Using On-Field Ohio Simulations to Evaluate Short-Term and Maximum Long-Term Phosphorus Bioavailability Risk of Eroded Soil

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Project Purpose:

1. Measure Phosphorus (P) bioavailability (NaOH and CBD extractable P) in On-Field Ohio field soils.
2. Evaluate the relationship between bioavailable P and soil P measures (e.g. soil total P content, Mehlich3-P).
3. Estimate the short-term and maximum long-term bioavailability of runoff particulate P across Ohio, using these relationships (Objective 2) in conjunction with On-Field Ohio P Index simulations.

Main Points:

- Edge-of-field monitoring data, used to develop On-Field Ohio, shows considerably greater particulate bound P than dissolved P loads (lb/A). Therefore, it is useful to understand the potential P bioavailability of freshly eroded field soils.
- Suspended sediments, from tributaries, drainage ditches streams etc., are an aggregate representation of the many acres/fields they originate from. Because the suspended sediment is separated from the field from which it came, it is impossible to evaluate relationships with field soil measures and determine a range in bioavailability.
- A major advantage of working with field soils rather than suspended sediments is the ability to know the soil P measures from the originating field.
- Using 57 soils from On-Field Ohio study fields, short-term, potential long-term and maximum potential long-term P bioavailability were evaluated.
- As a percent of soil total P, short-term bioavailable P, ranged from 16.6 to 65.4% with a median or 31.7%, long-term potential bioavailable P ranged from 20.4 to 70.5% with a median of 40.1% and maximum potential bioavailable P ranged from 37.1 to 110% with a median of 73%.
- Using simple linear regression, either soil total P and M3-P were significantly (*P<0.0001*) related to short-term, long-term or maximum potential P bioavailability. Bioavailability increases as soil test P and therefore soil total P increases
- Using these developed regression equations any of the bioavailable P fractions can be estimated if Mehlich3 or soil total P are known.
- Short-term runoff particulate P load bioavailability was approximately 50% as compared to the On-Field Ohio runoff particulate P estimates. However, the long-term maximum potential runoff particulate P bioavailability is very similar as compared to the On-Field Ohio estimated runoff.

Background:

On-Field Ohio provides long-term average, field-scale estimate of erosion potential and phosphorus (P) runoff risk based on field properties and farmer practices. Information provided by On-Field Ohio allows farmers to prioritize time and resources in making management decisions. The power is in the ability to compare multiple crop management scenarios and compare the effects on erosion and P runoff risk. Knowing the bioavailability of P in eroded soil/particulate bound runoff P is important to more fully evaluate P runoff risk.

There is no dispute that dissolved P is essentially all bioavailable to algae and much is also known regarding soil P solubility, which is important as it impacts dissolved P. A general discussion of soil P fixation across soil pH ranges can be found in Brady & Weil (1996). Discussed are both reactions with hydrous oxides, of iron (Fe), manganese (Mn) and aluminum (Al) and silicate clays as well as precipitation/dissolution of Ca-P (calcium phosphate) minerals across soil pH. As eroded soil moves into more dilute aqueous solution these Ca-P mineral phases begin to dissolve (Brady & Weil, 1996). The extent and limits (equilibrium constant) of potential solubility of Ca-P minerals varies widely but is well understood (Bohn et al., 1985; Chang, 1991; Lindsay, 1979; Sposito, 1989; Sposito,1994; Pierzynski et al., 2005; Miller and Gardiner, 1998; OEPA, 2010). Phosphorus fixation (binding) on hydrous oxide clay minerals through ligand exchange/specific adsorption phosphate as well as interferences with competing anions, such as sulfate, carboxylate, arsenate etc., are another important mechanism of P binding that can control P bioavailability (Bohn et al., 1985; Brady & Weil, 1996; Sposito, 1984; Sposito, 1989; Pierzynski et al., 2005; Miller and Gardiner, 1998; OEPA, 2010). Soil specific adsorption capacities are often evaluated using the Langmuir model (Olsen & Wantanabee, 1957; Sposito, 1989; Sposito, 1984; Bohn et al., 1985; Sposito, 1994; Pierzynski et al., 2005).

Under anoxic (low oxygen) conditions, as may be encountered in submerged sediments in drainage ditches, tributaries and lakes, the Fe & Mn hydrous oxides become vulnerable to dissolution, and can release P, due to reduction reactions (Pierzynski et al., 2005; Gachter and Imboden, 1985; Miller and Gardiner, 1998).

This project links potential soil P bioavailability to erosion, edge-of-field runoff suspended sediment and runoff particulate bound P as determined by On-Field Ohio. The hypothesis is P forms associated with freshly eroded soil particles at the edge-of-field are different than suspended sediment P forms in rivers due to dissolution and reduction reactions that happen as soil particles are transported through drainage ways, tributaries and rivers. A portion of edge-of-field particulate bound P begins to dissolve as it travels through the dilute waterway, tributary, river system and thus will be measured as dissolved P at monitoring stations.

Quantifying differences between edge-of-field runoff dissolved P (DRP) and runoff particulate bound P, in On-Field Ohio has sparked discussion regarding the bioavailability of runoff particulate bound P (RPP). Runoff particulate bound P is associated with runoff suspended sediment which is strongly related to erosion and soil P levels. For example, the contention is that in the Heidelberg University tributary monitoring data, dissolved P has increased while total and particulate bound P has decreased since 1995 (Richards et al., 2009). Therefore, the claim is that dissolved P is of greater environmental concern. However, the edge-of-field monitoring data, used to develop On-Field Ohio, shows considerably greater particulate bound P than dissolved P loads (lb/A). Therefore, it is useful to understand the potential bioavailability of freshly eroded field soils. Evaluated here is the bioavailability of On-Field Ohio study field soils vulnerable to erosion to determine if, in fact, they behave the same as tributary suspended sediments.

Methods:

Fifty-seven soil samples, from On-Field Ohio study fields, were used to evaluate the potential P bioavailability range, should they become eroded into drainageways (Table 1). Both the 0-2 and 0-8" sampling depths were included to determine if they behaved differently. Soil sample were from seven counties and sample textures ranged from loam to clays (Table 1). Samples were evaluated for P saturation based on an acid ammonium oxalate extraction. This measures the percent P saturation on aluminum/iron/manganese oxide binding sites (McKeague and Day 1966). Soil total P content was determined using a microwave assisted aqua regia digest (USEPA Method 3051a, 2007). Mehlcih3 (M3-P, Mehlich, 1984) and deionized water (WEP, Luscombe et al., 1979) extractable P were also evaluated. Short-term P bioavailability was determined using a sodium hydroxide (NaOH) extraction and long-term potential P bioavailability was determined, sequentially, using a citrate-bicarbonate-dithionite (CBD) extraction based on the method of Williams et al. (1971)

Results and Discussion:

Objective 1. Measure phosphorus (P) bioavailable P in soil samples from On-Field Ohio study fields.

Short-term bioavailability of suspended sediments is typically measured using a sodium hydroxide (NaOH) extraction (Wolf et al., 1985; Lee et al., 1980; Logan et al., 1979; Baker et al., 2014; Sonzogni et al., 1982, Nguyen et al., 2017, and Young et al., 1985) as it is strongly related to algae growth. Using a NaOH extraction, Baker et al. (2014) found the bioavailbility as a percent of tributary particulate bound P was 20 to 28% in the Maumee, 27 to 29% in the Sandusky and 21 to 36% in the Cuyahoga rivers in Ohio. This measure is appropriate for short-term bioavailability, however it does not account for the additional potentially bioavailable P found under anoxic conditions typical in drainageway/river/lake sediments, especially during warm weather. Maximum potential long-term bioavailable P can be determined by the sequential addition of a citrate-bicarbonate-dithionite (CBD) extraction which mimics anoxic (reduced) conditions (Logan et al., 1979 and Young et al., 1985). The sum of NaOH + CBD extractable P provides a more comprehensive estimate of maximum potential bioavailable P.

Table 1. Overview, by soil sampling depths (Depth), of soil series and texture, oxalate phosphorus (P) saturation (Ox P Sat), total soil P (Total P) and soil extractable P by Mehlich3 (M3-P) water (WEP), sodium hydroxide (NaOH) and citrate bicarbonate dithionite (CBD). Percent bioavailable P is based on NaOH, CBD and NaOH + CBD extractions as a percent of soil total P.

					Phosphorus Fractions							Percent Bioavailable		
#	Depth	Soil, *Texture	County	Fld	Ox P Sat	Total P	M3-P	WEP	NaOH P	CBD P	NaOH + CBD	NaOH	CBD	NaOH + CBD
	in				%	------------------------ mg/kg ------------------------						---------- % -----------		
1	0-2	Blount, SIL	Mercer	20	40.2	3116	741	34.3	1120	1499	2620	36.0	48.1	84.1
2	0-2	Centerburg, SIL	Knox	4	9.95	757	69.6	5.36	375	343	718	49.5	45.3	94.8
3	0-2	Bennington, SIL	Delaware	4	14.7	974	126	17.0	433	278	711	44.5	28.6	73.0
4	0-2	Centerburg, SIL	Delaware	5	8.99	903	39.1	8.10	302	266	568	33.5	29.5	62.9
5	0-2	Blount, SIL	Mercer	16	8.88	890	143	22.6	345	275	619	38.8	30.9	69.6
6	0-2	Pewamo, SICL	Mercer	17	9.66	893	170	26.5	236	357	592	26.4	39.9	66.3
7	0-2	Shoals, SIL,	Mercer	19	11.0	1214	177	19.3	300	467	767	24.7	38.5	63.2
8	0-2	Blount, SIL	Mercer	19	11.0	962	268	22.2	237	678	915	24.7	70.5	95.1
9	0-2	Glynwood, SIL	Mercer	20	19.7	2099	344	21.4	688	936	1624	32.8	44.6	77.4
10	0-2	Pewamo, SICL	Mercer	20	23.2	2455	343	24.6	897	978	1875	36.5	39.8	76.3
11	0-2	Lenawee, SICL	Henry	25	7.93	694	34.3	3.43	172	262	435	24.8	37.8	62.6
12	0-2	Nappanee, L	Defiance	26	13.3	1068	123	13.9	479	380	858	44.8	35.5	80.3
13	0-2	Millgrove, L	Defiance	26	10.2	1266	72.9	5.15	348	456	804	27.5	36.0	63.5
14	0-2	Condit, SIL	Morrow	6	7.13	933	35.2	5.21	491	381	872	52.7	40.8	93.4
15	0-2	Blount, SIL	Mercer	18	12.5	1038	189	19.3	345	529	874	33.3	50.9	84.2
16	0-2	Glynwood, SIL	Mercer	19	9.44	831	132	8.38	224	423	647	27.0	50.8	77.8
17	0-2	Blount, SIL	Mercer	20	17.4	1546	278	20.6	775	683	1458	50.2	44.2	94.3
18	0-2	Glynwood, SIL	Mercer	20	16.7	1000	292	17.4	576	512	1087	57.5	51.2	109
19	0-2	Pewamo, SICL	Mercer	20	34.5	2797	671	33.0	977	1637	2614	34.9	58.5	93.4
20	0-2	Blount, SIL	Mercer	21	26.6	1600	507	24.2	662	950	1612	41.4	59.4	101
21	0-2	Hoytville, C	Wood	29	10.4	683	40.6	3.48	184	212	397	27.0	31.1	58.1
22	0-2	Hoytville, SICL	Wood	31	13.6	817	121	10.0	291	273	565	35.7	33.5	69.1
23	0-2	Hoytville, C	Henry	25	11.2	808	19.9	3.08	155	324	479	19.2	40.1	59.3
24	0-2	Nappanee, L	Defiance	26	25.3	948	163	13.4	257	418	675	27.1	44.1	71.2
25	0-2	Millgrove, L	Defiance	26	15.1	1251	106	8.72	385	359	743	30.8	28.7	59.4
26	0-2	Paulding, C	Henry	33	8.54	1069	77.8	6.26	356	319	675	33.3	29.8	63.2
27	0-2	Nappanee, SICL	Wood	34	11.5	983	56.3	6.18	260	254	513	26.4	25.8	52.2
28	0-2	Hoytville, SICL	Wood	35	14.6	1259	86.5	5.62	324	518	842	25.8	41.1	66.9
29	0-8	Blount, SIL	Mercer	20	42.6	3381	814	33.8	1115	1678	2794	33.0	49.6	82.6

30	0-8	Centerburg, SIL	Knox	4	7.20	682	45.7	2.36	310	253	563	45.5	37.1	82.5
31	0-8	Bennington, SIL	Delaware	4	11.6	957	52.0	10.3	351	250	602	36.7	26.1	62.9
32	0-8	Centerburg, SIL	Delaware	5	7.66	894	25.5	5.05	253	275	529	28.3	30.8	59.1
33	0-8	Blount, SIL	Mercer	16	8.32	803	126	14.7	333	249	582	41.5	31.0	72.4
34	0-8	Pewamo, SICL	Mercer	17	9.29	828	179	19.6	242	456	698	29.2	55.1	84.3
35	0-8	Shoals, SIL	Mercer	19	10.3	1251	163	13.5	256	624	880	20.4	49.9	70.3
36	0-8	Blount, SIL	Mercer	19	9.15	988	205	9.08	204	543	747	20.7	54.9	75.6
37	0-8	Glynwood, SIL	Mercer	20	20.0	2159	376	22.6	845	982	1827	39.1	45.5	84.6
38	0-8	Pewamo, SICL	Mercer	20	24.5	2381	353	27.0	913	917	1830	38.4	38.5	76.9
39	0-8	Paulding, C	Paulding	22	6.74	929	38.4	4.45	165	367	532	17.8	39.5	57.3
40	0-8	Lenawee, SICL	Henry	25	8.34	797	30.9	2.87	150	178	328	18.9	22.3	41.2
41	0-8	Nappanee, L	Defiance	26	11.0	1147	76.6	6.59	400	243	643	34.8	21.2	56.0
42	0-8	Millgrove, L	Defiance	26	10.6	1196	60.1	4.21	287	427	714	24.0	35.7	59.7
43	0-8	Condit, SIL	Morrow	6	5.90	843	20.0	2.87	402	303	706	47.7	36.0	83.7
44	0-8	Blount, SIL	Mercer	18	10.1	816	142	6.94	233	524	757	28.5	64.2	92.7
45	0-8	Glynwood, SIL	Mercer	19	8.19	763	104	4.76	180	484	664	23.6	63.5	87.0
46	0-8	Blount, SIL	Mercer	20	16.2	1511	265	15.8	831	819	1650	55.0	54.2	109
47	0-8	Glynwood, SIL	Mercer	20	16.1	964	287	13.5	630	427	1057	65.4	44.3	110
48	0-8	Pewamo, SICL	Mercer	20	35.4	2839	675	30.2	1020	1655	2675	35.9	58.3	94.2
49	0-8	Blount, SIL	Mercer	21	26.6	1719	584	19.4	585	931	1516	34.1	54.2	88.2
50	0-8	Hoytville, C	Wood	29	9.69	682	28.1	3.07	163	262	424	23.9	38.4	62.2
51	0-8	Hoytville, SICL	Wood	31	11.9	754	89.1	7.02	239	215	454	31.7	28.5	60.2
52	0-8	Hoytville, C	Henry	25	11.4	838	32.3	3.13	139	171	311	16.6	20.4	37.1
53	0-8	Nappanee, L	Defiance	26	24.2	949	143	7.40	279	500	778	29.4	52.7	82.0
54	0-8	Millgrove, L	Defiance	26	13.4	1206	83.9	5.75	359	605	964	29.8	50.2	79.9
55	0-8	Paulding, C	Henry	33	6.61	880	27.2	2.80	248	291	539	28.2	33.1	61.2
56	0-8	Nappanee, SICL	Wood	34	8.40	838	21.5	2.44	181	373	554	21.6	44.5	66.1
57	0-8	Hoytville, SICL	Wood	35	11.7	1085	65.7	3.45	240	435	675	22.1	40.1	62.2
				Minimum	5.90	682	19.9	2.36	139	171	311	16.6	20.4	37.1
				Maximum	42.6	3381	813	34.3	1120	1678	2794	65.4	70.5	110
				Median	11.2	964	123	8.72	324	423	714	31.7	40.1	73.0

*C=Clay, SICL=Silty Clay Loam, L=Loam, SIL=Silt Loam

Sample NaOH extractable P (short-term bioavailable P) ranged from 139 to 1120 mg P/kg with a median of 324 mg P/kg (Table 1). Sample CBD extractable P (long-term potential bioavailable P) ranged from 171 to 1678 mg P/kg with a median of 423 mg P/kg. The sum of NaOH + CBD extractable P (Maximum potential bioavailable P) ranged from 311 to 2794 mg P/kg with a median of 714 mg P/kg (Table 1). Short-term bioavailable P, as a percent of soil total P, ranged from 16.6 to 65.4% with a median of 31.7% while long-term potential bioavailable P ranged from 20.4 to 70.5% with a median of 40.1% and maximum potential bioavailable P ranged from 37.1 to 110% with a median of 73% (Table 1).

Suspended sediments, from tributaries, drainage ditches streams etc., are an aggregate representation of the many acres/fields they originate from. This probably accounts for the relatively narrow range in short-term bioavailability found by Baker et al. (2014) for Ohio rivers (20-36%). Similarly, Logan et al. (1979) found short-term bioavailable P ranged from 11.5 to 33% in sediments from Eastern and Western Ohio as well as Michigan. In field soil, from On-Field Ohio study fields, the range in short-term bioavailable P of 16.6 to 65.4% is considerably larger. Baker et al. (2014) did not measure potential long-term bioavailability. However, Logan et al. (1979) found long-term maximum potential bioavailability ranging from 35 to 89%, which is in line with the range of 37.1 to 110% found in the On-Field Ohio soils.

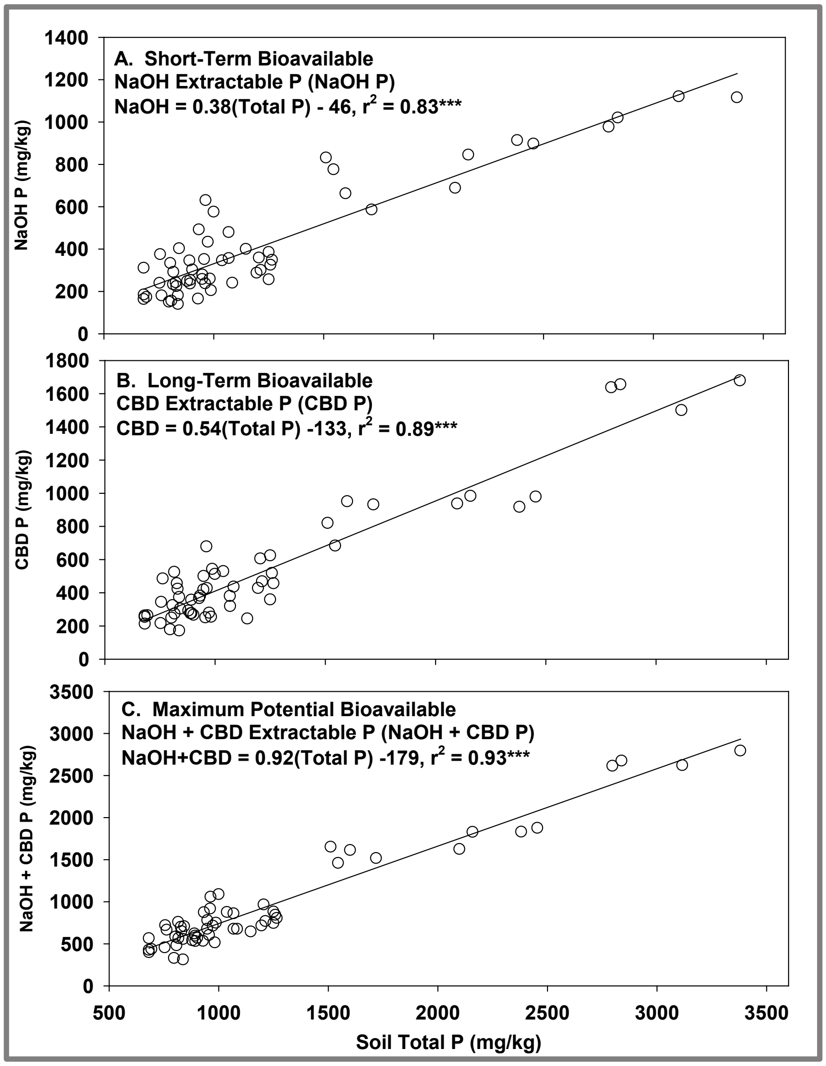


Figure 1. Relationship between A) short-term, B) long-term potential, and C) maximum potential P bioavailability and soil total P. ****P<0.0001*

Objective 2. Evaluate relationships between bioavailable P (NaOH & CBD extractable) & soil P measures (e.g. Total P, Mehlich3).

A major advantage of working with field soils rather than suspended sediments is the ability to know the sample soil total P and soil test P. With this information and using simple linear regression we established relationships necessary to estimate runoff particulate bound P bioavailability based on routine soil measures.

Using simple linear regression, either soil total P (Figure 1) and M3-P (Figure 2) were significantly (*P<0.0001*) correlated with short-term, long-term or maximum potential bioavailable P. Using these developed regression equations any of the bioavailable P fractions can be estimated if Mehlich3 or soil total P are known.

Objective 3. Estimate the bioavailability of runoff particulate P across Ohio, using On-Field Ohio P Index simulations.

Using regression equations developed in Objective 2. We can use the On-Field Ohio simulator to estimate the bioavailability of runoff particulate bound P.

The On-Field Ohio simulator is used to illustrate changes in outcomes based on “what-if” scenarios across >6000 point locations in Ohio. This allows for evaluation across a broad range of topography and soil types.

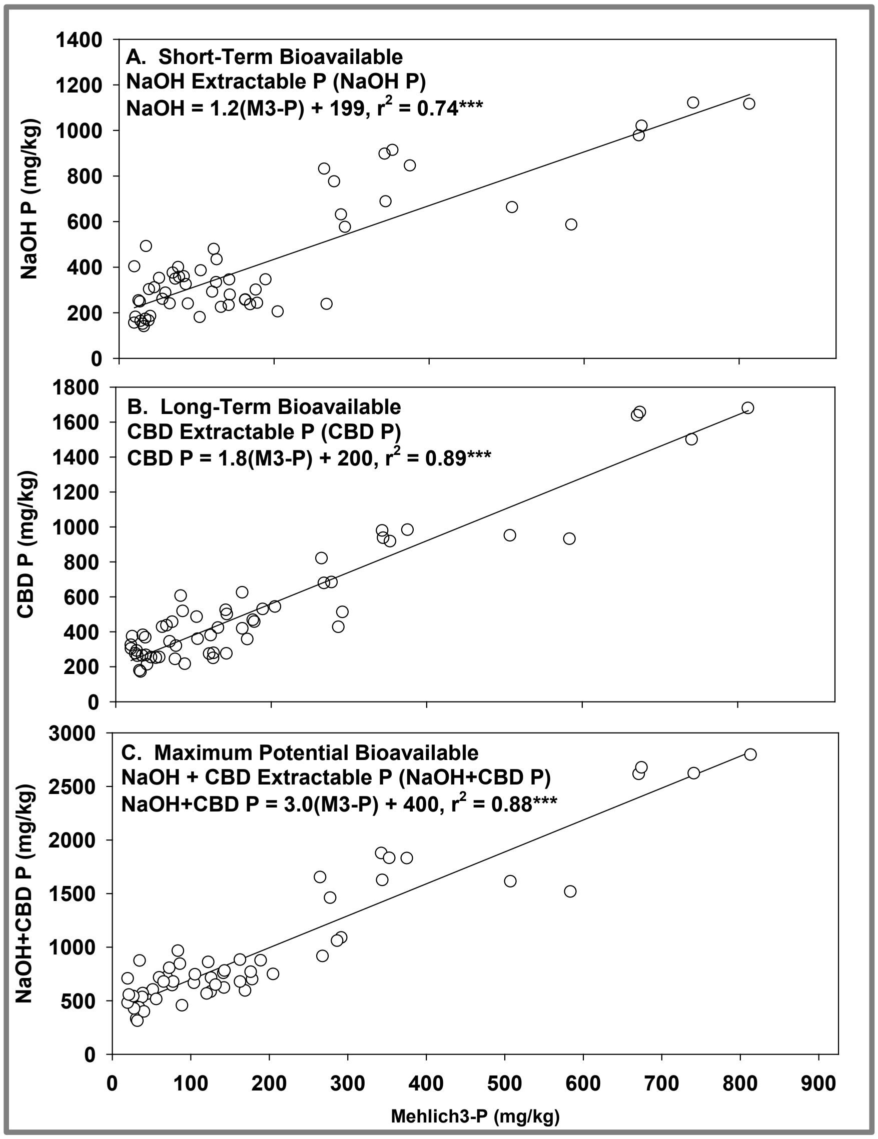
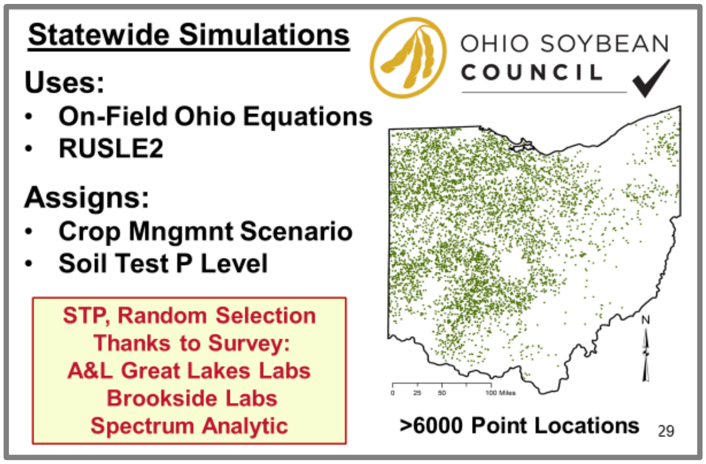


*Figure 2. Relationship between A) short-term, B) long-term potential, and C) maximum potential P bioavailability and Mehlich3 soil test P (M3-P). ***P<0.0001*

The soil test P (STP) values used in these simulations were assigned to the point locations based on 2015 soil test P data gathered from three major Ohio soil test laboratories (Figure 3). At each point location a soil test P value is randomly assigned from the STP survey data from the same sub-basin in which the point location resides.

Scenario simulations were run across four soybean/corn crop management (Figure 4) scenarios to evaluate outcomes across the full range of soil disturbance as demonstrated by the soil tillage intensity rating (STIR), which ranges from 0 to 100, as an indication of soil disturbance. In these scenarios STIR ranged from 2.6 to 94 (Figure 4).



Statewide Simulations

Uses:
- **On-Field Ohio Equations**
- **RUSLE2**

Assigns:
- **Crop Mngmnt Scenario**
- **Soil Test P Level**

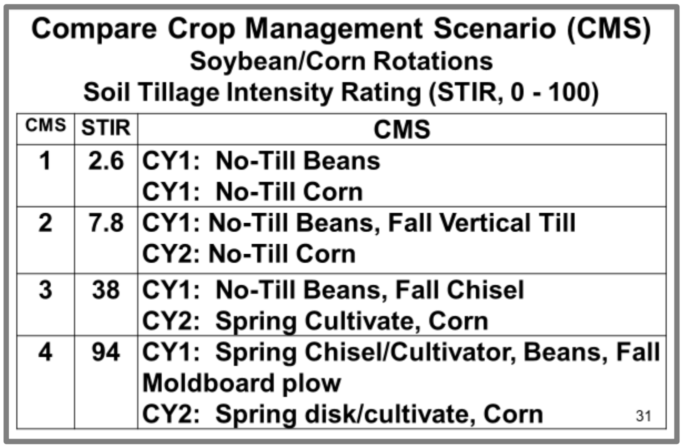
STP, Random Selection
Thanks to Survey:
A&L Great Lakes Labs
Brookside Labs
Spectrum Analytic

>6000 Point Locations

Figure 3. On-Field Ohio simulator. Allows for illustration of outcomes of "what-if" scenarios

Figure 5 shows frequency distributions for surface runoff short-term, maximum long-term potential bioavailable P and, for comparison, On-Field Ohio surface runoff particulate bound P across the four crop management scenarios and assigned soil test P. Percentiles (25th to 90th) are marked and plots are truncated at the 90th percentile for ease examination.

Short-term runoff particulate P bioavailability, as measured using an NaOH extraction ranged from 0.011 to 20 lb P/A with a median of 0.47 lb P/A (Figure 5A). On-Field Ohio runoff particulate P estimates ranged from 0.023 to 64.5 lb P/A with a median of 1.1 lb P/A. So, the estimated short-term bioavailable P (Figure 5A) is approximately 50% as compared to the On-Field Ohio runoff particulate P estimates (Figure 5C). However, the long-term maximum potential runoff particulate P bioavailability (Figure 5B), measured as the sum of NaOH and sequential CBD extractions, ranged from 0.024 to 48 lb P/A with a median of 1.0 lb P/A, which is very similar as compared to the On-Field Ohio estimated runoff particulate P (Figure 5C).



Compare Crop Management Scenario (CMS)
Soybean/Corn Rotations
Soil Tillage Intensity Rating (STIR, 0 - 100)

CMS	STIR	CMS
1	2.6	CY1: No-Till Beans CY1: No-Till Corn
2	7.8	CY1: No-Till Beans, Fall Vertical Till CY2: No-Till Corn
3	38	CY1: No-Till Beans, Fall Chisel CY2: Spring Cultivate, Corn
4	94	CY1: Spring Chisel/Cultivator, Beans, Fall Moldboard plow CY2: Spring disk/cultivate, Corn

Figure 4. Four crop management scenarios used in On-Field Ohio runoff particulate P bioavailability simulations.

Long-term maximum potential particulate P bioavailability is based on eroded sediment encountering anoxic (reduced) conditions once it moves into drainageways, streams, tributaries or lake. Under these conditions P bound to iron or manganese oxides may be released. However, not all the oxide-bound P will necessarily be released. In fact, if sediment re-oxidizes some of the released P may be re-bound. This is one of the main mechanisms behind the concept of "internal cycling" of P in lakes/rivers, where sediments alternate between acting as P sources or sinks.

For additional comparison, simulations of On-Field Ohio surface runoff dissolved P are shown in Figure 6. Surface runoff dissolved P ranged from 0.02 to 5.52 lb P/A with a median of 0.13 lb P/A. This is considerably less than the range of surface runoff particulate bound P (Figure 5C). Even though the short-term particulate P bioavailability (Figure 5A) is approximately half of either the maximum potential P bioavailability or the On-Field Ohio Particulate P (Figure 5C), it is still substantially higher than surface runoff dissolved P (Figure 6). This suggests that eroded soil remains a significant water quality risk even though all the particulate P may not be bioavailable.

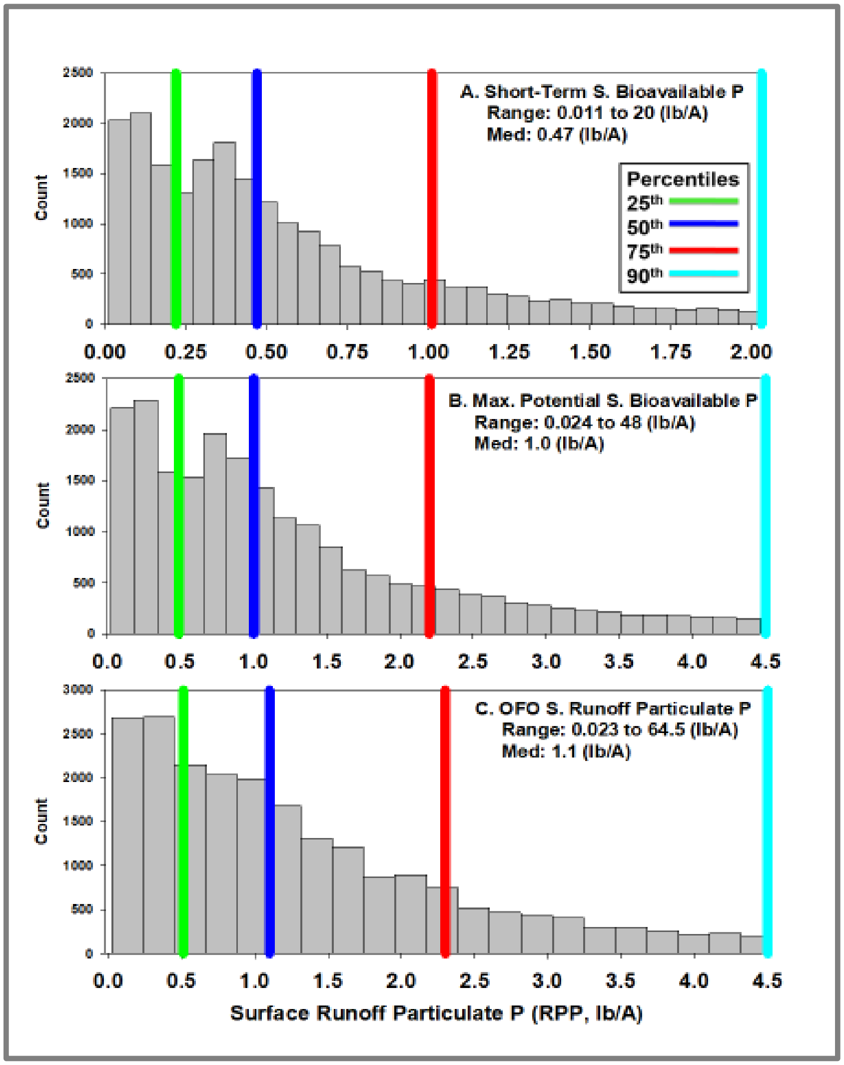


Figure 5. Frequency distributions across four crop management scenarios showing surface runoff P load estimates for A) short term, B) maximum long-term potential P bioavailability and C) On-Field Ohio particulate P.

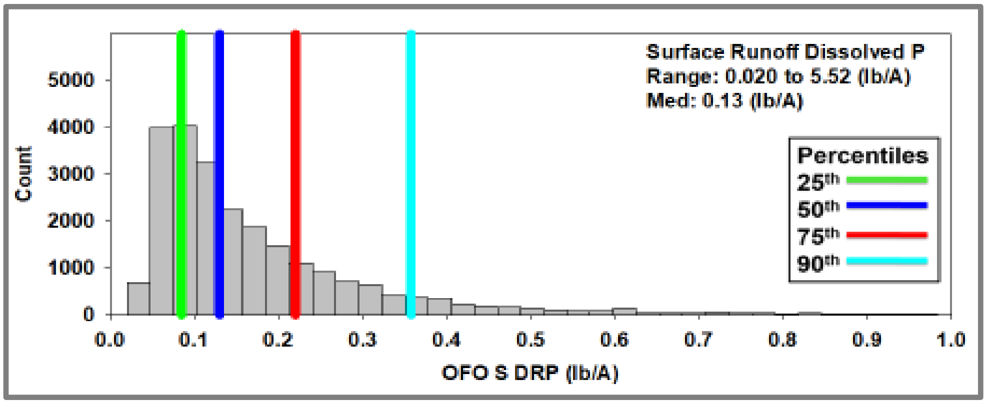


Figure 6. Frequency distribution across four crop management scenarios, showing On-Field Ohio surface runoff dissolved P load

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