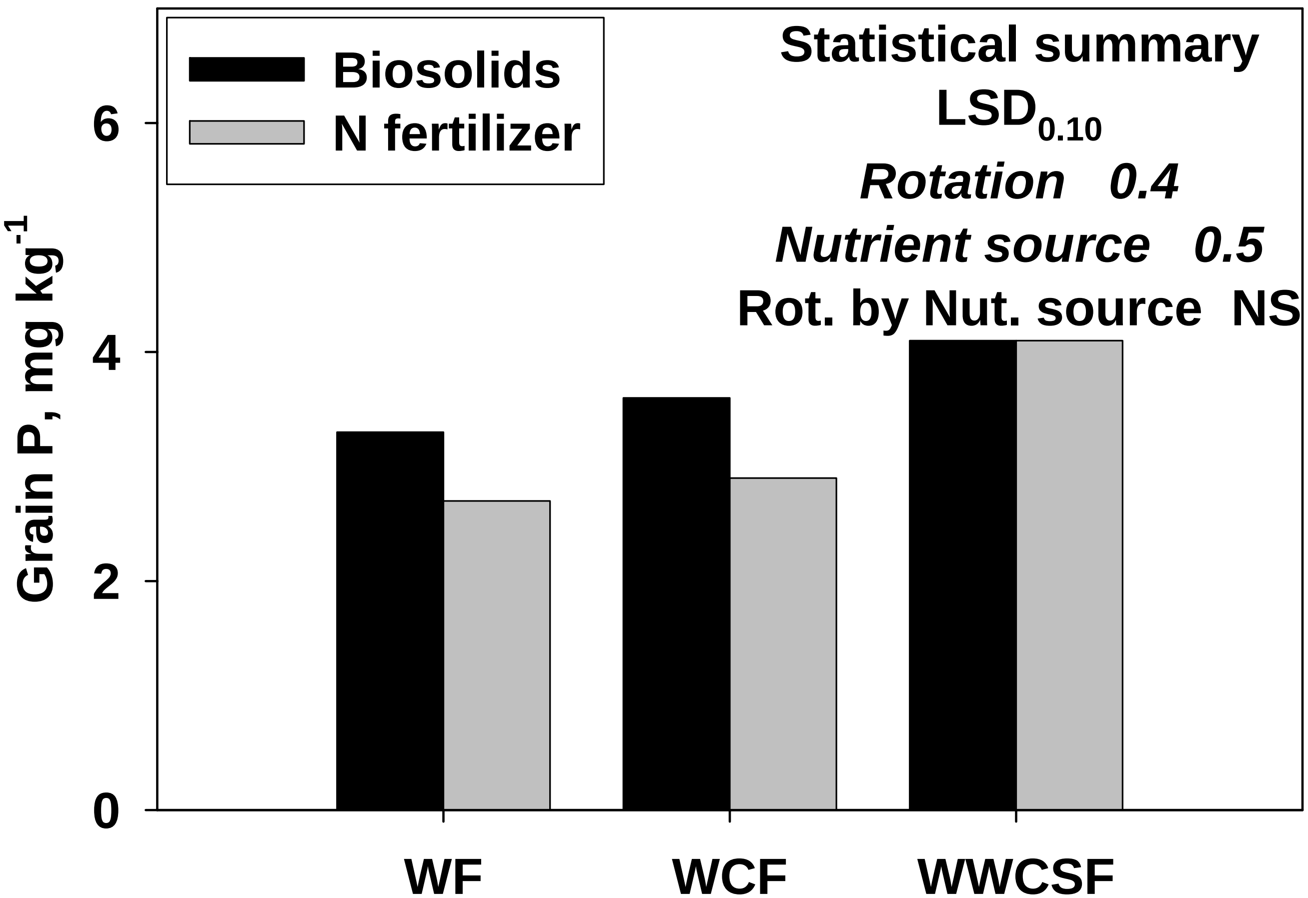


Figure 4. Wheat grain Zn concentrations for 2004 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences.

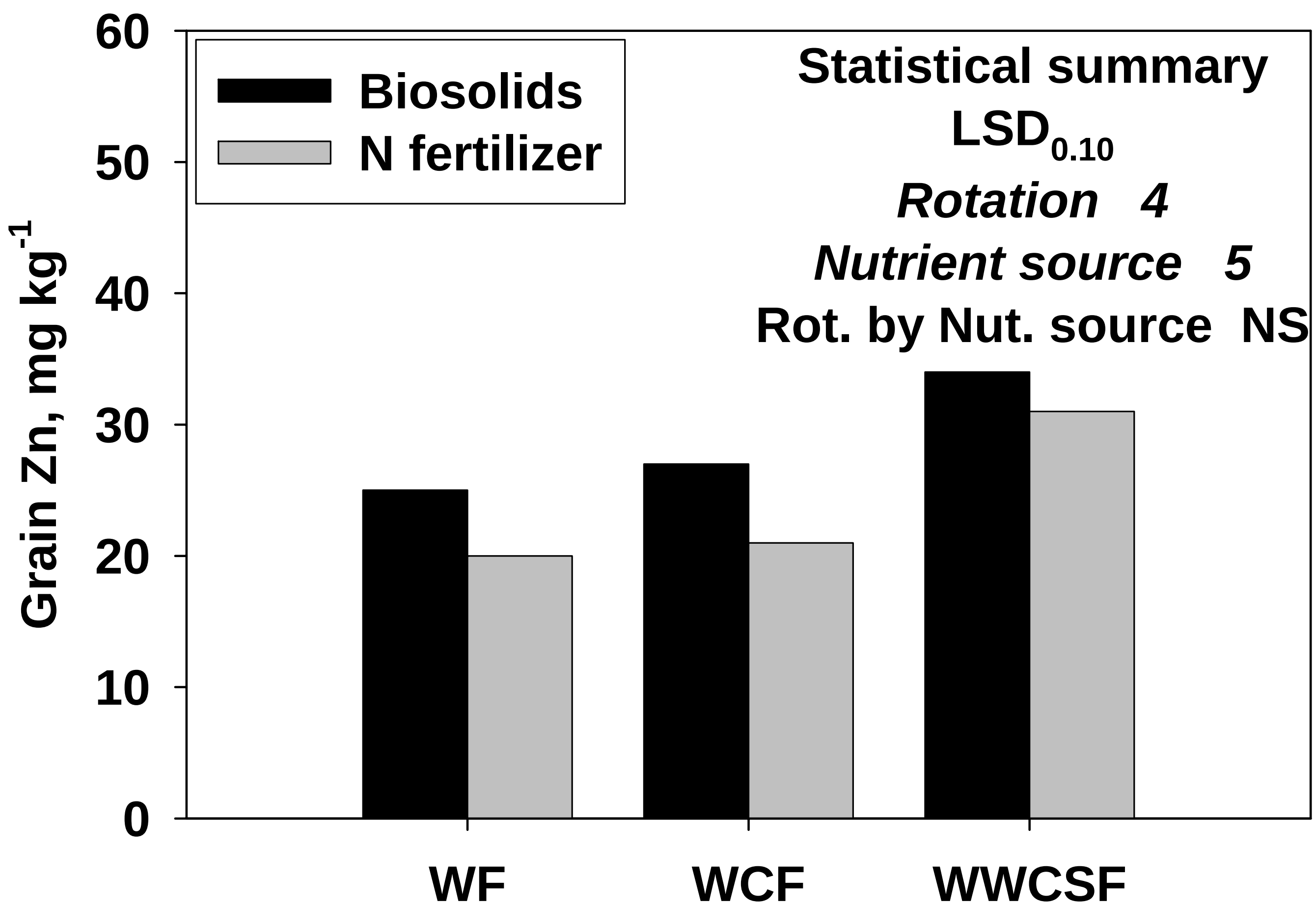


Figure 5. Wheat grain Cu concentrations for 2004 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences.

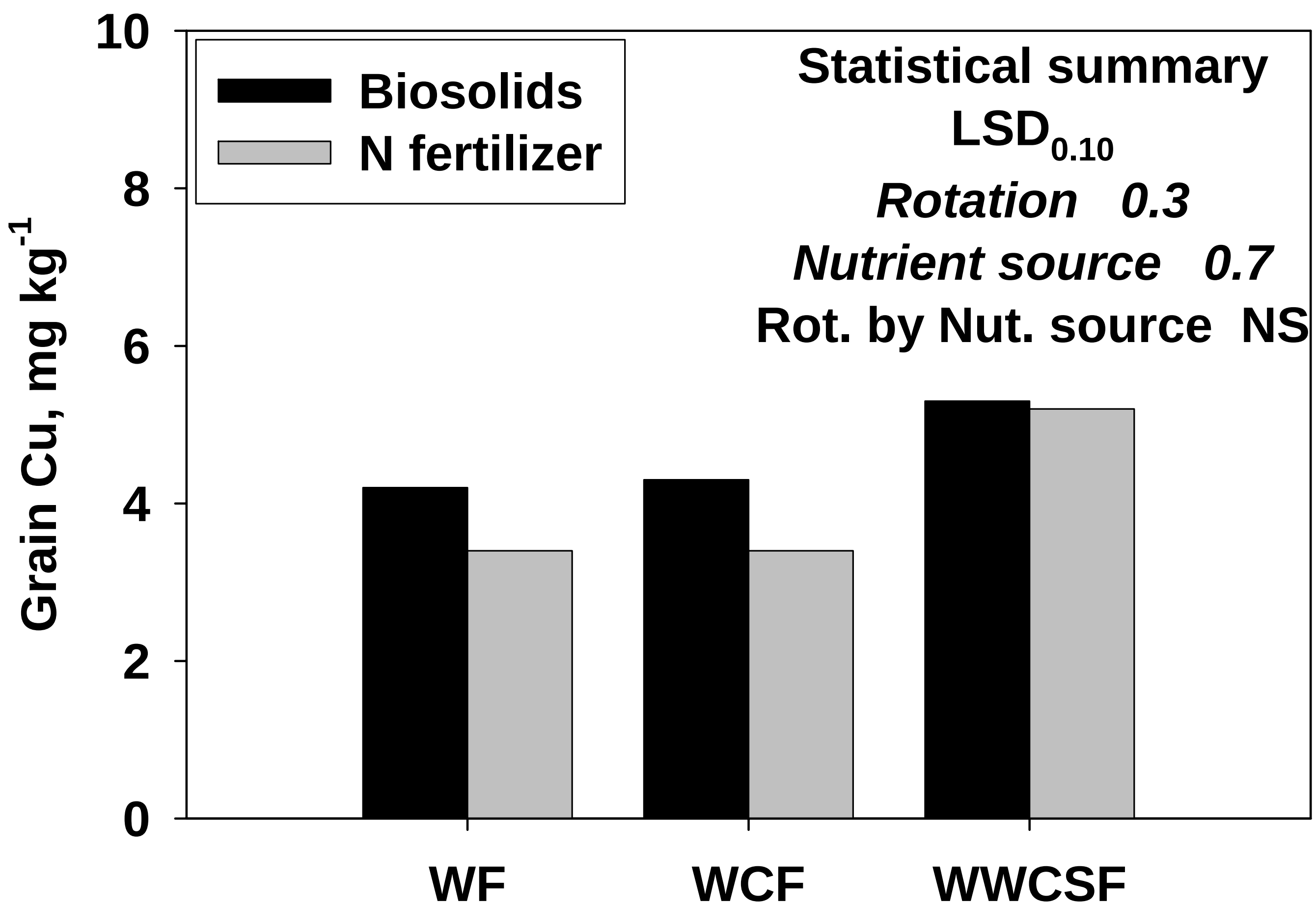
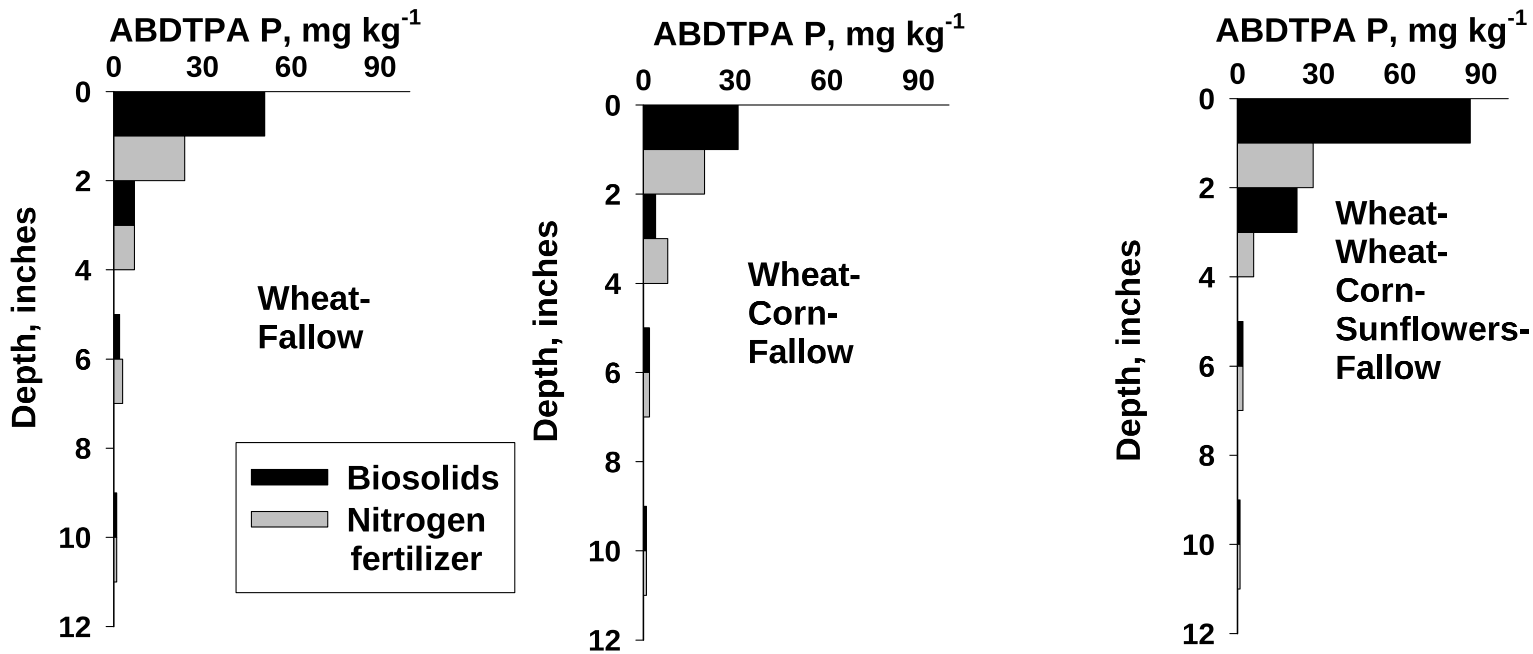


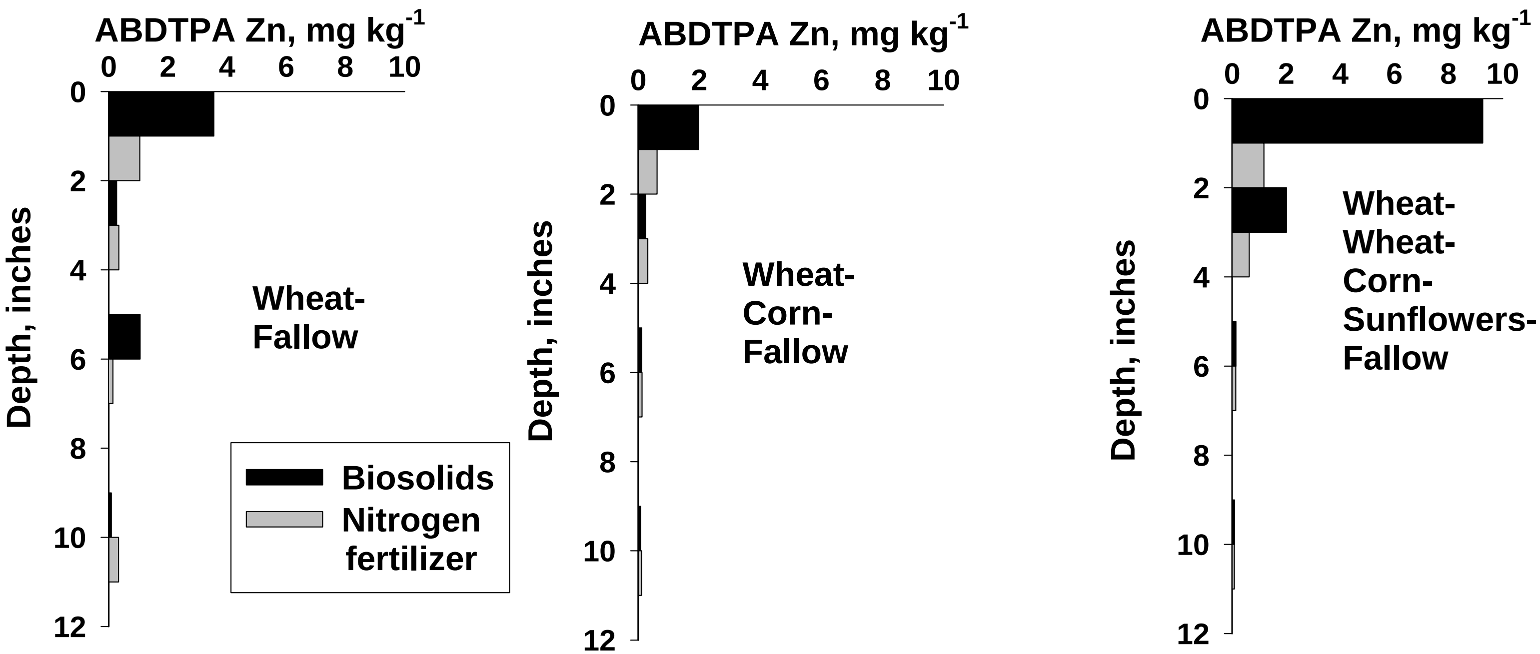
Figure 6. Soil AB-DTPA-extractable P concentration following 2004 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant 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 17	Rotations NS	Rotations NS	Rotations NS
Treatment 25	Treatment NS	Treatment NS	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

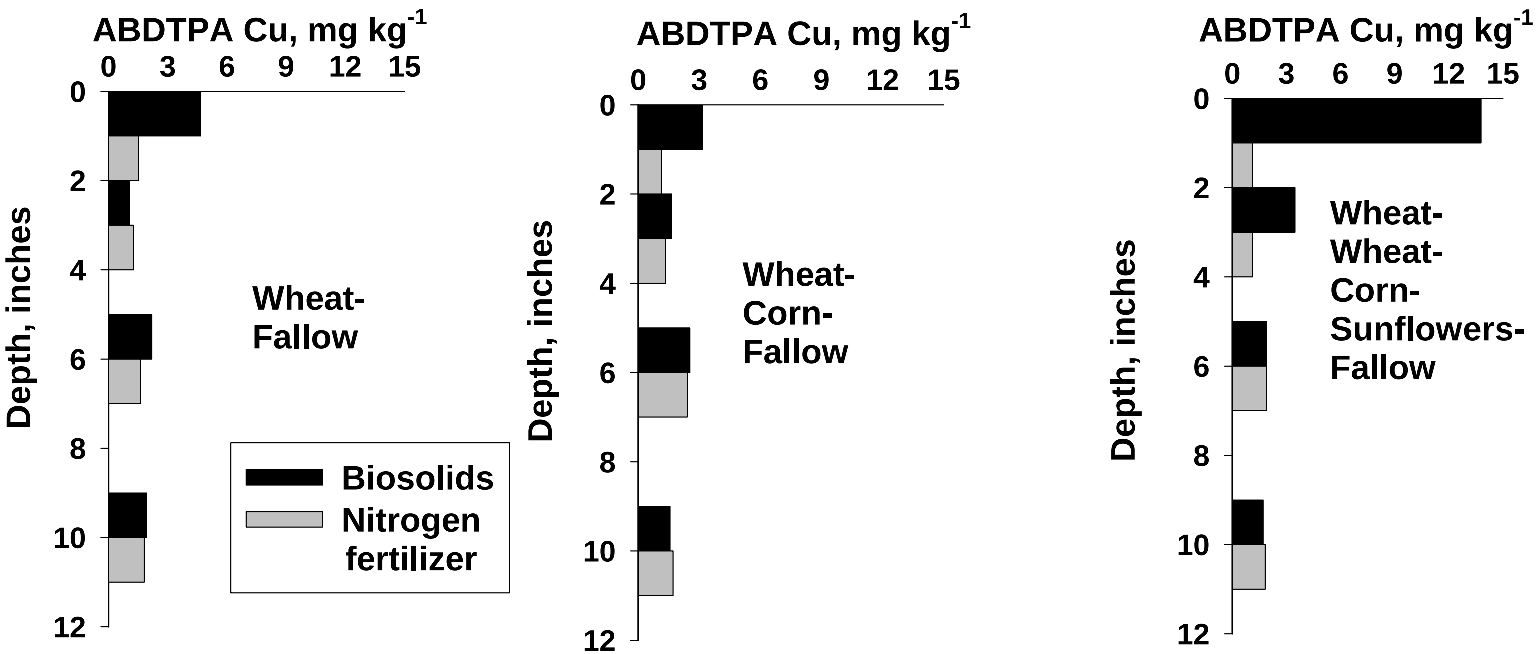
Figure 7. Soil AB-DTPA-extractable Zn concentration following 2004 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences.



Statistical summary by soil depth:

<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 1.9	Rotations NS	Rotations NS	Rotations NS
Treatment 1.6	Treatment NS	Treatment NS	Treatment NS
Rot. X Treat. 2.0	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

Figure 8. Soil AB-DTPA-extractable Cu concentration following 2004 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:

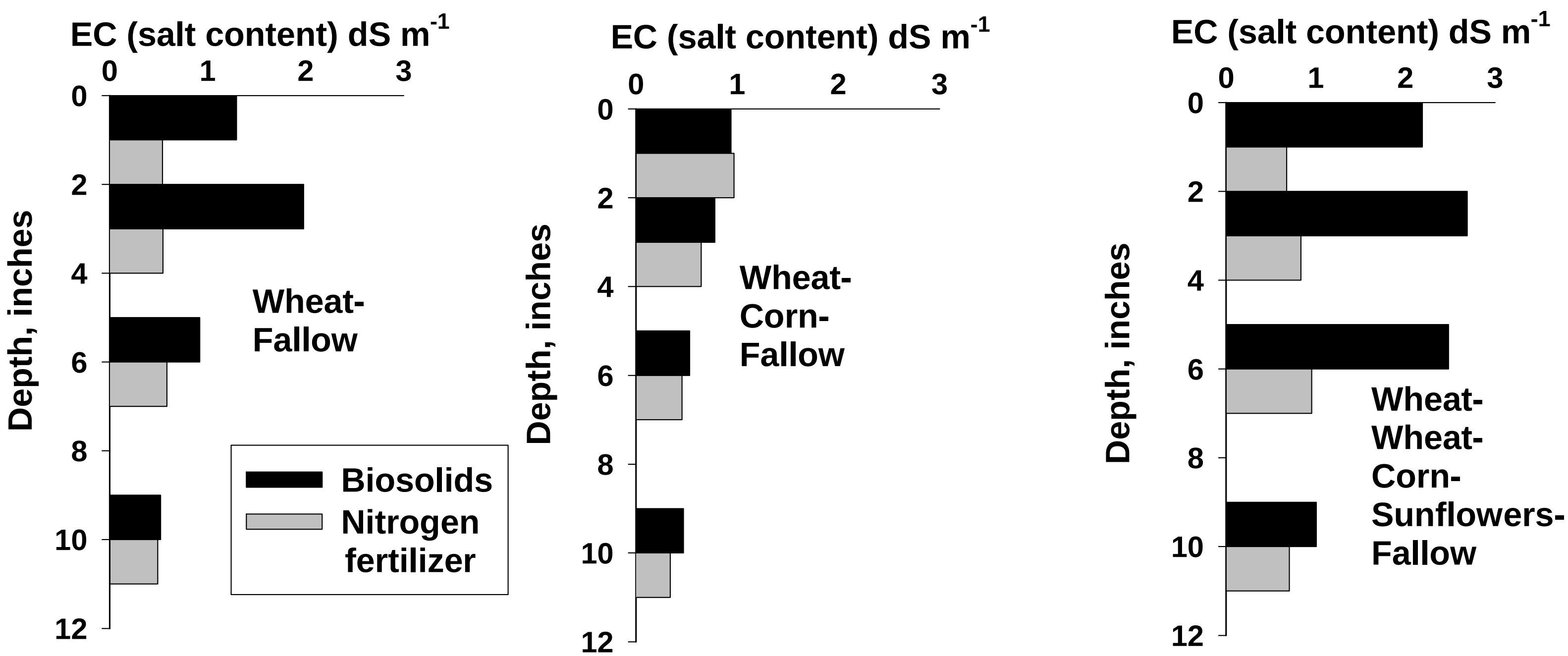
0-2 inches
$LSD_{0.10}$
Rotations 3.3
Treatment 2.6
Rot. X Treat. 3.2

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

4-8 inches
$LSD_{0.10}$
Rotations 1.8
Treatment 0.1
Rot. X Treat. NS

8-12 inches
$LSD_{0.10}$
Rotations 0.2
Treatment NS
Rot. X Treat. NS

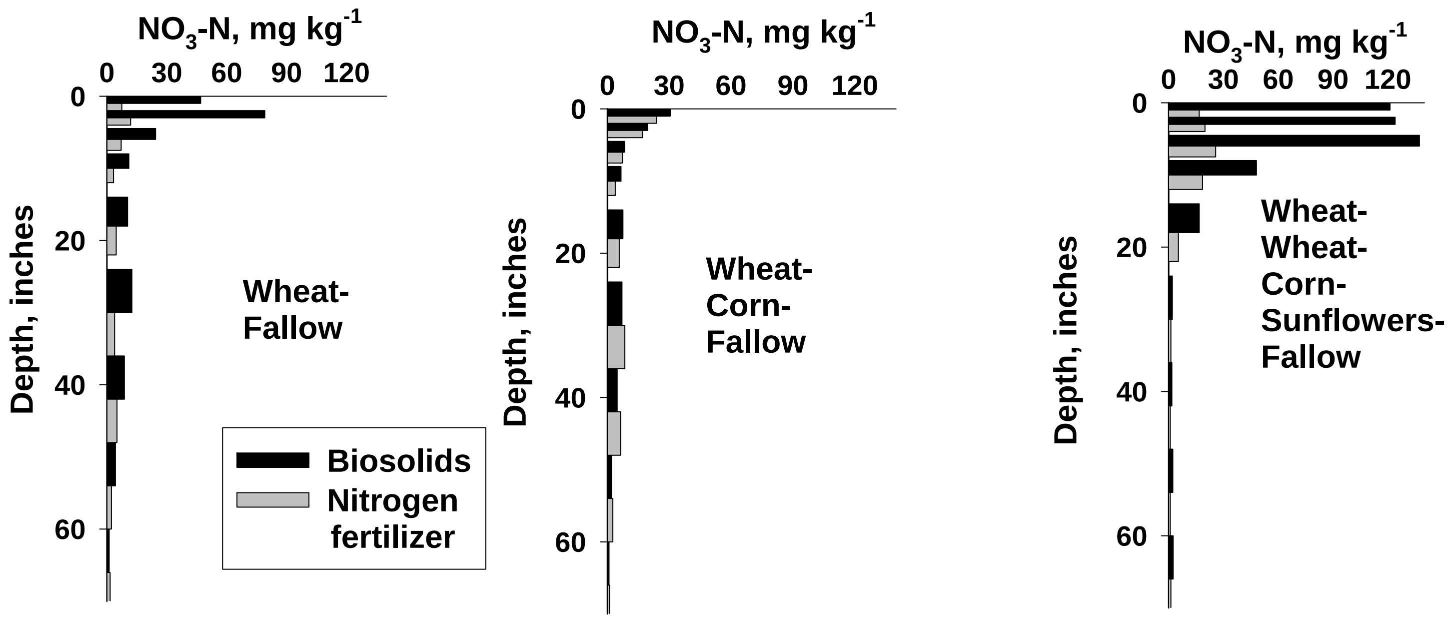
Figure 9. Soil saturated paste extract electrical conductivity (EC) following 2004 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and 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 0.5	Rotations NS	*Rotations 0.2*	Rotations NS
Treatment 0.9	*Treatment 1.0*	*Treatment 0.6*	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 2004 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 33.3
Rot. X Treat. NS

2-4 inches
$LSD_{0.10}$
Rotations NS
Treatment 54.1
Rot. X Treat. NS

4-8 inches
$LSD_{0.10}$
Rotations 9.1
Treatment 21.2
Rot. X Treat. 31.4

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

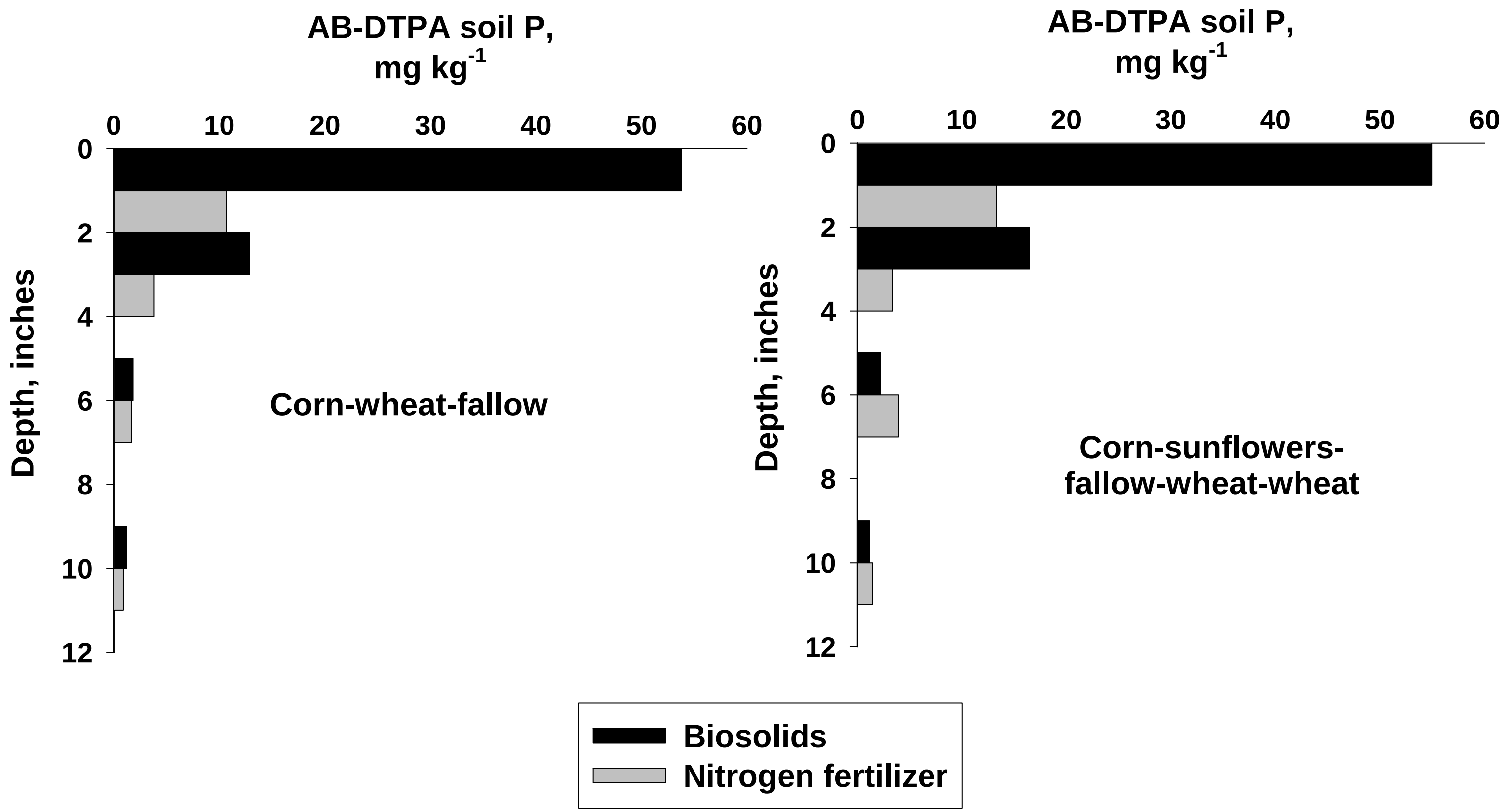
24-36 inches
$LSD_{0.10}$
Rotations NS
Treatment NS
Rot. X Treat. NS

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

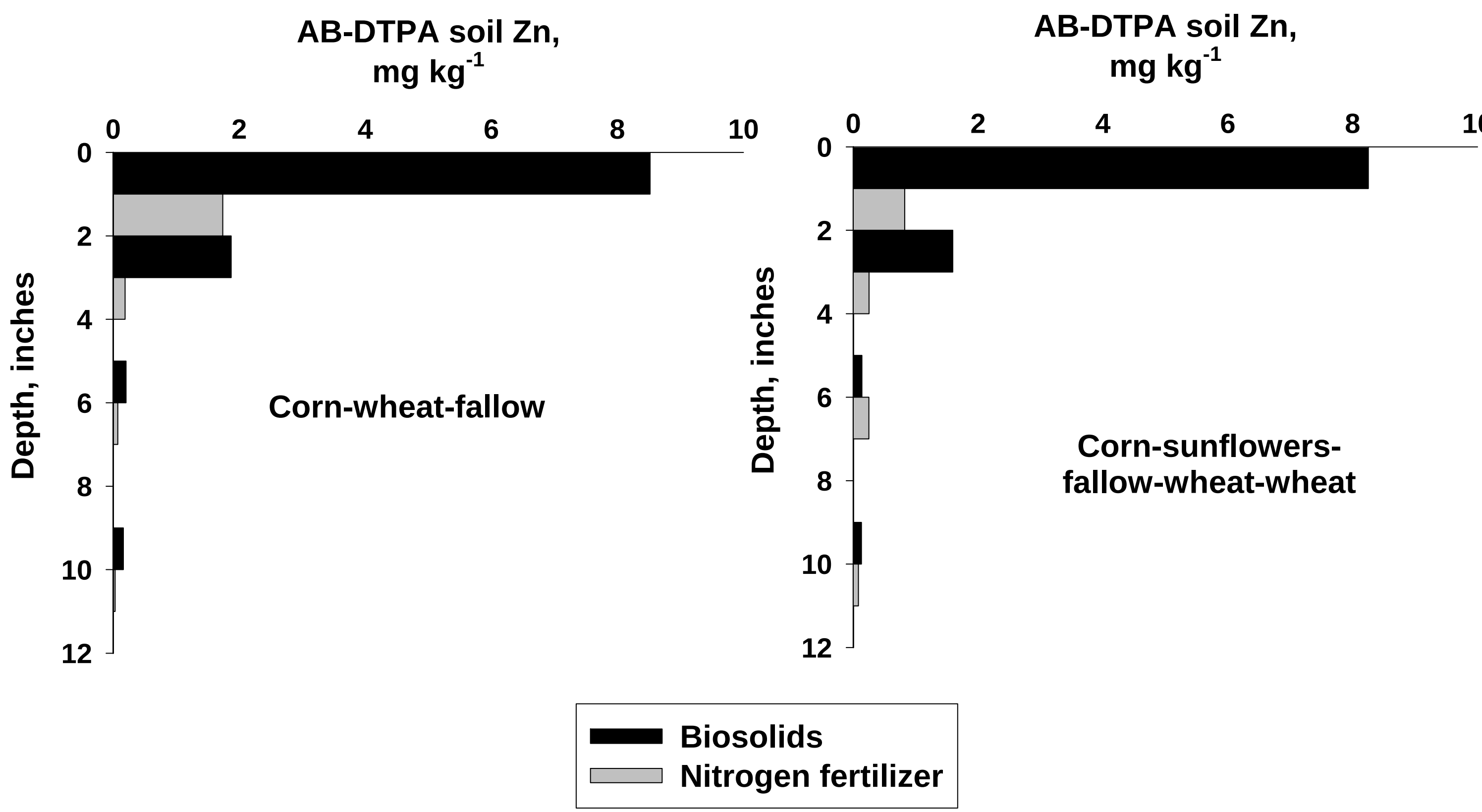
Figure 11. Soil AB-DTPA-extractable P concentration following 2004 dryland-corn-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant 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 41	Treatment NS	Treatment NS	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

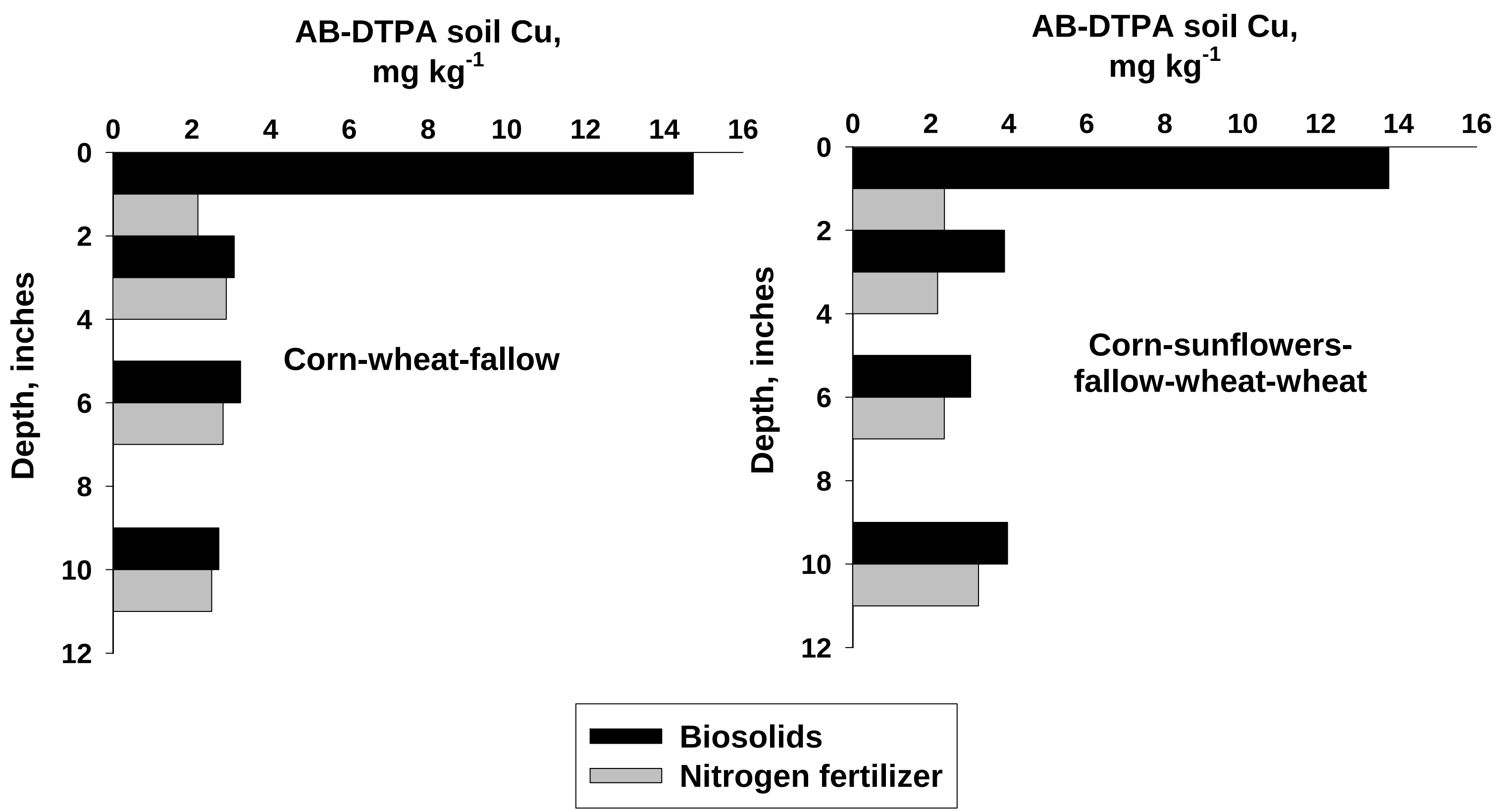
Figure 12. Soil AB-DTPA-extractable Zn concentration following 2004 dryland-corn-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant 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 5.2	Treatment NS	Treatment NS	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

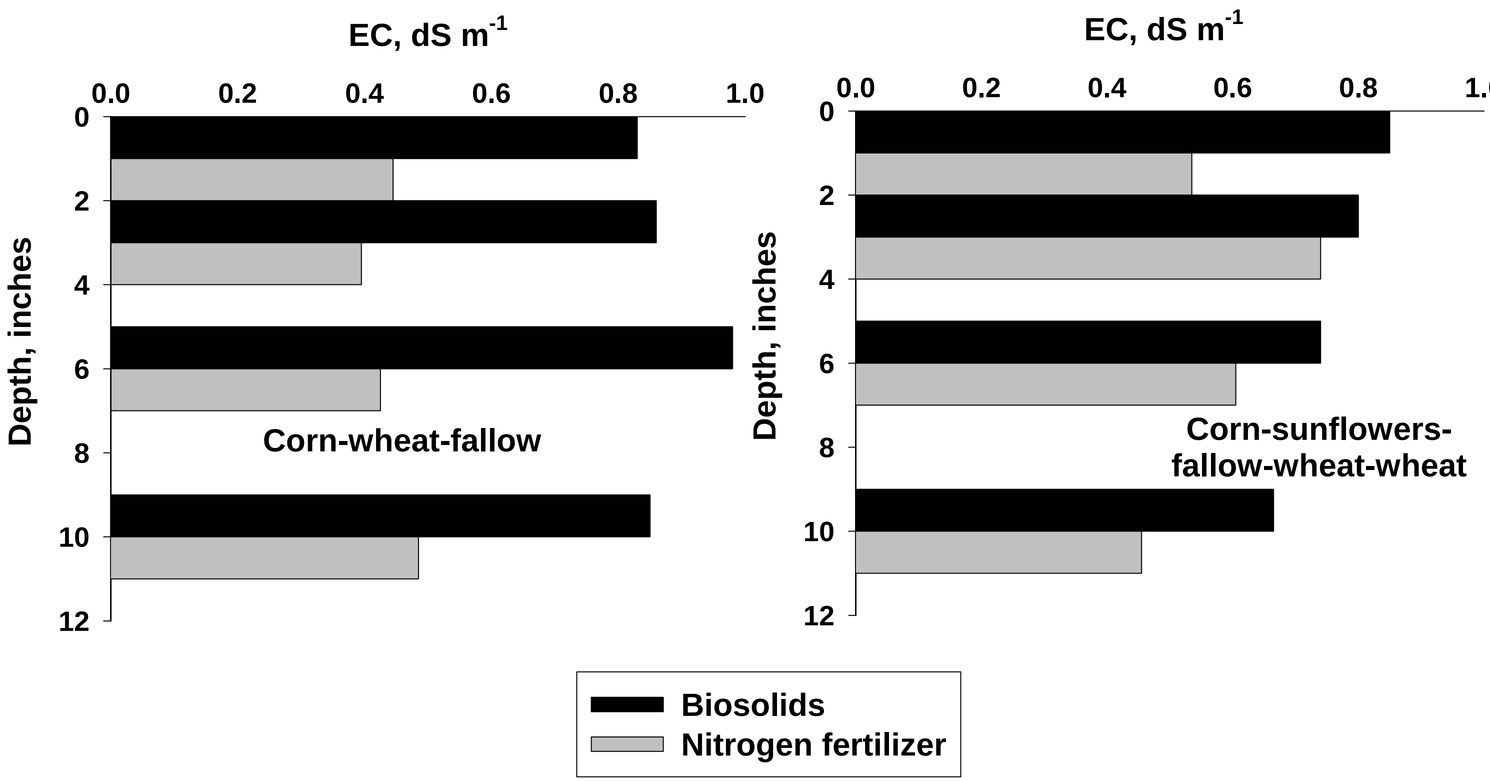
Figure 13. Soil AB-DTPA-extractable Cu concentration following 2004 dryland-corn-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant 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 10.3	Treatment NS	Treatment NS	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

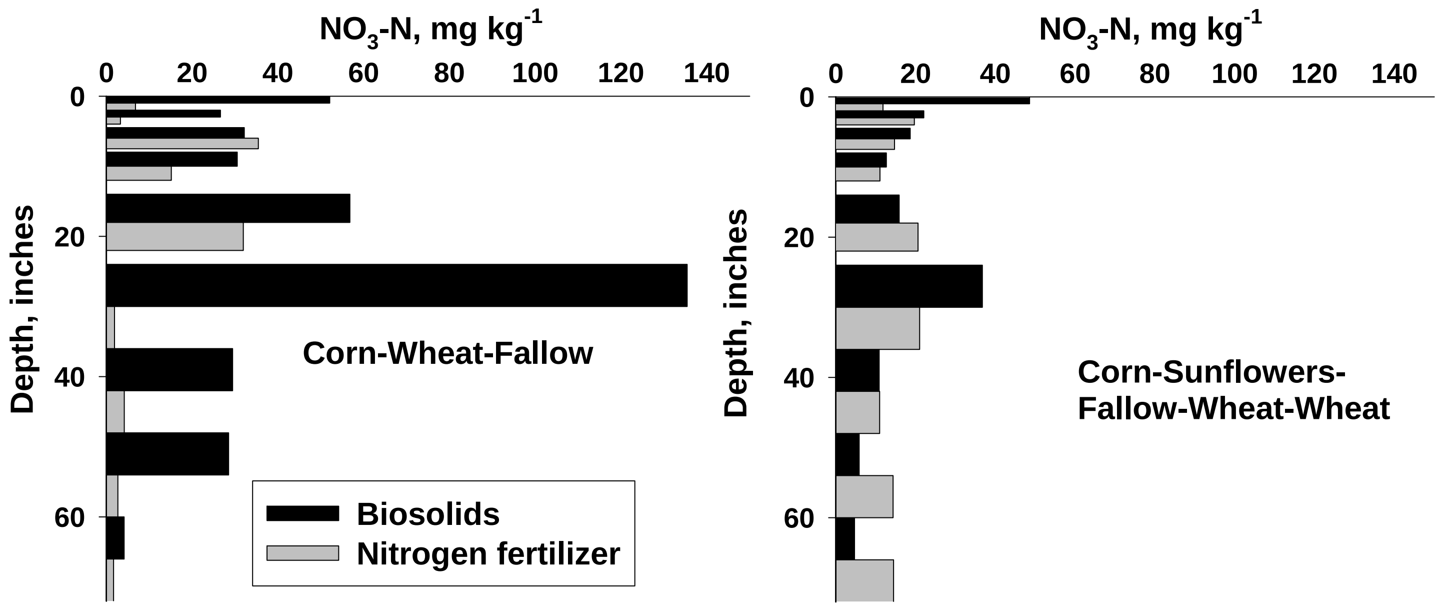
Figure 14. Soil saturated paste extract electrical conductivity (EC) following 2004 dryland-corn-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and 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 15. Soil NO_3^- following 2004 dryland-corn-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 1.4
Treatment NS
Rot. X Treat. NS

2-4 inches
$LSD_{0.10}$
Rotations NS
Treatment 16.9
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 2.2
Rot. X Treat. 3.1

12-24 inches
$LSD_{0.10}$
Rotations 2.2
Treatment NS
Rot. X Treat. NS

24-36 inches
$LSD_{0.10}$
Rotations 1.8
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