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CROP MANAGEMENT—BRIEFS

On-farm corn phosphorus response reveals importance of soil testing

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Concern for declining Great Lakes Basin water quality continues to emphasize improved phosphorus (P) management strategies. Nutrient (predominately P) and algae indicators used to gauge water quality were recently highlighted as fair and unchanging (U.S. Environmental Protection Agency, 2019). The Tri-State fertilizer recommendations, covering Ohio, Indiana, and Michigan, base P fertilizer applications on the build and maintain concept, which accounts for soil test value and yield potential while providing P recommendations at or slightly above a critical soil test phosphorus (STP) concentration (Culman et al., 2020; Vitosh et al., 1995; Warncke et al., 2009). Critical concentration is the concept of an empirically derived point on a curve that relates the level of a P indicator (e.g., STP) with yield. The probability of corn (*Zea mays* L.) grain yield response to P applications in mineral soils increases when STP concentrations are deficient or below a critical concentration of 15 ppm Bray1-extractable P (Bray-P1), or 20 ppm Mehlich-3 extractable phosphorus (Mehlich 3-P). The Tri-State soil fertility P framework recommends fertilizer based on crop nutrient removal (0.35 lb P_2O_5 bu^{-1}) for corn when STP concentrations are optimal (i.e., 15–30 ppm Bray-P1 or 20–40 ppm Mehlich 3-P). Recent revisions to the Tri-State P soil fertility recommendations consider STP concentrations above 30 ppm Bray-P1 (40 ppm Mehlich 3-P) sufficient with no agronomic reason to apply P fertilizer (Culman et al., 2020). However, many growers continue to apply P in excess of recommendations to increase profitability (Dodd & Mallarino, 2005). Some agricultural soils in Michigan have STP concentrations two to three times the recommended agronomic critical level with current distribution estimates of 19, 23, and 58% of soils testing deficient, optimal, or sufficient, respectively (TFI, 2020). Continued P fertilizer applications in excess of plant uptake have increased soil test P and resulted in legacy P accumulation which can impact water quality for years (Powers et al., 2016). In 2018, western Lake Erie's shoreline, open waters, and island shoreline were declared impaired predominantly from non-point source P loading (Ohio EPA, 2020). Corn production areas in Michigan include regions within the Saginaw Bay and western Lake Erie Basins. Assessment of nutrient stratification which may occur due to fertilization and reduced tillage is important where surface exports of P have increased water quality concerns and are determined with multiple soil sampling depths (0–2 and 0–8 inch) (Culman et al., 2020; NRCS, 2020). Trials across multiple locations are important for continued assessment of soil P trends as affected by cropping system and fertilizer application (Dodd & Mallarino, 2005). Growers across Michigan were asked to host on-farm P response trials to demonstrate the importance of soil testing for determining the likelihood of corn response to P fertilizer application. The objective was to determine corn grain yield response to P fertilizer application and evaluate critical STP concentrations at two soil sampling depths (0–2 and 0–8 inch) in relation to current guidelines.

Twenty-four trials were conducted 2016–2018 on different sites with no previous history of manure application. Plots were between 300 and 600 ft in length. Prior to P fertilizer applications, soils were sampled at 0-to-2- and 0-to-8-inch depths. Each soil sample was a composite of multiple cores collected randomly from within each replication.

Abbreviations: RGY, relative grain yield; STP, soil test phosphorus

TABLE A Useful conversions

To convert Column 1 to Column 2, multiply by	Column 1 suggested unit	Column 2 SI unit
0.304	foot, ft	meter, m
2.54	inch	centimeter, cm (10^{-2} m)
62.71	56-lb bushel per acre, bu acre^{-1}	kilogram per hectare, kg ha^{-1}
1	ppm	milligram per kilogram, mg kg^{-1}
0.437	P_2O_5	P

Core Ideas

- Increased soil test P values above the critical threshold reduces the likelihood of grain yield response to P fertilizer application.
- Soil test P critical concentrations of 14 ppm indicated no change from Tri-State Soil Fertility recommendations.
- Shallower soil sampling (0–2 inches) did not improve relationship between soil test P concentration and relative grain yield.

Soils were air-dried, ground to pass a 2-mm sieve, and analyzed for pH (0–8 inch only) and STP with Bray-P1 extractant (Table 1). Study sites represented a diversity of soil P including deficient, optimal, or sufficient concentrations. The study was arranged in a randomized complete block design with three or four replications and two treatments, with (+P) or without (–P) P fertilizer. The P fertilizer rate was determined as a product of the grower's estimated yield potential and crop removal (0.35 lb P_2O_5 bu^{-1}) and varied between site-years. Field-specific recommendations were used to guide production practices at on-farm locations and included non-limiting rates of nitrogen (N) balanced between treatments and if required, potassium (K) fertilizer. Corn harvest data included grain yield and moisture. Grain yield was adjusted to 15.5% moisture. Analysis of variance (ANOVA) was conducted using Proc Mixed procedures in SAS 9.3 (SAS Institute, Cary, NC) for grain yield by site-year, and utilized random location and rep effects ($p \le .10$). The UNIVARIATE procedure and Levene's test were utilized to validate normality and homoscedasticity of residuals, respectively ($p \le .05$). Relationships between soil pH and grain yield were investigated with Pearson product-moment correlations in SAS ($p \le .05$). Relative grain yields (RGY) were calculated per site-year as the mean of the zero-P plots divided by the mean of the P fertilized plots. The Cate–Nelson (Cate & Nelson, 1971) procedure was used to divide data into two groups and identity critical STP concentrations in relation to RGY which maximized the sums of squares using the "rcompanion" package of R (R Core Team, 2015; Mangiafico, 2020). The "rcompanion" package, as used in previous studies, does not rely on a user-defined specified RGY threshold but divides the data horizontally at the RGY which minimizes the number of observations occurring in error quadrants (Fulford & Culman, 2017).

At the 0-to-8-inch soil sampling depth, results from 24 site-years indicated STP levels were deficient at two sites, optimal at eight sites, and sufficient at 14 sites (Table 1). At 9 of 24 site-years, P fertilizer application increased grain yield 3–18 bu acre^{-1} across STP levels which were deficient, optimal, or sufficient at 1, 4, and 4 site-years, respectively. When STP levels are in the maintenance range (i.e., sufficient STP) growers should not expect a corn (*Zea mays* L.) yield response to P application (Culman et al., 2020). A yield response to +P was observed at 50% of sites (19–29 ppm STP) within the current recommended maintenance range illustrating the importance of sustaining soil P levels to reduce risk of yield loss. No grain yield response to P fertilizer should be expected when STP is sufficient, but an aboveground crop response may occur when cool wet conditions limit P diffusion and early-season P uptake requirements (Havlin et al., 2014). While a grain yield response to P fertilizer was expected at P deficient sites, one of two sites was non-responsive despite a non-significant trend where the +P treatment increased yield ($p = .16$). Mean grain yield at the non-responsive site was 133 bu acre^{-1} despite a grower estimated yield potential >250 bu acre^{-1}, which indicated other yield-limiting factors (e.g., lack of precipitation) may have contributed to a lack of P response. Grain yield data illustrate the reduced likelihood of P fertilizer response as STP concentrations increase above critical thresholds and emphasizes the importance of soil testing when determining P application rates.

Surface-applied fertilizers and crop residues combined with limited soil mixing has resulted in nutrient stratification, a non-uniform distribution with soil depth, and increased surface soil P concentrations (Mallarino et al., 1999). However, Cate–Nelson analyses identified similar critical STP values regardless of soil sampling depth. At the 0-to-2-inch depth, critical STP was 14 ppm (Figure 1). At the 0-to-8-inch depth, Cate–Nelson analysis identified two critical STP values of 11 and 16 ppm (RGY = 90%) which resulted in the same sum of squares and indicated flexibility in separating P deficient and optimal P soils (11 ppm presented; Figure 2). While a 95% RGY sufficiency level has been previously suggested, 90% has also been used in the analysis of critical corn STP concentrations and minimized observations in error quadrants of the current study (Mallarino & Blackmer, 1992). Shallower soil sampling (0–2 inch) did not improve the relationship between STP concentration and relative grain yield. However,

TABLE 1 Michigan corn phosphorus (P) response research trial locations, and mean soil pH, Bray-P1 extractable soil test phosphorus (STP) observed at two depths, and corn grain yield as affected by P fertilizer application, 2016–2018

				Soil pH	**STP**		**Grain yield**		
Year	**Site**	**Location**	**County**	**0–8 inch**	**0–2 inch**	**0–8 inch**	**–P**	**+P**	$p > f$
					ppm		bu acre^{-1}		
2016	1	Richville	Tuscola	6.6	62	62	208.3	213.0	0.48
	2	Vassar	Tuscola	7.6	78	70	133.7	124.7	0.63
	3	Freeland	Saginaw	6.9	106	101	173.7	179.0	0.03
	4	Midland	Midland	7.1	98	76	130.0	128.0	0.37
2017	5	Elsie	Clinton	6.1	86	65	171.7	170.6	0.83
	6	Portland	Ionia	6.4	41	34	186.4	180.5	0.25
	7	Charlotte	Eaton	6.6	35	28	218.1	216.3	0.60
	8	Union City I	Branch	6.9	27	19	220.7	234.6	0.08
	9	Union City II	Branch	6.2	62	56	223.3	230.6	0.16
	10	Carsonville I	Huron	7.4	38	36	180.6	198.9	0.09
	11	Carsonville II	Huron	6.8	38	21	174.6	185.8	0.05
	12	Fostoria[a]	Lapeer	7.3	7	6	125.9	140.9	0.16
	13	Richville	Tuscola	7.3	26	31	178.0	178.5	0.84
	14	Shepherd	Isabella	6.2	47	28	180.9	191.5	0.08
	15	Rosebush	Isabella	7.1	60	40	196.7	199.7	0.84
	16	Weidman	Isabella	7.0	26	31	178.3	195.4	0.04
2018	17	Carsonville	Huron	7.1	45	31	186.3	186.6	0.89
	18	Mason	Ingham	6.7	43	35	182.3	183.0	0.92
	19	Fostoria[a]	Lapeer	7.2	6	6	147.6	163.7	0.07
	20	Breckenridge	Gratiot	6.7	53	42	212.3	215.5	0.07
	21	Alma	Gratiot	7.2	23	16	82.3	84.0	0.50
	22	Shepherd	Isabella	6.9	47	29	172.0	184.7	0.08
	23	Winn	Isabella	6.7	46	24	170.7	166.3	0.57
	24	Weidman	Isabella	7.0	21	16	171.3	167.0	0.20

[a] Sites where grain yield response to P fertilizer application was expected based on STP analyses.

coefficients of determination ($r^2 = .34$) were low for the graphical relationships. In a similar study, Fulford and Culman (2018) observed similar coefficients and suggested including more P-deficient testing sites for improved validity of Cate–Nelson analyses. We used the Cate–Nelson test to identify the critical value for site conditions in the current study, not to make a statistical comparison to the current Tri-State fertility recommendations critical value. Additional sites where a P response is expected could help increase precision in identifying a new critical concentration if P response occurred. However P-deficient locations are not widespread, and often other growth-limiting factors can prevent or mask a P response in sites below 15 ppm Bray-P1, which may convolute results. The current critical STP analyses were similar to the recommended critical STP concentrations for corn grown on mineral soils (15 ppm, Bray-P1) and provides validation for current guidelines. Grower operations located in critically impaired watersheds may still consider variable soil sampling depths to identify other soil physical or chemical property limitations. However, the current data indicate that soil sampling depth does not require adjustment when determining critical STP values.

Validating and identifying critical STP concentrations provides a foundation for the development of effective P strategies across cropping systems. Results from the current study illustrated that current P recommendation guidelines reduce risk of yield loss potential due to insufficient soil P supply. Moreover, they supported critical STP concentrations recently published in the Tri-State fertility recommendations. Current guidelines suggest nutrient managers conduct soil sampling at least every 3–4 years as part of a comprehensive nutrient management program (Culman et al., 2020). Our study emphasized that soil testing should be considered prior to making P fertilizer decisions.

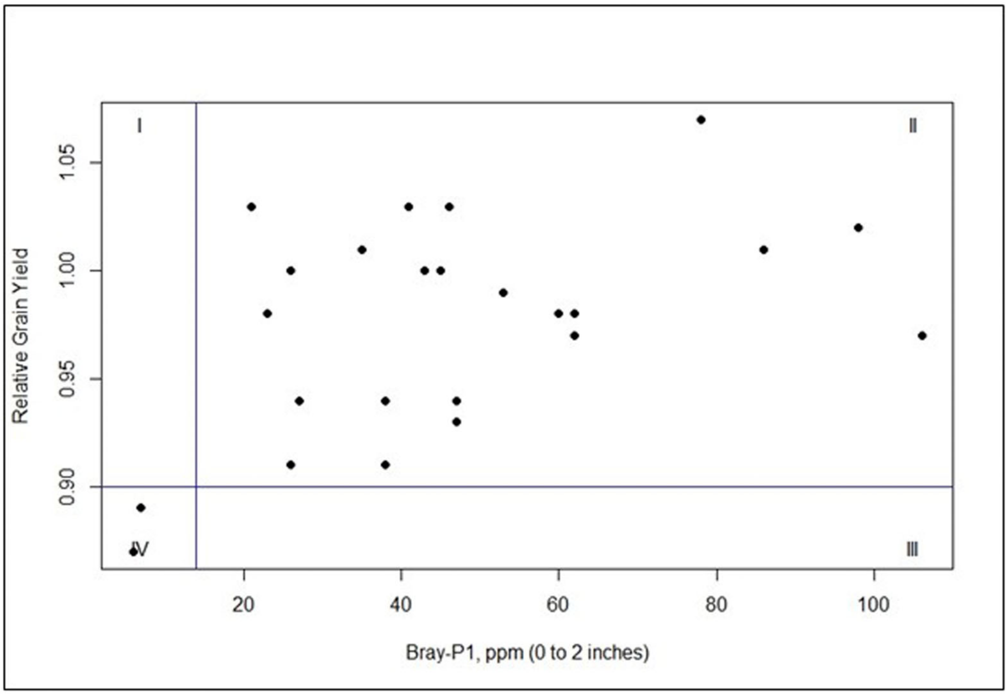

FIGURE 1 Relationship between soil test phosphorus (Bray-P1; STP) collected at a 2-inch depth and percentage relative corn grain yield across 24 Michigan site-years, 2016–2018. Graph was significantly divided into four Cate–Nelson quadrants indicated by blue lines and validated by the Fisher exact test ($p < .01$). Points in quadrants I and III are minimized and represent deviations from expected behavior while points in quadrants II and IV indicate changes in the x variable that are likely to correspond to changes in the y variable. Critical STP = 14 ppm; $r^2 = .34$

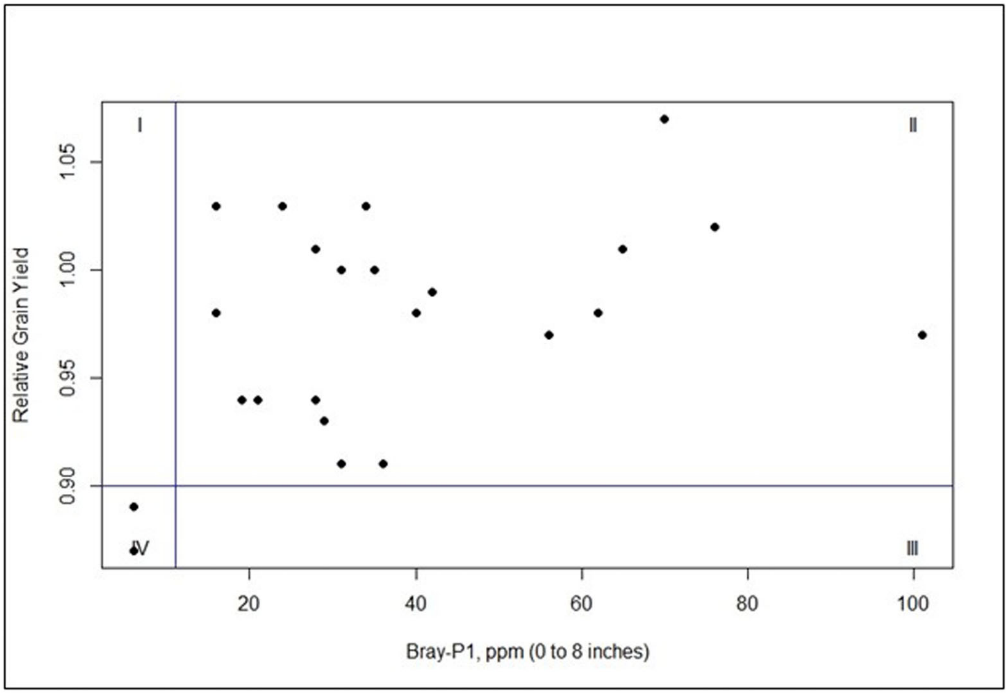

FIGURE 2 Relationship between soil test phosphorus (Bray-P1; STP) collected at an 8-inch depth and percent relative corn grain yield across 24 Michigan site-years, 2016–2018. Graph was significantly divided into four Cate–Nelson quadrants indicated by blue lines and validated by the Fisher exact test ($p < .01$). Points in quadrants I and III are minimized and represent deviations from expected behavior while points in quadrants II and IV indicate changes in the x variable that are likely to correspond to changes in the y variable. Critical STP = 11 ppm; $r^2 = .34$

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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