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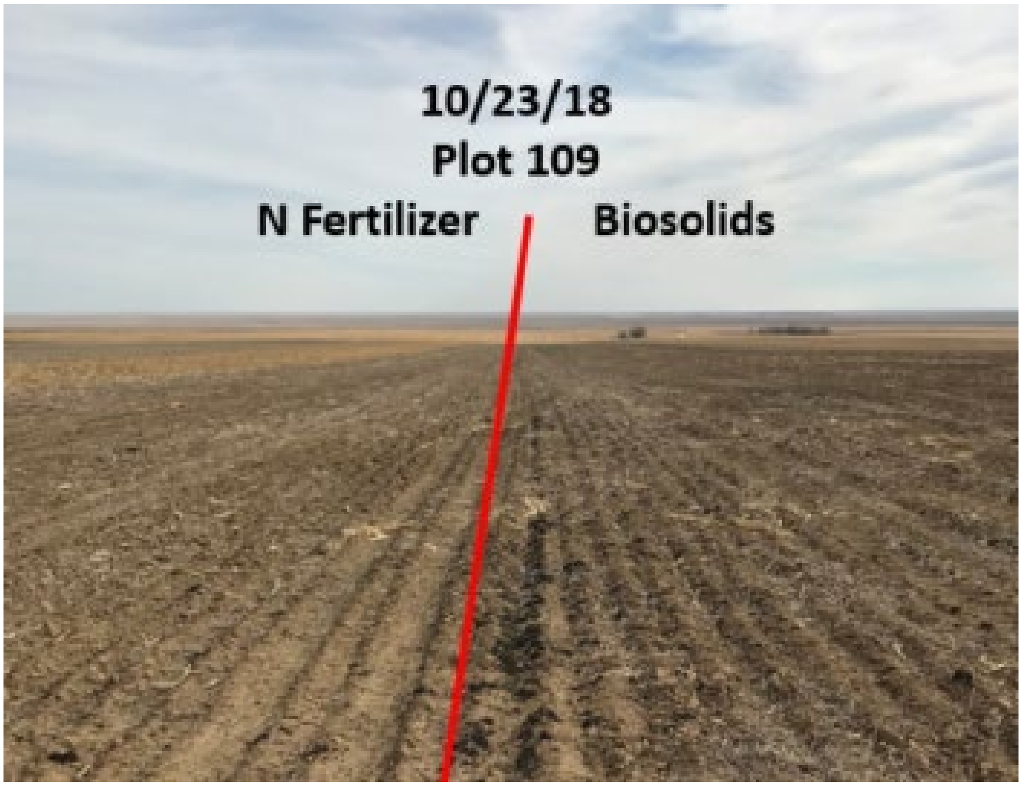
Biosolids or Inorganic Fertilizer Applications Affect Wheat Grain and Soil in Dryland Cropping Rotations: 2018-2019



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Cover photo of winter wheat, October 2018 (Jim Ippolito)

INTRODUCTION

A long-term biosolids land application site was established in 1999 near Byers, Colorado, with support from the South Platte Renew (SPR). 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 is increasing in popularity 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 affecting 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 health to improve agroecosystem resiliency.

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 (39º 45'47"N 103º47'50"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 SPR) 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 SPR biosolids = approximately 16 lbs N/ac. The above information was used to determine the biosolids-borne N needs of either dryland wheat or corn (e.g., the agronomic rate). A similar approach was taken for agronomic N fertilizer application requirements, with 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 2018 or May 2019, 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), 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 55 bushels acre^{-1} (Table 2). There were no significant differences between grain yields for the wheat-fallow (WF) and wheat-corn-fallow (WCF) rotations, or the interaction between nutrient source and rotation. However, N fertilizer produced greater wheat yields than biosolids in the 2018-19 crop year. Wheat grain protein averaged 17.0% in 2018-19, with the WCF rotation and biosolids producing a greater grain protein content as compared to the WF rotation or N fertilizer application, respectively. Regardless, a protein premium may have been paid for this grain from any portion of the field.

Biosolids application also produced wheat grain that contained greater Cd, Cu and Zn as compared to N fertilizer; other wheat grain nutrient concentrations were comparable between biosolids and N fertilizer. The increase in wheat grain Zn concentration with biosolids, as compared to inorganic fertilizer, supports a biofortification effect as observed previously at this site. Overall, findings suggests that biosolids act relatively similarly to inorganic fertilizers that producers would utilize to produce winter wheat in Colorado.

Soil Characteristics:

Figures 1A through 1I 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. Biosolids application caused significant increases in plant-available soil P concentrations in the 0-2 and 2-4" depths as compared to inorganic fertilizer; the WF rotation contained slightly greater plant-available soil P content in the 4-6" depth as compared to the WCF rotation (Figure 1A). Biosolids application caused a slight yet significant increase in plant-available soil Cd content in the 0-2" depth as compared to inorganic fertilizer; the WF rotation contained slightly greater plant-available Cd content in the 2-4" depth as compared to the WCF rotation (Figure 1B). Plant-available soil Cr concentrations were all below detection regardless of nutrient source or rotation (Figure 1C). Biosolids application caused a significant increase in plant-available soil Cu content in the 0-2" depth as compared to inorganic fertilizer; the WF rotation contained slightly greater plant-available Cu content in the 6-12" depth as compared to the WCF rotation (Figure 1D). Biosolids application caused a significant increase in plant-available soil Fe content in the 0-2", and a slight increase in plant-available Ni in the 0-2 and 4-6" depths as compared to inorganic fertilizer (Figure 1E and 1F, respectively). The WF rotation contained slightly greater Pb concentrations as compared to the WCF in the 2-4" depth; a significant interaction between rotation and fertilizer source existed for plant-available Pb concentrations in the 4-6” depth (Figure 1G). Biosolids application increased plant-available Zn concentrations in the 0-2 and 4-6” depths as compared to inorganic fertilizer application (Figure 1H). Finally, biosolids application increases soil nitrate-nitrogen in the 0-2, 2-4, and 4-6” depths as compared to inorganic fertilizer (Figure 1I).

The above findings are similar to previous years’ findings where differences were evident in the upper soil depths due to 1) biosolids being surface applied with no incorporation, and 2) biosolids typically containing appreciable quantities of N, P, Fe, Cu, and Zn. These biosolids typically contains elevated Fe concentrations due to Fe additions within the wastewater treatment facility in order to offset hydrogen sulfide formation in the anaerobic digesters. Biosolids also typically contain relatively elevated Cu and Zn concentrations due to municipality infrastructure (e.g., Cu piping and Zn solder). 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. More importantly, although winter wheat deficiencies have never been observed in Colorado, based on our results, biosolids is supplied plant-available Zn to the soil and improving winter wheat grain Zn content over inorganic fertilizers. In soils where winter wheat is grown, increasing plant-available soil Zn concentrations above 2 mg/kg may be beneficial to the crop. Overall, biosolids supports dryland winter wheat yields comparable to inorganic fertilizer applications, with this finding supported over the past 20 study years.

Table 1. Biosolids and fertilizer applications and crop varieties used at the Byers research site, 1999-2019.

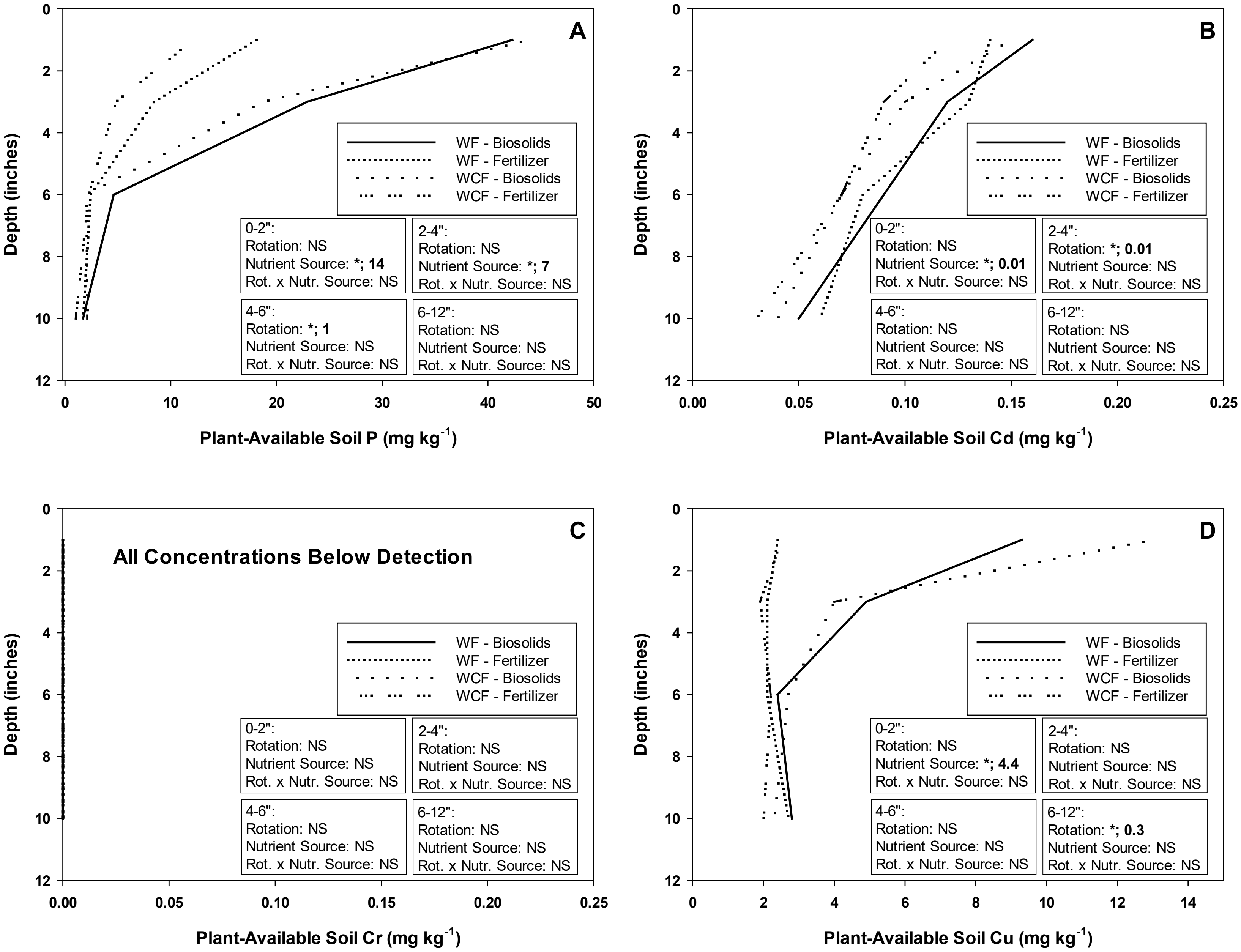
Year Planted	**Date Planted**	**Crop**	**Variety**	**Biosolids Biosolids tons/acre**	**Treatment Bio/N equiv. lbs**	**Nitrogen N lbs/acre with seed**	**Fertilizer N lbs/acre after planting**	**Treatment Total N lbs/acre**	**P_2O_5 lbs/acre**	**Zn lbs/acre**
1999	Early Oct.	Wheat	Halt	2.4	38.4	5	40	45	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

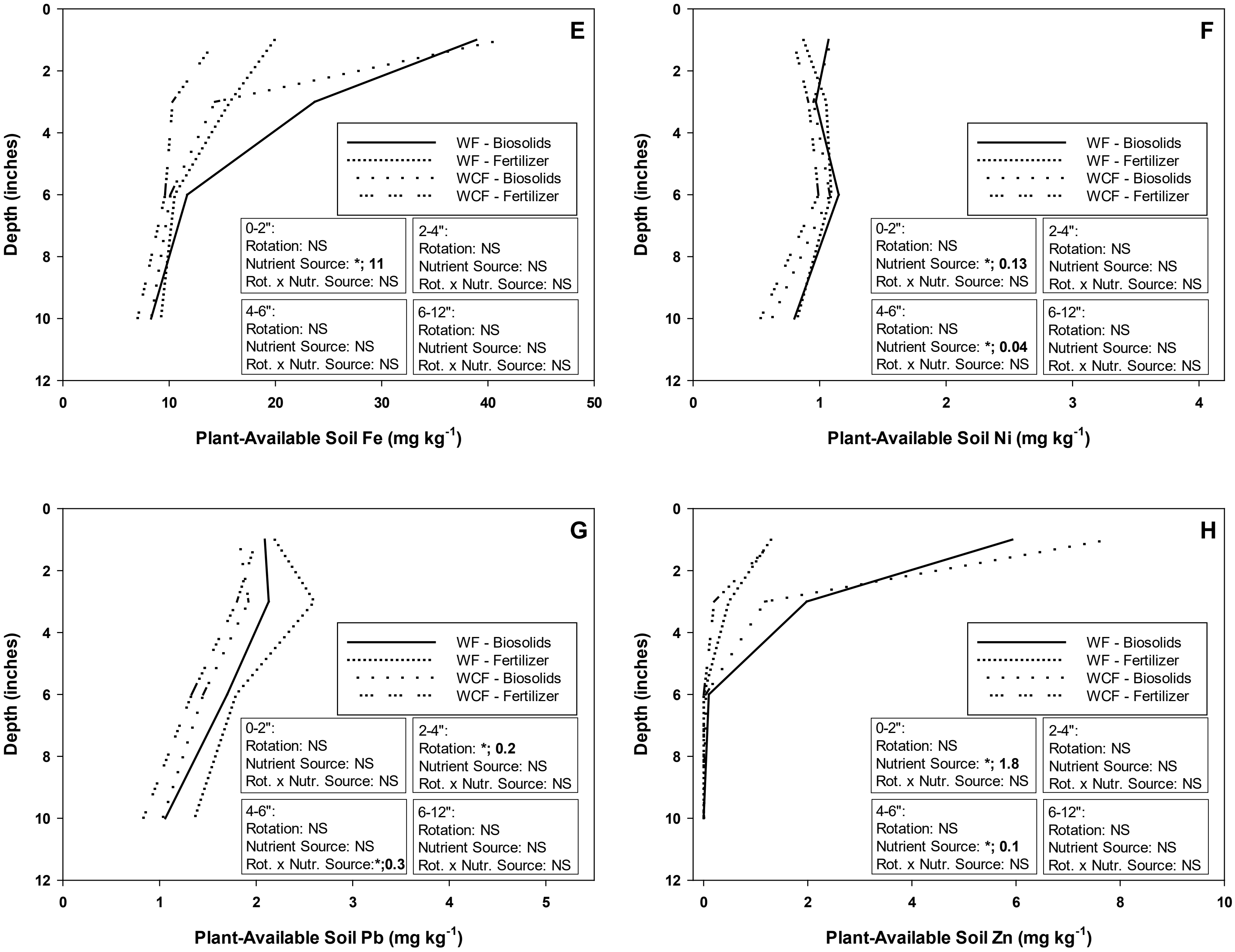
2008	Sept.	Wheat	Yumar	0	0	0	0	0	0	0
2009	May	Corn	Pioneer J99	0	0	0	0	0	0	0
2009	Sept.	Wheat	Yumar	0	0	0	0	0	0	0
2010	May	Corn	Pioneer J99	0	0	0	0	0	0	0
2010	Sept.	Wheat	Yumar	0	0	0	0	0	0	0
2011	May	Corn	Pioneer J99	0	0	0	0	0	0	0
2011	Sept.	Wheat	Snowmass	2	32	5	30	35	20	0
2012	May	Corn	Triumph 9958	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
2017	Sept.	Wheat	Snowmass	2	32	0	45	45	0	0
2018	May	Corn	Pioneer 9697	0	0	0	50	50	0	0
2018	Sept.	Wheat	Avery and Breck	1.5	24	7	40	47	10	0
2019	May	Corn	Pioneer 9608	2	32	0	50	50	0	0

Table 2. Mean wheat grain characteristics for the 2018-2019 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	53.7	17.6	3.5	0.12	BD[*]	5.9	34	0.47	0.39	BD	22.9
	N	60.0	15.7	2.8	0.11	BD	5.4	32	0.48	0.33	0.02	15.0
WCF	Biosolids	50.0	19.1	3.6	0.12	BD	6.1	34	0.50	0.43	BD	25.5
	N	57.0	15.8	3.0	0.09	BD	5.6	45	0.74	0.30	0.06	17.7
WF	Mean Over Nutri. Source	56.9	16.7	3.2	0.11	BD	5.6	33	0.48	0.36	0.01	19.0
WCF		53.5	17.5	3.3	0.10	BD	5.9	39	0.62	0.37	0.03	21.6
Mean over Rotation	Biosolids	51.9	18.3	3.6	0.12		6.0	34	0.49	0.41	BD	24.2
	N	58.5	15.8	2.9	0.10		5.5	38	0.61	0.32	0.04	16.4
Analyses of Variance		P>F	P>F	P>F	P>F		P>F	P>F	P>F	P>F	P>F	P>F
Rotation		0.4625	**0.0651**	0.5309	0.5854		0.2036	0.3107	0.3215	0.9702	**-----**	0.2073
Nutrient Source		**0.0120**	**0.0179**	**0.0015**	**0.0701**		**0.0651**	0.5561	0.4599	0.1113	**0.3751**	**0.0103**
Rotation X Nutrient Source		0.7770	0.2720	0.3535	0.2067		0.8615	0.3902	0.4872	0.4897	-----	0.9708
		$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$		$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$	$LSD_{0.10}$		$LSD_{0.10}$
Rotation		NS[‡]	**0.4**	NS	NS		NS	NS	NS[‡]	NS	**-----**	NS[‡]
Nutrient Source		**3.3**	**1.3**	**0.3**	**0.01**		**0.3**	NS	NS	NS	NS	**3.9**
Rotation X Nutrient Source		NS	NS	NS	NS		NS	NS	NS	NS	-----	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)
Plant-Available Soil P (mg kg^{-1})
WF - Biosolids
WF - Fertilizer
WCF - Biosolids
WCF - Fertilizer
0-2": Rotation: NS Nutrient Source: *; 14 Rot. x Nutr. Source: NS
2-4": Rotation: NS Nutrient Source: *; 7 Rot. x Nutr. Source: NS
4-6": Rotation: *; 1 Nutrient Source: NS Rot. x Nutr. Source: NS
6-12": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
B
Depth (inches)
Plant-Available Soil Cd (mg kg^{-1})
WF - Biosolids
WF - Fertilizer
WCF - Biosolids
WCF - Fertilizer
0-2": Rotation: NS Nutrient Source: *; 0.01 Rot. x Nutr. Source: NS
2-4": Rotation: *; 0.01 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
All Concentrations Below Detection
Depth (inches)
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: NS Rot. x Nutr. Source: NS
6-12": Rotation: NS Nutrient Source: NS Rot. x Nutr. Source: NS
D
Depth (inches)
Plant-Available Soil Cu (mg kg^{-1})
WF - Biosolids
WF - Fertilizer
WCF - Biosolids
WCF - Fertilizer
0-2": Rotation: NS Nutrient Source: *; 4.4 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: *; 0.3 Nutrient Source: NS Rot. x Nutr. Source: NS


E
Depth (inches)
0
2
4
6
8
10
12
0
10
20
30
40
50
Plant-Available Soil Fe (mg kg^{-1})
WF - Biosolids
WF - Fertilizer
WCF - Biosolids
WCF - Fertilizer
0-2":
Rotation: NS
Nutrient Source: *; 11
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)
0
2
4
6
8
10
12
0
1
2
3
4
Plant-Available Soil Ni (mg kg^{-1})
WF - Biosolids
WF - Fertilizer
WCF - Biosolids
WCF - Fertilizer
0-2":
Rotation: NS
Nutrient Source: *; 0.13
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
G
Depth (inches)
0
2
4
6
8
10
12
0
1
2
3
4
5
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: *; 0.2
Nutrient Source: NS
Rot. x Nutr. Source: NS
4-6":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source:*;0.3
6-12":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS
H
Depth (inches)
0
2
4
6
8
10
12
0
2
4
6
8
10
Plant-Available Soil Zn (mg kg^{-1})
WF - Biosolids
WF - Fertilizer
WCF - Biosolids
WCF - Fertilizer
0-2":
Rotation: NS
Nutrient Source: *; 1.8
Rot. x Nutr. Source: NS
2-4":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS
4-6":
Rotation: NS
Nutrient Source: *; 0.1
Rot. x Nutr. Source: NS
6-12":
Rotation: NS
Nutrient Source: NS
Rot. x Nutr. Source: NS

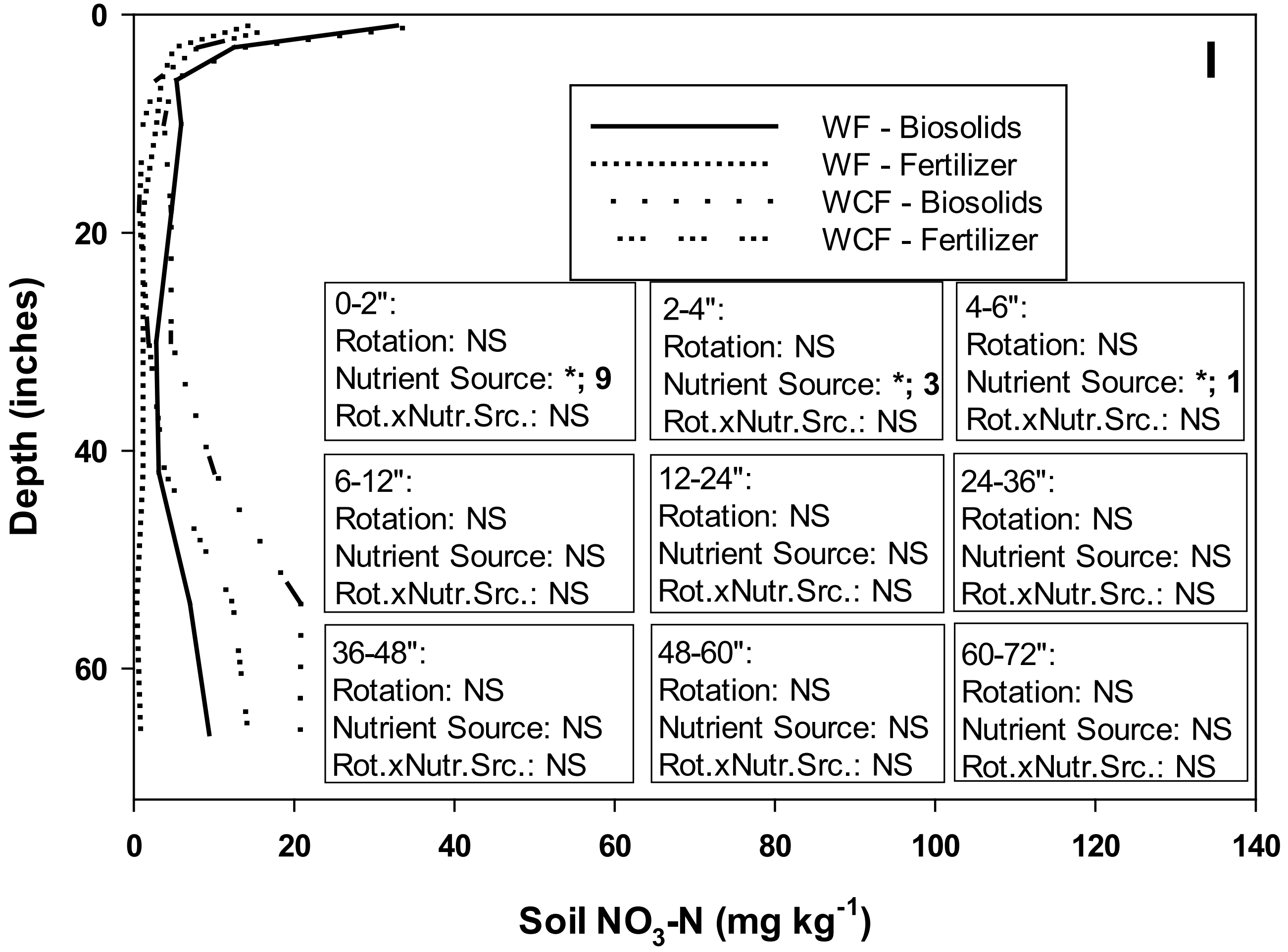


Figure 1. Plant-available soil A) phosphorus, B) cadmium, C) chromium, D) copper, E) iron, F) nickel, G) lead, H) zinc, and I) nitrate-nitrogen concentrations with depth after wheat harvest, 2019.