Biosolids Application to No-Till Dryland Crop Rotations[†]

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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 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 yields.
2. Will not differ in grain levels (Ippolito and Barbarick, 2000) or soil concentrations of P, Zn, and Cu (AB-DTPA extractable, 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 Table 1 for precipitation data).

Biosolids application initiated the study in August followed by wheat planting in September 1999 (see Table 2). We designed the experiment so that every phase of each rotation is present during each year (10 total plots/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 and 2001, 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 sunflower in October 2000 and 2001. We experienced corn and sunflower crop failures in 2002 due to lack 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 elemental 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.

Since the 2000 harvest was the first year of the study, we did not distinguish between crop rotations for our statistical calculations of grain and soil characteristics. We completed t-tests to determine the effects of N fertilizer compared to biosolids (Tables 4-9). We considered differences at the 0.10 probability level as significant.

We calculated the total yields from 2000 to 2003 for the wheat, corn, and sunflower rotations (Figures 1-3). 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.

RESULTS AND DISCUSSION

Precipitation Data

Table 1 presents the monthly precipitation records since we established the weather station at the Byers research site. We received more than 11 inches of total annual rainfall in both 2000 and 2001. 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.

2000 Crop and Soil Properties

There were no differences between biosolids or commercial N fertilizer effects on wheat, corn, or sunflower yields in 2000 (Tables 4-6). Biosolids addition significantly increased wheat and corn Zn concentrations and corn protein content compared to commercial N fertilizer. Commercial N fertilizer produced significantly higher protein and grain P, Zn, and Cu concentrations in sunflower seeds compared to those in the biosolids-treated plots (Tables 4-6).

Wheat plots that received biosolids in 1999-2000 contained significantly larger AB-DTPA P, Zn, and Cu concentrations in the 0-2 inch soil depth and NO_3-N levels in the 4-8, 8-12, 24-36, 36-48, and 48-60 inch depths than did the N fertilizer plots (Table 7). Corn plots treated with biosolids in 1999-2000 had significantly larger AB-DTPA Zn and Cu concentrations in the 0-2 inch depth, AB-DTPA Cu concentrations in the 2-4 inch depth, and NO_3-N levels in the 2-4, and 4-8 inch depths (Table 8). Commercial N fertilizer produced larger NO_3-N concentrations in the 48-60 inch soil depth compared to the biosolids plots (Table 8). Sunflower plots receiving biosolids in 1999-2000 contained significantly larger AB-DTPA Cu levels in the 8-12 inch depth and NO_3-N concentrations in the 2-4, 4-8, and 8-12 inch depths (Table 9) compared to those in the N-fertilizer treated plots.

Biosolids (see Table 3) application led to increased grain and soil levels of P, Zn, and Cu relative to the N-fertilized plots. The soil NO_3-N accumulation may indicate that we underestimated the N availability of the biosolids for no-till management. We will not be able to determine the efficacy of the biosolids application under no-till conditions until we have completed two or more complete sets of crop rotations (10 or more years of data).

2000-2002 Total Grain Yields

Despite not having completed a full set of crop rotations, we decided to observe the effects on total crop yields for the first three years of study. This allows us to look at overall effects of rotation and type of nutrient addition, since one year out of three had very low amounts of precipitation (2002; see Table 1).

Crop rotation affected total wheat yields (Figure 1). The WCF rotation had larger yields than all other rotations while the second year wheat in the WCSFW rotation had smaller yields than all other rotations. These results suggest that WCF more effectively used available soil moisture while wheat following wheat in WCSFW did not allow sufficient storage of soil moisture for wheat following wheat in the second year.

Type of rotation or nutrient addition did not affect total corn yields (Figure 2). The total yields are for 2000 and 2001; we experienced a crop failure due to droughty conditions in 2002 (Table 1).

To date, we have had no successful sunflower crops (Figure 3). Our cooperating farmers are still trying to determine the best herbicide to use for sunflower in the no-till environment. We did not find any trends regarding the comparison of biosolids to commercial N application.

2001 Soil Properties

We found several significant type of rotation by type of nutrient addition interactions for the soil properties from the 2001 wheat phases (Figures 4-8). We did not observe any consistent trends associated with these interactions. We observed significant rotation effects on soil NO_3-N, where the WF rotation contained higher concentrations than all other rotations at 0-2, 2-4, and 36-48 inches (Figure 8). We also found that commercial N fertilizer led to higher soil NO_3-N in the 0-2 inch soil depth (Figure 8). We need to go through at least two complete rotation cycles to determine if these trends are consistent over time.

Soil properties in the corn phase (Figures 9-13) provided more consistent trends than we found in the wheat phases. Biosolids addition, compared to commercial N fertilizer, resulted in larger concentrations of ABDTPA P at 0-2 inches (Figure 9), AB-DTPA Cu at 0-2 and 2-4 inches (Figure 11), and soil NO_3-N at 2-4 and 4-8 inches (Figure 13). We also found that CSFWW contained higher NO_3-N at 36-48 inches than the CFW rotation.

CONCLUSIONS

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

1. Biosolids has produced the same yields as 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. Again, we have not observed consistent trends in most cases. 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, 2000-2003. (Weather station was installed in April, 2000).

Month	2000	2001	2002	2003
January	†	0.2	0.1	0.0
February	†	0.1	0.2	0.1
March	†	0.2	0.2	1.0
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	1.1

† 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	P_2O_5 lbs/acre	Zn lbs/a cre
1999	Early Oct.	Wheat	Halt	2.4	38	5	40	45	20	0
2000	May	Corn	Pioneer 3752	4	64	5	40	45	15	5
2000	June	Sunflower	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	Sunflower	Triumph 765C	2	32	5	40	45	15	5

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	6.7	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	7.0	5.8
Hg, mg kg^{-1}	3.4	0.5	2.6	2.0

Table 4. Wheat-grain characteristics at the Byers research site, 2000. ***Highlighted parameters*** are significant at the 10% probability level.

Parameter	Biosolids	N fertilizer	T-test probability of being equal
Yield, bushels acre^{-1}	13	14	0.40
Protein, %	18	18	0.72
P, mg kg^{-1}	3.65	3.65	0.96
Zn, mg kg^{-1}	***31***	***28***	***0.04***
Cu, mg kg^{-1}	5.9	5.8	0.91

Table 5. Corn-grain characteristics at the Byers research site, 2000. ***Highlighted parameters*** are significant at the 10% probability level.

Parameter	Biosolids	N fertilizer	T-test probability of being equal
Yield, bushels acre^{-1}	14	19	0.14
Protein, %	***11***	***10***	***0.02***
P, mg kg^{-1}	2.53	2.50	0.67
Zn, mg kg^{-1}	***16***	***15***	***0.05***
Cu, mg kg^{-1}	0.67	0.84	0.70

Table 6. Sunflower-seed characteristics at the Byers research site, 2000. ***Highlighted parameters*** are significant at the 10% probability level.

Parameter	Biosolids	N fertilizer	T-test probability of being equal
Yield, lbs acre^{-1}	44	40	0.64
Protein, %	***20***	***23***	***<0.01***
P, mg kg^{-1}	***5.89***	***6.58***	***<0.01***
Zn, mg kg^{-1}	***59***	***65***	***0.06***
Cu, mg kg^{-1}	***22***	***26***	***0.04***

Table 7. Soil characteristics at the Byers research site immediately following the 2000 wheat harvest. ***Highlighted parameters*** are significant at the 10% probability level.

Parameter	Depth, inches	Biosolids	N fertilizer	T-test probability of being equal
AB-DTPA extractable				
P, mg kg^{-1}	***0-2***	***8.9***	***6.9***	***0.03***
	2-4	2.6	2.8	0.81
	4-8	1.7	2.0	0.16
	8-12	1.2	1.2	0.23
Zn, mg kg^{-1}	***0-2***	***0.75***	***0.36***	***<0.01***
	2-4	0.17	0.20	0.60
	4-8	0.08	0.08	0.85
	8-12	0.04	0.04	0.76
Cu, , mg kg^{-1}	***0-2***	***1.3***	***0.8***	***<0.01***
	2-4	1.0	1.0	0.80
	4-8	1.3	1.4	0.74
	8-12	1.3	1.4	0.24
EC, dS m^{-1}	0-2	0.68	0.59	0.36
	2-4	0.56	0.48	0.41
	4-8	0.51	0.41	0.11
	8-12	0.45	0.45	0.99
pH	0-2	6.6	6.6	0.88
	2-4	6.8	6.7	0.67
	4-8	7.3	7.1	0.23
	8-12	7.7	7.6	0.20
NO_3-N, mg kg^{-1}	0-2	18.7	13.2	0.11
	2-4	8.8	6.1	0.18
	4-8	***6.1***	***2.7***	***0.04***
	8-12	***4.4***	***1.4***	***0.09***
	12-24	1.8	1.7	0.95
	24-36	***1.0***	***0.2***	***0.01***
	36-48	***1.1***	***0.4***	***0.08***
	48-60	***0.8***	***0.2***	***0.10***
	60-72	0.6	0.4	0.34

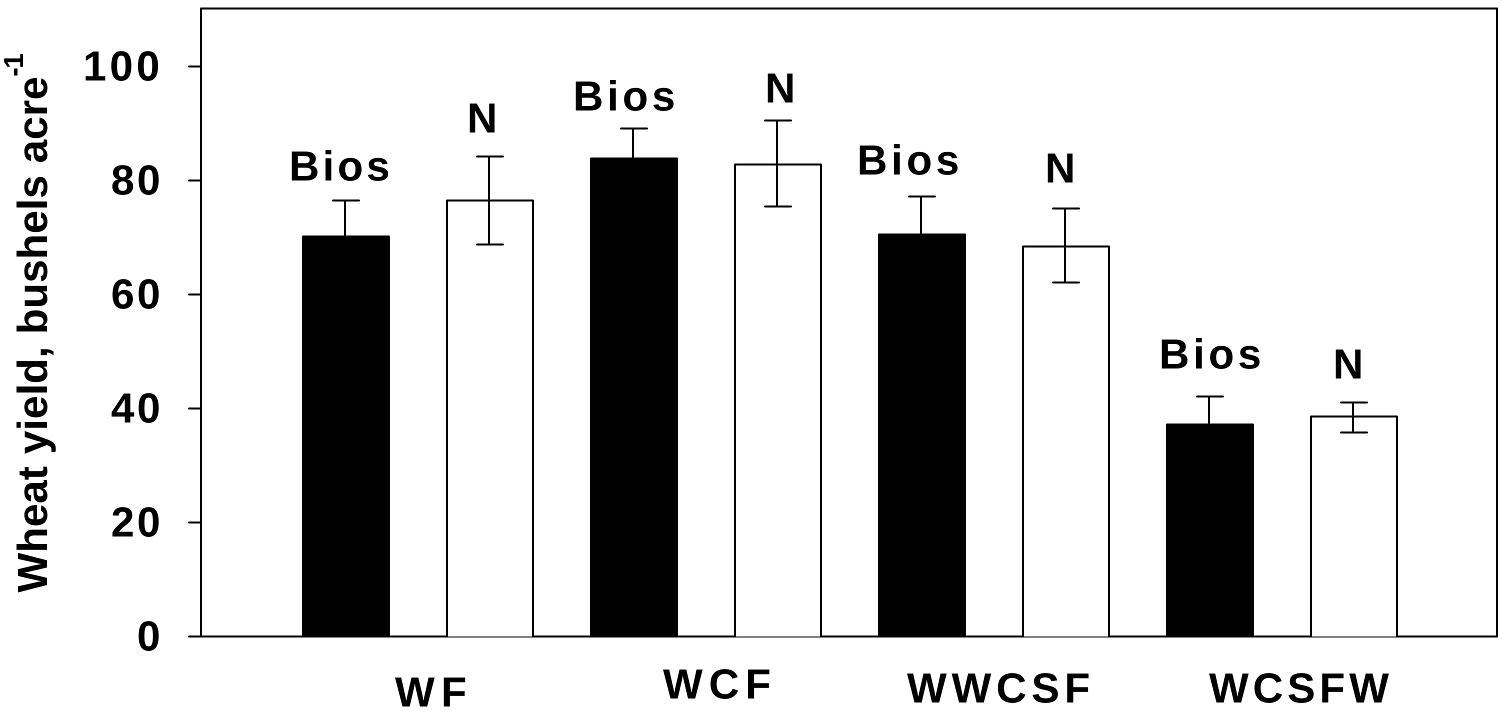
Table 8. Soil characteristics at the Byers research site immediately following the 2000 corn harvest. ***Highlighted parameters*** are significant at the 10% probability level.

Parameter	Depth, cm	Biosolids	N fertilizer	T-test probability of being equal
AB-DTPA extractable				
P, mg kg^{-1}	0-2	31	29	0.71
	2-4	23	14	0.21
	4-8	10	7	0.25
	8-12	6	4	0.34
Zn, mg kg^{-1}	***0-2***	***0.62***	***0.15***	***0.07***
	2-4	0.20	0.18	0.89
	4-8	0.09	0.05	0.26
	8-12	0.09	0.04	0.20
Cu, , mg kg^{-1}	***0-2***	***1.5***	***0.5***	***0.05***
	2-4	***0.7***	***0.5***	***<0.01***
	4-8	0.7	0.7	0.66
	8-12	0.8	0.7	0.21
EC, dS m^{-1}	0-2	0.78	0.74	0.72
	2-4	0.54	0.54	0.96
	4-8	0.59	0.48	0.33
	8-12	0.48	0.49	0.90
pH	0-2	6.6	6.8	0.15
	2-4	6.8	6.8	1.00
	4-8	7.1	7.1	1.00
	8-12	7.6	7.6	0.90
NO_3-N, mg kg^{-1}	0-2	7.3	3.4	0.11
	2-4	***4.3***	***1.7***	***0.07***
	4-8	***3.5***	***1.7***	***0.06***
	8-12	4.2	2.5	0.22
	12-24	8.0	5.0	0.48
	24-36	7.1	9.4	0.56
	36-48	2.2	3.2	0.33
	48-60	***0.8***	***1.1***	***0.09***
	60-72	1.2	1.3	0.89

Table 9. Soil characteristics at the Byers research site immediately following the 2000 sunflower harvest. ***Highlighted parameters*** are significant at the 10% probability level.

Parameter	Depth, cm	Biosolids	N fertilizer	T-test probability of being equal
AB-DTPA extractable				
P, mg kg^{-1}	0-2	33	27	0.63
	2-4	11	10	0.66
	4-8	6	6	0.76
	8-12	5	4	0.20
Zn, mg kg^{-1}	0-2	0.39	0.13	0.43
	2-4	0.08	0.07	0.71
	4-8	0.03	0.04	0.64
	8-12	0.10	0.02	0.26
Cu, , mg kg^{-1}	0-2	0.9	0.6	0.52
	2-4	0.6	0.5	0.63
	4-8	0.7	0.8	0.79
	8-12	***0.7***	***0.8***	***0.08***
EC, dS m^{-1}	0-2	0.81	0.56	0.15
	2-4	0.58	0.51	0.40
	4-8	0.44	0.43	0.69
	8-12	0.47	0.48	0.81
pH	0-2	7.2	7.1	0.88
	2-4	7.3	7.3	0.93
	4-8	7.5	7.4	0.76
	8-12	7.8	7.6	0.29
NO_3-N, mg kg^{-1}	0-2	5.9	3.1	0.17
	2-4	***4.2***	***1.8***	***0.07***
	4-8	***5.4***	***1.6***	***0.01***
	8-12	***8.0***	***3.0***	***0.01***
	12-24	5.5	11.2	0.38
	24-36	7.0	11.8	0.71
	36-48	0.4	0.9	0.66
	48-60	1.0	10.0	0.52
	60-72	1.3	4.4	0.58

Figure 1. Total wheat yields (plus standard-error bars) for 2000-2002 for dryland crop rotations comparing Littleton/Englewood biosolids to commercial N fertilizer. (WF = wheat fallow, WCF = wheat-corn-fallow; WWCSF = wheat-wheat-corn-sunflowers-fallow; WCSFW = wheat-corn-sunflowers-fallow-wheat).



Statistical Summary

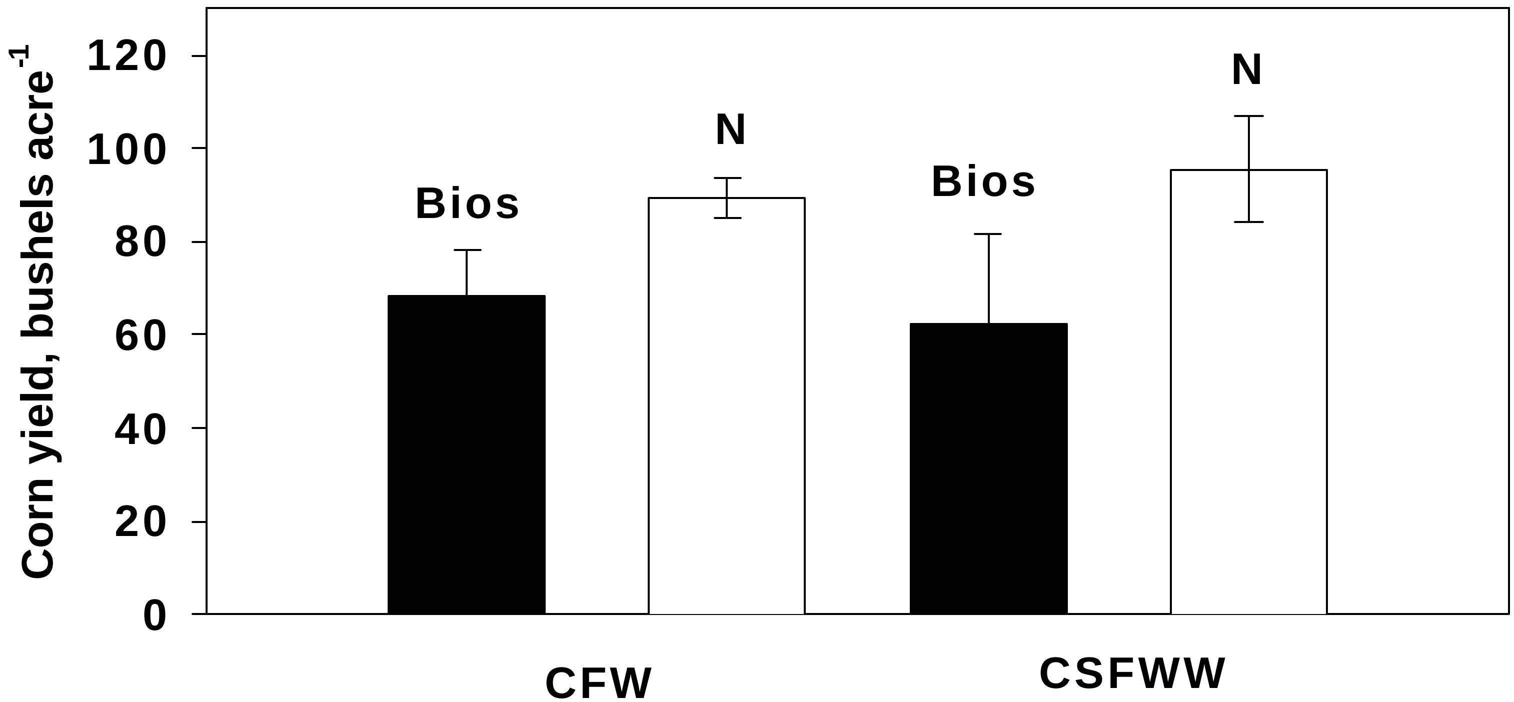
$LSD_{0.10}$

Rotations 5

Treatment NS

Rot. X Treat. NS

Figure 2. Total corn yields (plus standard-error bars) for 2000-2001 for dryland crop rotations comparing Littleton/Englewood biosolids to commercial N fertilizer. (CFW = corn-fallow-wheat; CSFWW = corn-sunflowers-fallow-wheat-wheat).



Statistical Summary

$LSD_{0.10}$

Rotations NS

Treatment NS

Rot. X Treat. NS

Figure 3. Sunflower yields (plus standard-error bars) for 2000-2002 for dryland crop rotations comparing Littleton/Englewood biosolids to commercial N fertilizer. (SFWWC = sunflowers-fallow-wheat-wheat-corn).

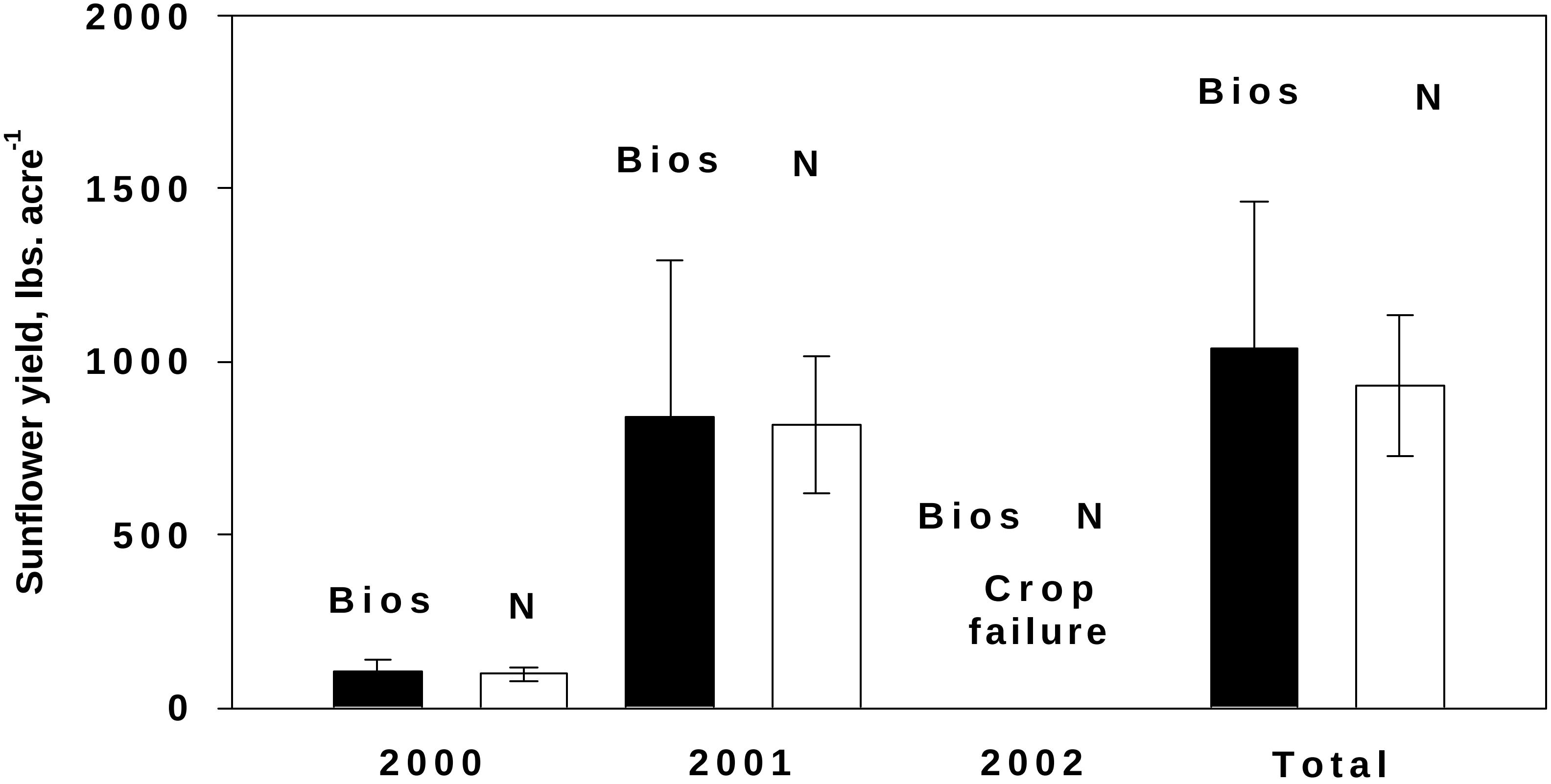
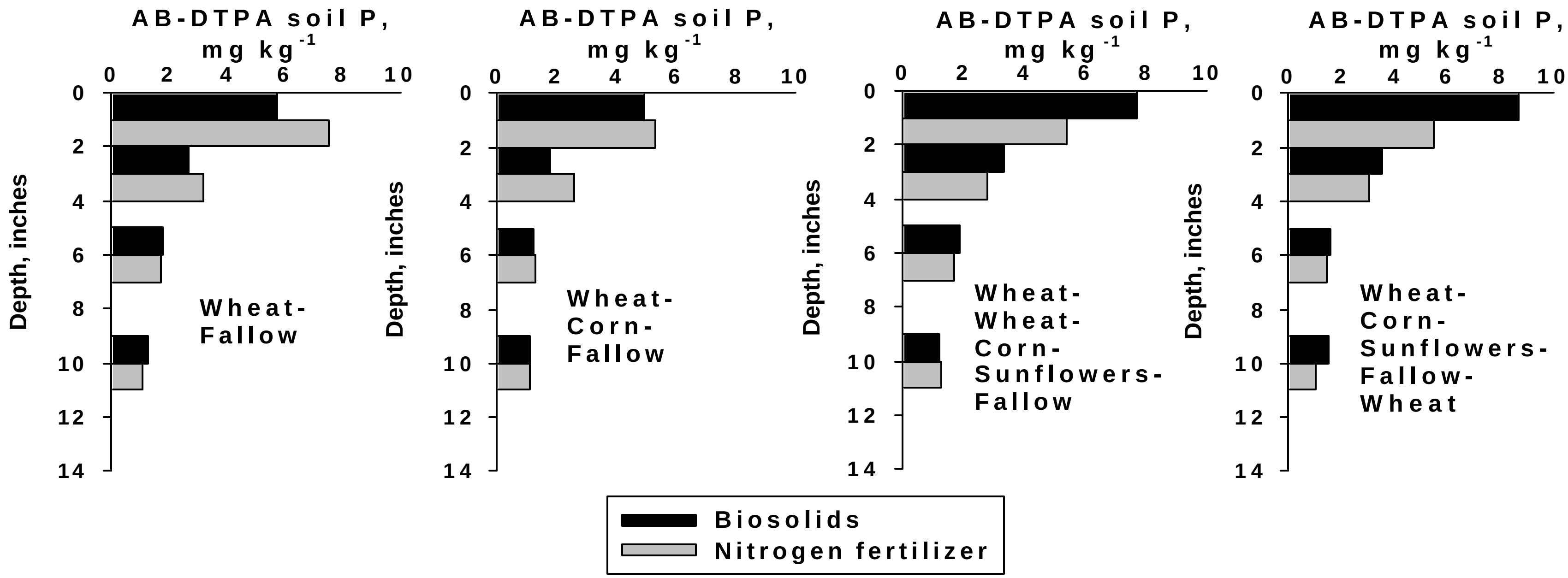


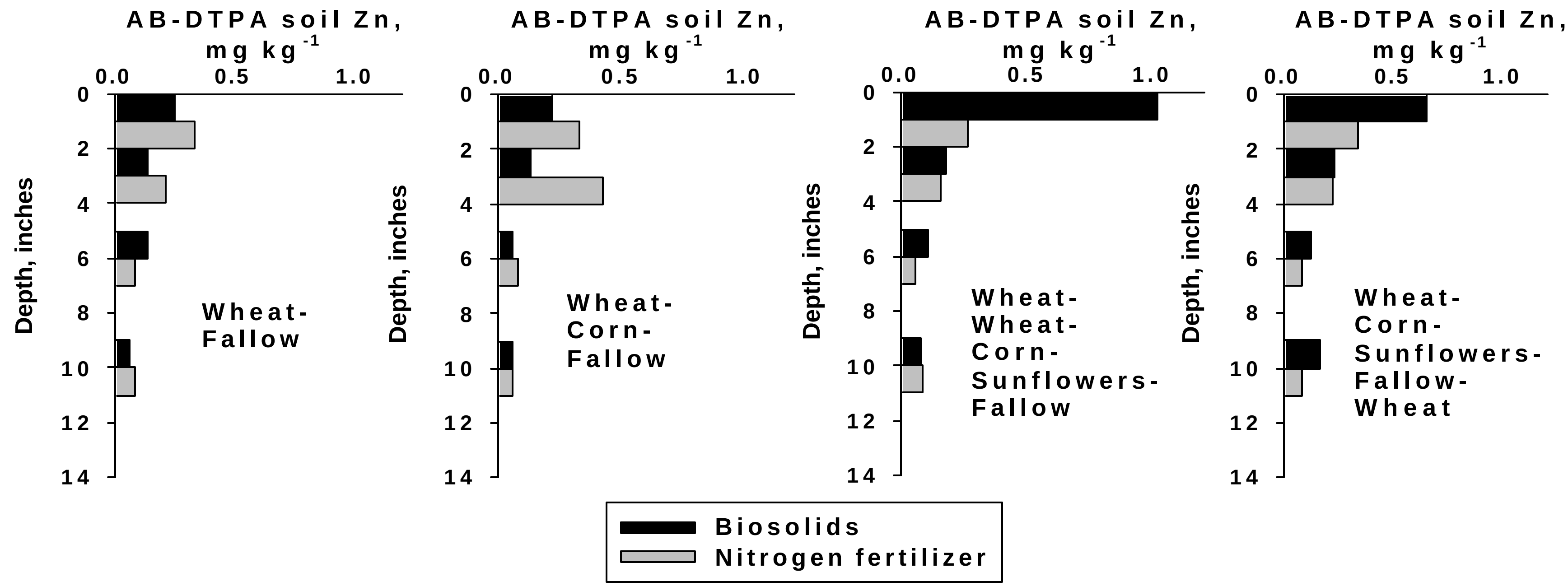
Figure 4. Soil-extractable AB-DTPA P for 2001 for dryland wheat rotations comparing Littleton/Englewood biosolids to commercial N fertilizer.



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 0.1
Rot. X Treat. 2.1	Rot. X Treat. 1.2	Rot. X Treat. NS	Rot. X Treat. 0.3

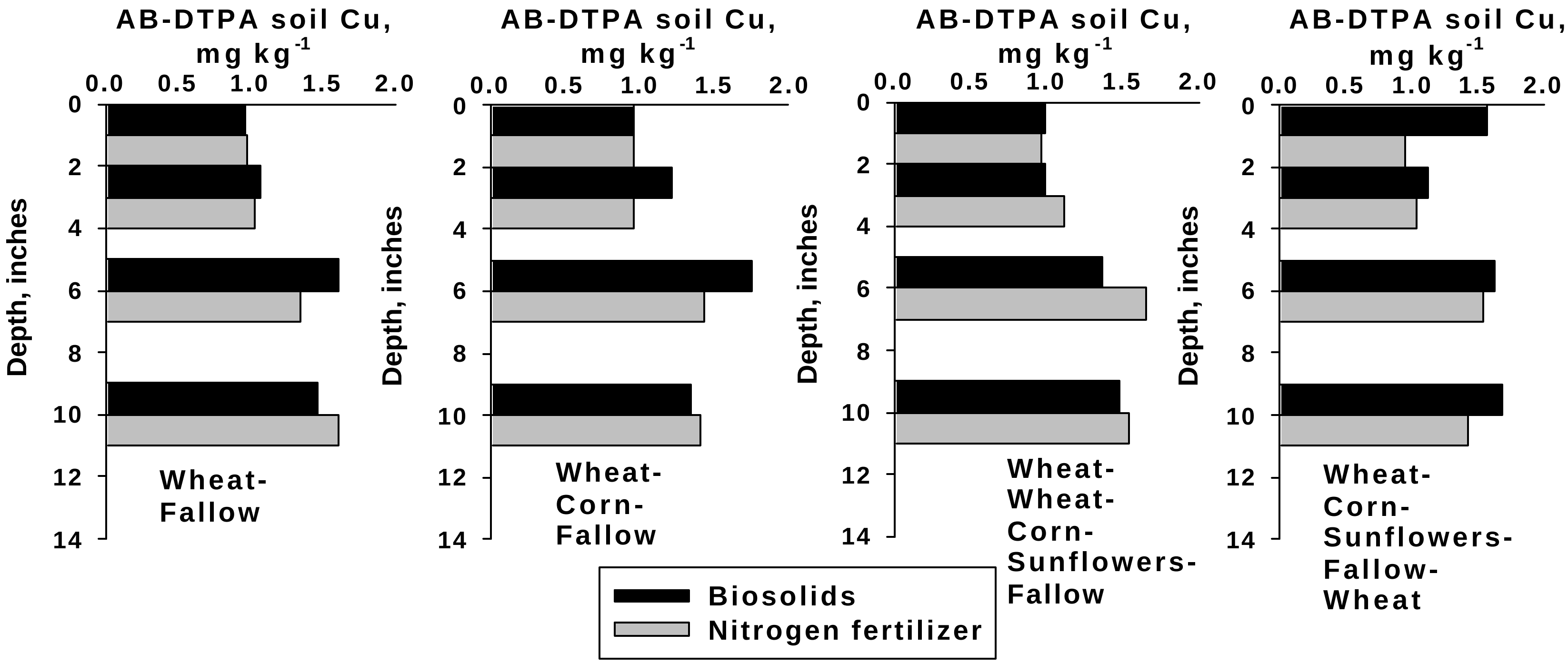
Figure 5. Soil-extractable AB-DTPA Zn for 2001 for dryland wheat rotations comparing Littleton/Englewood biosolids to commercial N fertilizer.



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 0.02
Treatment NS	Treatment NS	Treatment NS	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. 0.04

Figure 6. Soil-extractable AB-DTPA Cu for 2001 for dryland wheat rotations comparing Littleton/Englewood biosolids to commercial N fertilizer.



Statistical summary by soil depth:

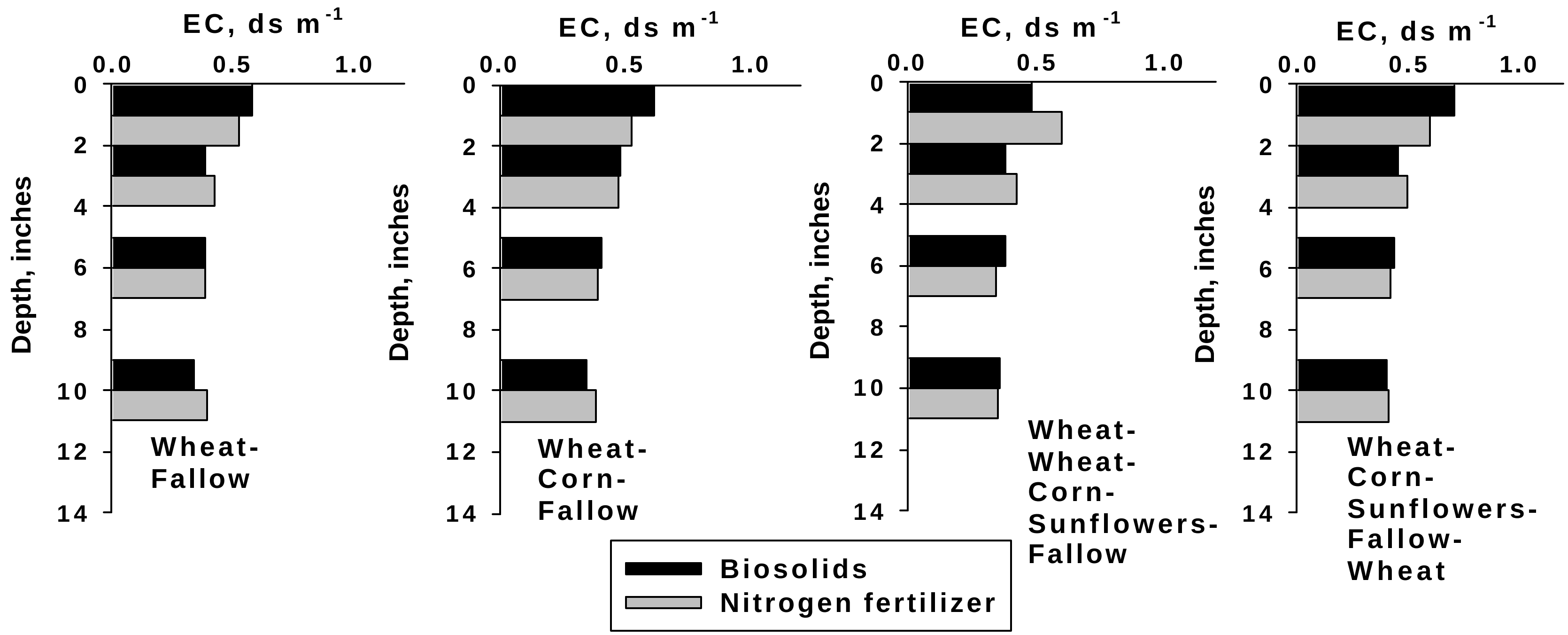
0-2 inches
$LSD_{0.10}$
Rotations NS
Treatment NS
Rot. X Treat. NS

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

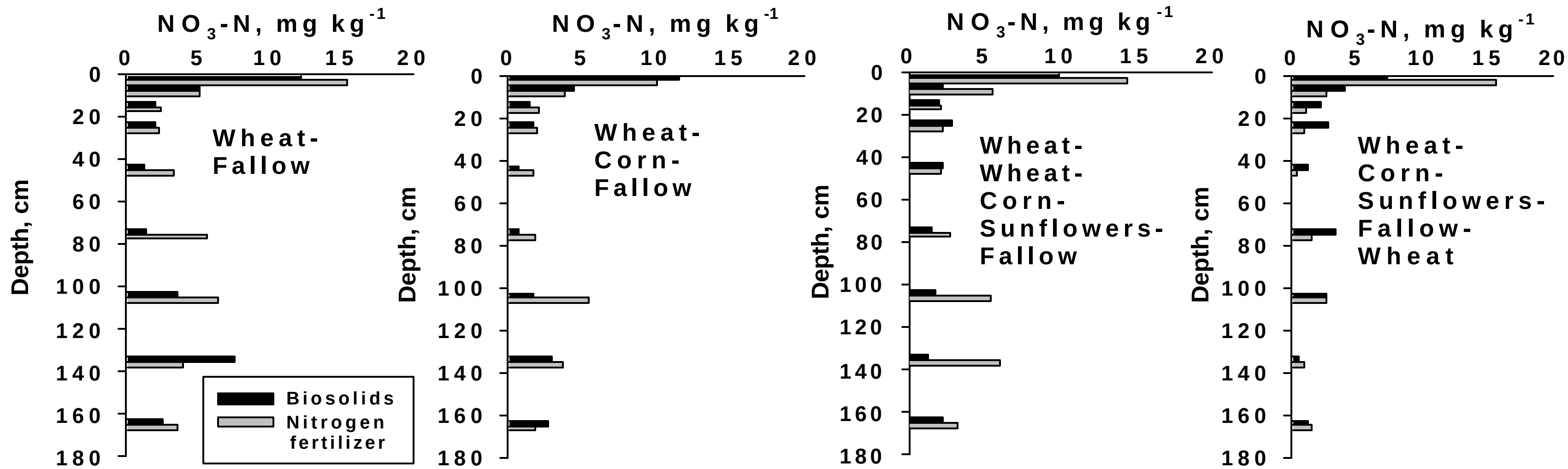
Figure 7. Electrical conductivity (EC) of the saturated soil paste extract (measure of soil salinity) for 2001 for dryland wheat rotations comparing Littleton/Englewood biosolids to commercial N fertilizer.



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. 0.14	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

Figure 8. Soil NO_3-N concentrations for 2001 for dryland wheat rotations comparing Littleton/Englewood biosolids to commercial fertilizer.

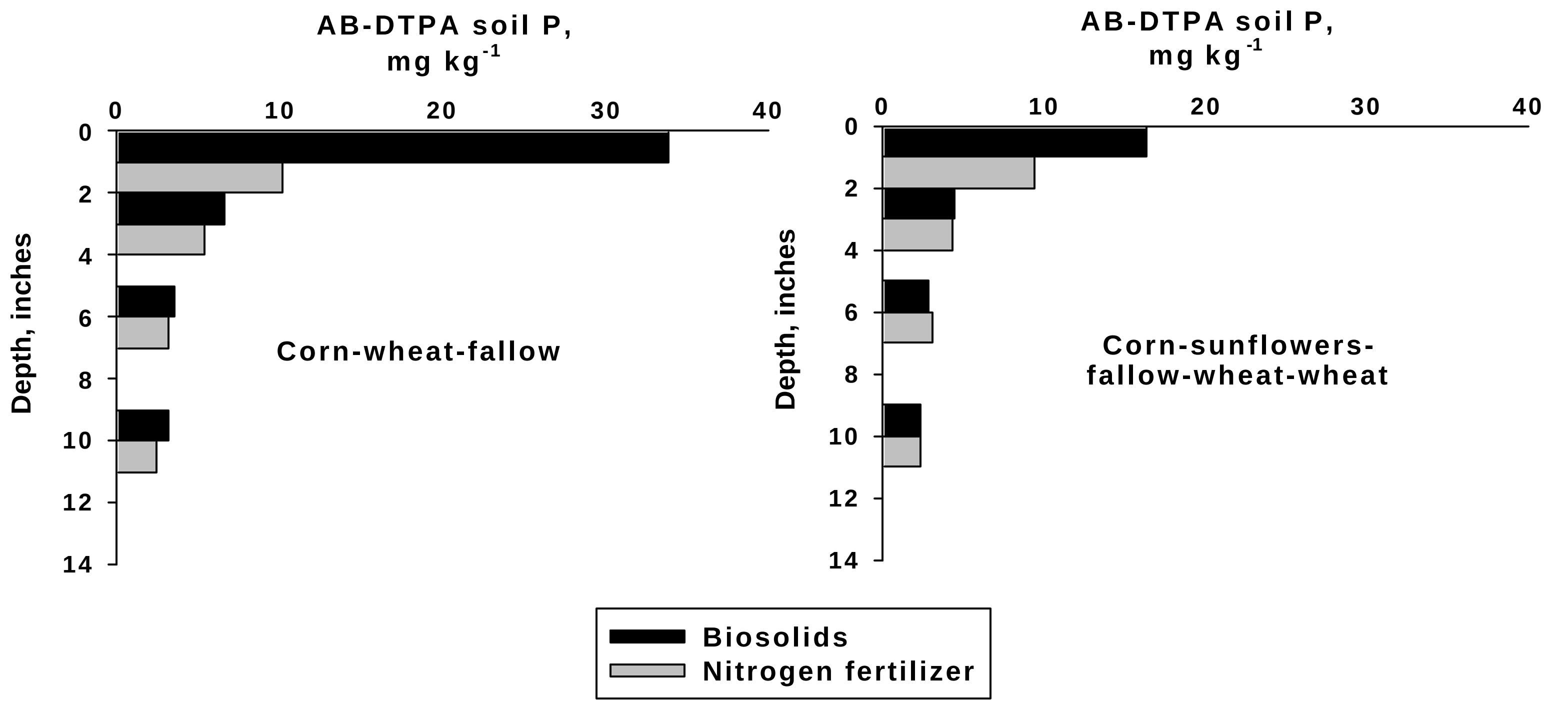


Statistical summary by soil depth:

0-2 inches	2-4 inches	4-8 inches	8-12 inches	12-24 inches
$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$
Rotations 0.6	Rotations 1.0	Rotations NS	Rotations NS	Rotations NS
Treatment 0.6	Treatment NS	Treatment NS	Treatment NS	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

24-36 inches	36-48 inches	48-60 inches	60-72 inches
$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$
Rotations 1.0	Rotations 0.9	Rotations NS	Rotations NS
Treatment 1.1	Treatment NS	Treatment NS	Treatment NS
Rot. X Treat. 1.9	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

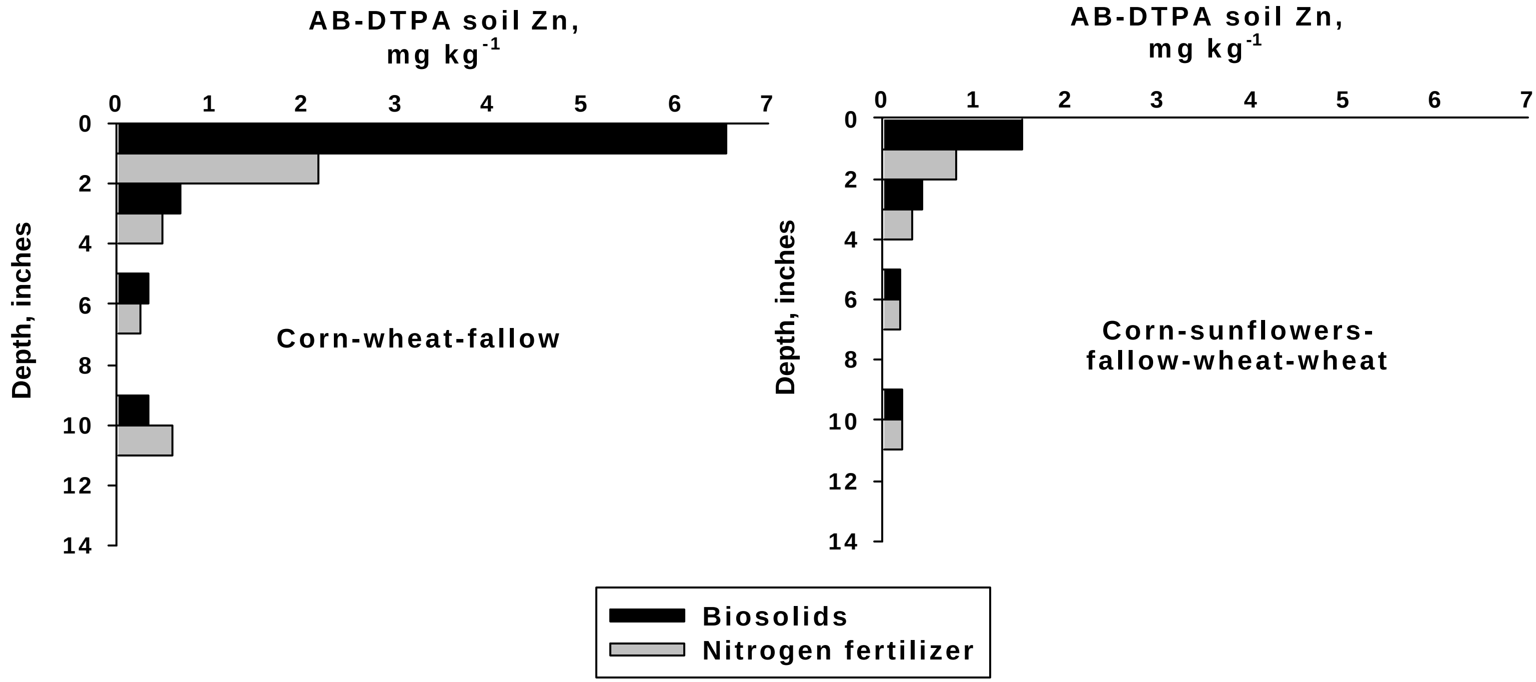
Figure 9. Soil-extractable AB-DTPA P for 2001 for dryland corn rotations comparing Littleton/Englewood biosolids to commercial N fertilizer.



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 13.9	Treatment NS	Treatment NS	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

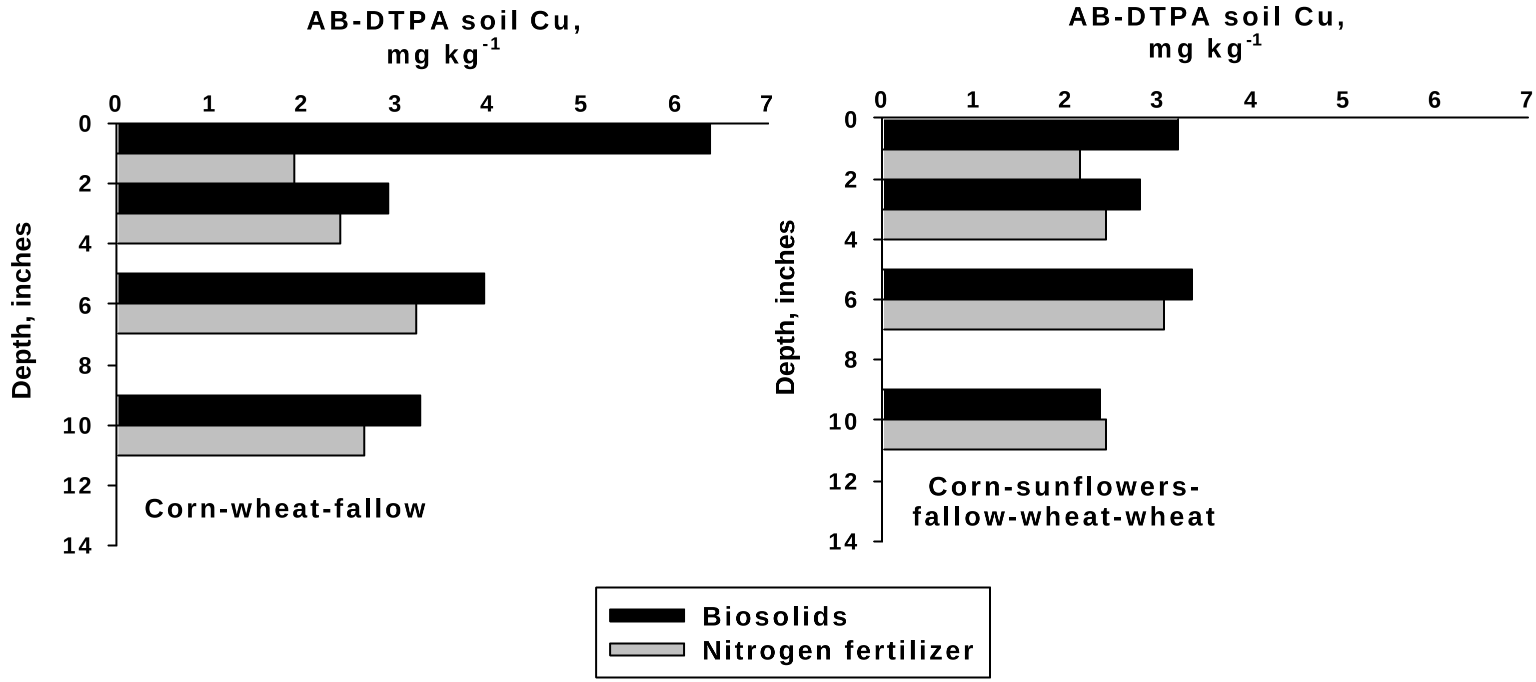
Figure 10. Soil-extractable AB-DTPA Zn for 2001 for dryland corn rotations comparing Littleton/Englewood biosolids to commercial N fertilizer.



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 0.05	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. 0.09	Rot. X Treat. NS

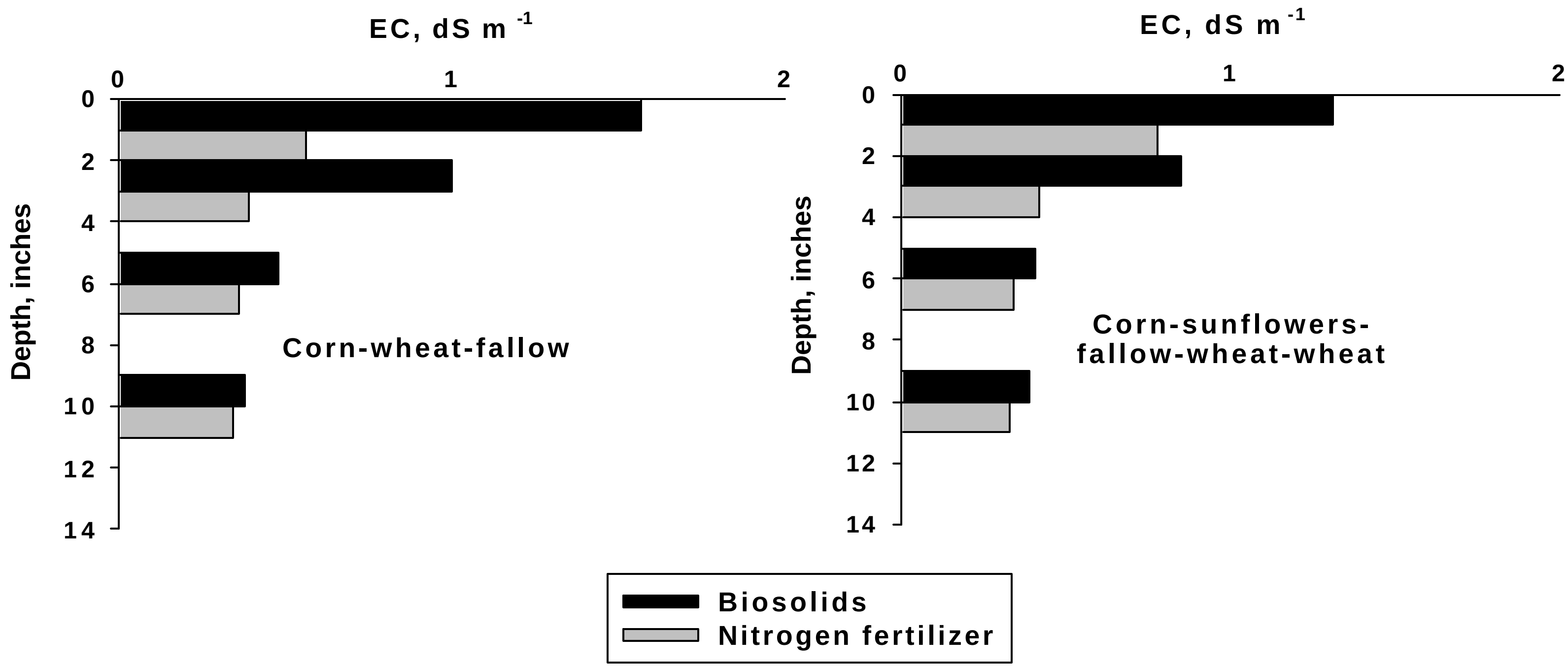
Figure 11. Soil-extractable AB-DTPA Cu for 2001 for dryland corn rotations comparing Littleton/Englewood biosolids to commercial N fertilizer.



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 2.3	Treatment 0.3	Treatment NS	Treatment NS
Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS	Rot. X Treat. NS

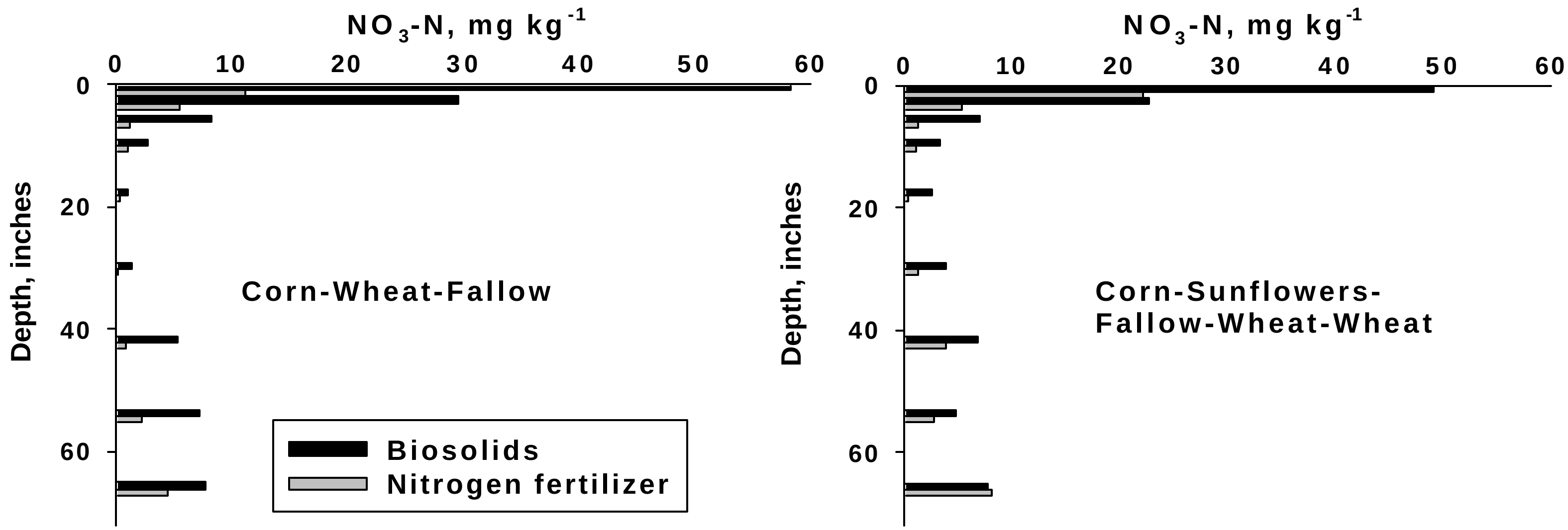
Figure 12. Electrical conductivity (EC) of the saturated soil paste extract (measure of soil salinity) for 2001 for dryland corn rotations comparing Littleton/Englewood biosolids to commercial N fertilizer.



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 0.03	Treatment 0.01	Treatment NS
Rot. X Treat. NS	Rot. X Treat. 0.22	Rot. X Treat. 0.05	Rot. X Treat. NS

Figure 13. Soil NO_3-N concentrations for 2001 for dryland corn rotations comparing Littleton/Englewood biosolids to commercial fertilizer.



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 16
Rot. X Treat. NS

4-8 inches
$LSD_{0.10}$
Rotations NS
Treatment 4
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 0.6
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