Technical Report 18-8

Agricultural
Experiment Station

College of
Agricultural Sciences

Department of
Soil and Crop Sciences

CSU Extension

Biosolids or Inorganic Fertilizer Applications Affect Wheat Grain and Soil in Dryland Cropping Rotations: 2016-2017

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This work was supported by the
USDA National Institute of Food and Agriculture,
Hatch project COL00292C - accession number 1004834.

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Cover photo of winter wheat, June 2017 (Jim Ippolito)

INTRODUCTION

A long-term biosolids land application site was established in 1999 near Byers, Colorado, with support from the South Platte Water Renewal Partners (SPWRP). This site has supported practical, never-performed-before research focused on true production agricultural practices and the effects of biosolids or inorganic fertilizer application to dryland crops grown in Eastern Colorado. No-till and minimum tillage management continues to be popular in eastern Colorado because it improves water conservation and allows more intensive cropping. Biosolids application could enhance the benefits of no-till or minimum tillage by working in concert with crop residues to maintain or enhance crop yields and grain nutrient content, without negatively impacting environmental quality. Thus, continued, long-term biosolids applications could provide production and economic advantages, along with building agroecosystems that could be more resilient in the face of ever-changing and erratic climatic conditions. More producers in eastern Colorado (and elsewhere under similar climatic conditions and agroecosystem practices) could eventually use biosolids as an integral part of a conservation program, along with enhancing soil quality/soil health to improve agroecosystem resiliency. This is especially important in Colorado as the state has added approximately 100,000 new residence per year over the past 10 years. Wastewater facilities treat an ever-increasing waste stream, generating biosolids that can be beneficially utilized by the state's producers.

Historically, dryland cropping systems in eastern Colorado have utilized a wheat-fallow rotation. However, based on work by former Colorado State University cropping systems experts (Drs. Gary Peterson and Dwayne Westfall, both retired), it appears that adding another crop in the rotation may benefit producers by raising two crops out of three years versus raising one crop out of two years. Thus, the long-term study objectives are to understand:

1. If biosolids can play an integral role in wheat-fallow and wheat-corn-fallow dryland agroecosystems.
2. If increasing biosolids application from once every two years to twice every three years is a feasible management alternative.
3. The effects of biosolids application at an agronomic rate compared to commercial inorganic fertilizer in two cropping systems on winter wheat grain and soil accumulation of plant nutrients and trace elements limited by the Colorado Department of Public Health and Environment biosolids application regulations.

MATERIALS AND METHODS

The project began in 1999 at a dryland agroecosystem site west of Byers, Colorado (39° 45’47”N 103°47’50”W) utilizing wheat-fallow (WF), wheat-corn-fallow (WCF), and wheat-wheat-corn-sunflower-fallow (WWCSF) dryland cropping rotations. Due to crop failures with the WWCSF rotation, beginning in fall 2005 we replaced this rotation with either WF or WCF rotations. We now use four blocks (replications) of each treatment arranged in a split-plot design. The main plots consist of the cropping rotations (e.g., WF or WCF). Each main plot is split to accommodate biosolids application on half the plot and commercial fertilizer addition on the other half. All phases of each rotation are present each year to allow assessment of all soil and crop responses each year. This requires a total of 20 main plots and 40 split plots (4 replications, 5 cropping rotations, biosolids/fertilizer treatment splits). Each main plot is 0.5 miles long by 100 feet wide. Each biosolids/fertilizer split is therefore 50 feet wide.

Biosolids (supplied by the SPWRP) surface-application (i.e., no incorporation) recommendations were based on soil NO_3-N concentration and soil organic matter content to a depth of 2 feet, determined prior to application; our past research suggested that 1 ton SPWRP biosolids = approximately 16 lbs N/ac. The above information was used to determine the biosolids-N needs of either dryland wheat or corn (e.g., the agronomic rate). A similar approach was taken with agronomic N fertilizer applications, utilizing other inorganic fertilizers applied based on cooperating producer input. In some years, residual soil N suggested that no biosolids or inorganic fertilizers were required. For dryland winter wheat or dryland corn, biosolids and inorganic fertilizers were applied either in September 2016 or May 2017, respectively. Table 1 illustrates the biosolids or inorganic fertilizer applications and timing, for individual crops and varieties, since project inception in 1999.

For purposes of this report, following wheat harvest from within the WF or WCF rotations, we determined yields (by harvesting each entire plot and using a combine-mounted laod cell), grain protein content, and grain total P, Cd, Cr, Cu, Fe, Mo, Ni, Pb, and Zn concentrations (using a concentrated nitric acid + peroxide digestion). We determined plant-available soil P, Cd, Cr, Cu, Fe, Mo, Ni, Pb, and Zn (using an AB-DTPA extraction), and NO_3-N concentrations (using a 2M potassium chloride extraction) in the 0-2, 2-4, 4-6, and 6-12 inch depths, and soil NO_3-N in the 12-24, 24-36, 36-48, 48-60, and 60-72 inch depths.

RESULTS AND DISCUSSION

Winter Wheat Grain Characteristics

Wheat grain yields averaged 40 bushels acre^{-1} (Table 2). Although there was no significant difference between the wheat-fallow (WF) and wheat-corn-fallow (WCF) rotations or interaction between nutrient source and rotation, there was a significant difference between biosolids and N fertilizer; in 2016-17, biosolids produced more wheat grain as compared to N fertilizer. Winter wheat protein content averaged 14.7%, and thus a protein premium would have been paid for this grain. Table 2 also illustrates that biosolids application produced similar grain P, Zn, and Cu as compared to N fertilizer. However, biosolids produced greater grain Fe as compared to commercial fertilizer, and a rotation by nutrient source interaction was present for grain protein and Ni concentration, with larger content mostly associated with the WCF rotation and biosolids application.

Soil Characteristics:

Figures A through I illustrate changes in soil P, Cd, Cr, Cu, Fe, Ni, Pb, Zn, and NO_3-N concentrations due to biosolids or fertilizer application, or due to cropping rotation, with depth. Nutrient source (e.g., biosolids versus inorganic fertilizer) affected soil surface plant-available P, Cu, Zn, and NO_3-N concentrations with relatively little effect with depth. The 0 to 2 inch soil results were not surprising since 1) biosolids were surface applied with no incorporation, and 2) biosolids typically contain appreciable quantities of N, P, Cu, and Zn. It is important to note that biosolids Cu and Zn concentrations have never been above EPA regulatory limits for these biosolids over the course of this study. We also found several other significant effects, yet consistent trends with these results have not been observed over time. When differences were present, the WCF plots had greater NO_3-N as compared to the WF plots. This may have been due to greater biosolids amounts (i.e., greater N amounts) applied to the WCF rotation as compared to the WF rotation, with less NO_3-N removed with crops over time. Overall, biosolids support dryland winter wheat yields comparable to inorganic fertilizer applications, with this finding supported over the past 18 study years.

Table 1. Biosolids and fertilizer applications and crop varieties used at the Byers research site, 1999-2017.

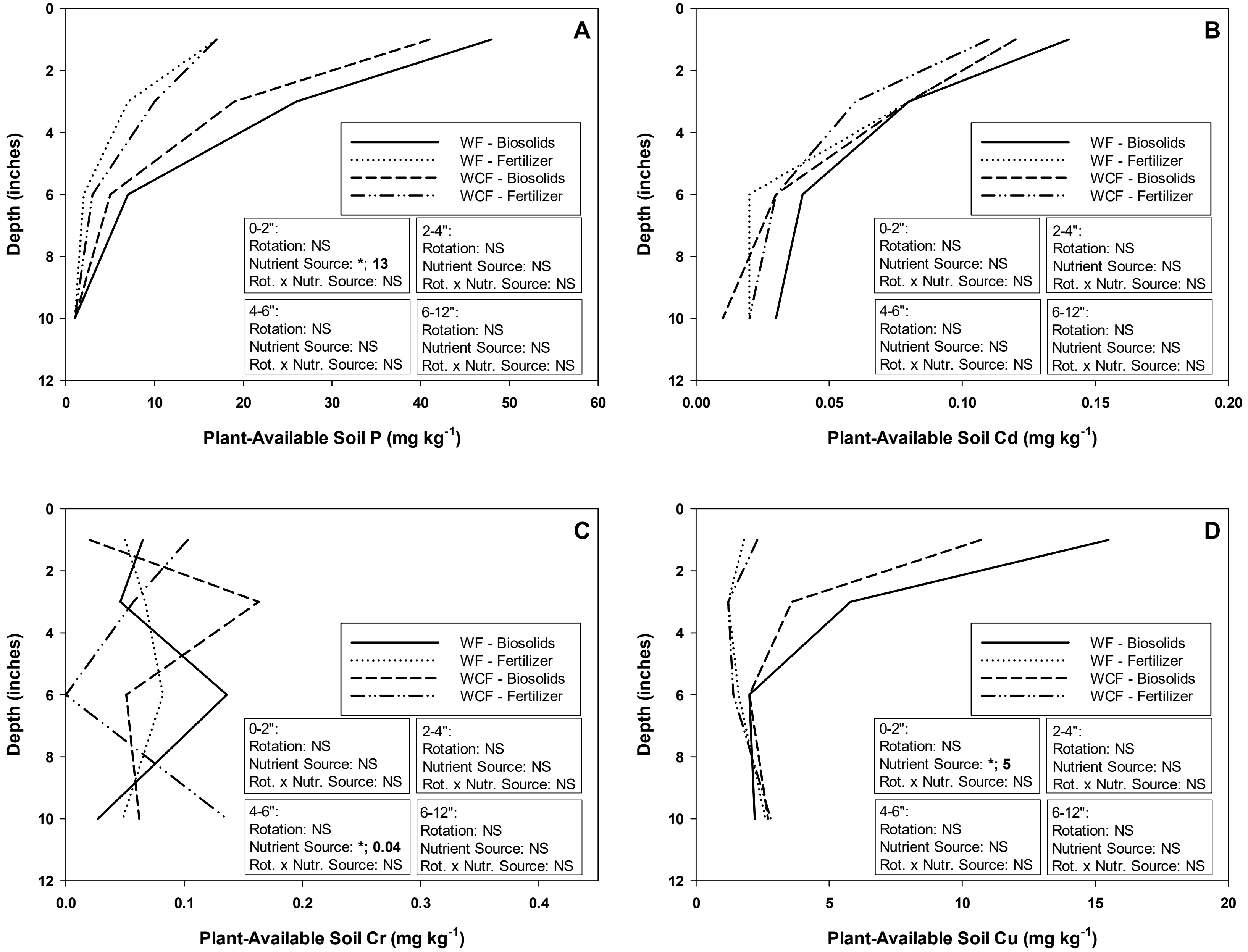
Year Planted	Date Planted	Crop	Variety	Biosolids Biosolids tons/acre	Treatment Bio/N equiv. lbs	Nitrogen N lbs/acre with seed	Fertilizer N lbs/acre after planting	Treatment Total N lbs/acre	P_2O_5 lbs/acre	Zn lbs/acre
1999	Early Oct.	Wheat	Halt	2.4	38.4	5	40	45	20	0
2000	May	Corn	Pioneer 3752	4	64	5	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
2006	Sept.	Wheat	Yumar	0	0	0	0	0	0	0
2007	May	Corn	Pioneer J99	0	0	0	0	0	0	0
2007	Sept.	Wheat	Yumar	0	0	0	0	0	0	0
2008	May	Corn	Pioneer J99	0	0	0	0	0	0	0

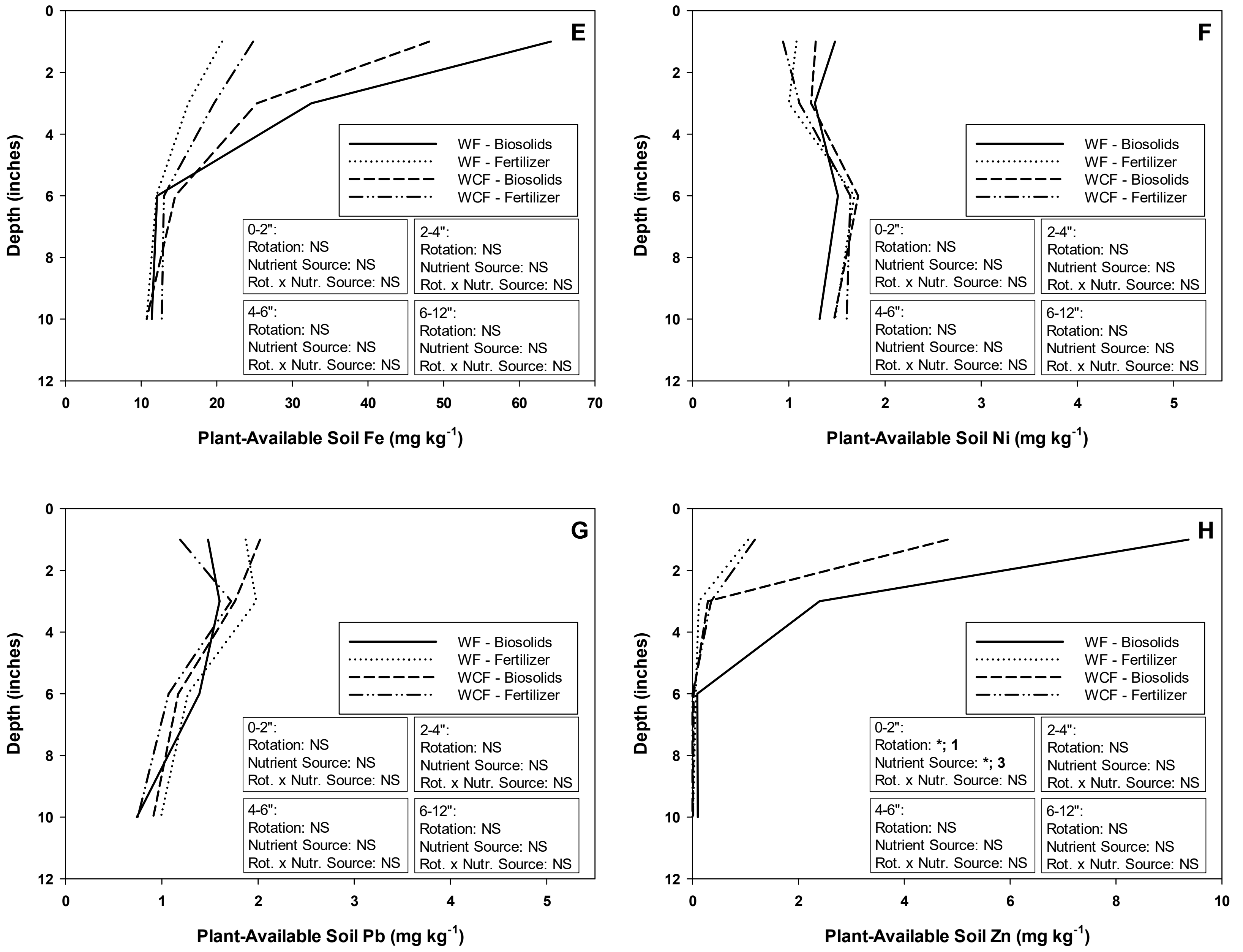
2008	Sept.	Wheat	Yumar	0	0	0	0	0	0	0
2009	May	Corn	Pioneer J99	0	0	0	0	0	0	0
2009	Sept.	Wheat	Yumar	0	0	0	0	0	0	0
2010	May	Corn	Pioneer J99	0	0	0	0	0	0	0
2010	Sept.	Wheat	Yumar	0	0	0	0	0	0	0
2011	May	Corn	Pioneer J99	0	0	0	0	0	0	0
2011	Sept.	Wheat	Snowmass	2	32	5	30	35	20	0
2012	May	Corn	Triumph 9958	2	32	5	30	35	20	0
2012	Sept.	Wheat	Snowmass	2	32	5	30	35	20	0
2013	May	Corn	Triumph 9958	2	32	5	30	35	15	5
2013	Sept.	Wheat	Byrd	2	32	5	30	35	20	0
2014	May	Corn	Triumph 9811	2	32	5	30	35	15	5
2014	Sept.	Wheat	Byrd	2	32	5	30	35	20	0
2015	May	Corn	Triumph 9811	2	32	5	30	35	15	5
2015	Sept.	Wheat	Snowmass	2	32	0	45	45	0	0
2016	May	Corn	Pioneer 0157	0	0	0	50	50	0	0
2016	Sept.	Wheat	Snowmass	2	32	0	45	45	0	0
2017	May	Corn	Pioneer 0157	0	0	0	50	50	0	0

Table 2. Mean wheat grain characteristics for the 2016-2017 harvest from within wheat-fallow or wheat-corn-fallow rotations treated with agronomic rates of either biosolids or inorganic N fertilizer (and other inorganic fertilizers; see Table 1) at the Byers research site.

Rotation[†]	Nutrient source	Grain Yield	Protein	P	Cd	Cr	Cu	Fe	Mo	Ni	Pb	Zn
		bu ac^{-1}	%	g kg^{-1}	----------	----------	----------	mg kg^{-1}	----------	----------	----------	----------
WF	Biosolids	44.8	14.7	2.6	BD[*]	BD	4.8	26	2.0	BD	BD	14
	N	35.6	14.0	2.5	BD	BD	5.1	22	1.9	0.26	BD	13
WCF	Biosolids	42.8	14.8	2.8	BD	BD	5.2	23	1.8	0.44	BD	14
	N	37.0	15.2	2.6	BD	BD	5.3	24	1.3	0.10	BD	13
WF	Mean Over	40.2	14.4	2.6	BD	BD	4.9	24	2.0	0.13	BD	14
WCF	Nutri.	39.9					5.3	24	1.6	0.27		14
	Source		15.0	2.6	BD	BD					BD	
Mean over	Biosolids	43.9	14.8	2.7			4.9	25	1.9	0.20		14
Rotation	N	36.2	14.6	2.5			5.2	23	1.6	0.19		13
Analyses of Variance		P>F	P>F	P>F			P>F	P>F	P>F	P>F		P>F
Rotation		0.410	0.186	0.222			0.221	0.1115	0.346	0.516		0.225
Nutrient Source		**0.013**	0.445	0.199			0.143	**0.0489**	0.491	0.638		0.276
Rotation X Nutrient Source		0.266	**0.099**	0.799			0.822	0.8855	0.680	**0.096**		0.300
		$LSD_{0.10}$[††]	$LSD_{0.10}$	$LSD_{0.10}$			$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$		$LSD_{0.10}$
Rotation		NS[⁋]	NS	NS			NS	NS	NS	NS		NS
Nutrient Source		**3.7**	NS	NS			NS	**2**	NS	NS		NS
Rotation X Nutrient Source		NS	**0.6**	NS			NS	NS	NS	**0.26**		NS

[†] WF = wheat-fallow and WCF = wheat-corn-fallow. [††] LSD = least significant difference at a probability of 90%. [⁋] NS = not significant. [*] BD = Below detection.


A
Depth (inches)
0
2
4
6
8
10
12
0
10
20
30
40
50
60
Plant-Available Soil P (mg kg-1)
WF - Biosolids
WF - Fertilizer
WCF - Biosolids
WCF - Fertilizer
0-2":
Rotation: NS
Nutrient Source: *; 13
Rot. x Nutr. Source: NS
2-4":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS
4-6":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS
6-12":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS
B
Depth (inches)
0.00
0.05
0.10
0.15
0.20
Plant-Available Soil Cd (mg kg-1)
WF - Biosolids
WF - Fertilizer
WCF - Biosolids
WCF - Fertilizer
0-2":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS
2-4":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS
4-6":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS
6-12":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS
C
Depth (inches)
0.0
0.1
0.2
0.3
0.4
Plant-Available Soil Cr (mg kg-1)
WF - Biosolids
WF - Fertilizer
WCF - Biosolids
WCF - Fertilizer
0-2":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS
2-4":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS
4-6":
Rotation: NS
Nutrient Source: *; 0.04
Rot. x Nutr. Source: NS
6-12":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS
D
Depth (inches)
0
5
10
15
20
Plant-Available Soil Cu (mg kg-1)
WF - Biosolids
WF - Fertilizer
WCF - Biosolids
WCF - Fertilizer
0-2":
Rotation: NS
Nutrient Source: *; 5
Rot. x Nutr. Source: NS
2-4":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS
4-6":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS
6-12":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS


E
Depth (inches)
Plant-Available Soil Fe (mg kg-1)
WF - Biosolids
WF - Fertilizer
WCF - Biosolids
WCF - Fertilizer
0-2": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
2-4": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
4-6": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
6-12": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
F
Depth (inches)
Plant-Available Soil Ni (mg kg-1)
WF - Biosolids
WF - Fertilizer
WCF - Biosolids
WCF - Fertilizer
0-2": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
2-4": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
4-6": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
6-12": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
G
Depth (inches)
Plant-Available Soil Pb (mg kg-1)
WF - Biosolids
WF - Fertilizer
WCF - Biosolids
WCF - Fertilizer
0-2": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
2-4": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
4-6": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
6-12": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
H
Depth (inches)
Plant-Available Soil Zn (mg kg-1)
WF - Biosolids
WF - Fertilizer
WCF - Biosolids
WCF - Fertilizer
0-2": Rotation: *; 1 Nutrient Source: *; 3 Rot. x Nutr. Source: NS
2-4": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
4-6": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
6-12": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS

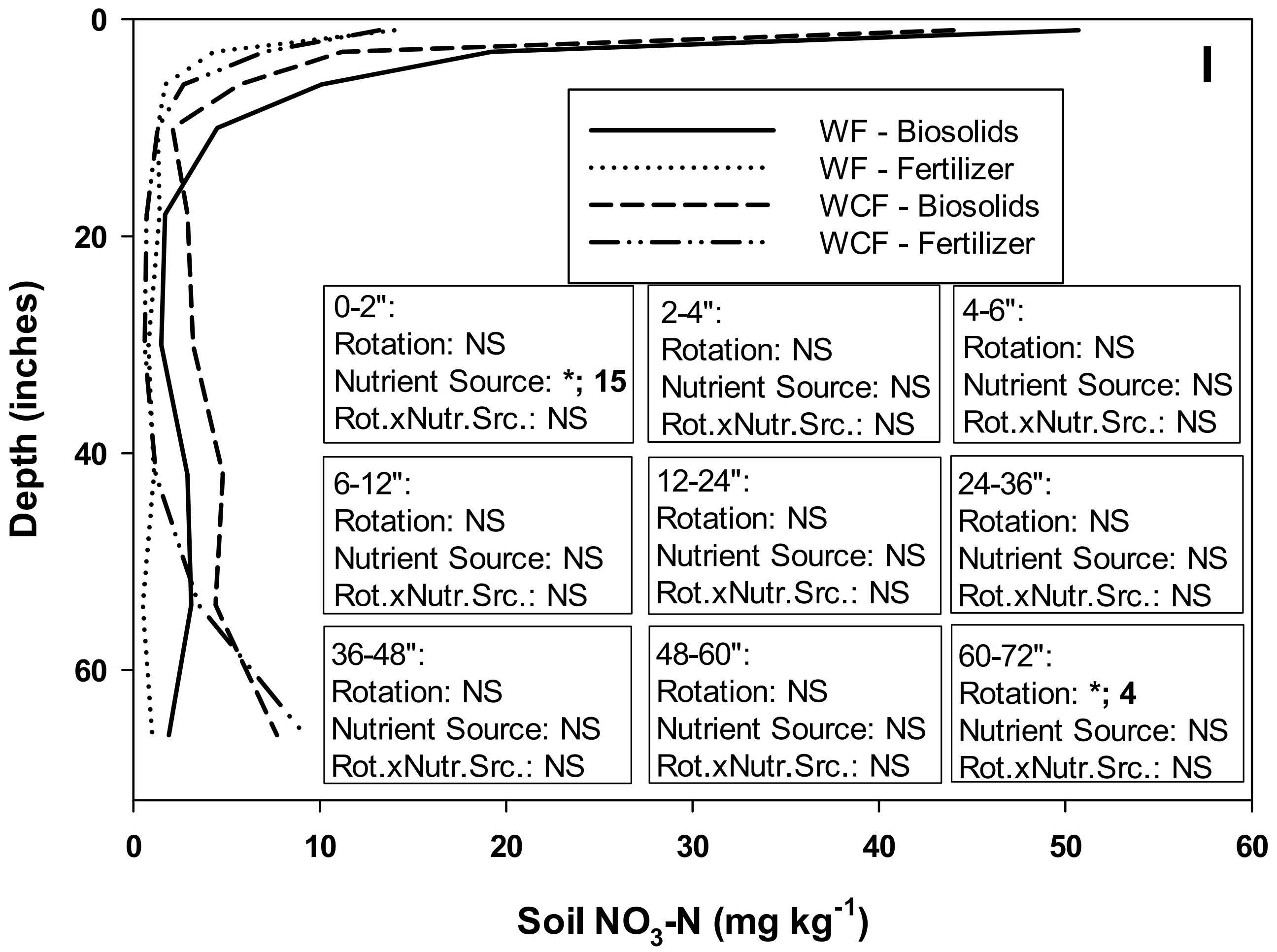


Figure 1. Plant-available soil A) phosphorus, B) cadmium, C) chromium, D) copper, E) iron, F) nickel, G) lead, H) zinc, and I) nitrate-nitrogen concentrations with depth after wheat harvest, 2017.