EFFECT OF SLURRY AND FIELD MANAGEMENT ON SOIL NUTRIENTS

Contents

Summary

1. The nutrient distribution in soils of three fields (Fields 1, 5a, and 12) were determined by repeating soil sampling on a 0.25-acre grid in 2014, 2016, and 2018. Using GPS to locate the initial soil sample locations in 2014, subsequent sampling in 2016 and 2018 was made at the same point (with a 1-m accuracy). This provided data on soil nutrient status as a function of slurry application, along with grazing management on Fields 1 and 12. As slurry was not applied to Field 5a, data from this field provided a reference point for normal pasture management in the region, with mineral fertilizer applied annually. Furthermore, Fields 5a and 12 are adjacent to Big Creek while Field 1 is at a higher elevation, providing contrasting topographic positions common to the watershed.

2. Data from the grid sampling enables an assessment of the impact of field management on soil nutrient status and potential for nutrient accumulation or decline over time.

3. On a whole-field basis at the 0 to 4 inch depth, there was an increase (at 0.05 level of probability) in Mehlich-3 P (59 – 91 mg/kg), K (204 – 258 mg/kg), and Mg (113 – 143 mg/kg) in Field 1 between 2014 and 2018. For Field 5a, there was little change in Mehlich-3 P from 2014 to 2018 (45 – 47 mg/kg). Similar to Field 1, P, K, and Mg for Field 12 were greater in 2018 than 2014 and 2016 in 0 to 4 inch samples, with P increasing from 63 to 122 mg/kg.

4. An increase in Mehlich-3 P of the buffer zone of Field 12 (90 – 112 mg/kg) illustrates the complexity of cattle movement and preferential grazing areas, as an additional source of P. The accelerated accumulation of P occurs in Field 12 adjacent to the gate where cattle are consistently fed and thus, loaf. Additional areas of accumulation outside the slurry application zones of Fields 1 and 12 can be seen adjacent to shade trees.
5. Soil P sorption saturation, an estimate of soil P availability (i.e., Mehlich-3 P) as well as the capacity of that soil to bind further additions of P in fertilizer or manure, increased between the 2014 and 2018 grid-samplings for Fields 1 and 12 and showed a similar spatial distribution in these fields as to Mehlich-3 P.
6. It should be noted that the accumulation of Mehlich-3 P and increase in soil P sorption saturation in the southwest corner of Field 12 was evident in the 2014 grid soil sampling, which was completed January 31, 2014 prior to the first application of swine slurry to Field 12, which occurred April 22, 2014.
7. Findings from the 2014 to 2018 grid-soil sampling reinforce current nutrient management recommendations, that the continued, long-term application of P (as fertilizer or manure) in amounts greater than pasture offtake (removal in cut hay), result in a rapid accumulation of P at the soil surface and thus, potential for runoff. Increases in soil test P will eventually elevate the P-Index risk value to high and further limit P additions as fertilizer or manure in future iterations of nutrient management planning. Separation of solid and liquid slurry in adjacent holding ponds provides an opportunity for a farmer to more closely match the application of P in slurry to crop needs.
8. Future additions of any nutrients (i.e., as mineral fertilizer, swine slurry, or poultry litter) to fields, which received slurry from C&H Farms, should be carefully managed, so as not to lead further increases in soil test P. This can be achieved by application of nitrogen (N) fertilizer or slurry and poultry litter at P-based rates, where P applied is equivalent to expected forage uptake of P.

List of Tables

List of Figures

List of Supplemental Tables

Soil Sampling and Analysis

Grid-soil sampling

Grid-soil sampling of Fields 1, 5a and 12 was conducted in February 2014, January 2015, and February 2014, respectively. Note that in 2014 – 2015, Field 5a was sampled later than Fields 1 and 12 as Fields 5 and 5a were incorrectly located on the original C&H CNMP. In subsequent Tables and Figures, the Field 5a sampling is noted as 2014 for simplicity and comparison to 2014 sampling of Fields 1 and 12 data. Fields 1, 5a, and 12 were grid-sampled in February 2016 and March 2018. In each field, sampling points were geo-referenced so that bi-annually sampling could be collected at the same location in each field.

A grid network of approximately 0.25 acres was overlain on each field to determine the point of sampling, which were recorded with GPS. Each sample-hole remaining after the soil core was removed was carefully back-filled with commercial top soil. Where rock stopped the core penetrating below a specific layer, no sample was collected beyond that point. The 2018 sampling was a repeat of the 2014 and 2016 sampling and was conducted within a 5-foot radius of the original geo-referenced point in order to document any changes in soil composition with time and land management. In 2016 and 2018, Fields 1, 5a, and 12 soil were grid-sampled at 0 to 4 and 4 to 8 inch depths only. Due to rocks at or near the soil surface, only 0 to 4 inch samples were collected from Field 1 in 2018.

Maps of the grid sampling for each field are given in Figures 1, 2, and 3 for Fields 1, 5a, and 12, respectively, along with the buffers imposed by the C&H ADEQ permit for ponds, school, slope, and stream where no slurry can be applied. On field 12, the farm owners have implemented a 100 ft buffer along the south neighboring field. Based on these delineations, the area slurry can be applied to Fields 1 and 12 along with buffer areas of all three fields are given in Table 1.

Table 1. Whole field, slurry application, and buffer (no slurry application allowed) areas for Fields 1, 5a, and 12.

Site	Site ID	Field area		Slurry application zone		Buffer	
		acres	hectares	acres	hectares	acres	hectares

Field 1	BC 1	15.59	6.31	15.44	6.25	0.15	0.06
Field 5a [1]	BC 2	23.50	9.51	22.96	9.29	0.54	0.22
Field 12	BC 3	28.69	11.61	28.21	11.42	0.48	0.19

[1] Slurry has not been applied to Field 5a or the adjacent Field 5.

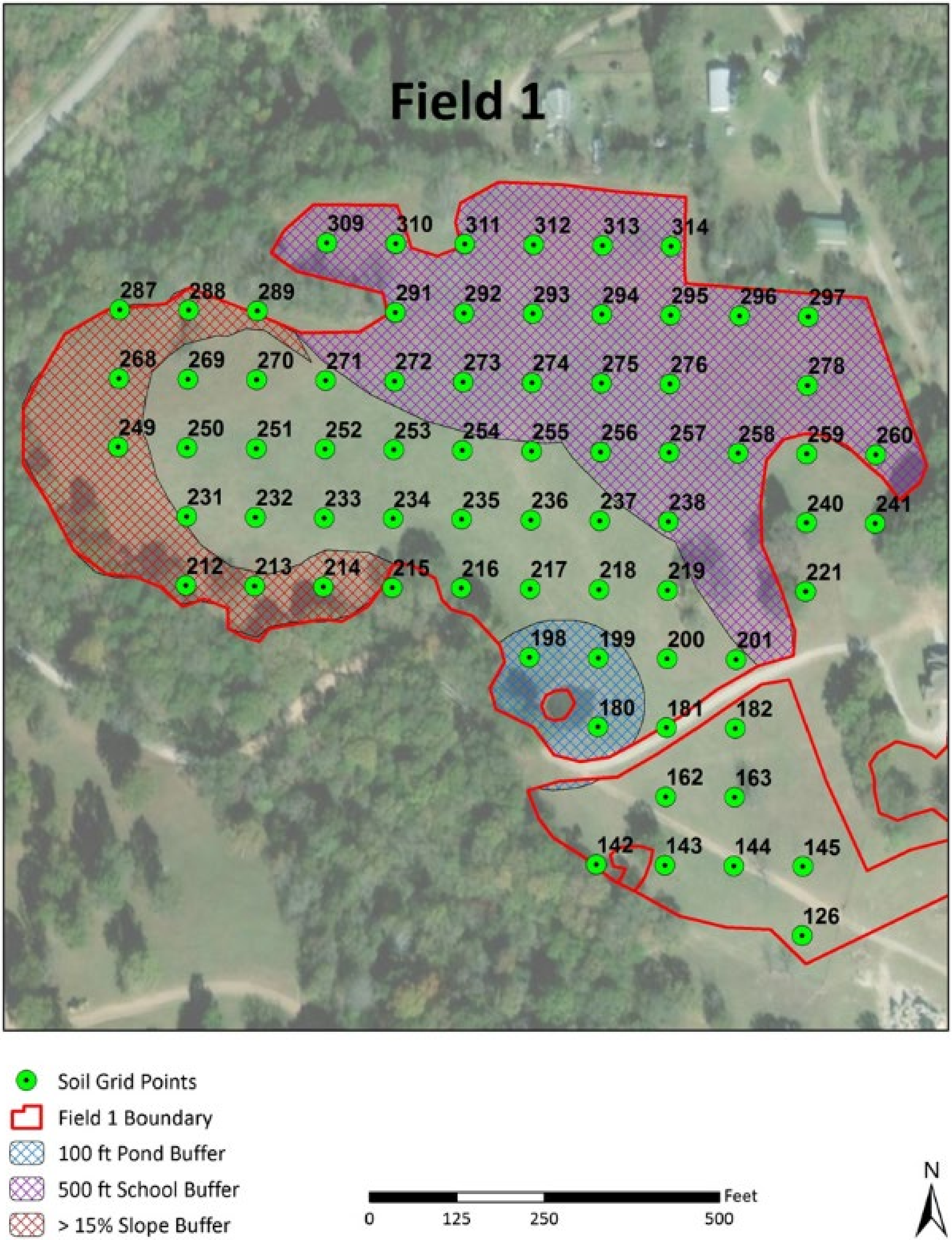


Figure 1. Grid-soil sampling locations for Field 1.

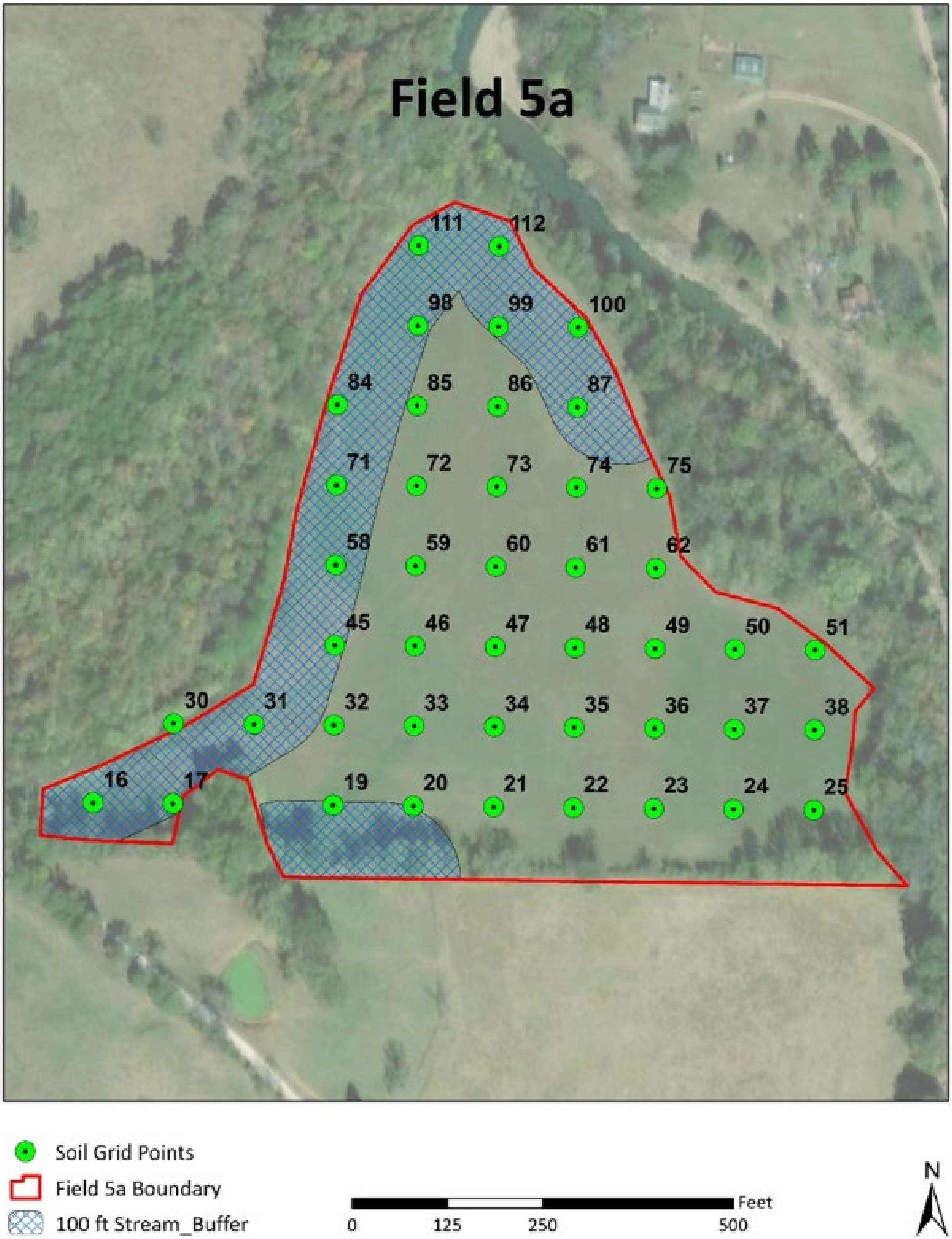


Figure 2. Grid-soil sampling locations for Field 5a.

Figure 3. Grid-soil sampling locations for Field 12.

Annual amounts and rates of commercial fertilizer (Field 5a) and slurry from the C&H operation (Fields 1 and 12) are given in Table 2. The slurry rates are obtained from ADEQ annual management reports for the farm and commercial fertilizer application from the landowner.

Table 2. Slurry (i.e., Fields 1 and 12) and fertilizer (i.e., Fields 5a) application to the monitored fields for 2014 to 2018.

Site	2014		2015		2016		2017		2018	
Slurry applied, gals										
Field 1	46,000		48,000		78,000		60,000		57,000	
Field 12	48,000		93,000		156,000		90,000		105,000	
Nutrients applied in slurry, lbs/1000 gallons										
	P	N	P	N	P	N	P	N		
Field 1	18.1	16.8	60.4	53.2	17.5	30.3	60.3	47.2	12.4	12.2
Field 12	18.1	16.8	4.8	20.1	17.5	30.3	60.3	47.2	12.4	12.2
Nutrients applied to field, lbs/acre										
Field 1	53	50	186	164	88	152	232	182	45	45
Field 5a [1]	25	57	25	57	25	57	25	57	25	57
Field 12	30	28	16	65	95	165	189	148	45	44
Nutrients applied to field, kg/ha										
Field 1	60	55	208	183	98	170	260	203	51	50
Field 5a [1]	28	64	28	64	28	64	28	64	28	64
Field 12	34	31	17	73	107	184	212	166	51	50

[1] Nutrient applied as 19-19-19 mineral fertilizer (i.e., 19% N, 19% P_2O_5, and 19% K_2O) in early spring at a rate of 300 lbs/acre.

Particle-size analysis

Soil samples were collected along a transect in Fields 1, 5a, and 12 in March 2014 for textural analysis by the hydrometer method (Huluka and Miller, 2014). Transect and sampling points are shown in Figures 4, 5, and 6, respectively. In each field, 10 sampling points were equidistant along a total transect length of approximately 457 ft (140 m).

Figure 4. Transect sampling points for soil texture analysis for Field 1.

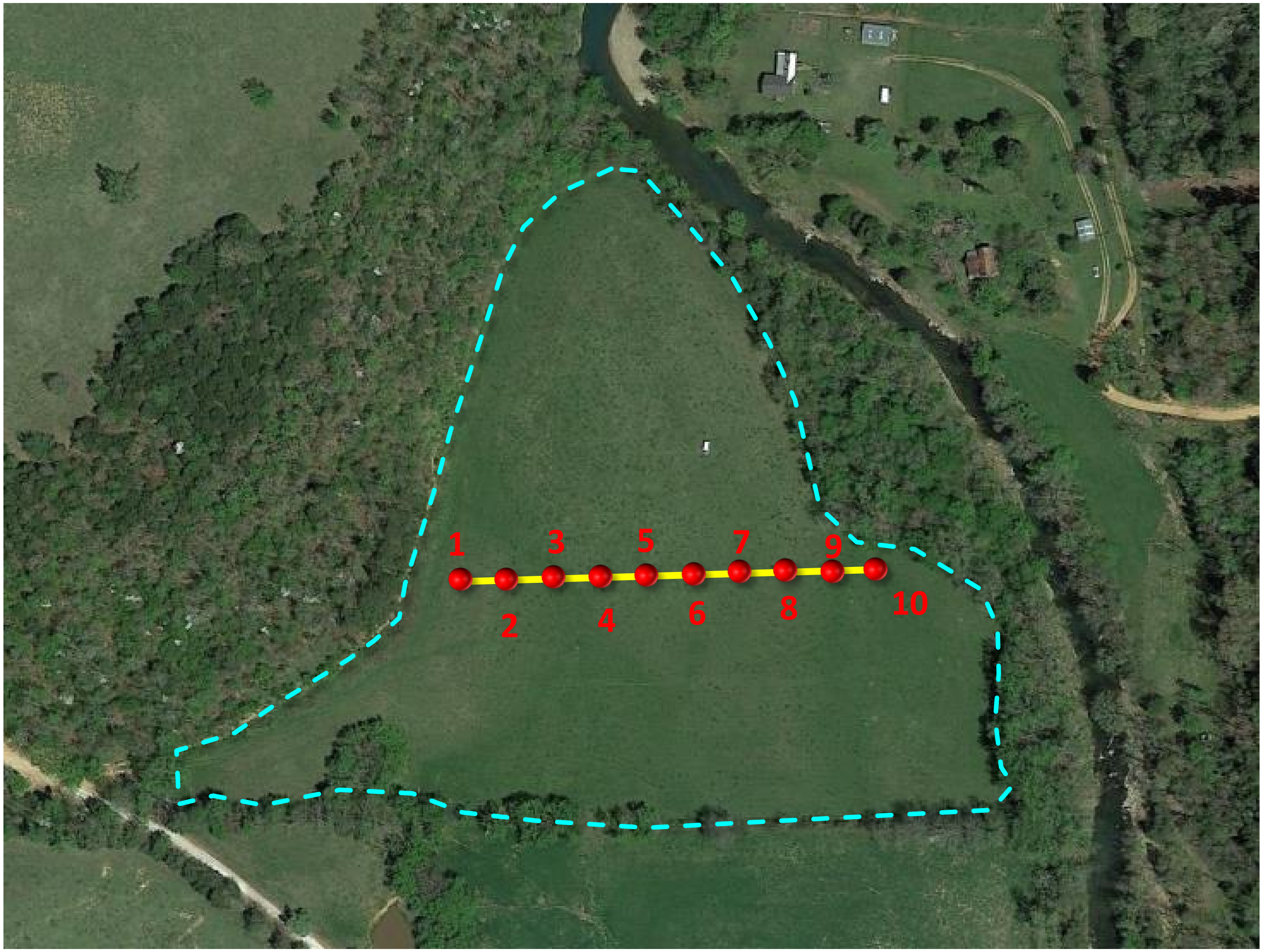


Figure 5. Transect sampling points for soil texture analysis for Field 5a.

Figure 6. Transect sampling points for soil texture analysis for Field 12.

Mehlich-3 soil extraction

Samples were sent to the University of Arkansas Soil Testing and Research Laboratory, Marianna, AR for analysis. All core samples were dried at 60 ^{o}C and ground to pass through a 2mm sieve. Any material that would not crush (mortar and pestle) to pass the 2mm screen was discarded. All analyses used subsamples from the ground material. Laboratory QA/QC includes among other standard protocols, that with every set of environmental samples digested, a blank, a duplicate, and a North American Proficiency Test Program certified soil sample (http://www.naptprogram.org/) are analyzed and compared. If the check is out of acceptable limits, more than 2.5 times the Mean Absolute Deviation value, the sample is digested again and rerun. The digest and duplicate for this set of core samples all met this analytical criterion.

Soil nutrients P, K, Ca, Mg, S, Na, Fe, Al, Mn, Zn, Cu, and B, were determined by Mehlich-3 extraction (Mehlich, 1984); and soil pH in a 1:2 soil:water mixture. Details of these methods are available at https://aaes.uark.edu/research-locations/soil-testing-and-research-laboratory/lab-analytical-services-and-methods/.

Degree of Soil Phosphorus Saturation

The degree of soil P sorption saturation (PSS) has been used as an environmental indicator for soil P, based on the observations that more P is released from soil to surface runoff or leaching water as PSS increases (Dari et al., 2018; Pote et al., 1996; Sibbesen and Sharpley, 1997; Vadas et al., 2005). The degree of soil P sorption saturation also provides an indication of the remaining potential of soil to adsorb and retain P that may be added in fertilizer, manure, or from grazing animals.

The degree of soil P sorption saturation was originally determined by Breeuwsma and Schoumans (1987) and Breeuwsma et al. (1995) as;

$$\mathrm{PSS} = \frac{\text{Oxalate extractable soil P}}{\alpha\ (\text{Oxalate extractable soil Fe} + \text{Oxalate extractable soil Al})} \qquad \text{[Equation 1]}$$

A disadvantage of the definition of the PSS is that the parameter α, is a function of the phosphate sorption capacity of the soil representing the proportion of oxalate extractable Fe and Al dedicated to P sorption [Equation 1]. For the study of Breeuwsma and Schoumans (1987) for Dutch noncalcareous sandy soils used in the study was 0.5.

However, the function α varies among soil types and from layer to layer in a soil profile (Schoumans, 2009). Since the initial work of Breeuwsma and Schoumans (1987), the determination of PSS has been modified for wider use. Firstly, the acid ammonium oxalate extraction of soil was replaced by Mehlich-3 extraction, due to the instability of the oxalate solution under normal laboratory conditions (i.e., the oxalate solution has to kept in the dark), which required the extractant to be made fresh on a daily basis (Kleinman and Sharpley, 2002; Schoumans, 2009). The oxalate extraction cannot be applied to calcareous soils, where Ca dominates P sorption reactions, as oxalic acid precipitates Ca during oxalate extraction and reacts with carbonate to change the pH of the acid buffered extractant (Loeppert and Inskeep, 1996)

For this project, the PSS (% basis) of soils in Fields 1, 5a, and 12 was calculated from $P_{M\text{-}3}$, $Al_{M\text{-}3}$ and $Fe_{M\text{-}3}$ (in mmol/kg), as in Equation [2] below;

$$PSS = \left(\frac{\text{Mehlich−3 extractable soilP}/31}{(\text{Mehlich−3 extractable soil Fe}/56) + (\text{Mehlich−3 extractable soilAl}/27)} \right) * 100 \quad \text{[Equation 2]}$$

Kleinman and Sharpley found that PSS estimated from Mehich-3 P, Fe, and Al was highly correlated with PSS estimated from ammonium oxalate extraction (r of 0.94) as well as with a Langmuir P sorption maximum (r of 0.89; determined according to Syers et al., 1973) for 37 acidic and 25 alkaline soils from across the U.S. As most Land-Grant and private Soil Testing Laboratories currently conducting Mehlich-3 extraction employ Inductively-coupled plasma spectrometry (ICP), analytes required to estimate PSS in Equation [2] are measured simultaneously and routinely. Thus, this method has been widely adopted to estimate PSS for a wide range of soils and management practices (Dari et al., 2018; Schoumans, 2009).

Soil Particle Size and Texture

Soil distribution across Fields 1, 5a, and 12 are shown in Figures 7, 8, and 9, respectively. Field 1 was dominated by Noark very cherty silt loam, Field 5a by Razort loam, and Field 12 by Spadra loam.

Textural analysis for transects across Fields 1, 5a, and 12 is given in Table 3. On average, surface soil (0 – 4 inches) in Fields 5a and 12 had a higher clay content (28.2 and 29.8% clay, respectively) in than in Field 1 (20.6% clay), which is indicative of the dominant soils in those fields (Razort loam, Spadra loam, and Noark very cherty silt loam, respectively).

Table 3. Particle size analysis and texture of surface 0 – 4 inch samples collected March 2014 along a ~450 ft transect in Fields 1, 5a, and 12.

Location	Sand	Silt	Clay	Texture
	- - - - - - - - - -	%	- - - - - - - - -	
Field 1				
1	11.0	67.7	21.3	Silt loam
2	19.9	58.8	21.3	Silt loam
3	18.7	58.4	22.9	Silt loam
4	21.5	63.6	14.9	Silt loam
5	16.9	62.0	21.1	Silt loam
6	16.2	64.9	18.9	Silt loam
7	15.6	61.5	22.9	Silt loam
8	15.5	65.7	18.8	Silt loam
9	9.0	69.9	21.1	Silt loam

Location	Sand	Silt	Clay	Texture
10	14.1	62.8	23.1	Silt loam
Average	*15.8*	*63.5*	*20.6*	
Field 5a				
1	42.2	29.5	28.3	Sandy clay loam
2	46.8	25.9	27.2	Sandy clay loam
3	47.4	25.2	27.4	Sandy clay loam
4	41.0	22.0	37.0	Clay loam
5	48.2	24.8	27.0	Sandy clay loam
6	49.9	22.8	27.3	Sandy loam
7	48.4	23.6	28.0	Sandy clay loam
8	49.2	26.9	23.8	Sandy clay loam
9	43.9	24.0	32.1	Sandy clay loam
10	44.6	24.5	30.9	Sandy clay loam
Average	*43.4*	*28.4*	*28.2*	
Field 12				
1	38.3	32.8	28.9	Loam
2	39.7	26.2	34.2	Clay loam
3	38.8	33.2	28.0	Clay loam
4	38.7	31.6	29.7	Clay loam
5	43.0	27.3	29.7	Clay loam
6	44.8	27.2	28.0	Clay loam
7	39.5	27.3	33.2	Clay loam
8	52.8	20.8	26.4	Loam
9	44.0	26.8	29.2	Clay loam
10	41.7	30.2	28.1	Clay loam
11	31.0	36.7	32.4	Clay loam
Average	*41.1*	*29.1*	*29.8*	

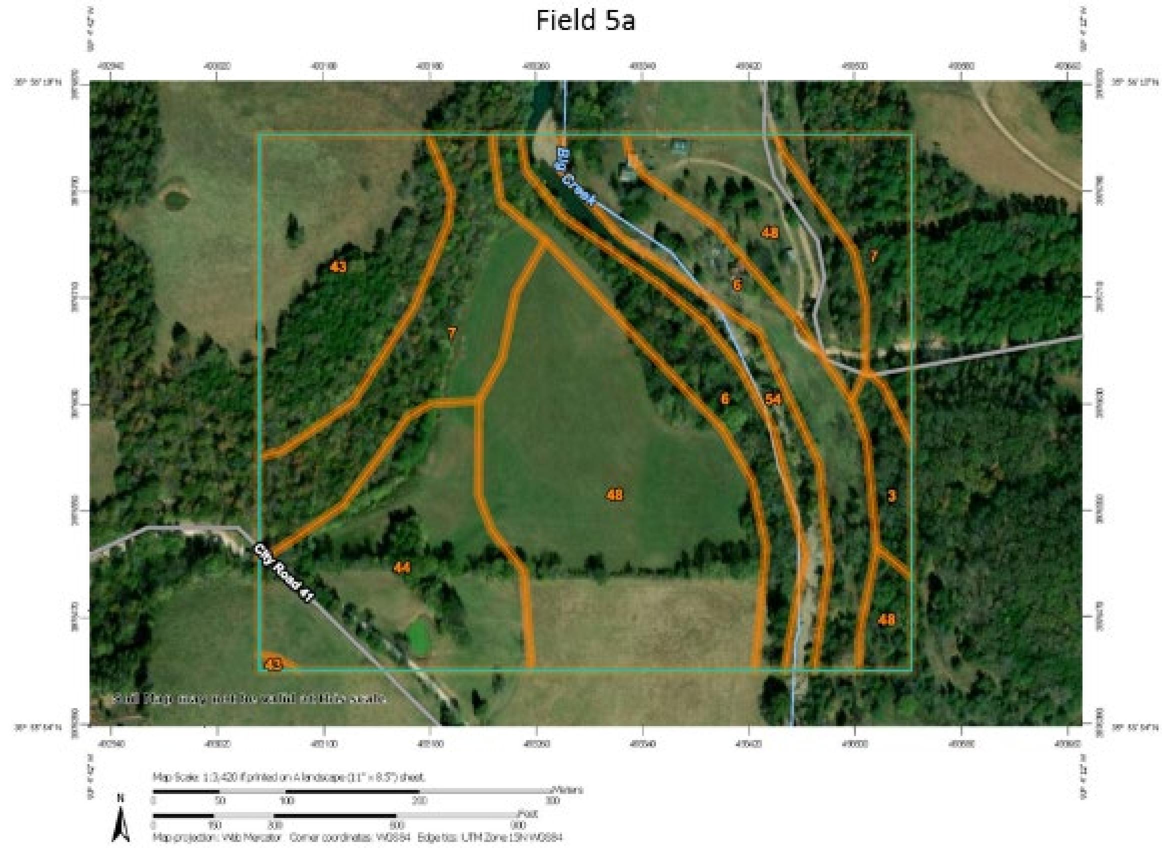
Soil Map – Newton County, Arkansas
Field 1

Map unit symbol	Soil name	Acres in AOI [1]	Percent of AOI
42	Noark very cherty silt loam, 3 to 8% slopes	18.4	35%
43	Noark very cherty silt loam, 8 to 20% slopes	14.7	28%
44	Noark very cherty silt loam, 20 to 40% slopes	19.9	38%

[1] AOI is area of interest defined by the green rectangle

Figure 7. Soil map for Field 1.

Soil Map – Newton County, Arkansas
Field 5a

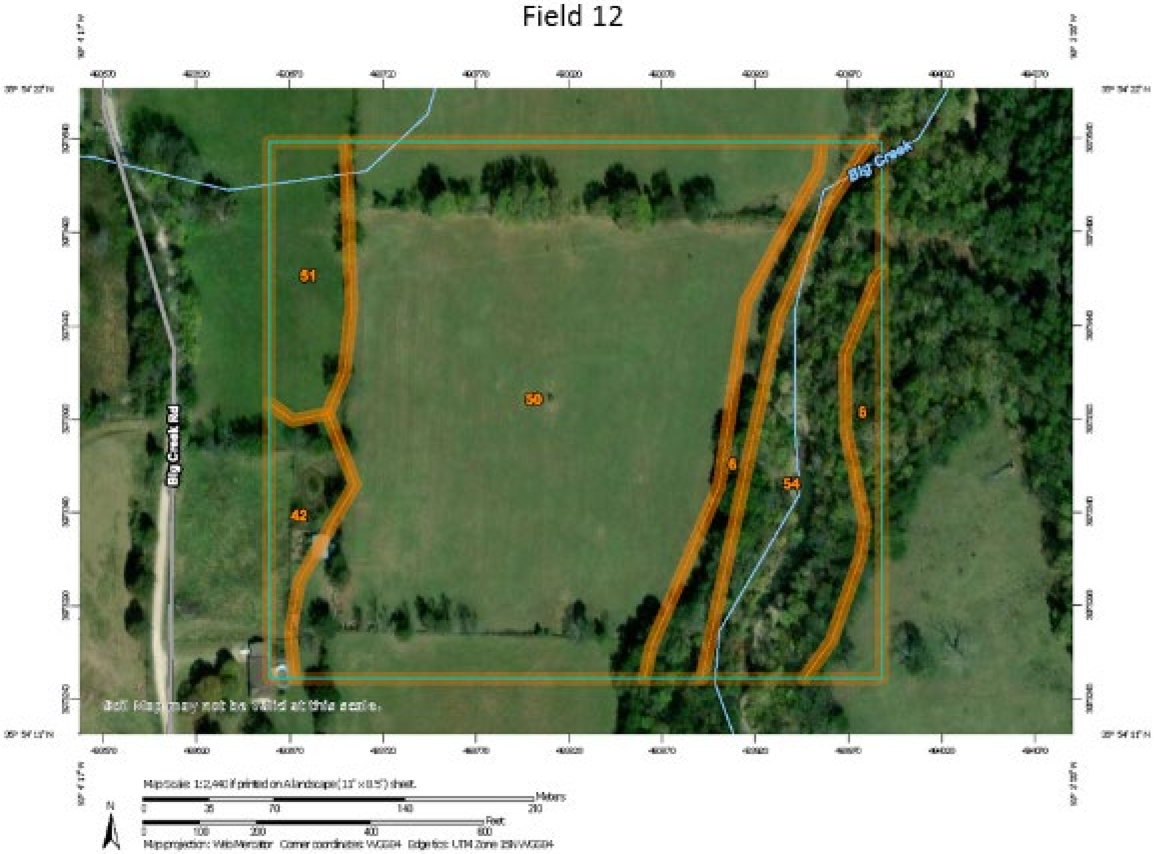


Map unit symbol	Soil name	Acres in AOI	Percent AOI
6	Ceda-Kenn complex, 0 to 3 percent slopes, frequently flooded	8.3	17%
7	Clarksville very cherty silt loam, 20 to 50 percent slopes	7.7	16%
43	Noark very cherty silt loam, 8 to 20% slopes	6.4	13%
44	Noark very cherty silt loam, 20 to 40% slopes	7.0	14%
48	Razort loam, occasionally flooded	16.2	33%

[1] AOI is area of interest defined by the green rectangle

Figure 8. Soil map for Field 5a.

Soil Map – Newton County, Arkansas
Field 12



Map unit symbol	Soil name	Acres in AOI	Percent AOI
6	Ceda-Kenn complex, 0 to 3% slopes, frequently flooded	2.3	10%
42	Noark very cherty silt loam, 3 to 8% slopes	0.9	4%
50	Spadra loam, occasionally flooded	15.2	65%
51	Spadra loam, 2 to 5 percent slopes	1.5	6%

[1] AOI is area of interest defined by the green rectangle

Figure 9. Soil map for Field 12.

In-Field Distribution of Soil Nutrients

The spatial distribution of Mehlich-3 extractable soil P (Mehlich-3 P) for Fields 1, 5a, and 12 are depicted in Figures 10 to 15 for both the 0 – 4 inch and 4 – 8 inch depths. Also, differences in Mehlich-3 P from the 2014 to 2018 samplings are depicted in Figures 16 and 17. Individual values at the grid points are noted on these Figures. The ranges in Mehlich-3 P concentrations depicted are <25, 25 to 50, 50 – 100, and >100 mg/L, which depict general soil fertility and plant response categories of deficiency levels, optimum levels for cool season grasses, little response to additional P expected for cool and warm season grasses, and no plant growth response expected to added P, respectively. Statistically significant differences of paired sampling points (<0.05 level of probability) between sampling dates for each field and Mehlich-3 analyte are listed in Supplemental Tables S1 to S5.

Mean values of Mehlich-3 extractable elements at a 0 – 4 inch soil depth for the whole field, slurry application zone, and buffer zone in 2014, 2016, and 2018, are given in Table 4. Individual analyses for each grid point, sample depth, and field are listed in Appendix C for whole field and application / buffer zones, respectively. Mean Mehlich-3 P values for Fields 1 and 5a decreased slightly from 2014 (59 and 45 mg/kg, respectively) to 2016 (57 and 39 mg/kg respectively). For Field 12, however, Mehlich-3 P increased from 63 mg/kg in 2014 to 122 mg/kg L in 2016 (Table 4).

It is evident from the Mehlich-3 P spatial distribution maps that accumulation of P occurs in some areas within the surface 0 – 4 inch depth of Fields 1 and 12 (Figures 10 to 15). These areas are generally located around areas of shade on Fields 1 and 12 (northern boundary of this field), where grazing cattle congregate to avoid the sun. On Field 12, the area of Mehlich-3 P greater than 100 mg/kg occurs on the southwest corner of the field and is located at the gated entrance to the field, where cattle are routinely fed hay. Further, individual points with elevated P levels on these fields may be due to cow pats that may no longer be visible at the surface.

It should be noted that the accumulation of Mehlich-3 P in the southwest corner of Field 12 was evident in the 2014 grid soil sampling (Figure 14), which was completed January 31, 2014 and that the first application of swine slurry to Field 12 did not occur until April 22, 2014. Thus, in-field spatial variations in Mehlich-3 P for Field 12 are likely a function of land use and management prior to any swine slurry application. Amounts of swine slurry applied to these fields in 2014, 2016, and 2018 are presented in Table 2.

We informed the owner of C&H, who discussed with the owner of Field 12, the use of alternative areas to feed cattle on Field 12, and the owners of C&H Farms have agreed to not spread slurry on this area of the field in order to not contribute to any further increase in surface soil Mehlich-3 P levels. While these areas are not adjacent to the Big Creek river channel, which minimizes the potential for this P to reach the river, management changes are in place to address the accumulation.

Table 4. Mean pH and concentrations of Mehlich-3 extractable elements for 0 to 4 inch soil samples collected in the 2014, 2016, and 2018 grid sampling of Fields 1, 5a, and 12, based on whole field, slurry application zone, and no application buffer zone samples. For a given field, zone, and element, means followed by the same letter are not significantly different as determined by unpaired *t* test with a <0.05 level of probability.

Year	No. samples	pH	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
			---------- mg/kg ----------									
Field 1: Whole field												
2014	71	6.4 a	59 b	204 b	1936 a	113 b	18 a	109 a	262 a	0.6 b	4.3 b	0.4 b
2016	71	5.9 b	57 b	183 b	1845 a	110 b	15 b	118 a	209 b	1.4 a	5.1 b	0.5 a
2018	71	6.4 a	91 a	258 a	1909 a	143 a	19 a	106 a	213 b	1.3 a	7.1 a	0.4 b
Field 1: Application zone												
2014	39	6.5 a	65 b	266 ab	2046 a	118 b	19 b	116 a	256 a	0.6 c	4.7 b	0.5 a
2016	39	6.0 b	73 b	228 b	2106 a	125 b	15 c	125 a	213 b	1.7 a	6.5 b	0.5 a
2018	39	6.6 a	115 a	318 a	2205 a	164 a	21 a	118 a	213 b	1.3 b	8.8 a	0.5 a
Field 1: Buffer zone												
2014	32	6.2 a	52 ab	128 b	1803 a	106 a	18 a	101 a	269 a	0.6 c	3.9 a	0.3 ab
2016	32	5.6 b	38 b	127 b	1527 a	91 a	15 b	109 a	205 b	1.1 b	3.4 a	0.4 a
2018	32	6.3 a	62 a	185 a	1549 a	117 a	17 ab	92 a	214 b	1.3 a	5.1 a	0.3 b
Field 5a: Whole field												

Year	No. samples	pH	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
			---------------------------------- mg/kg ----------------------------------									
2014	33	5.6 ab	45 a	59 a	1315 a	70 a	13 a	154 a	205 a	1.4 b	3.0 a	0.3 ab
2016	44	5.4 b	39 a	68 a	1258 a	73 a	13 a	148 a	171 b	1.5 b	2.8 a	0.4 a
2018	44	5.9 a	47 a	63 a	1341 a	72 a	13 a	128 b	166 b	2.1 a	3.4 a	0.3 b
Field 5a: Application zone												
2014	23	5.5 b	50 a	57 a	1076 a	69 b	12 a	163 a	220 a	1.3 b	2.7 b	0.2 b
2016	28	5.4 b	42 a	66 a	1198 a	78 a	12 a	157 a	175 b	1.6 b	3.0 ab	0.4 a
2018	28	5.8 a	45 a	60 a	1200 a	74 ab	12 a	134 b	169 b	2.2 a	3.5 a	0.2 b
Field 5a: Buffer zone												
2014	10	6.0 a	33 a	65 a	1864 a	71 a	13 a	131 a	171 a	1.4 b	3.6 a	0.4 a
2016	16	5.3 a	34 a	72 a	1364 a	63 a	15 a	132 a	163 a	1.5 b	2.5 a	0.4 a
2018	16	5.9 a	51 a	68 a	1588 a	69 a	16 a	116 a	162 a	2.0 a	3.2 a	0.3 a
Field 12: Whole field												
2014	40	5.9 b	63 b	92 b	1184 a	77 b	13 b	127 c	148 b	1.2 c	2.2 c	0.2 c
2016	45	5.5 c	104 a	129 ab	1301 a	118 a	16 a	182 a	177 a	1.7 b	4.9 b	0.5 a
2018	45	6.0 a	122 a	155 a	1205 a	125 a	14 b	154 b	164 ab	1.9 a	6.1 a	0.4 b
Field 12: Application zone												

Year	No. samples	pH	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
			----- mg/kg -----									
2014	31	5.9 b	56 b	81 b	1210 a	75 b	13 b	121 c	144 b	1.2 b	2.1 c	0.2 c
2016	34	5.4 c	107 a	131 a	1364 a	124 a	17 a	177 a	173 a	1.8 a	5.1 b	0.5 a
2018	34	6.0 a	126 a	153 a	1239 a	131 a	14 b	149 b	162 ab	2.0 a	6.2 a	0.4 b
Field 12: Buffer zone												
2014	9	5.8 b	81 a	110 a	1062 a	80 a	14 a	146 b	161 a	1.0 b	2.9 b	0.2 b
2016	11	5.6 b	95 a	120 a	1105 a	101 a	14 a	200 a	187 a	1.5 a	4.4 ab	0.4 a
2018	11	6.1 a	112 a	161 a	1100 a	107 a	13 a	168 ab	173 a	1.7 a	5.6 a	0.4 a

Table 5. Mean pH and concentrations of Mehlich-3 extractable elements for 4 to 8 inch soil samples collected in the 2014, 2016, and 2018 grid sampling of Fields 5a and 12, based on whole field, slurry application zone, and no application buffer zone samples. For a given field, zone, and element, means followed by the same letter are not significantly different as determined by unpaired *t* test with a <0.05 level of probability.

Year	No. samples	pH	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
			----- mg/kg -----									
Field 5a: Whole field (4-8")												
2014	22	6.3 a	45 a	123 a	2307 a	88 a	8 b	107 b	104 b	1.9 a	4.7 a	0.0 c
2016	44	5.4 c	27 b	59 b	1183 b	47 b	10 b	136 a	157 a	1.6 a	2.0 b	0.3 b
2018	43	5.7 b	33 b	56 b	1210 b	43 b	12 a	134 a	171 a	1.5 a	1.9 b	0.6 a
Field 5a: Application zone (4-8")												
2014	17	6.2 a	46 a	132 a	2321 a	90 a	8 b	114 b	104 b	1.9 a	5.3 a	0.1 c
2016	28	5.6 b	27 b	59 b	1241 b	48 b	9 b	141 a	151 a	1.7 a	2.0 b	0.3 b
2018	27	5.8 b	34 b	56 b	1214 b	44 b	10 a	142 a	171 a	1.7 a	2.0 b	0.6 a
Field 5a: Buffer zone (4-8")												
2014	5	6.4 a	43 a	93 a	2260 a	83 a	7 b	86 b	106 a	1.9 a	2.8 a	0.0 c
2016	16	5.2 b	27 a	58 b	1082 a	47 b	12 ab	128 a	169 a	1.4 a	1.9 a	0.3 b
2018	16	5.5 b	31 a	56 b	1204 a	43 b	16 a	121 a	171 a	1.3 a	1.6 a	0.6 a
Field 12: Whole field (4-8")												

Year	No. samples	pH	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
			---------------------------------- mg/kg ----------------------------------									
2014	39	6.0 a	36 b	68 a	1235 a	54 b	11 a	104 b	97 b	1.2 b	1.4 b	0.1 c
2016	45	5.7 b	50 a	81 a	1332 a	72 a	12 a	134 a	128 a	1.7 a	2.0 a	0.4 b
2018	35	6.0 a	52 a	72 a	1296 a	74 a	10 a	134 a	123 a	1.6 a	2.5 a	0.6 a
Field 12: Application zone (4-8")												
2014	31	6.0 a	33 b	67 a	1318 a	57 b	11 a	102 b	96 b	1.3 b	1.5 b	0.1 c
2016	34	5.7 b	47 a	78 a	1434 a	75 a	12 a	131 a	126 a	1.8 a	2.0 b	0.4 b
2018	28	6.1 a	55 a	78 a	1383 a	81 a	11 a	135 a	128 a	1.7 a	2.8 a	0.6 a
Field 12: Buffer zone (4-8")												
2014	8	5.9 ab	49 a	74 a	915 a	46 a	11 a	110 b	102 a	0.9 b	1.3 b	0.1 b
2016	11	5.7 b	58 a	90 a	1019 a	63 a	10 a	141 a	136 a	1.5 a	2.2 a	0.3 a
2018	7	6.0 a	36 a	48 a	948 a	45 a	8 b	131 ab	104 a	1.2 ab	1.5 b	0.4 a

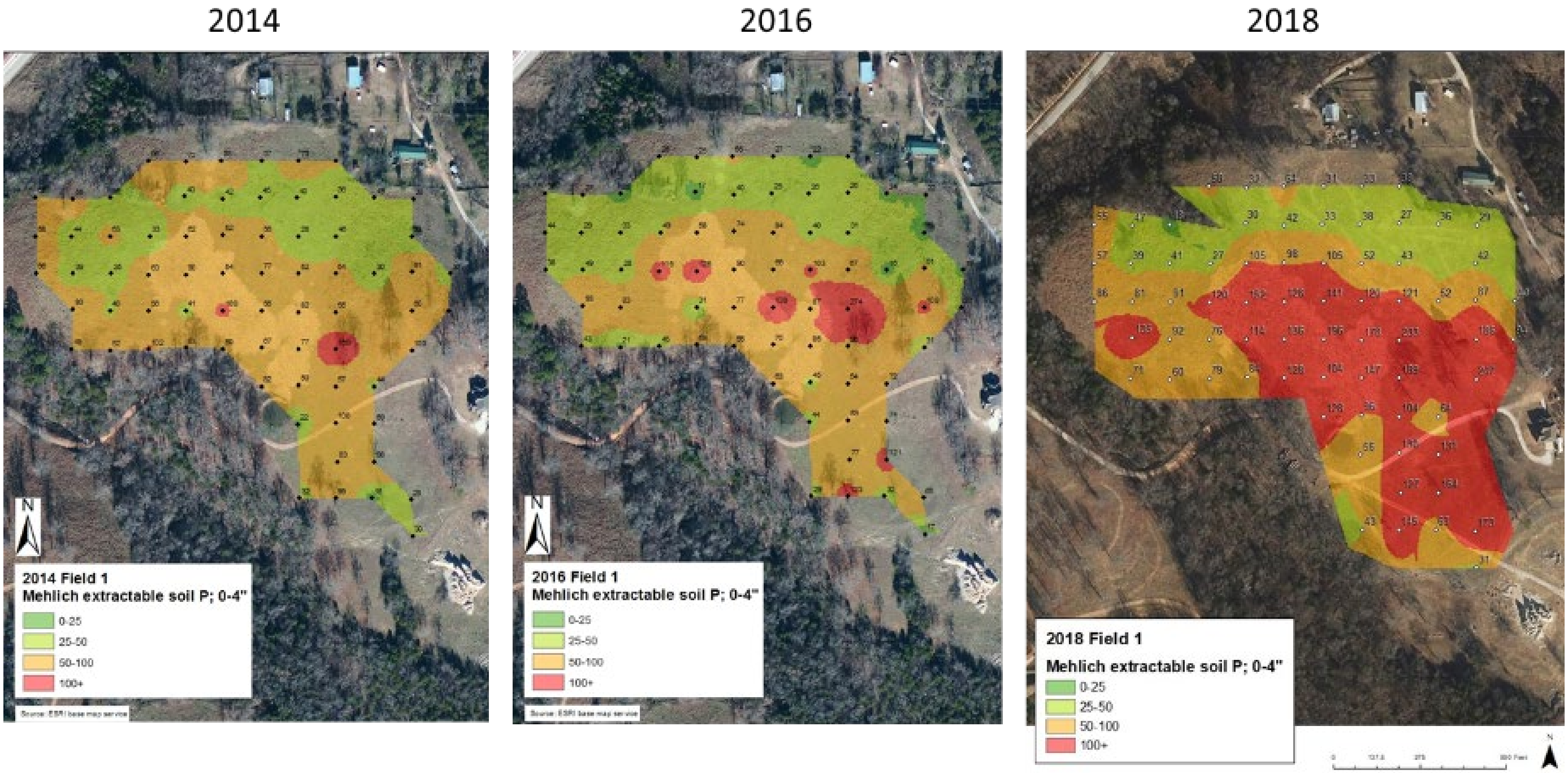


Figure 10. Mehlich-3 extractable soil P values for 0 to 4 inch depth for 2014, 2016, and 2018 grid-soil sampling of Field 1.

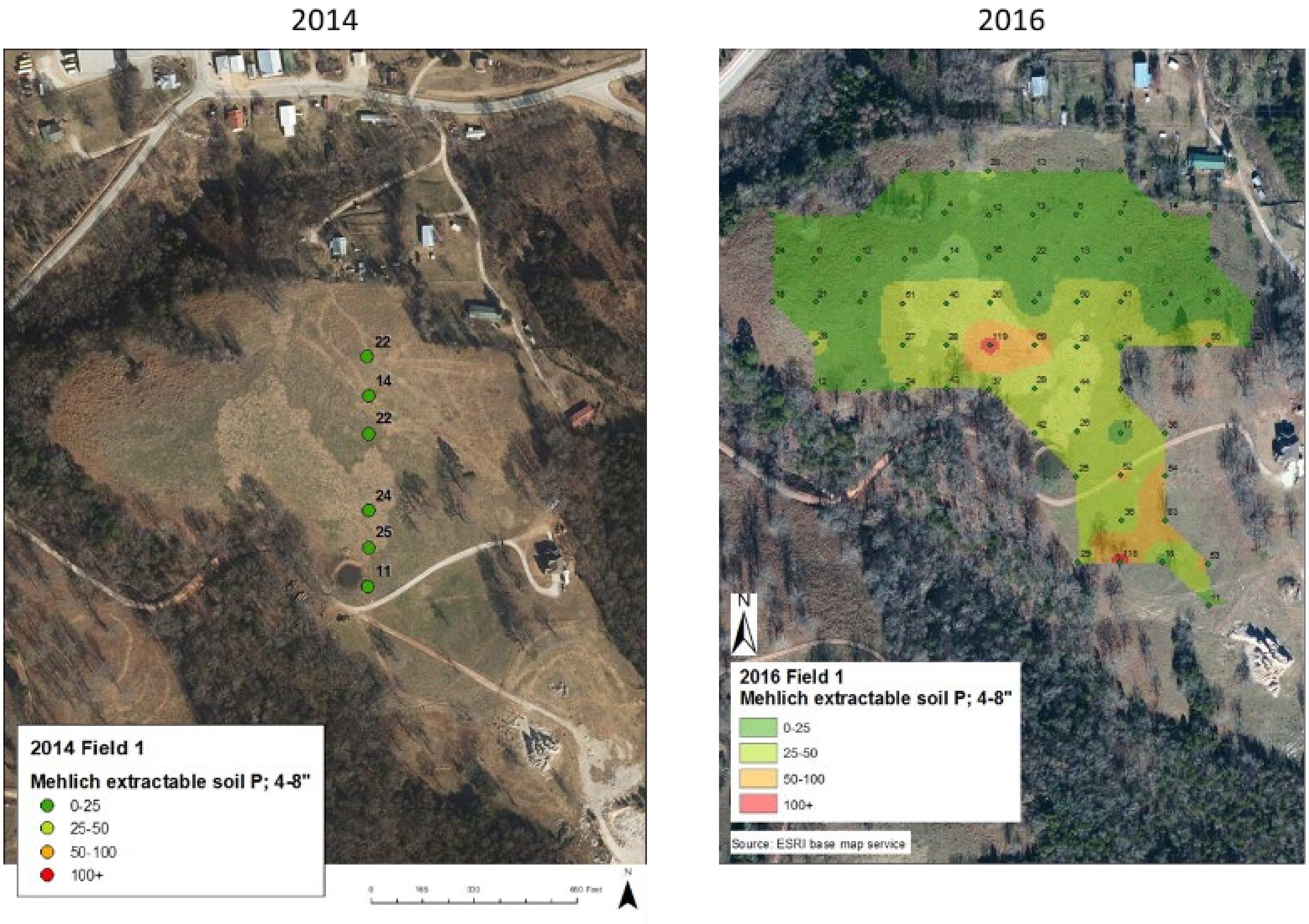


Figure 11. Mehlich-3 extractable soil P values for 4 to 8 inch depth for 2014, 2016, and 2018 grid-soil sampling of Field 1.

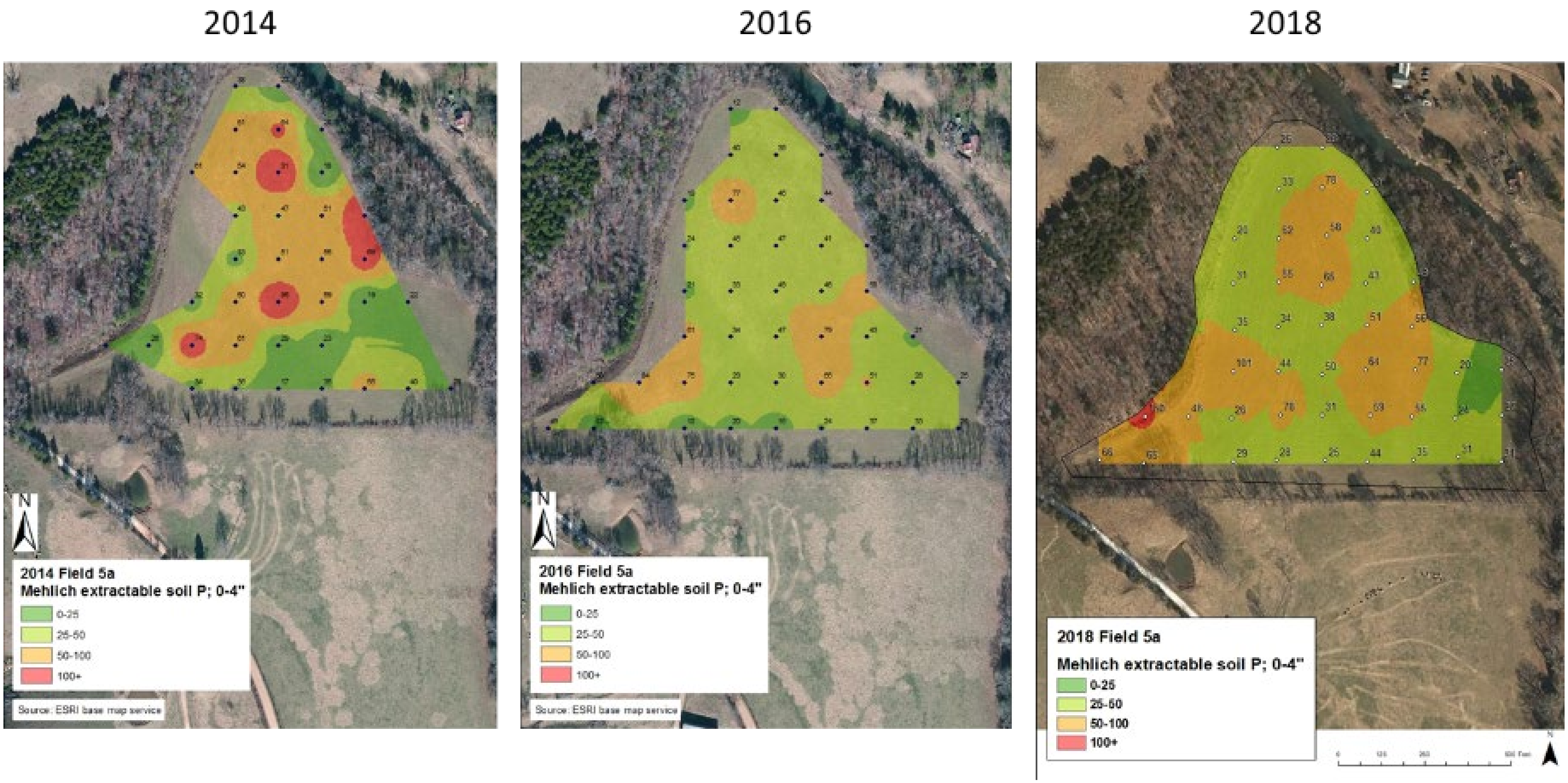


Figure 12. Mehlich-3 extractable soil P values for 0 to 4 inch depth for 2014, 2016, and 2018 grid-soil sampling of Field 5a.

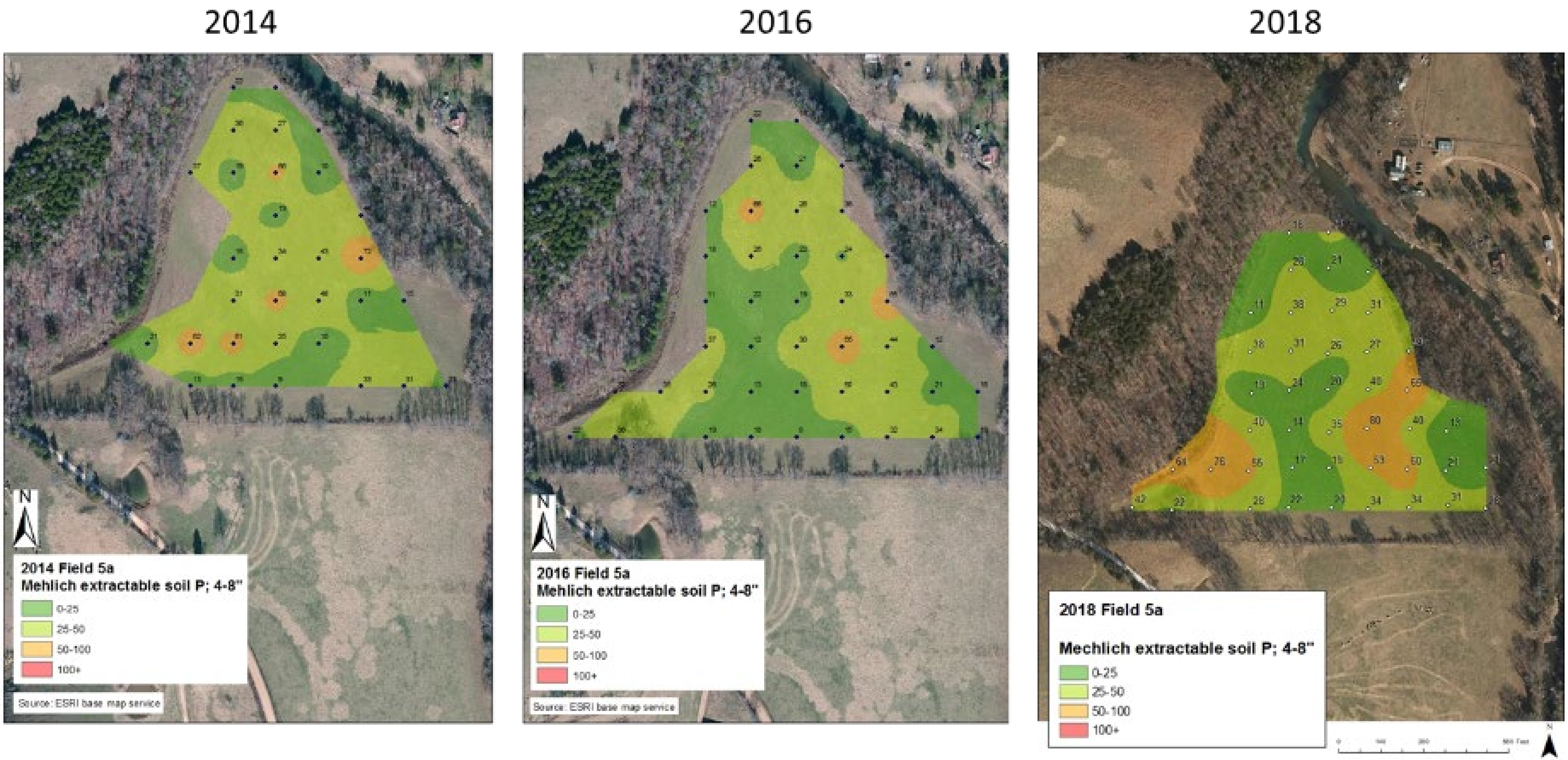


Figure 13. Mehlich-3 extractable soil P values for 4 to 8 inch depth for 2014, 2016, and 2018 grid-soil sampling of Field 5a.

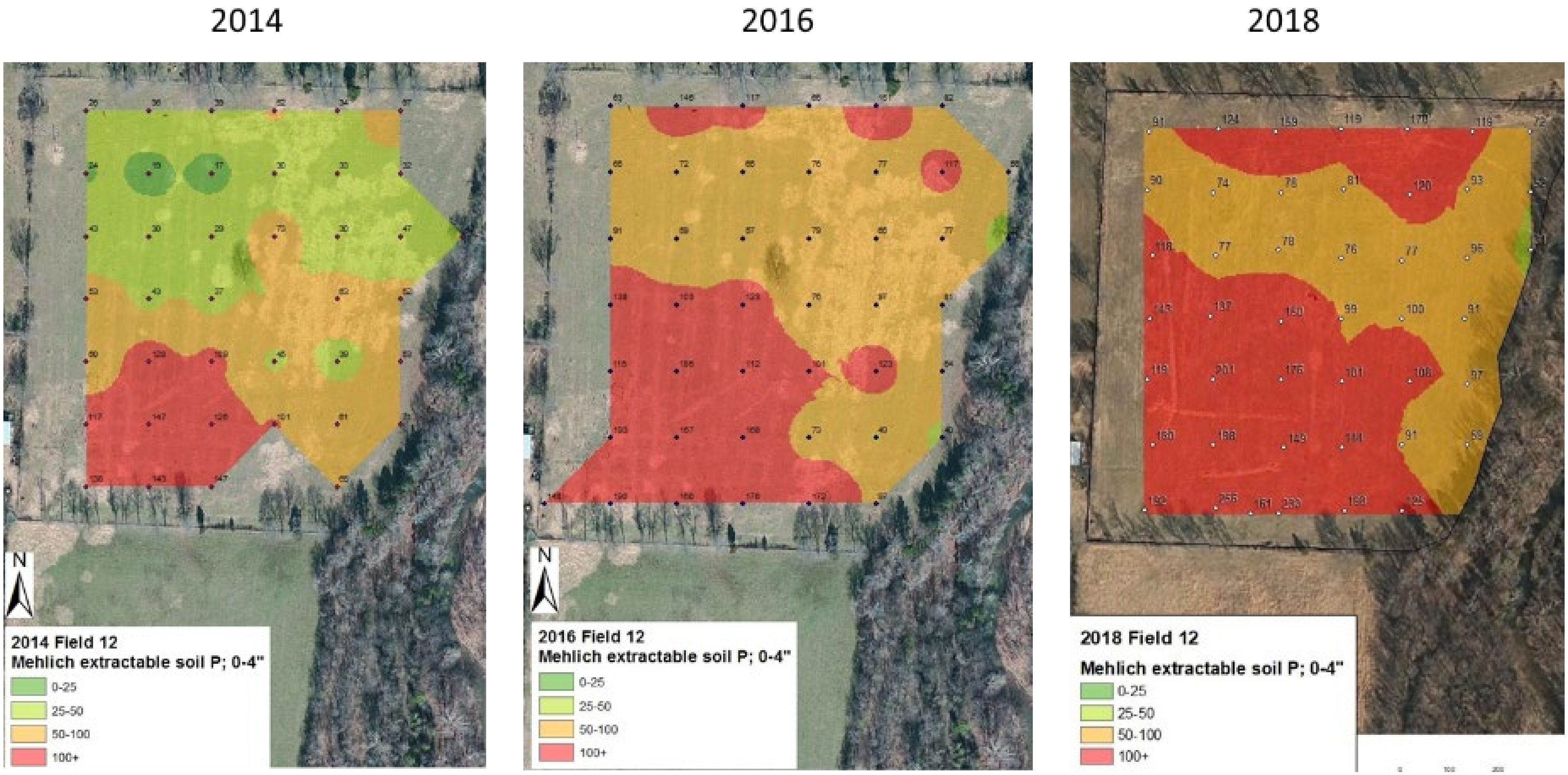


Figure 14. Mehlich-3 extractable soil P values for 0 to 4 inch depth for 2014, 2016, and 2018 grid-soil sampling of Field 12.

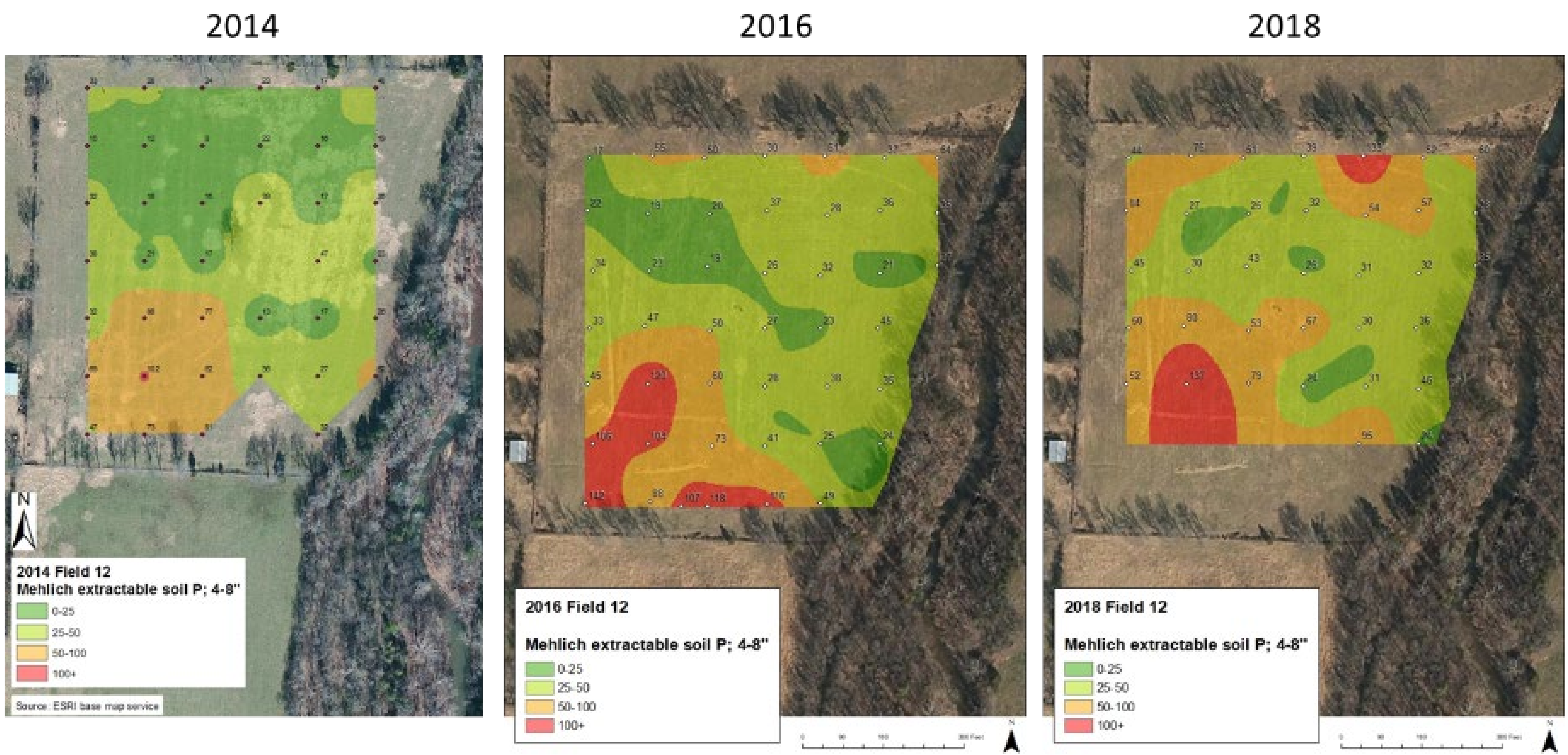


Figure 15. Mehlich-3 extractable soil P values for 4 to 8 inch depth for 2014, 2016, and 2018 grid-soil sampling of Field 12.

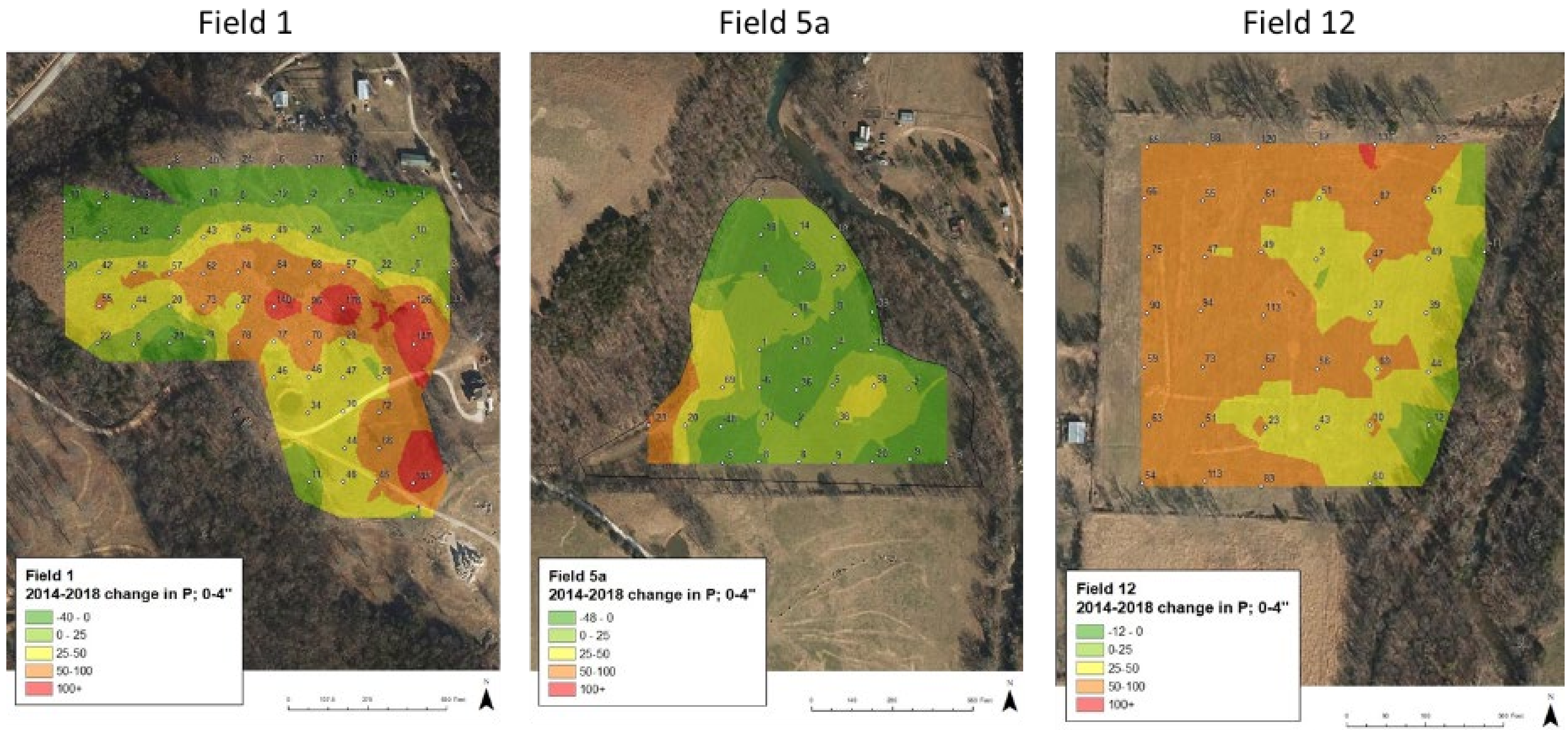


Figure 16. Difference in Mehlich-3 extractable soil P values between 2014 and 2018 grid-soil sampling of Fields 1, 5a, and 12.

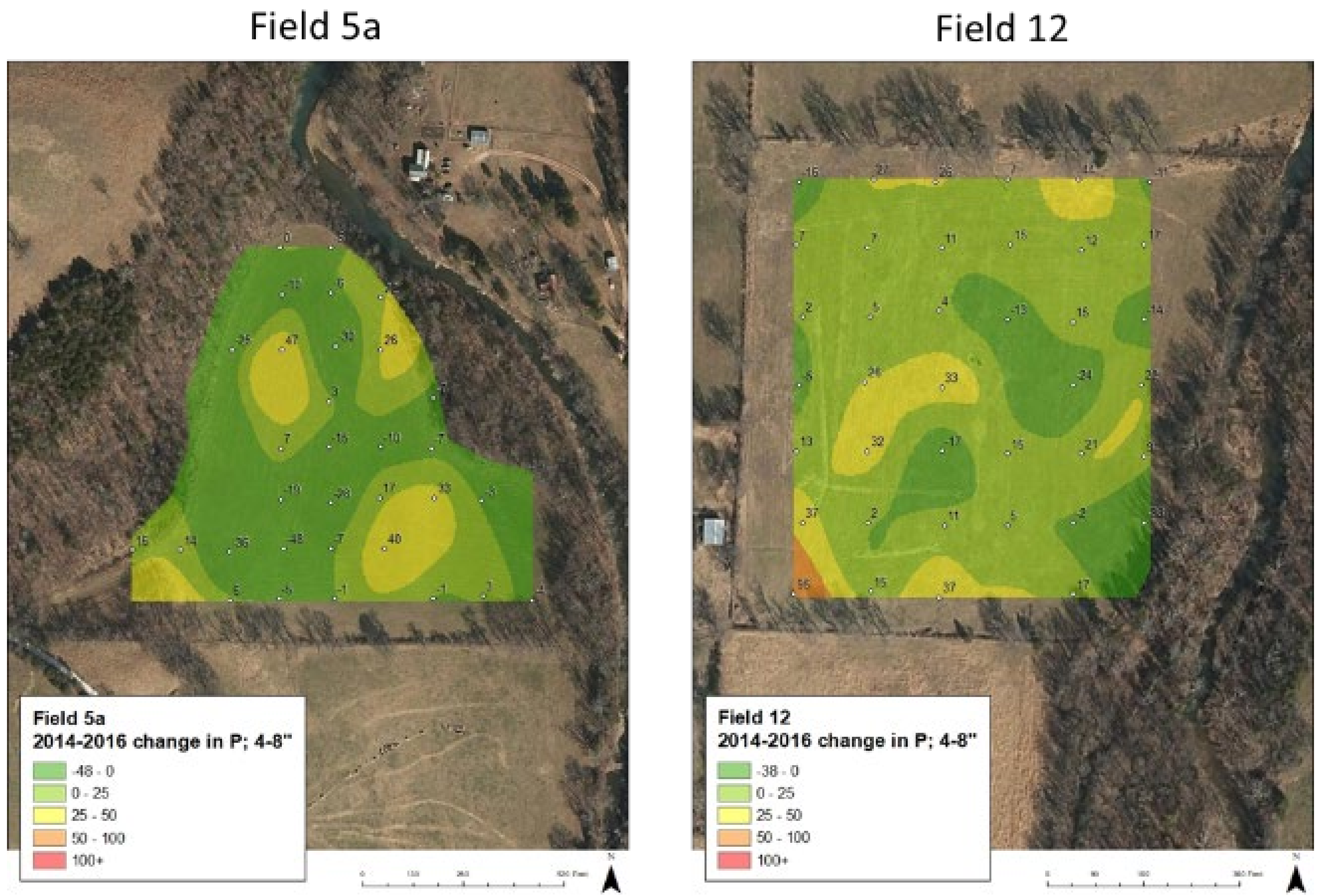


Figure 17. Difference in Mehlich-3 extractable soil P values between 2014 and 2016 grid-soil sampling of Fields 5a and 12.

Soil P sorption saturation

Soil P sorption saturation was calculated using Equation [2] and values given in Table 6 averaged on a whole field, slurry application zone, and buffer zone basis for Fields 1, 5a, and 12 for grid-soil sampling conducted in 2014, 2016, 2018. Differences among sampling dates are given in Table 7, with significantly different values (<0.05 level of probability) between years noted by different letters and bolded. Soil P sorption saturation values are also depicted on a grid-sampling basis in Figures 20 to 24 for Fields 1, 5a, and 12.

Table 6. Mean soil P sorption saturation and Mehlich-3 soil P for 0 to 4 inch grid-soil samples Fields 1, 5a, and 12 for 2014, 2016, and 2018 grid-soil sampling.

Field	Field position	Sampling depth	Mehlich-3 soil P				P sorption saturation		
			2014	2016	2018		2014	2016	2018
		inches	- - - - - mg/kg - - - - -				- - - - - - - % - - - - - - -		
Field 1	Whole field	0 to 4"	59	57	91		7.8	7.5	12.0
	Whole field	4 to 8"	20	27	--		2.3	3.1	--
	Application zone	0 to 4"	65	73	115		8.5	9.5	15.1
	Application zone	4 to 8"	20	35	--		2.3	4.0	--
	Buffer zone	0 to 4"	52	38	62		6.9	5.1	8.3
	Buffer zone	4 to 8"	19	17	--		2.3	1.9	--
Field 5a	Whole field	0 to 4"	45	39	47		4.4	3.7	4.6
	Whole field	4 to 8"	45	27	33		4.2	2.4	2.9
	Application zone	0 to 4"	50	42	45		4.9	3.8	4.3
	Application zone	4 to 8"	46	27	34		4.2	2.4	3.0
	Buffer zone	0 to 4"	33	34	51		3.3	3.6	5.0
	Buffer zone	4 to 8"	43	29	31		4.0	3.7	2.8
Field 12	Whole field	0 to 4"	63	104	122		6.0	9.2	11.0
	Whole field	4 to 8"	36	50	52		3.2	4.3	4.4
	Application zone	0 to 4"	56	107	126		5.3	9.5	11.3
	Application zone	4 to 8"	33	48	55		2.9	4.1	4.8

Field	Field position	Sampling depth	Mehlich-3 soil P				P sorption saturation		
			2014	2016	2018		2014	2016	2018
	Buffer zone	0 to 4"	90	95	112		8.4	8.3	10.0
	Buffer zone	4 to 8"	49	56	36		4.3	4.8	3.1

Soil P sorption saturation (PSS) reflects the degree to which potential P sorbing sites in a soil have P attached to them. As the degree (percent) of soil PSS increases, there are fewer sorption sites remaining. Soil PSS also provides an indication of the remaining potential of soil to adsorb and retain P that may be added in fertilizer, manure, or from grazing animals. The spatial distribution of PSS across fields and sampling dates is similar to that for Mehlich-3 P (Figures 20 to 24).

On a whole field basis, surface soil PSS (0 – 4 inch depth) increased from 7.8 to 12.0% for Field 1 and from 6.0 to 11% for Field 12 between 2014 and 2018 samplings (Table 6). A similar increase in PSS of the application zone of these Fields was observed (Table 12). These increases were significant at the <0.05 level of probability (Table 7). For Field 5a, PSS actually decreased between 2014 and 2018 samplings (Table 13). Increases in PSS were also apparent at the 4 – 8 inch soil depth in the slurry application zone Field 12, which translated to an increase in the whole field mean PSS (Table 7; at a <0.05 level of probability).

Table 7. Mean P sorption saturation (%) for Fields 1, 5a, and 12 for the 2014, 2016, and 2018 grid soil sampling at 0 – 4 inch and 4 – 8 inch depths (Field 1 is 0 – 4 inch sampled only). Parameters followed by the same letter for any given fields are not significantly different among 2014, 2016, and 2018 grid-soil samplings, as determined by paired *t* test with a <0.05 level of probability (bolded values are significantly greater).

	2014	2016		2016	2018		2014	2018
Field 1 (0-4 inch depth)								
Whole field	7.8 a	7.5 a		7.5 b	**12.0 a**		7.8 b	**12.0 a**
Application zone	8.5 a	9.5 a		9.5 b	**15.1 a**		8.5 b	**15.1 a**
Buffer zone	**6.9 a**	5.1 b		5.1 b	**8.3 a**		6.9 a	8.3 a
Field 5a (0-4 inch depth)								
Whole field	4.4 a	4.0 a		3.8 b	**4.6 a**		4.4 a	4.8 a
Application zone	4.8 a	4.0 a		4.0 a	4.3 a		4.9 a	4.5 a
Buffer zone	3.3 a	3.9 a		3.4 a	5.1 a		3.3 a	5.6 a

Field 5a (4-8 inch depth)						
Whole field	**4.2 a**	2.8 b	2.4 b	**2.9 a**	**4.2 a**	2.8 b
Application zone	**4.3 a**	2.8 b	2.4 b	**2.9 a**	4.4 a	3.2 a
Buffer zone	4.0 a	2.4 a	2.2 a	2.9 a	4.0 a	2.1 a
Field 12 (0-4 inch depth)						
Whole field	6.0 b	**9.1 a**	9.2 b	**11.0 a**	6.0 b	**11.0 a**
Application zone	5.3 b	**9.2 a**	9.5 b	**11.3 a**	5.3 b	**10.8 a**
Buffer zone	7.6 a	8.2 a	8.3 a	10.0 a	7.6 a	10.9 a
Field 12 (4-8 inch depth)						
Whole field	3.2 b	**4.1 a**	3.2 b	**4.4 a**	2.6 b	**4.5 a**
Application zone	2.9 b	**3.9 a**	3.3 b	**4.8 a**	2.5 b	**4.7 a**
Buffer zone	3.9 a	5.2 a	2.8 a	3.1 a	3.2 a	3.0 a

Further evaluation of PSS and Mehlich-3 P for soils from the three fields grid-sampled, shows a strong correlation between these two parameters describing soil P chemistry (Figure 18). The PSS – Mehlich-3 P relationship was similar for Fields 5a and 12, which had similar textures described as Razort and Spadra occasionally flooded loams, respectively (Figures 8 and 9). In contract, the PSS – Mehlich-3 P regression for Field 1 soils had a higher slope (0.137 compared to 0.097 and 0.091; Figure 18). The dominant soil type for Field 1 was the coarser Noark very cherty silt loam (Figure 7). The differing relationship between PSS and Mehlich-3 P among the three soils, reflects the added information on the dynamics of soil P availability provided by PSS compared to Mehlich-3 P. The greater regression slope for Noark than Razort and Spadra soils, reflects the lower clay content of the Noark soil than the other two soils, as clay-sized particles are the single most active and thus, dominant factor determining P sorption by soil. Although there are only three soil types in this comparison, there was a close relationship between soil clay content and the slope of the PSS – Mehlich-3 P regression shown in Figure 19.

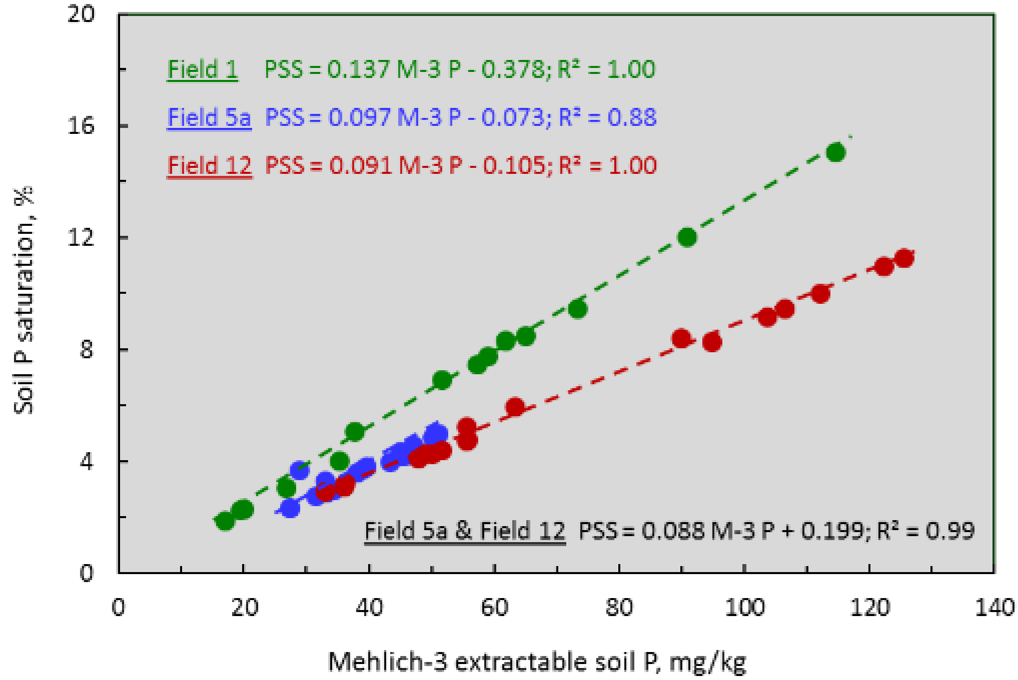


Figure 18. Relationship between Mehlich-3 extractable soil P and soil P sorption saturation for 0 to 4 and 4 to 8 inch sample depths; Fields 1, 5a, and 12; and 2014, 2016, and 2018 samplings.

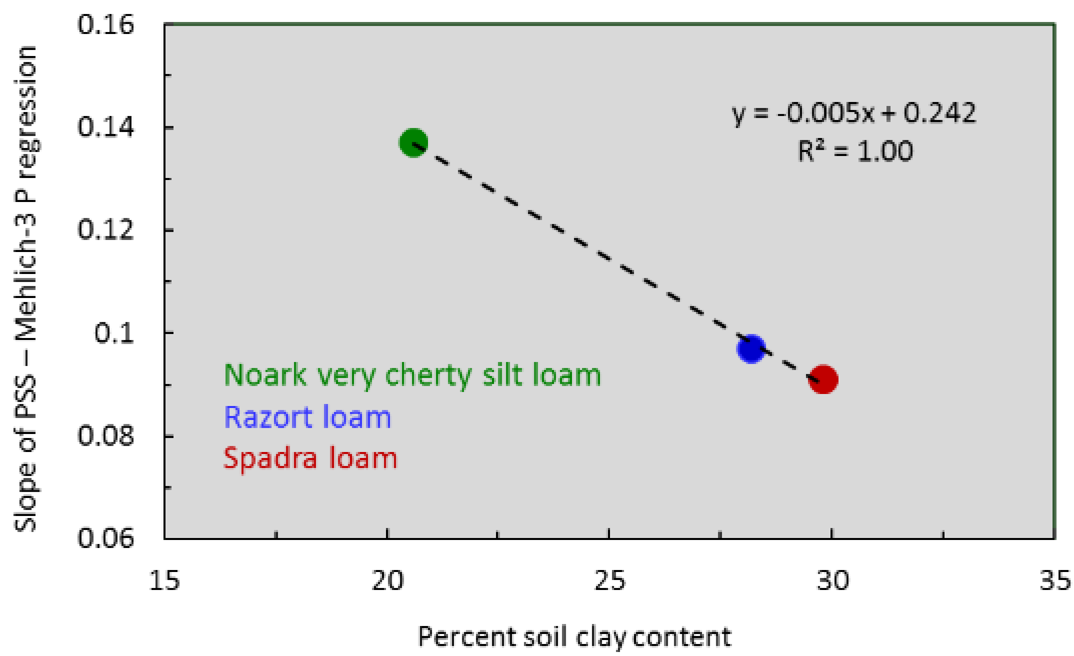


Figure 19. Relationship between the slope of the linear regression between soil P sorption saturation (PSS) and percent clay content of Noark (Field 1), Razort (Field 5a), and Spadra soils (Field 12).

Because of the Mehlich-3 P, PSS, and clay relationships; PSS reflects an estimate of soil P availability (i.e., Mehlich-3 P), as well as the capacity of that soil to bind further additions of P in fertilizer or manure. For example, assuming a Mehlich-3 P concentration of 100 mg/kg for all three fields using the regressions between PSS and Mehlich-3 P of Figure 18, a Noark soil would have a PSS value of 13.6% and the Razort and Spadra soils a value of 9.9 and 8.9%, respectively.

The capacity of the Noark soil of Field 1 to bind additional P is less than that for the Razort and Spadra soils of Field 5a and 12. Thus, the Mehlich-3 P concentration of Noark soil is likely to increase more quickly than that for Razort or Spadra soils, if the same amount of P was added to each soil. Hence PSS can provide additional information relevant to P management and fertility status of a soil.

Using the same method to estimate PSS as in the project (i.e., Equation 2), Pote at al. (1996) found PSS to range from 16 to 80% for a Captina silt loam in Arkansas. Using simulated rainfall and 54 small runoff plots (1.5 wide by 6 m long) under fescue, Pote et al. (1996) observed that PSS (r^2 of 0.77) was more closely related than Mehlich-3 P (r^2 of 0.72) to the concentration of dissolved P in runoff. Using a different method to estimate PSS (molar P, Fe and Al not used), Vadas et al. (2005) also showed PSS was more closely related to the concentration of dissolved P I runoff (r^2 of 0.83) than Mehish-3 or Bray-1 extractable soil P (r^2 of 0.77) for 31 soils ranging in clay content (6 to 24%) and PSS (1 to 82%). However, the limited in-field use of PSS to date and a variety of methods used to estimate PSS, there is limited information relating PSS to edge-of-field P runoff or the establishment of baseline values to enable valid quantitative comparisons at the present time.

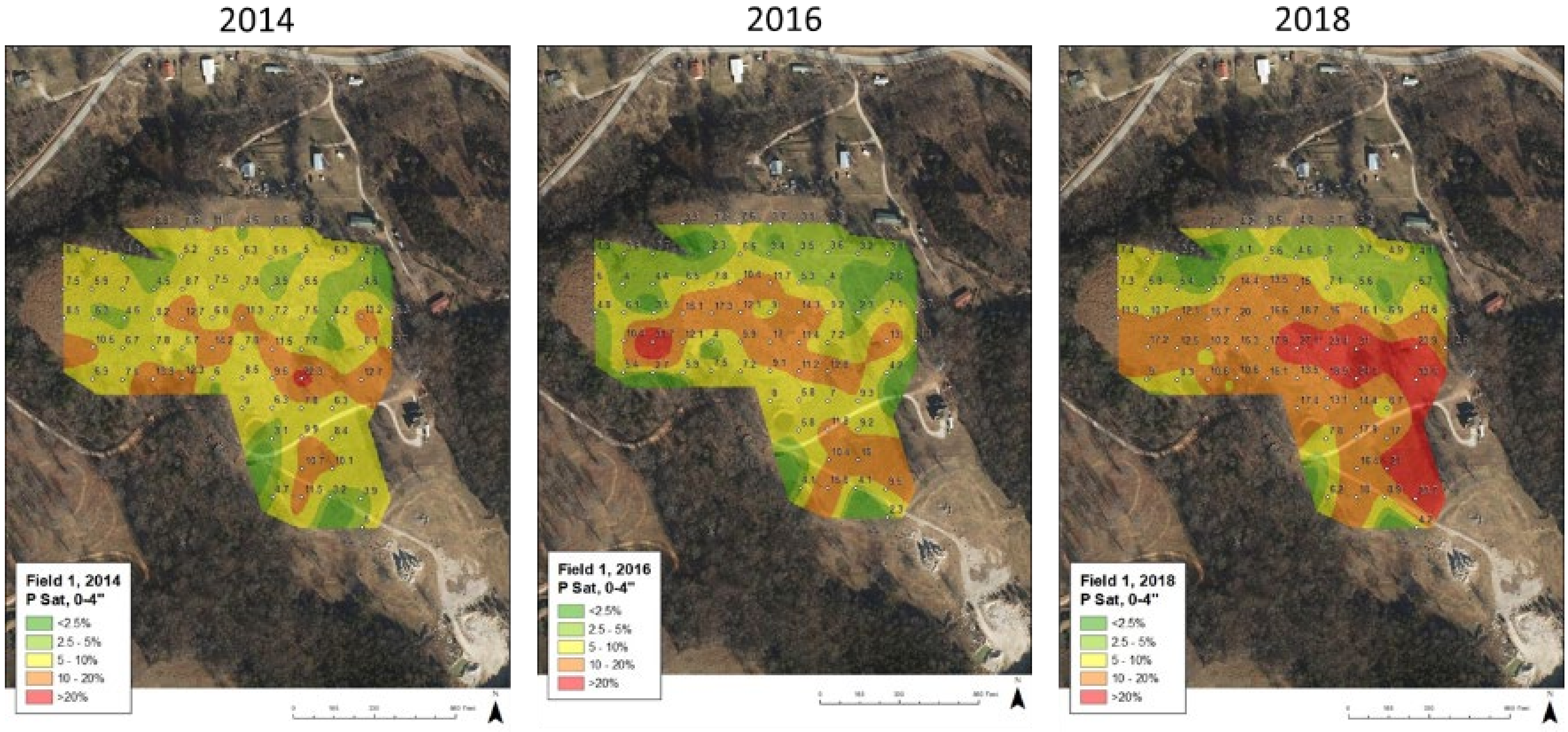


Figure 20. Soil P sorption saturation values for 0 to 4 inch depth for 2014, 2016, and 2018 grid-soil sampling of Field 1.

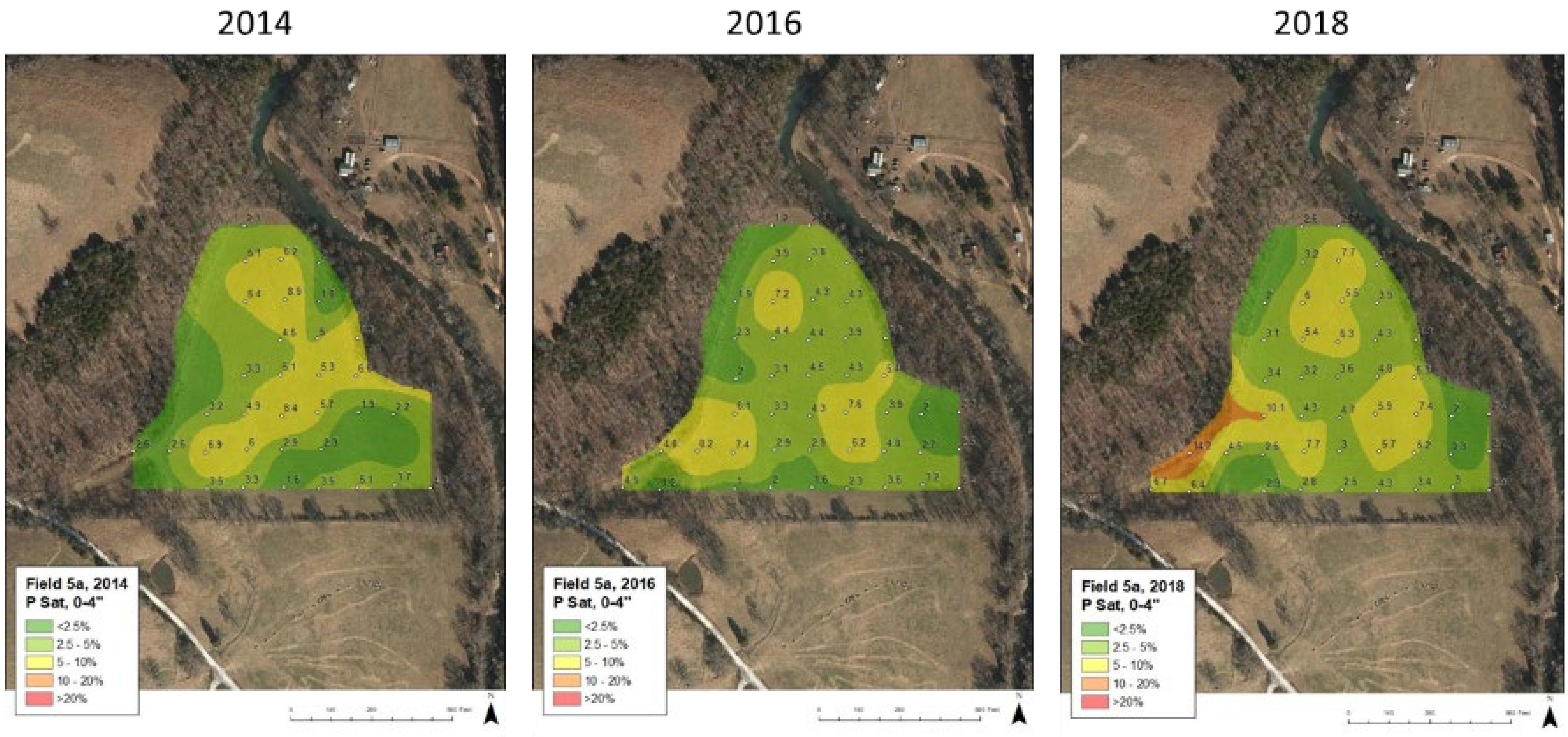


Figure 21. Soil P sorption saturation values for 0 to 4 inch depth for 2014, 2016, and 2018 grid-soil sampling of Field 5a.

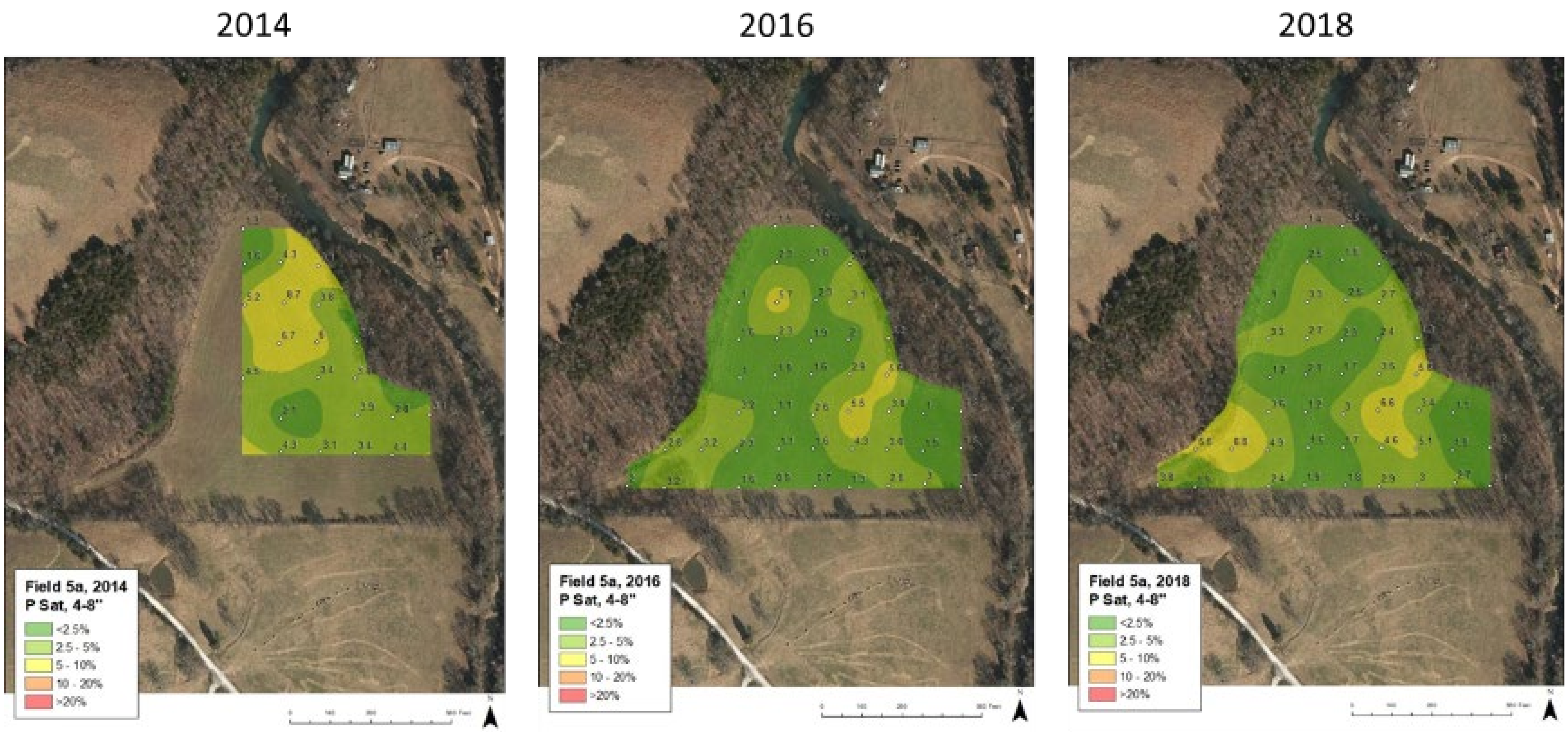


Figure 22. Soil P sorption saturation values for 4 to 8 inch depth for 2014, 2016, and 2018 grid-soil sampling of Field 5a.

2014 2016 2018

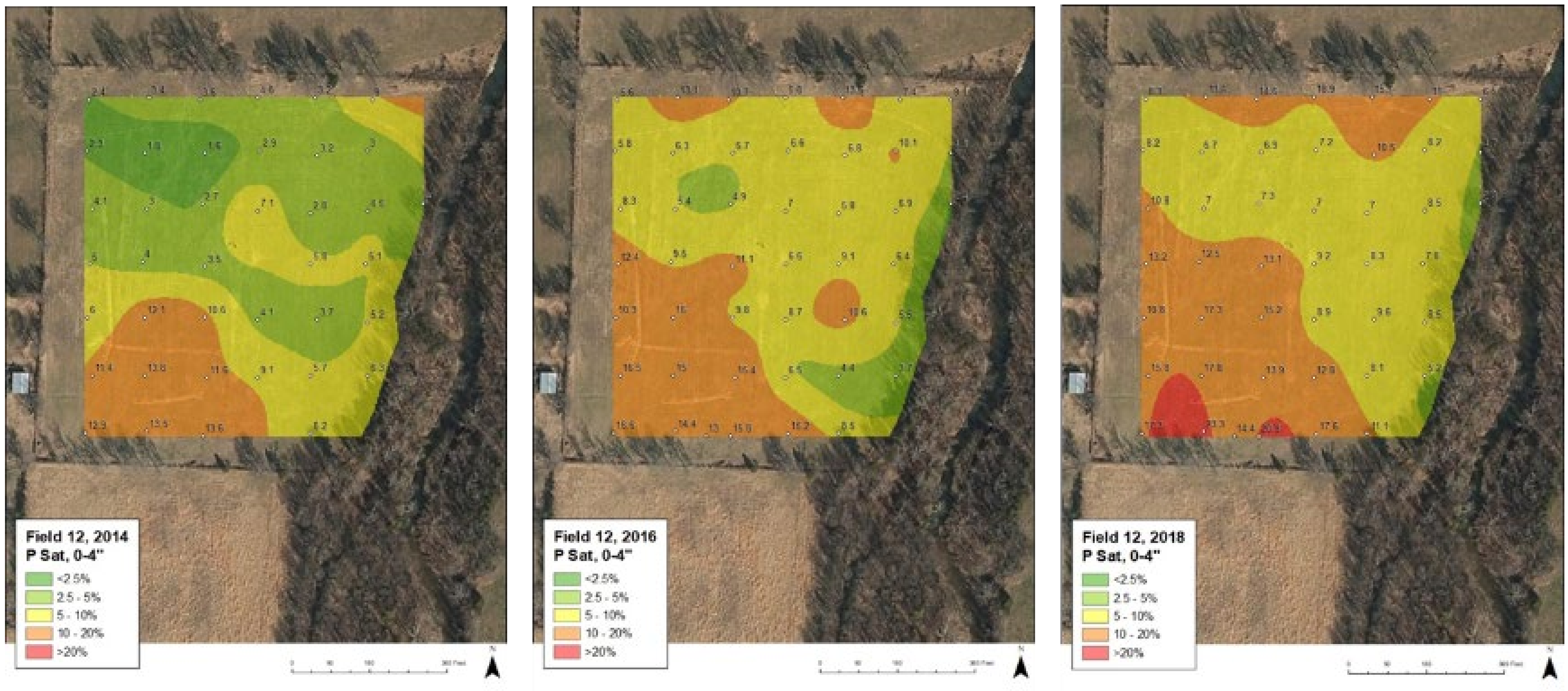


Figure 23. Soil P sorption saturation values for 0 to 4 inch depth for 2014, 2016, and 2018 grid-soil sampling of Field 12.

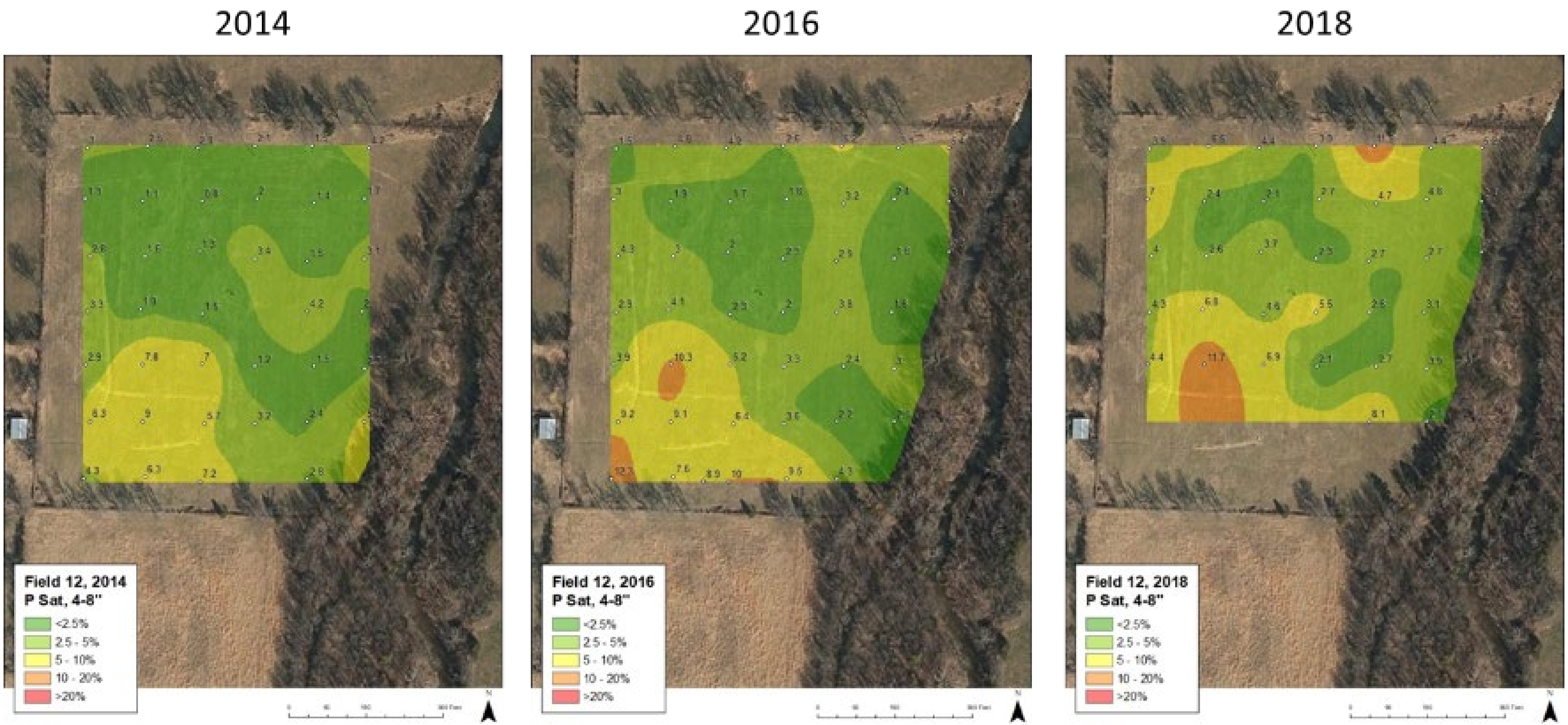


Figure 24. Soil P sorption saturation values for 4 to 8 inch depth for 2014, 2016, and 2018 grid-soil sampling of Field 12.

References

Breeuwsma, A., and O.F. Schoumans. 1987. Forecasting phosphate leaching on a regional scale. p. 973-981. *In:* W. van Duijvenboode and H.G. van Waegeningh, Editors. Proceedings of the Int. Conf. on Vulnerability of soil and groundwater to pollutants on March 30 to April 3, 1987 at Noordwijk aan Zee. The Hague: TNO Committee on Hydrological Research, The Hague, Proceedings and Information No. 38.

Breeuwsma, A., J.G.A. Reijerink, and O.F. Schoumans. 1995. Impact of manure on accumulation and leaching of phosphate in areas of intensive livestock farming. p. 239–249. *In*: K. Steele, Editor. Animal Waste and the Land-Water Interface. Lewis Publication, NY.

Dari, B., V.D. Nair, A.N. Sharpley, P.J.A. Kleinman, D. Franklin, and W.G. Harris. 2018. Consistency of the threshold phosphorus saturation ratio across a wide geographic range of acid soils. Agrosyst. Geosci. Environ. 1:180028. Available at https://dl.sciencesocieties.org/publications/age/articles/1/1/180028.

Huluka, G., and R. Miller. 2014 Particle Size determination by hydrometer method. Chapter 6.3. p. 180-184. *In*: F.J. Sikora an K.P. Moore, Editors. Soil Test Methods from the Southeastern United States. Southern Cooperative Series Bulletin No. 419. Southern Extension and Research Activity Information Exchange Group - 6 (SERA-IEG-6). Available at http://aesl.ces.uga.edu/sera6/MethodsManualFinalSERA6.asp.

Kleinman, P.J.A., and A.N. Sharpley. 2002. Estimating soil phosphorus sorption saturation from Mehlich-3 data. Commun. Soil Sci. Plant Anal. 33:1825-1839.

Loeppert, R.H., and W.P. Inskeep. 1996. Iron. P. 639-664. *In:* D.L. Sparks, Editor. Methods of Soil Analysis. Part 3. Chemical Methods, Soil Science Society of America Book Series No. 5 Soil Science Society of America, Madison, WI.

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Commun. Soil Sci. Plant Anal. 15:1409–1416.

Pote, D.H., T.C. Daniel, A.N. Sharpley, P.A. Moore, D.R. Edwards, D.J. Nichols. 1996. Relating extractable soil phosphorus to phosphorus losses in runoff. Soil Sci. Soc. Am. J. 60:855-859.

Schoumans, O.F. 2009. Determination of the degree of phosphate saturation in noncalcareous soils. *In*: J.L. Kovar and G.M. Pierzynski, Editors, Methods for phosphorus analysis for soils, sediments, residuals, and water. 2nd ed. SERA 17 Bull. 408. Virginia Tech, Blacksburg, VA. p. 29– 32.

Sibbesen, E. and A.N. Sharpley. 1997. Setting and justifying upper critical limits for phosphorus in soils. p. 151-176. *In:* H. Tunney, O. T. Carton, P. C. Brookes, and A. E.Johnston, Editors. Phosphorus loss from soil to water. CAB International Press, Cambridge, England.

Syers, J.K., M.G. Browman, G.W. Smillie, R.B. Corey. 1973. Phosphate sorption by soils evaluate by the Langmuir adsorption equation. Soil Sci. Soc. Am. Proc. 37:358-363.

Vadas, P.A., P.J.A. Kleinman, A.N. Sharpley, and B.L. Turner. 2005. Relating soil phosphorus to dissolved phosphorus in runoff: A single extraction coefficient for water quality modeling. J. Environ. Qual. 34:572-580.

Supplemental Tables

Table S 1. Mean nutrient content of Field 1 for the 2014, 2016, and 2018 grid soil sampling at 0 – 4 inch and 4 – 8 inch depths. Parameters followed by the same letter for any given fields are not significantly different between 2014, 2016, and 2018 grid-soil samplings, as determined by paired t test with a <0.05 level of probability (bolded values are greater).

Nutrient	Field 1 (0-4 inch depth)					
	2014	2016	2016	2018	2014	2018
P	58.9 a	57.1 a	57.1 b	**90.7 a**	58.9 b	**90.7 a**
K	203.8 a	182.7 a	182.7 b	**258.1 a**	203.8 b	**258.1 a**
Ca	1936.3 a	1844.7 a	1844.7 a	1909.2 a	1936.3 a	1909.2 a
Mg	112.6 a	109.8 a	109.8 b	**142.5 a**	112.6 b	**142.5 a**
S	18.3 a	15.4 b	15.4 b	**19.0 a**	18.3 a	19.0 a
Fe	109.0 b	**118.0 a**	**118.0 a**	106.3 b	109.0 a	106.3 a
Mn	**261.7 a**	209.4 b	209.4 a	213.2 a	**261.7 a**	213.2 b
Cu	0.6 b	**1.4 a**	1.4 a	1.3 a	0.6 b	**1.3 a**
Zn	4.3 a	5.1 a	5.1 b	**7.1 a**	4.3 b	**7.1 a**
B	0.4 b	**0.5 a**	**0.5 a**	0.4 b	0.4 a	0.4 a

Nutrient	Field 1 (4-8 inch depth)	
	2014	2016
P	19.7 b	**26.7 a**
K	76.7 b	**120.9 a**
Ca	1234.3 b	**1758.8 a**
Mg	**74.7 a**	72.1 b
S	10.3 a	10.4 a
Fe	**101.7 a**	96.2 b
Mn	**287.7 a**	196.1 b
Cu	0.5 a	1.1 a
Zn	2.2 b	**2.7 a**
B	0.2 b	**0.4 a**

Table S 2. Mean nutrient content of Field 5a for the 2014, 2016, and 2018 grid soil sampling at 0 – 4 inch and 4 – 8 inch depths. Parameters followed by the same letter for any given fields are not significantly different between 2014, 2016, and 2018 grid-soil samplings, as determined by paired t test with a <0.05 level of probability (bolded values are greater).

Nutrient	Field 5a (0-4 inch depth)							
	2014	2016		2016	2018		2014	2018
P	45.0 a	39.0 a		39.0 a	47.1 a		45.0 a	47.1 a
K	59.4 a	68.5 a		**68.5 a**	63.0 b		**59.4 a**	63.0 b
Ca	1314.7 a	1258.3 a		1258.3 a	1341.3 a		1314.7 a	1341.3 a
Mg	70.6 a	72.9 a		72.9 a	72.2 a		70.6 a	72.2 a
S	12.8 a	13.3 a		13.3 b	**13.2 a**		12.8 a	13.2 a
Fe	153.7 a	148.2 a		**148.2 a**	127.6 b		**153.7 a**	127.6 b
Mn	**205.3 a**	170.7 b		**170.7 a**	166.3 b		205.3 a	166.3 a
Cu	1.4 a	1.5 a		1.5 a	2.1 a		1.4 a	2.1 a
Zn	3.0 a	2.8 a		2.8 a	3.4 a		3.0 a	3.4 a
B	0.3 a	0.4 a		**0.4 a**	0.3 b		0.3 a	0.3 a

Nutrient	Field 5a (4-8 inch depth)							
	2014	2016		2016	2018		2014	2018
P	**37.7 a**	27.3 b		27.3 b	**33.2 a**		37.7 a	33.2 a
K	**98.5 a**	58.5 b		58.5 b	**55.7 a**		98.5 a	55.7 a
Ca	**2256.3 a**	1182.8 b		1182.8 b	**1210.3 a**		2256.3 a	1210.3 a
Mg	**80.4 a**	47.5 b		47.5 a	43.5 a		**80.4 a**	43.5 b
S	8.3 a	9.9 a		9.9 a	12.4 a		8.3 a	12.4 a
Fe	107.8 b	**136.2 a**		136.2 a	134.0 a		107.8 b	**134.0 a**
Mn	105.0 b	**157.4 a**		157.4 a	170.9 a		105.0 b	**170.9 a**
Cu	1.8 a	1.6 a		1.6 a	1.5 a		1.8 a	1.5 a
Zn	**4.9 a**	2.0 b		2.0 a	1.9 a		4.9 a	1.9 a
B	0.2 b	**0.3 a**		0.3 a	0.6 a		0.2 b	0.6 a

Table S 3. Mean nutrient content of Field 12 for the 2014, 2016, and 2018 grid soil sampling at 0 – 4 inch and 4 – 8 inch depths. Parameters followed by the same letter for any given fields are not significantly different between 2014, 2016, and 2018 grid-soil samplings, as determined by paired t test with a <0.05 level of probability (bolded values are greater).

Nutrient	Field 12 (0-4 inch depth)					
	2014	2016	2016	2018	2014	2018
P	63.3 b	**103.6 a**	103.6 a	122.2 a	63.3 b	**122.2 a**
K	91.6 b	**128.5 a**	128.5 a	155.3 a	91.6 b	**155.3 a**
Ca	1183.9 a	1300.8 a	1300.8 a	1204.9 a	1183.9 a	1204.9 a
Mg	77.4 b	**118.5 a**	118.5 a	125.5 a	77.4 b	**125.5 a**
S	13.4 b	**16.1 a**	**16.1 a**	13.6 b	13.4 a	13.6 a
Fe	126.7 b	**182.4 a**	**182.4 a**	153.6 b	126.7 a	153.6 a
Mn	147.7 b	**176.6 a**	**176.6 a**	164.3 b	147.7 a	164.3 a
Cu	1.2 b	**1.7 a**	1.7 a	1.9 a	1.2 b	**1.9 a**
Zn	2.2 b	**4.9 a**	4.9 a	6.1 a	2.2 b	**6.1 a**
B	0.2 b	**0.5 a**	**0.5 a**	0.4 b	0.2 a	0.4 a

Nutrient	Field 12 (4-8 inch depth)					
	2014	2016	2016	2018	2014	2018
P	36.2 b	**49.7 a**	49.7 a	51.5 a	36.2 b	**51.5 a**
K	68.3 a	80.7 a	80.7 a	71.8 a	68.3 a	71.8 a
Ca	1235.5 a	1332.3 a	**1332.3 a**	1295.9 b	**1235.5 a**	1295.9 b
Mg	54.4 b	**71.8 a**	71.8 a	73.6 a	54.4 b	**73.6 a**
S	11.0 a	11.8 a	**11.8 a**	10.5 b	**11.0 a**	10.5 b
Fe	103.7 b	**133.1 a**	133.1 a	134.1 a	103.7 b	**134.1 a**
Mn	96.8 b	**128.0 a**	128.0 a	123.4 a	96.8 b	**123.4 a**
Cu	1.2 b	**1.7 a**	**1.7 a**	1.6 b	1.2 a	1.6 a
Zn	1.4 b	**2.0 a**	2.0 a	2.5 a	1.4 b	**2.5 a**
B	0.1 b	**0.4 a**	0.4 a	0.6 a	0.1 b	**0.6 a**

Table S 4. Differences in mean nutrient content of whole Fields 1, 5a, and 12 among the 2014, 2016, and 2018 grid soil sampling. Parameters followed by the same letter for any given fields are not significantly different among 2014, 2016, and 2018 grid-soil samplings, as determined by paired t test with a <0.05 level of probability (bolded values are greater).

Nutrient	Whole field differences		
	2014-2016	2016-2018	2014-2018
Field 1			
P	-1.8 b	**33.6 a**	**31.2 a**
K	-21.0 a	75.3 a	54.3 a
Ca	-91.6 a	64.5 a	-27.0 a
Mg	-2.8 b	32.7 a	29.9 a
S	-2.9 b	**3.6 a**	0.7 b
Fe	**9.0 a**	-11.7 b	**-2.7 a**
Mn	-52.3 b	**3.9 a**	-48.5 b
Cu	**0.8 a**	-0.2 b	**0.7 a**
Zn	0.8 a	2.0 a	2.8 a
B	**0.07 a**	-0.07 b	**0.01 a**
Field 5a			
P	-2.2 a	7.3 a	5.1 a
K	10.6 a	-4.0 a	6.6 a
Ca	-151.9 a	74.9 a	-77.0 a
Mg	4.2 a	0.9 a	5.2 a
S	**12.3 a**	**9.7 a**	0.4 b
Fe	0.6 a	-0.2 a	-23.3 a
Mn	-2.9 a	-20.3 a	-18.6 a
Cu	-17.6 a	-7.2 a	0.9 a
Zn	0.2 b	**0.7 a**	**0.5 a**
B	-0.1 a	0.6 a	-0.02 a
Field 12			
P	**39.7 a**	18.7 b	**59.8 a**

Nutrient	Whole field differences		
	2014-2016	2016-2018	2014-2018
K	33.7 a	16.6 a	50.3 a
Ca	**139.5 a**	-112.6 b	**26.9 a**
Mg	**42.6 a**	7.4 b	**49.9 a**
S	11.5 b	**23.6 a**	**0.2 a**
Fe	2.9 a	-2.7 b	26.5 a
Mn	**53.8 a**	-27.3 b	**14.2 a**
Cu	**26.2 a**	-12.0 b	**0.7 a**
Zn	**0.6 a**	0.2 b	**3.9 a**

Table S 5. Differences in mean nutrient content of slurry application zones for Fields 1, 5a, and 12 among the 2014, 2016, and 2018 grid soil sampling. Parameters followed by the same letter for any given fields are not significantly different among 2014, 2016, and 2018 grid-soil samplings, as determined by paired t test with a <0.05 level of probability (bolded values are greater).

Nutrient	Slurry application zone differences		
	2014-2016	2016-2018	2014-2018
Field 1			
P	8.3 b	**41.4 a**	**49.7 a**
K	-37.7 b	**89.6 a**	**51.9 a**
Ca	59.8 a	99.2 a	159.0 a
Mg	7.4 b	**38.5 a**	**45.9 a**
S	-4.8 b	**7.3 a**	2.4 b
Fe	9.2 a	-6.8 a	2.3 a
Mn	-43.1 b	**-0.5 a**	-43.6 b
Cu	**1.1 a**	-0.5 b	**0.6 a**
Zn	1.8 a	2.3 a	4.1 a
B	**0.1 a**	-0.02 b	**0.04 a**

Nutrient	Slurry application zone differences		
	2014-2016	2016-2018	2014-2018
Field 5a			
P	-7.1 a	3.0 a	-4.1 a
K	**12.6 a**	-6.2 b	**6.4 a**
Ca	94.7 a	19.5 a	114.2 a
Mg	9.9 a	-2.6 a	7.3 a
S	**12.3 a**	9.7 b	**-1.1 a**
Fe	-0.2 a	-1.0 a	-30.7 a
Mn	**-6.9 a**	**-23.9 a**	-53.5 b
Cu	-44.9 b	**-8.6 a**	**1.0 a**
Zn	0.3 a	0.7 a	0.8 a
B	0.2 a	0.6 a	0.01 a
Field 12			
P	**46.3 a**	18.2 b	**64.5 a**
K	49.9 a	20.2 a	70.1 a
Ca	**189.9 a**	-139.5 b	**50.4 a**
Mg	**52.0 a**	6.9 b	**58.8 a**
S	11.5 b	**23.6 a**	1.0 a
Fe	**4.2 a**	-3.1 b	**26.3 a**
Mn	**54.2 a**	-28.0 b	**18.2 a**
Cu	**25.2 a**	-7.0 b	**0.8 a**
Zn	**0.6 a**	0.2 b	**4.2 a**

Table S 6. Differences in mean nutrient content of buffer zones for Fields 1, 5a, and 12 among the 2014, 2016, and 2018 grid soil sampling. Parameters followed by the same letter for any given fields are not significantly different among 2014, 2016, and 2018 grid-soil samplings, as determined by paired t test with a <0.05 level of probability (bolded values are greater).

Nutrient	Buffer zone differences		
	2014-2016	2016-2018	2014-2018
Field 1			
P	-14.1 b	**24.1 a**	10.1 b
K	-0.7 b	**57.9 a**	**57.3 a**
Ca	-276.0 b	**22.3 a**	**-253.8 a**
Mg	-15.3 b	**25.8 a**	10.4 b
S	-2.7 b	**1.3 a**	-1.8 b
Fe	**8.7 a**	-17.6 b	**-8.9 a**
Mn	-63.7 b	**9.3 a**	-54.4 b
Cu	**0.5 a**	0.2 b	**0.7 a**
Zn	-0.5 b	**1.7 a**	**1.2 a**
B	**0.07 a**	-0.10 b	**-0.03 a**
Field 5a			
P	6.4 a	17.5 a	23.9 a
K	5.7 a	-2.7 a	3.0 a
Ca	-697.9 b	**171.3 a**	**-526.6 a**
Mg	-13.9 a	13.1 a	-0.8 a
S	1.6 a	1.6 a	3.2 a
Fe	4.1 a	-13.9 a	-9.8 a
Mn	4.4 a	-4.8 a	-0.4 a
Cu	0.1 a	0.6 a	0.7 a
Zn	-1.2 b	**0.8 a**	**-0.4 a**
B	-0.04 a	-0.08 a	-0.12 a
Field 12			
P	13.6 a	27.4 a	41.0 a

Nutrient	Buffer zone differences		
	2014-2016	2016-2018	2014-2018
K	-6.4 a	14.4 a	8.0 a
Ca	85.3 a	-38.7 a	46.6 a
Mg	16.3 a	9.6 a	25.9 a
S	-0.4 a	-1.4 a	-1.9 a
Fe	54.9 a	-27.3 a	27.6 a
Mn	24.6 a	-20.0 a	4.6 a
Cu	0.5 a	0.09 a	0.6 a
Zn	1.2 a	1.2 a	2.4 a