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Biosolids Application to No-Till Dryland Crop Rotations: 2002 Results

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INTRODUCTION

Recycling of biosolids on dryland 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 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 applied in a no-till dryland agroecosystem?

Our objective was to compare agronomic rates of N fertilizer to an equivalent rate of biosolids in combination with wheat-fallow (WF), wheat-corn (*Zea mays*, L.) -fallow (WCF), and wheat-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, measure of plant availability; Barbarick and Workman, 1987) concentrations.
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 Table 1 for precipitation data).

With biosolids application in August 1999, we initiated the study. Wheat planting occurred in September 1999 (see Table 2). 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 2) 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 3. We based the N fertilizer and biosolids applications on soil test recommendations determined on each plot. The Cities of L/E completed biosolids application for the summer crops in March 2000, 2001, and 2002.

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, and 2002, corn rotations in May 2001 and 2002, and sunflower plantings in June 2001 and 2002.

We completed wheat harvests in July 2000, 2001, and 2002 and corn and sunflowers in October 2000 and 2001. We experienced corn and sunflower crop failures in 2002 due to lack and timing of precipitation (Table 1). We also experienced a wheat crop failure in the WCSFW rotation since the soil-moisture had been depleted in this wheat following wheat sequence. 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, 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 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.

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 but only 5 inches in 2002. The critical months for corn are July and August (Nielsen et al., 1996). The Byers site received 6.0, 3.8, and 1.3 inches of precipitation in July and August 2000, 2001, and 2002 respectively.

2002 Grain Data

As shown in Figure 1, WCF produced significantly larger wheat yields than all other rotations while WF yields were greater than the WWCSF. The WCSFW rotation experienced a crop failure since the soil-moisture had been depleted in this wheat following wheat sequence.

Grain protein (Figure 2) was not affected by any treatment effect. For grain P content (Figure 3), no consistent trends were observed. Type of rotation or nutrient source did not affect grain Zn and Cu concentrations (Figures 4 and 5, respectively).

Due to lack of July-August precipitation (Table 1), we experienced corn and sunflower crop failures in 2002.

2002 Soil Data

As shown in Figure 6, WCF, compared to the other rotations, plus biosolids, compared to commercial N fertilizer, produced the largest AB-DTPA-extractable P for the 2-4 inch soil depth. None of the treatments affected the AB-DTPA-extractable Zn (Figure 7). For AB-DTPA Cu (Figure 8), L/E biosolids application resulted in higher concentrations in the top two soil depths compared to the commercial N fertilizer. While the type of rotation and the rotation by nutrient source interaction affected the EC (Figure 9) and soil NO_3-N (Figure 10) at various depths, we did not observe any consistent trends. Biosolids did produce higher NO_3-N than commercial N fertilizer at the 4-8-, 8-12-, 24-36-, and 48-60-inch soil depths.

For the corn rotations, none of the treatments affected AB-DTPA-extractable P concentrations at any soil depth (Figure 11). While the type of rotation and the rotation by nutrient source interaction affected the AB-DTPA-extractable Zn (Figure 12) and Cu (Figure 13) and the EC (Figure 14) and soil NO_3-N (Figure 15) at various depths, we did not observe any consistent trends. Biosolids did produce higher NO_3-N than commercial N fertilizer in the 0-2-inch soil depth.

CONCLUSIONS

Relative to our three objectives listed on page 1, we have found the following trends:

1. Application of biosolids has produced the same crop yields as that of commercial N fertilizer.
2. We have not observed consistent trends regarding biosolids effects on grain or soil levels of P, Zn, and Cu.
3. We have not observed consistent trends regarding biosolids effects on grain or soil salinity or the soil accumulation of NO_3-N.

We have also found some grain and soil differences associated with crop rotation or the interaction of rotation and type of nutrient addition; but, we have not observed consistent trends in most cases. Our 2002 results are similar to those we reported for 2001 (Barbarick et al., 2003). We may not be able to draw solid conclusions until we have completed at least two complete cycles of the longest rotation (a total of at least 10 years).

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Table 1. Monthly precipitation in inches at the Byers research site, 2000-2002.

Month	2000	2001	2002
January	†	0.2	0.1
February	†	0.1	0.2
March	†	0.2	0.2
April	0.6	1.5	0.3
May	0.9	2.4	0.7
June	0.9	2.4	1.2
July	2.5	1.9	0.2
August	3.5	1.9	1.1
September	0.8	0.8	0.7
October	1.6	0.2	0.2
November	0.3	0.8	0.1
December	0.3	0.0	0.0
Total	11.4	12.4	5.0

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

Table 2. Biosolids and fertilizer applications and crop varieties used at the Byers research site, 1999-2002.

Year Planted	Date Planted	Crop	Variety	Biosolids tons/acre	Bio/N equiv. lbs	N lbs/acre with seed	N lbs/acre after planting	Total N lbs/acre	P2O5 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	May	Corn	Pioneer 37M81	Variable	Variable	5	Variable	Variable	15	5
2002	June	Sunflowers	Triumph 545A	0	0	5	0	0	15	5
2002	Early Oct.	Wheat	Stanton	Variable	Variable	5	Variable	Variable	20	0

† We applied biosolids rates that matched soil-test concentrations and crop-yield goals. We assumed each dry ton of biosolids supplied 16 lbs N.

Table 3. Littleton/Englewood biosolids used at the Byers Research site, 1999-2001.

Parameter	1999 Wheat	2000 Corn Sunflowers	2001 Corn Sunflowers	2001 Wheat
Total solids, g kg^{-1}	217	---	210	220
pH	7.6	7.8	8.4	8.1
EC, dS m^{-1}	6.2	11.2	10.6	8.7
Organic N, g kg^{-1}	50	47	58	39
NH_4-N, g kg^{-1}	12	7	14	16
NO_3-N, g kg^{-1}	0.023	0.068	0.020	0.021
K, g kg^{-1}	5.1	2.6	1.6	1.9
P, g kg^{-1}	29	18	34	32
Al, g kg^{-1}	28	18	15	18
Fe, g kg^{-1}	31	22	34	33
Cu, mg kg^{-1}	560	820	650	750
Zn, mg kg^{-1}	410	543	710	770
Ni, mg kg^{-1}	22	6	11	9
Mo, mg kg^{-1}	19	22	36	17
Cd, mg kg^{-1}	6.2	2.6	1.6	1.5
Cr, mg kg^{-1}	44	17	17	13
Pb, mg kg^{-1}	43	17	16	18
As, mg kg^{-1}	5.5	2.6	1.4	3.8
Se, mg kg^{-1}	20	16	7	6
Hg, mg kg^{-1}	3.4	0.5	2.6	2.0

Table 4. Soil characteristics for the sunflower rotation (SFWWC) at the Byers research site for 2002. ***Highlighted parameters*** are significant at the 10% probability level.

Parameter, units	Depth, cm	N treatment	Biosolids treatment	Probability level
AB-DTPA P, mg kg^{-1}	***0-5***	***2.85***	***6.73***	***0.048***
	5-10	1.72	1.16	0.262
	10-20	0.43	0.50	0.130
	20-30	0.41	0.47	0.320
AB-DTPA Zn, mg kg^{-1}	***0-5***	***0.43***	***1.12***	***0.050***
	5-10	0.09	0.12	0.186
	10-20	0.08	0.10	0.368
	20-30	0.06	0.07	0.250
AB-DTPA Cu, mg kg^{-1}	***0-5***	***0.52***	***1.78***	***0.040***
	5-10	0.52	1.21	0.190
	10-20	0.90	0.93	0.413
	20-30	0.67	0.78	0.219
EC dS m^{-1}	***0-5***	***0.79***	***1.65***	***0.038***
	5-10	0.67	1.03	0.237
	10-20	1.21	0.61	0.295
	20-30	1.22	0.77	0.289
NO_3-N mg kg^{-1}	0-5	10.1	24.1	0.104
	5-10	***5.2***	***12.2***	***0.007***
	10-20	***2.8***	***6.3***	***0.042***
	20-30	2.4	3.2	0.185
	30-60	0.4	0.8	0.226
	60-90	***0.1***	***1.7***	***0.093***
	90-120	1.2	2.1	0.300
	120-150	0.3	0.7	0.204
	150-180	***0.9***	***2.2***	***0.009***

Figure 1. Grain yields for 2002 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.

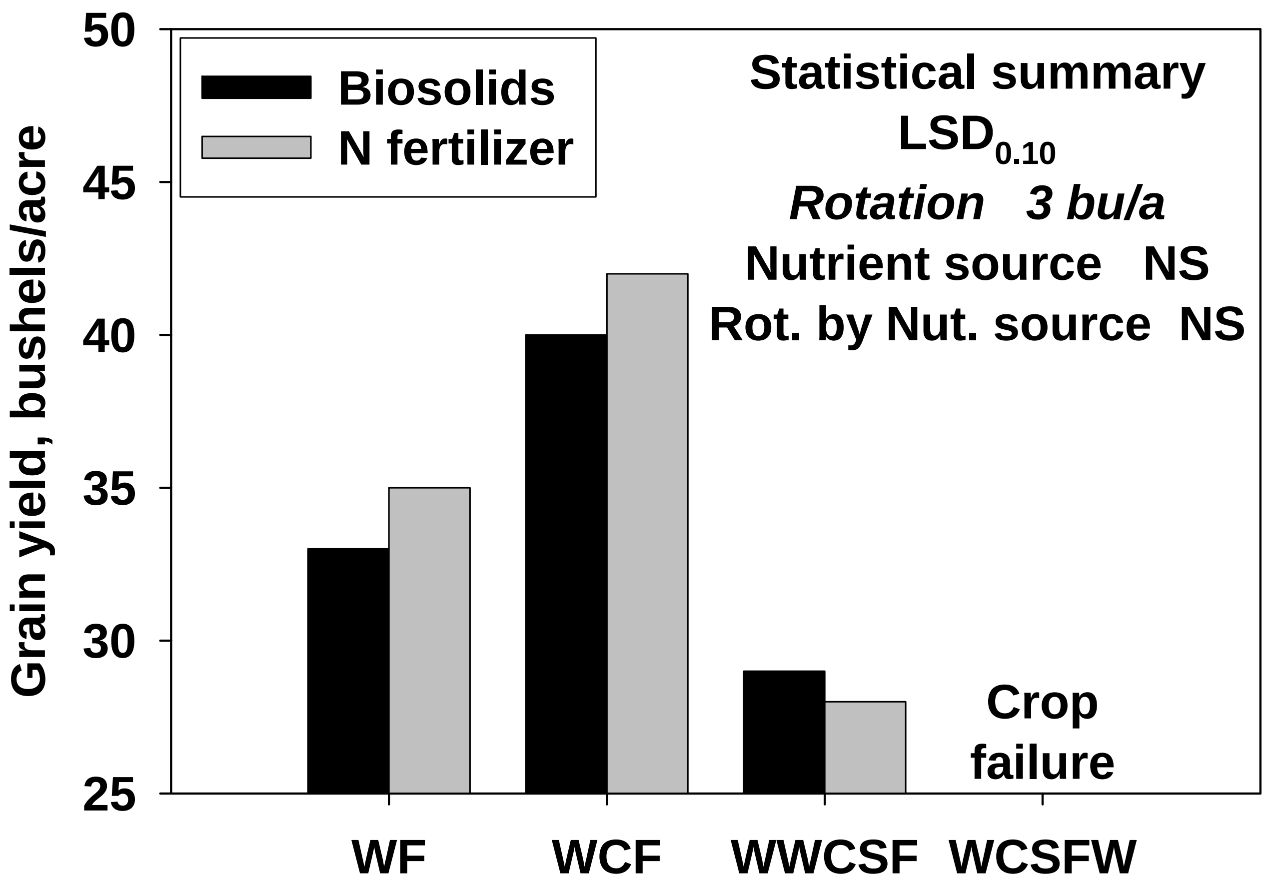


Figure 2. Grain protein for 2002 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences.

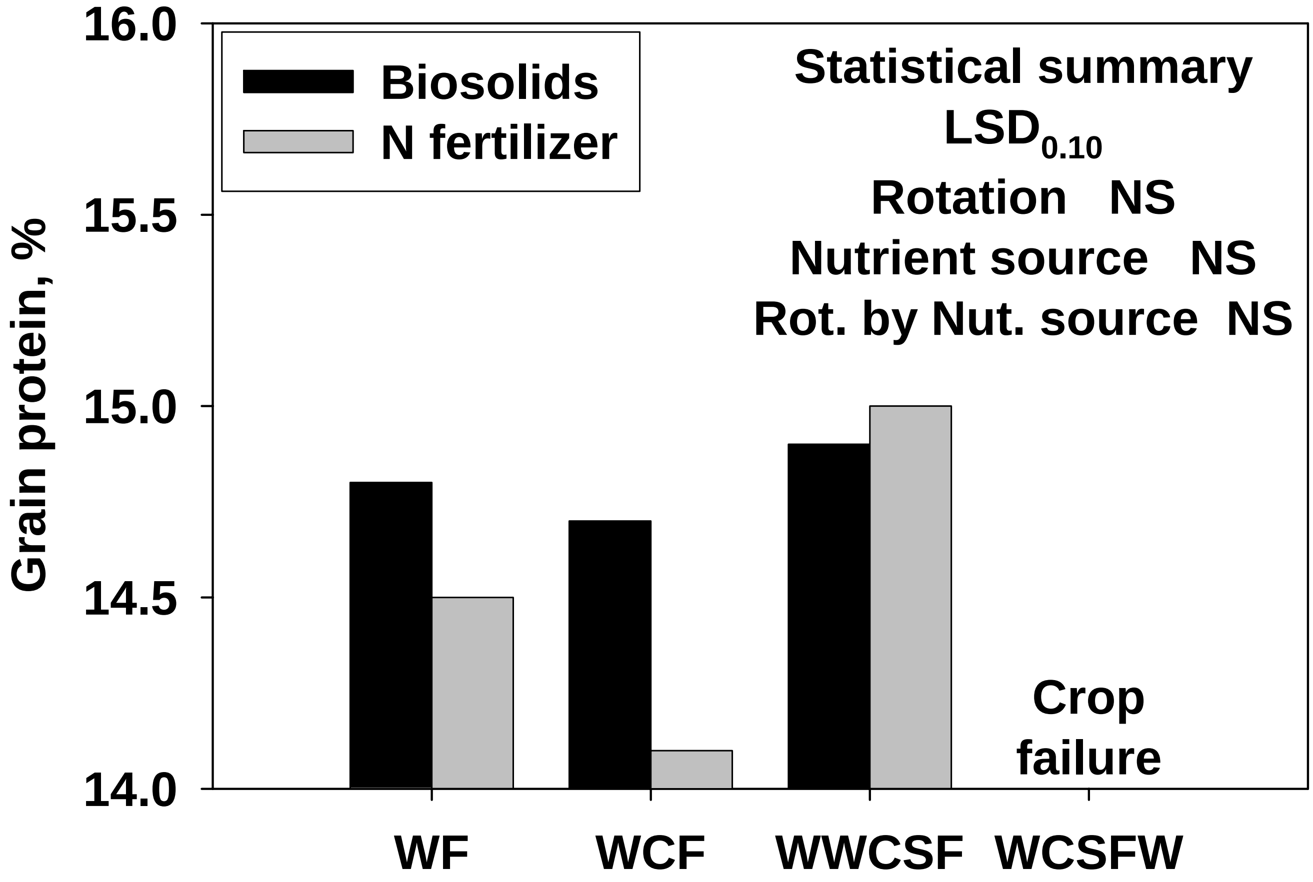


Figure 3. Grain P concentration for 2002 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences.

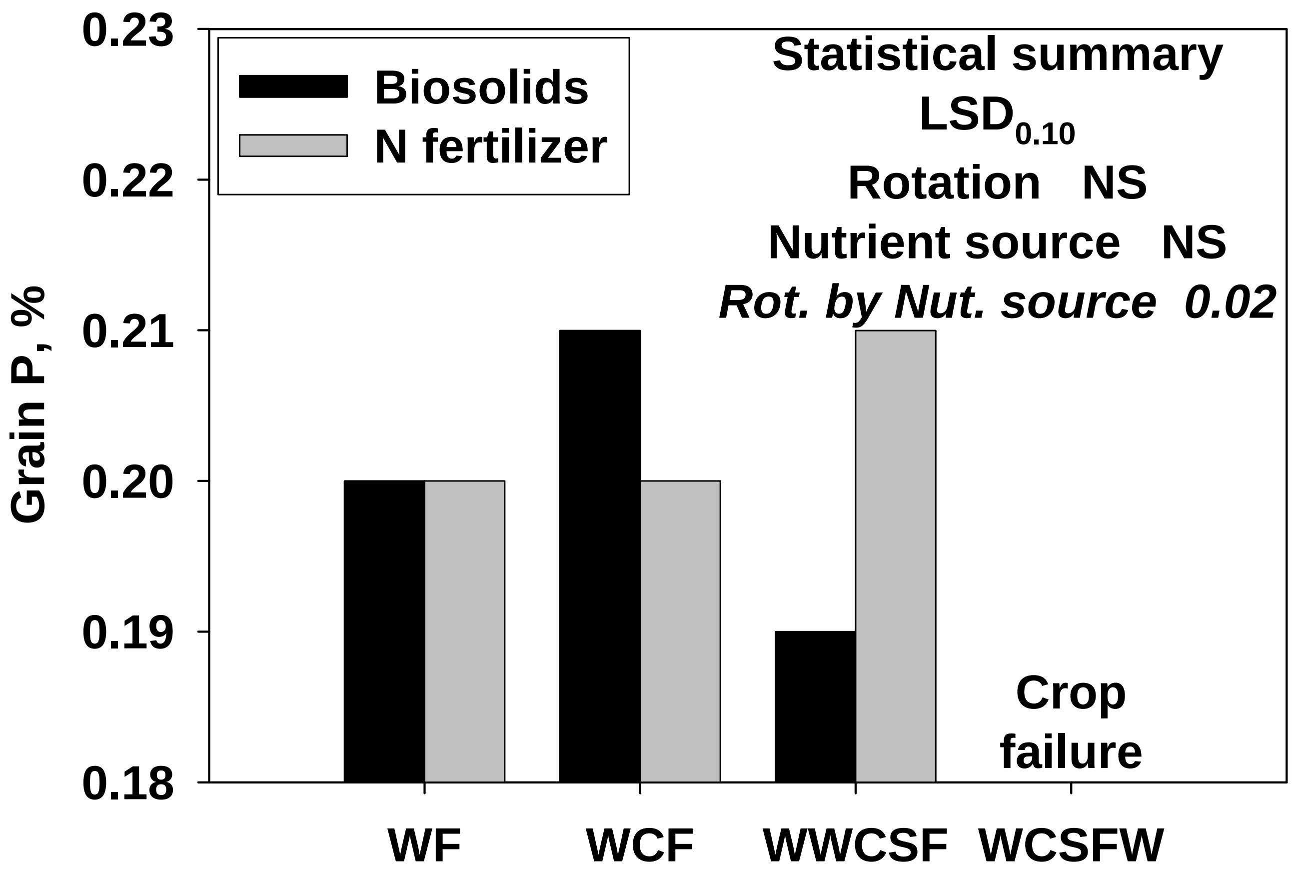


Figure 4. Grain Zn concentration for 2002 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences.

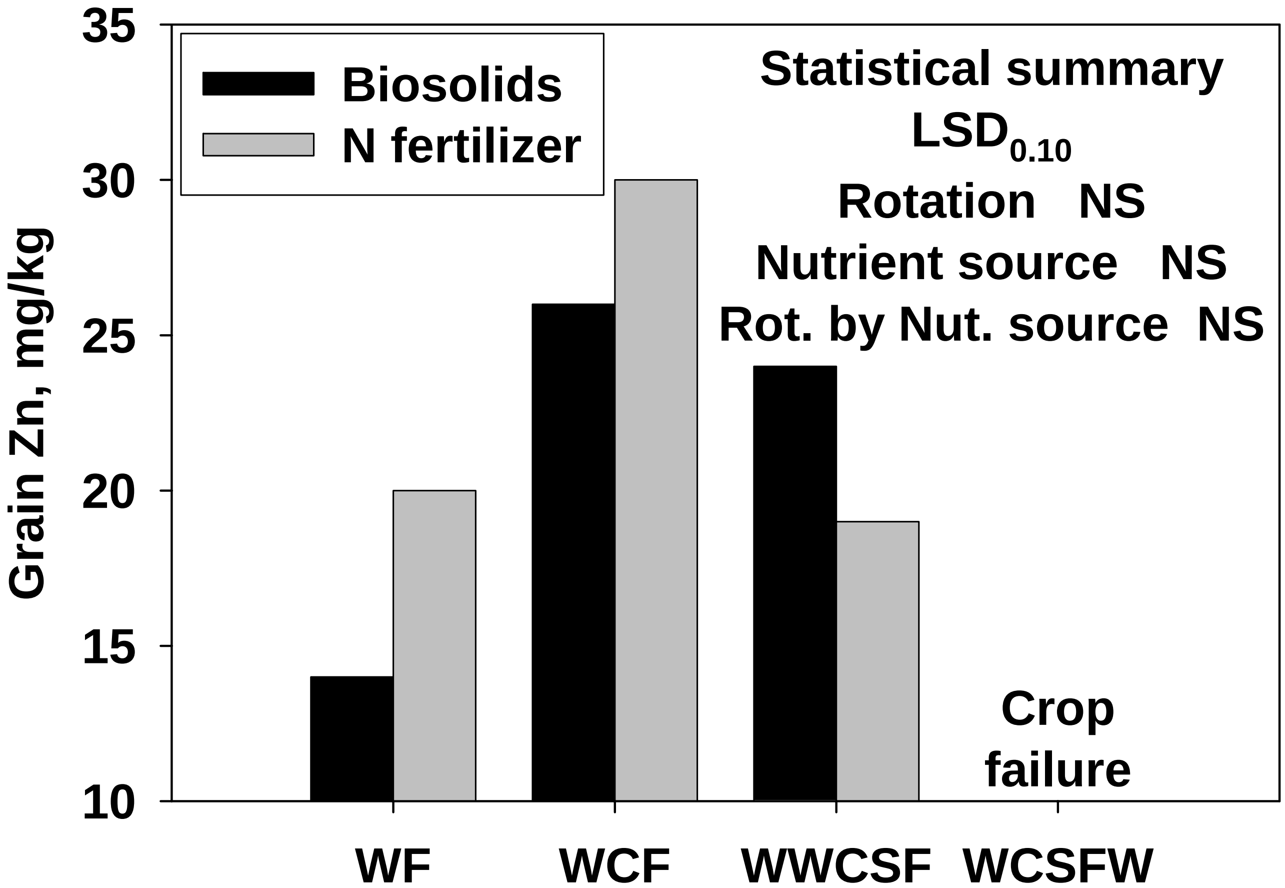


Figure 5. Grain Cu concentration for 2002 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences.

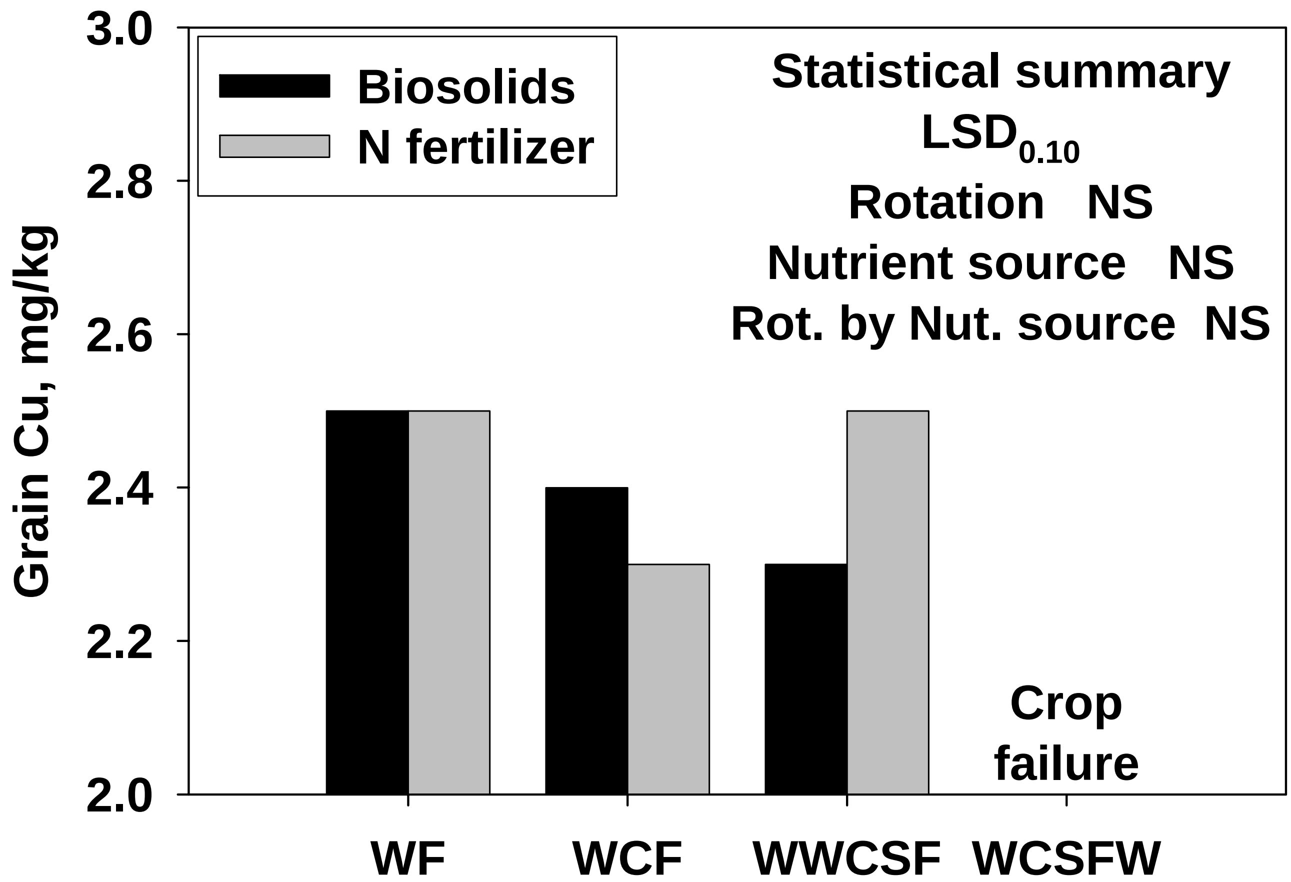
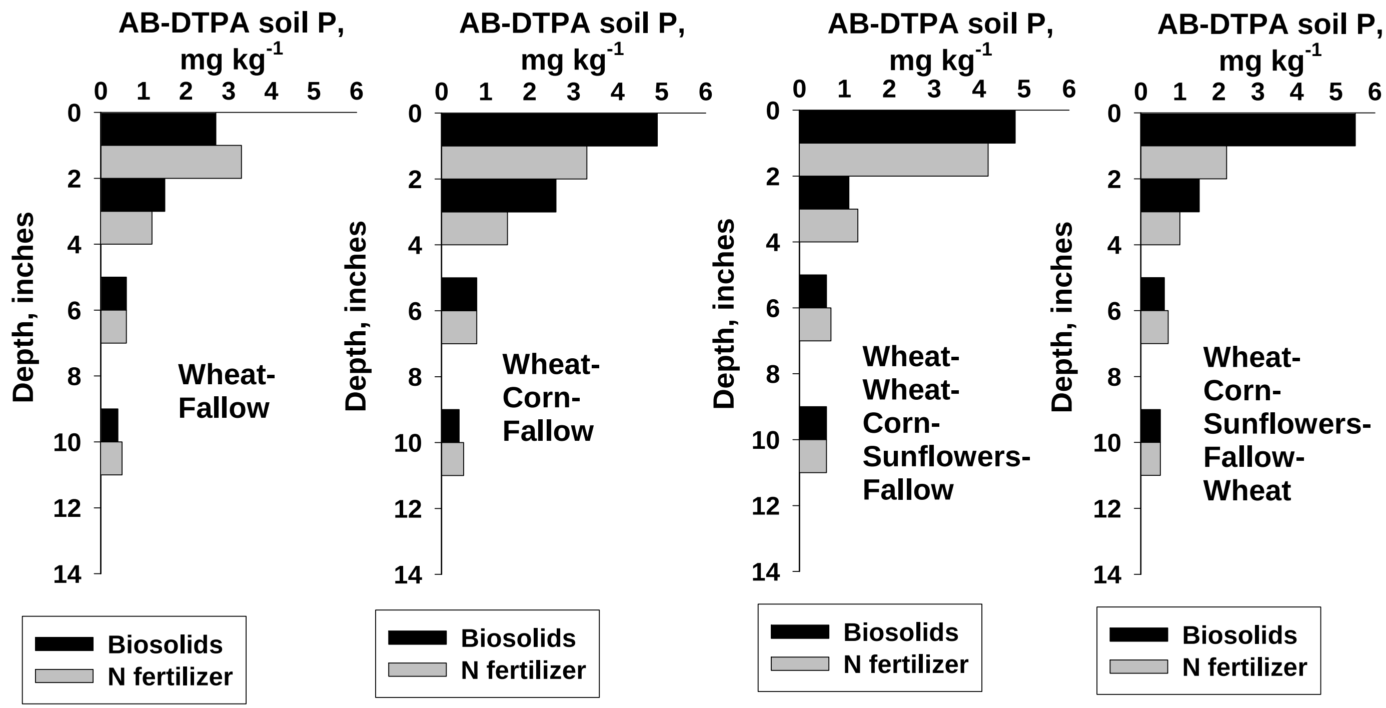


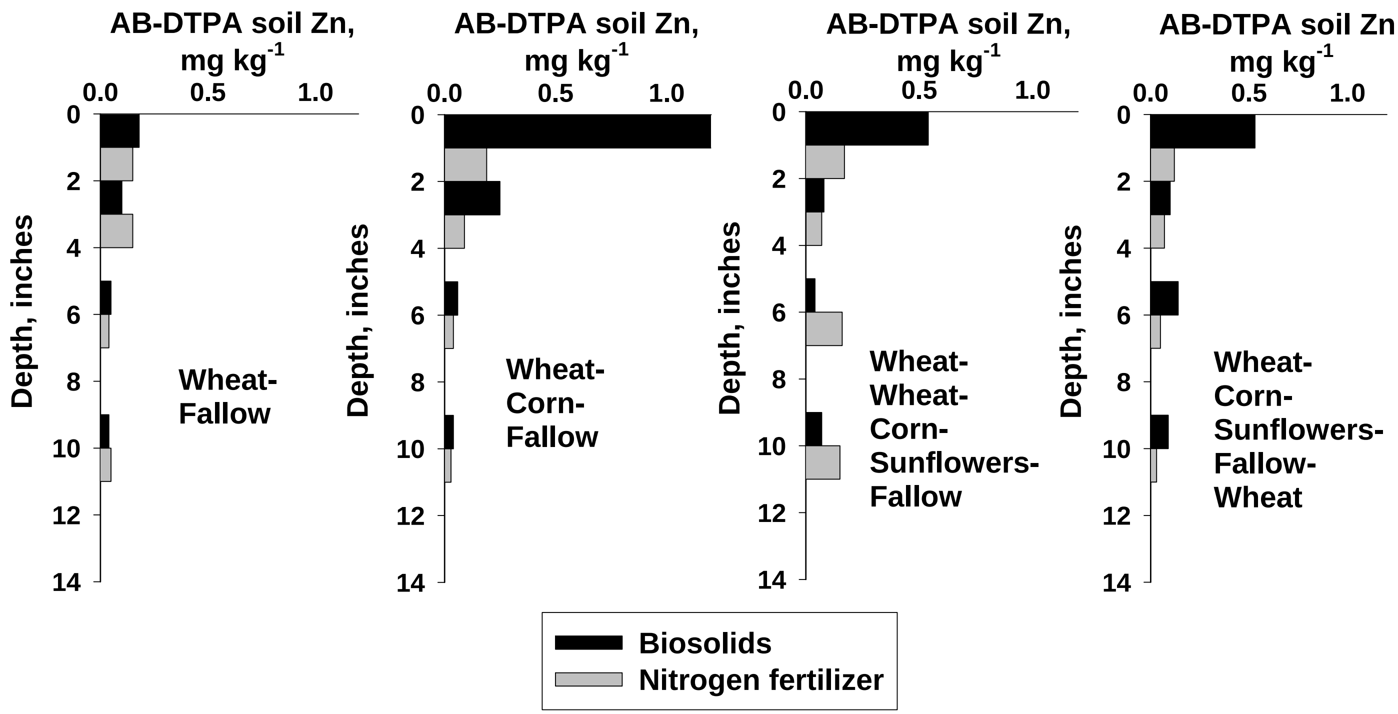
Figure 6. Soil AB-DTPA-extractable P concentration following 2002 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant 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 0.5*	Rotations NS	Rotations NS
Treatment NS	*Treatment 0.4*	Treatment NS	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

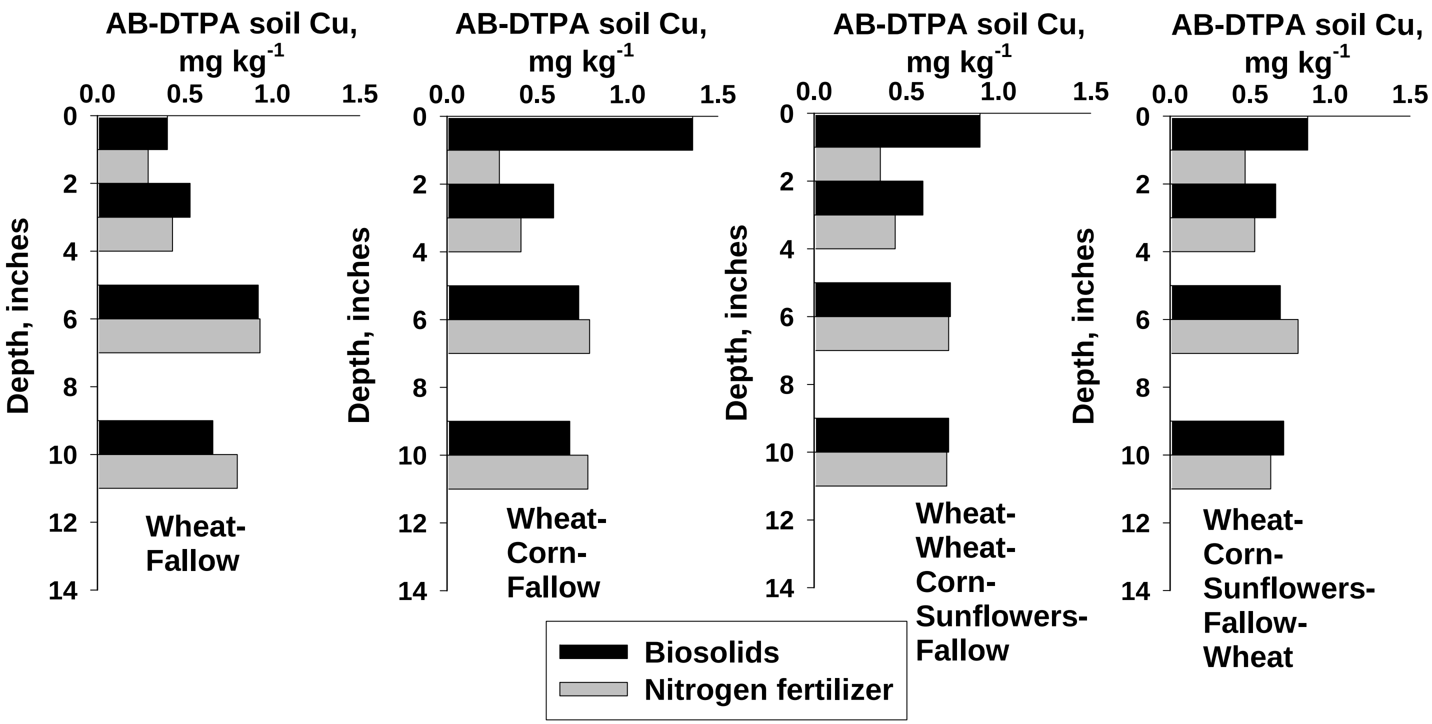
Figure 7. Soil AB-DTPA-extractable Zn concentration following 2002 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant 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

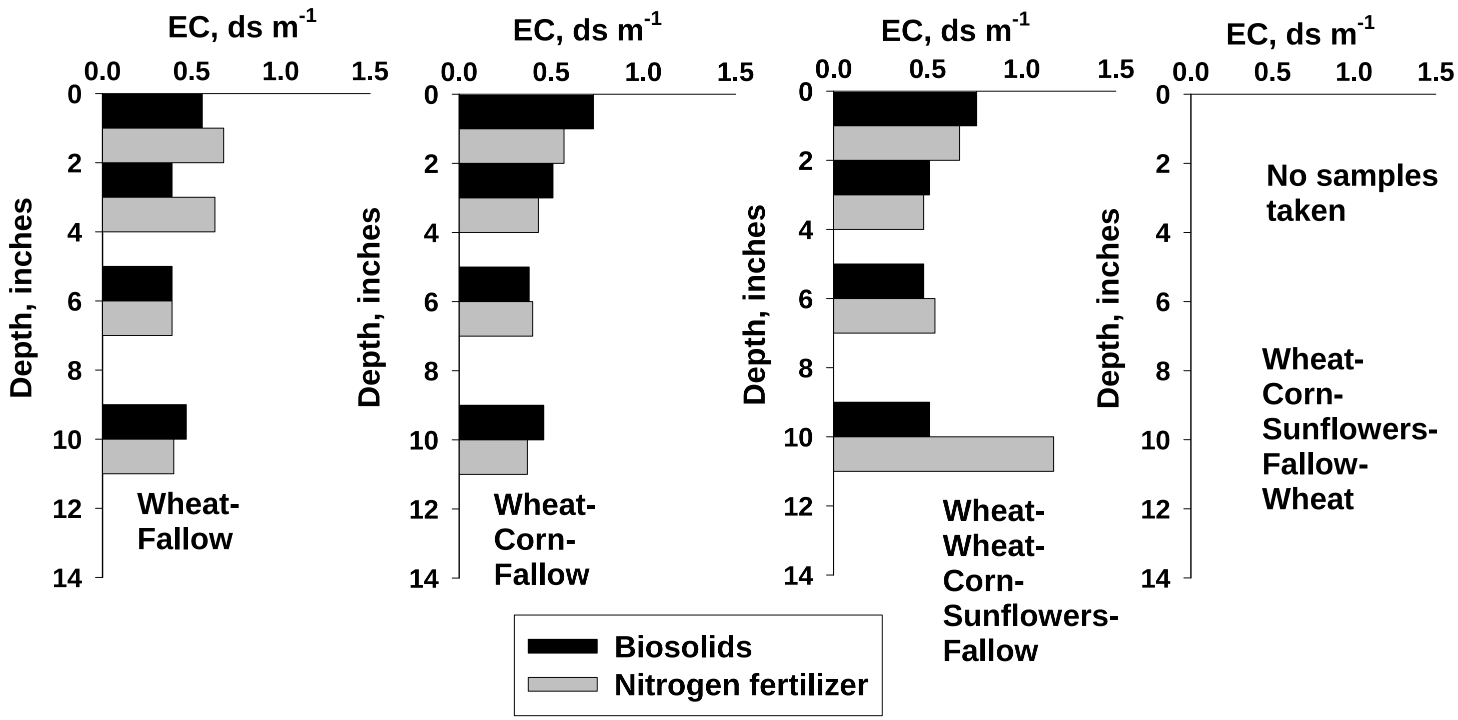
Figure 8. Soil AB-DTPA-extractable Cu concentration following 2002 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant 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 NS	Rotations NS	Rotations NS	Rotations NS
Treatment 0.50	*Treatment 0.12*	Treatment NS	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

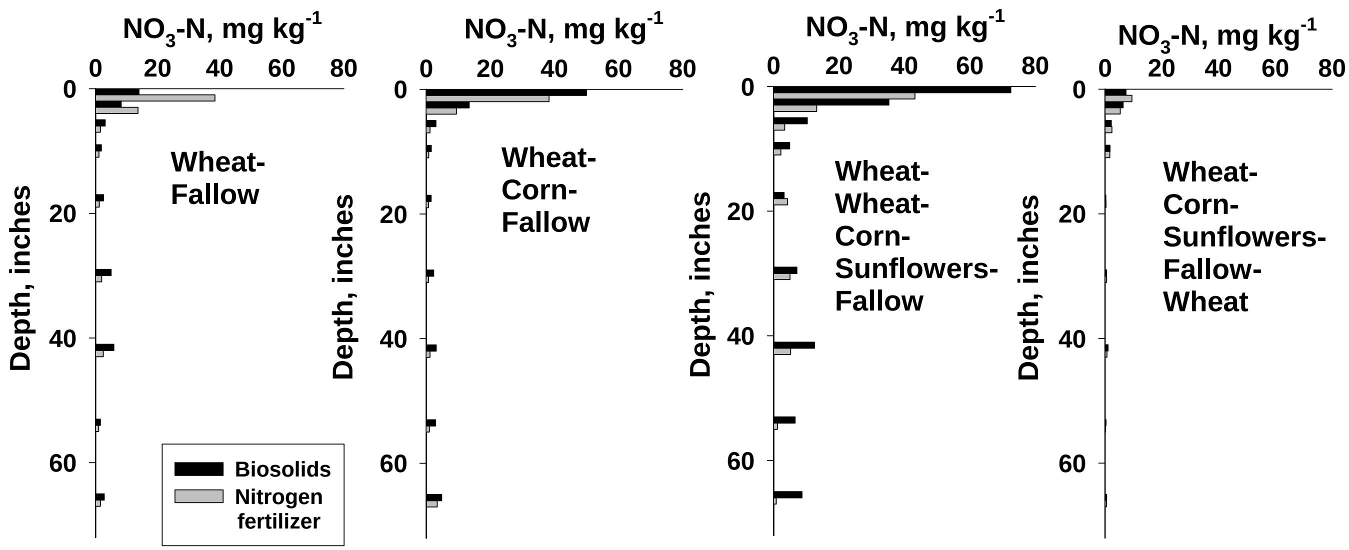
Figure 9. Soil saturated paste extract electrical conductivity (EC) concentration following 2002 dryland-wheat-rotation harvests comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability 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 0.12*	*Rotations 0.07*
Treatment NS	Treatment NS	Treatment NS	Treatment NS
Rot. X Treat. NS	*Rot. X Treat. 0.25*	Rot. X Treat. NS	*Rot. X Treat. 0.29*

Figure 10. Soil NO_3-N concentrations following 2002 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 3.3
Treatment NS
Rot. X Treat. NS

4-8 inches
$LSD_{0.10}$
Rotations NS
Treatment 2.5
Rot. X Treat. NS

8-12 inches
$LSD_{0.10}$
Rotations NS
Treatment 1.0
Rot. X Treat. NS

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

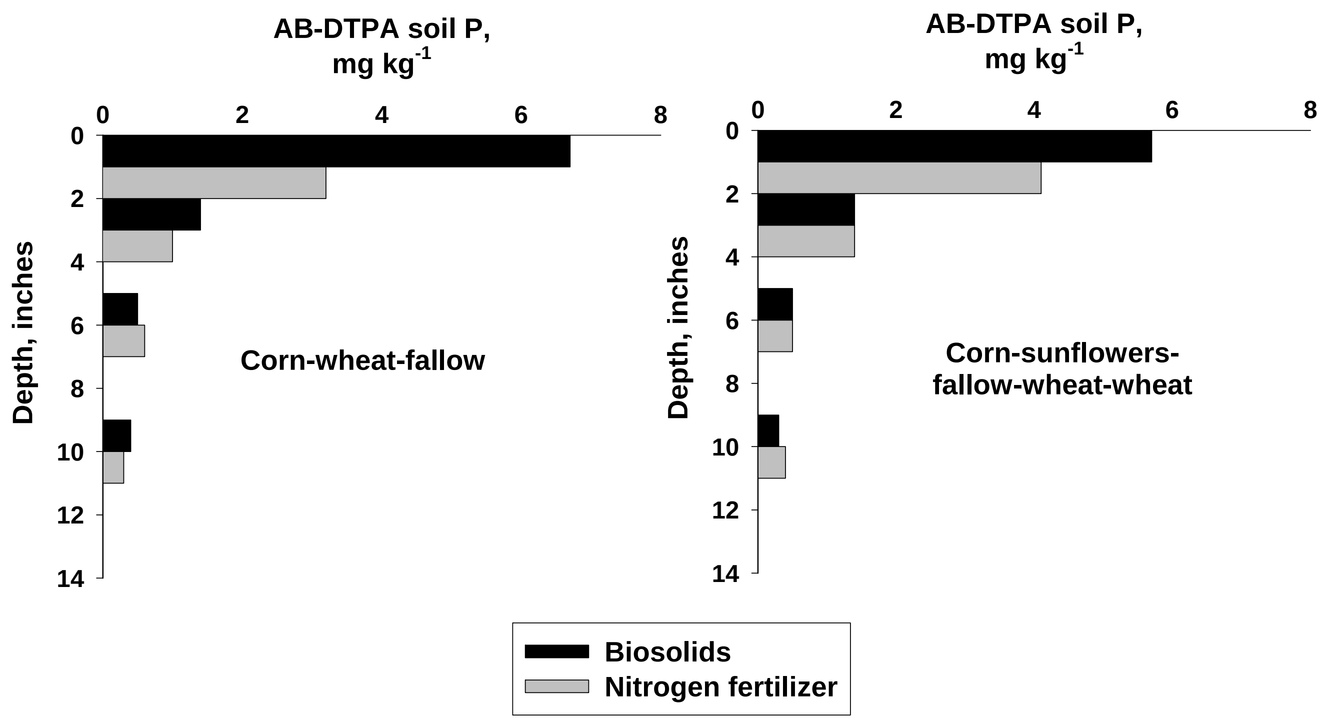
24-36 inches
$LSD_{0.10}$
Rotations NS
Treatment 0.6
Rot. X Treat. 0.9

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 2.3
Treatment 2.2
Rot. X Treat. NS

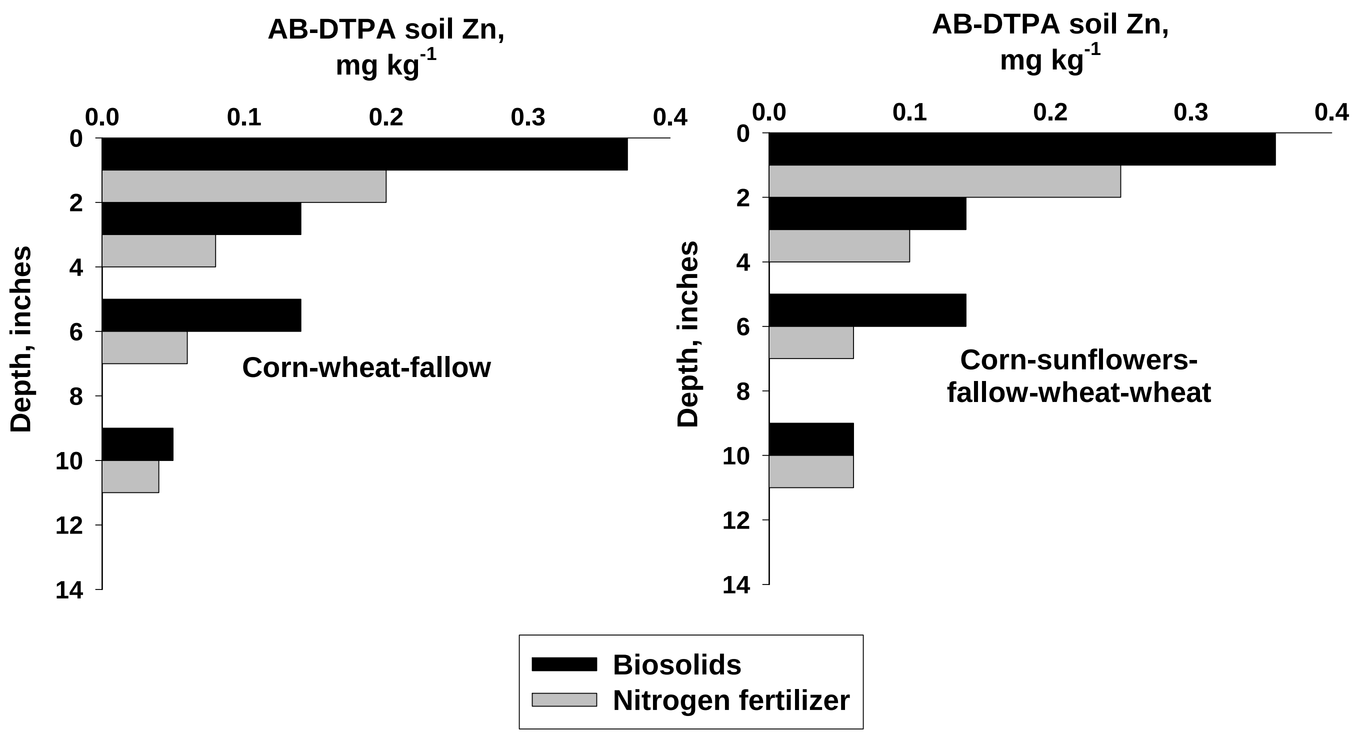
Figure 11. Soil AB-DTPA-extractable P concentration for 2002 dryland corn rotations comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences.



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

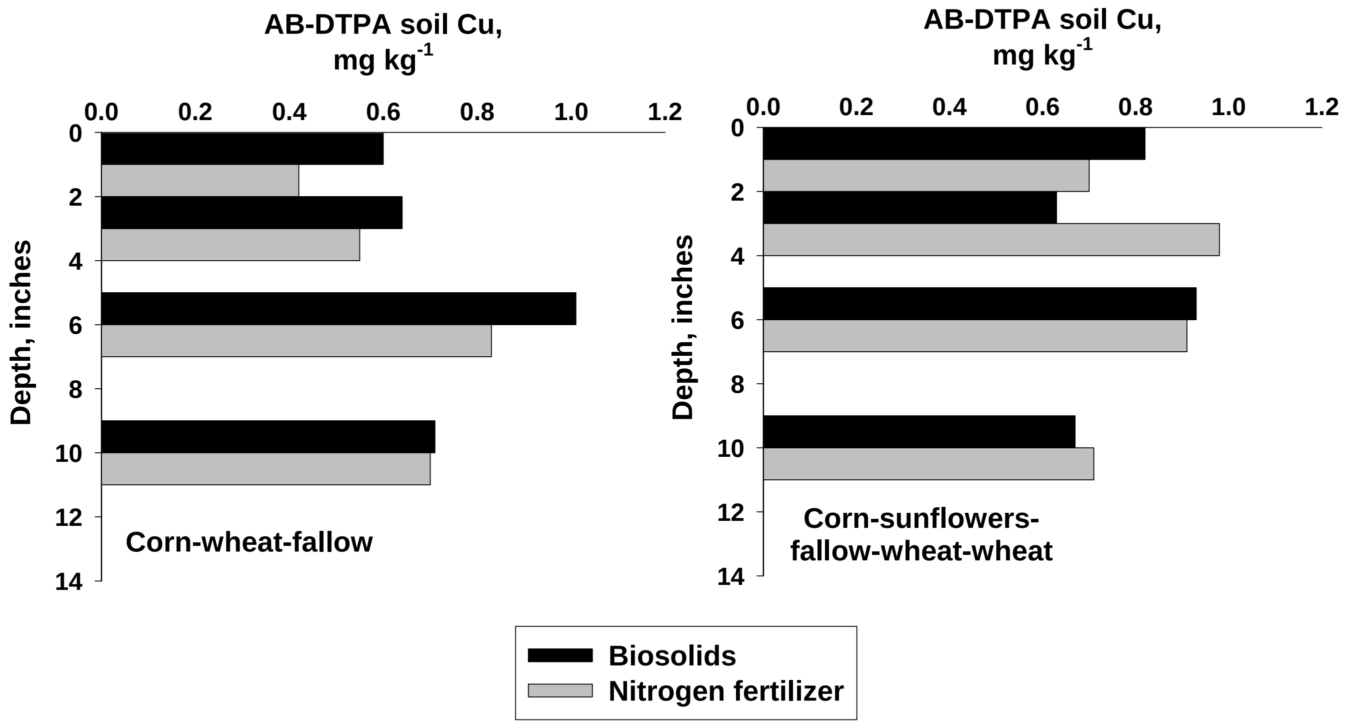
Figure 12. Soil AB-DTPA-extractable Zn concentration for 2002 dryland corn rotations comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences.



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 0.01*	*Treatment 0.01*	Treatment NS
Rot. X Treat. NS	*Rot. X Treat. 0.01*	Rot. X Treat. NS	Rot. X Treat. NS

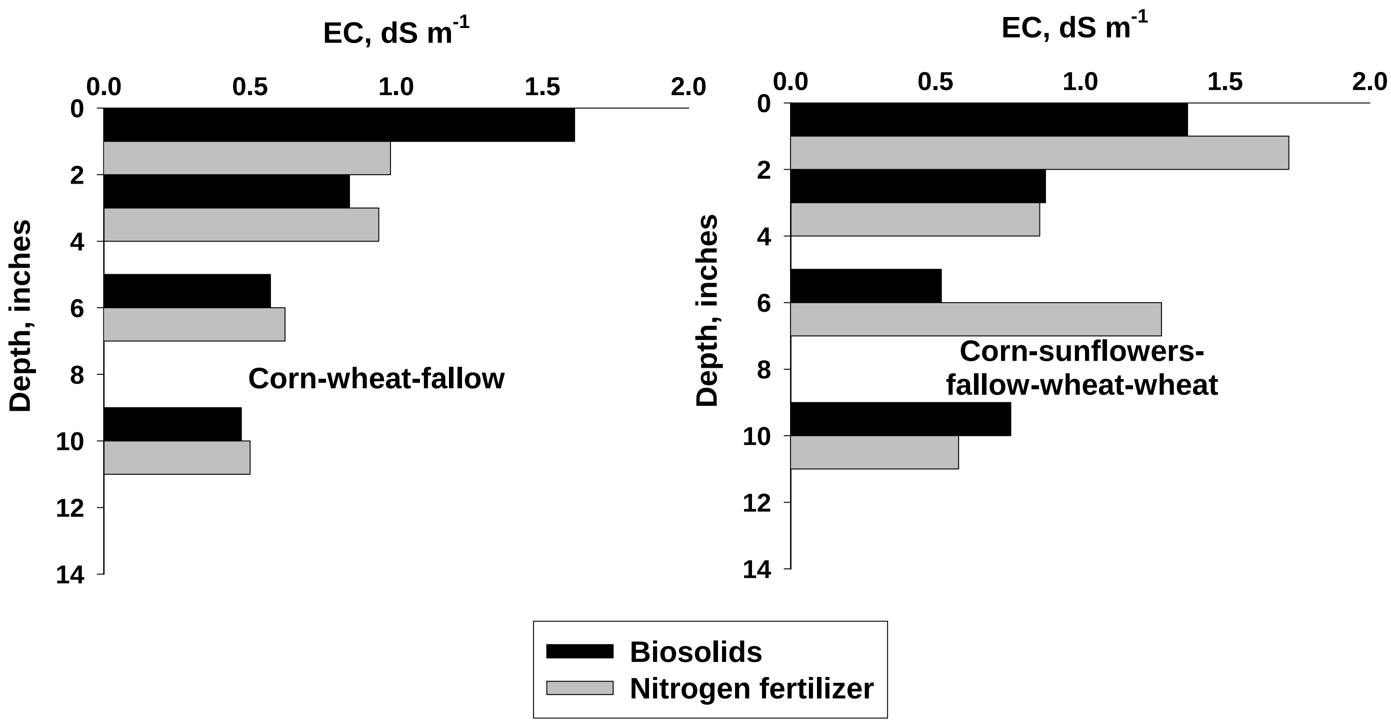
Figure 13. Soil AB-DTPA-extractable Cu concentration for 2002 dryland corn rotations comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant differences.



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 0.2*	Rotations NS	Rotations NS
Treatment NS	Treatment NS	*Treatment 0.02*	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	*Rot. X Treat. 0.02*	Rot. X Treat. NS

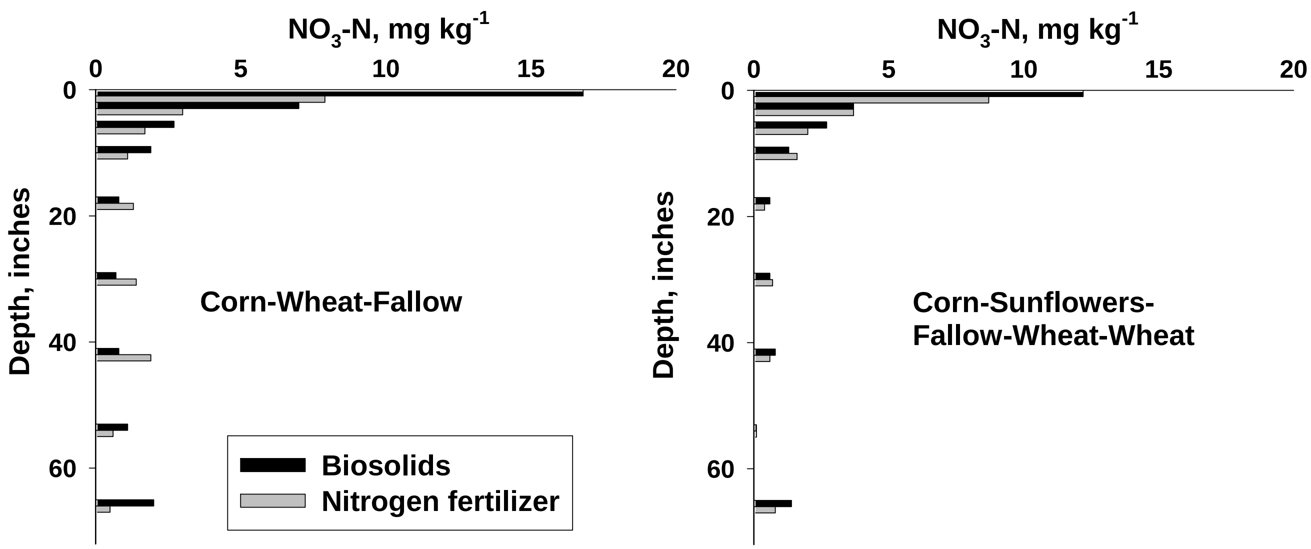
Figure 14. Soil saturated paste extract electrical conductivity (EC) for 2002 dryland corn rotations comparing Littleton/Englewood biosolids to commercial N fertilizer. In the statistical summary, $LSD_{0.10}$ represents the least significant difference at the 10% probability level and NS indicates non-significant 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 NS	Rotations NS	Rotations NS	Rotations NS
Treatment 0.01	*Treatment 0.03*	*Treatment 0.01*	Treatment NS
Rot. X Treat. 0.01	*Rot. X Treat. 0.22*	*Rot. X Treat. 0.05*	Rot. X Treat. NS

Figure 15. Soil NO_3-N for 2002 dryland corn rotations 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 1.5
Rot. X Treat. 2.1

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