CROP AND SOIL RESPONSE TO DIFFERENT PHOSPHORUS MANAGEMENT APPROACHES

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ABSTRACT

Phosphorus (P) management has implications for crop production and water quality in Ohio. Recent data from 457 field P trials conducted in Ohio reported less than 25% positive yield response to P fertilization. It warrants further evaluation of crop P uptake, soil P levels and other relevant factors to improve the predictability of crop yield response. Therefore, we collected soil and plant data from three P fertilizer trials (Northwest, Western and Wooster) established in 2006. These sites have three P-fertilization approaches: no P (0x), maintenance approach (1x), and build up approach (3x), replicated four times with a corn-soybean rotation. Data show that soil P levels were different across the treatments with 0x treatment with the lowest soil P levels. Despite different soil P levels, yield differences during the study period were sporadic. We observed a significant correlation of soil P content and grain P uptake. The soil P budget over six years was negative for no P plots, near zero for maintenance and positive for build up approach. Overall, the findings of the study provided insights into how soil P levels and yield could change with different P management strategies. The study will have implications on P management in Ohio.

INTRODUCTION

Phosphorus (P) management is crucial for Ohio growers, not only for optimizing crop yield and productivity but also to mitigate its impact on water quality (Hanrahan et al., 2019; Brooker et al., 2017). Phosphorus management practices have long been guided by the Tri-State Fertilizer Recommendations, which provide nutrient management guidelines for Ohio, Michigan, and Indiana (Culman et al.,2020; Vitosh et al., 1995). These recommendations follow a build-up and maintenance strategy, specifying application rates and conditions under which a yield response may be expected. When soil test phosphorus (STP) falls within the maintenance range of 20-40 ppm (Mehlich-3), P additions are recommended at crop removal rates. Below this maintenance range, P applications include a build-up component to replenish STP to these maintenance levels over 4 years (Vitosh et al., 1995). The 20-ppm threshold is considered the critical STP level for corn and soybean, above which the likelihood of a significant positive yield response to additional P decreases (Culman et al., 2023; Culman et al.,2020; Vitosh et al., 1995).

Growers and researchers implementing the recommended strategies frequently report inconsistent yield responses or failure to build STP even when exceeding Tri-State Recommendations (Culman et al., 2023; Wade et al., 2019; Fulford & Culman 2018). Out of 457 trials evaluating crop yield response to P fertilization, only 23% showed a positive yield response (Culman et al., 2023). The occurrence of responsive sites was sporadic, with no clear trends or identifiable factors driving these responses.

While the intuitive response may be to further increase P application rates, the economic viability and efficacy of such practices remain questionable. To ensure sustainable P management, a better understanding of best management strategies is essential to balance crop nutrient requirements with continuous efforts to minimize agricultural P losses. Here, our study evaluated soil and crop response to three P management approaches, 1):no P (0x), 2): maintenance (1x: crop removal rate) and 3) build up approach (3x crop removal rate). The objective is to determine crop response to these management strategies and their implication on P- budgets.

MATERIAL AND METHODS

An experiment was established in 2006 at three sites at the Northwestern, Western and Wooster Research and Development centers in Ohio. Soil characteristics varied between sites. Northwest site has a Hoytville clay loam, Western has a Kokomo silt loam and Wooster has a canfield silt loam. The soil pH varies from 5.8 to 6.7 and organic matter range from 1.6 to 2.5 percent across sites. Baseline nutrient analysis showed initial available P at 22 ppm, 27 and 29 ppm at Northwest, Western and Wooster, respectively.

The study consisted of three fertilizer treatments: no P (0x), maintenance approach (1x), and build up approach (2x), x represents the P removal rates. Treatments were replicated four times on a corn-soybean and corn-corn-soybean rotation until 2014. Phosphorus fertilizer was applied following soybean harvest only. In 2015, the fertilizer application rate was increased in 2x treatment to three times of crop removal P rate (3x) and the corn-corn-soybean was changed to corn-soybean. In this paper, we summarized crop and soil response to different P approaches from 2015-2020.

Soil samples were collected each fall after crop harvest from 0 to 8 inches. The samples were air-dried, ground, and analyzed for available P using Mehlich-3 extraction procedure (NCERA-13, 2015). Leaf tissue samples were collected at reproductive stage (R1) to determine plant P concentration. At harvest, grain yield data was collected by harvesting the two center rows of corn plots and center six rows of soybean plots. Grain yield is reported at 15.5% moisture content for corn and 13% for soybeans. A sub-sample of harvested grain was used to determine P concentration for both crops.

Analysis of variance was conducted by site, crop, and year using proc mixed in SASv9.3 (SAS Institute, Cary, NC) to determine the effect of P management on soil P and crop yield. The significance level was set at $P \leq 0.05$ for all statistical analysis. All subsets regression models were constructed to identify the most parsimonious sets of predictors of corn and soybean yields based on the AIC values using the olsrr package in R.v4.3.3 (Hebbali, 2024). To determine P budget, the following equation was used for the plots with corn-soybean rotation.

P budget (2015-2020) = P input (fertilizer amount)- P removal (crop yield x grain P concentration) for each site and P-management combination.

RESULTS AND DISCUSSION

Management strategies significantly affected available soil P (Fig 1). The soil P levels were the highest for buildup approach (3x) whereas no P approach (0x) had the lowest soil P across sites. The magnitude of soil P level difference varied among P treatments and varied by year and site. For example, at Northwest, the 3x treatment had 41 ppm more soil P compared to the 0x treatment in 2015. At the same site, the difference of soil P between 0x and 3x treatments increased to 117 ppm by 2020. At Wooster, the soil P difference among 0x and 3x treatments changed from 30 to 49 ppm over the six-year time-period. The observed difference can be explained by two factors: First, soil P decreased in no P treatment over six years, but the magnitude of decrease differed across sites. The highest drawdown was observed at the Northwest with 14 ppm, Wooster location showed only 1 ppm drop in soil P level over six years. Second, soil P build up showed substantial difference across sites. The soil P level increased from 76 to 138 ppm at Northwest whereas it changed from 49 to 67 ppm at the Wooster location. Our data suggest that different P approaches can significantly affect the soil P levels, however the magnitude of change is site-specific. Our findings have important implications for future research that should evaluate the fixation and distribution of P into different P pools with fertilizer input.

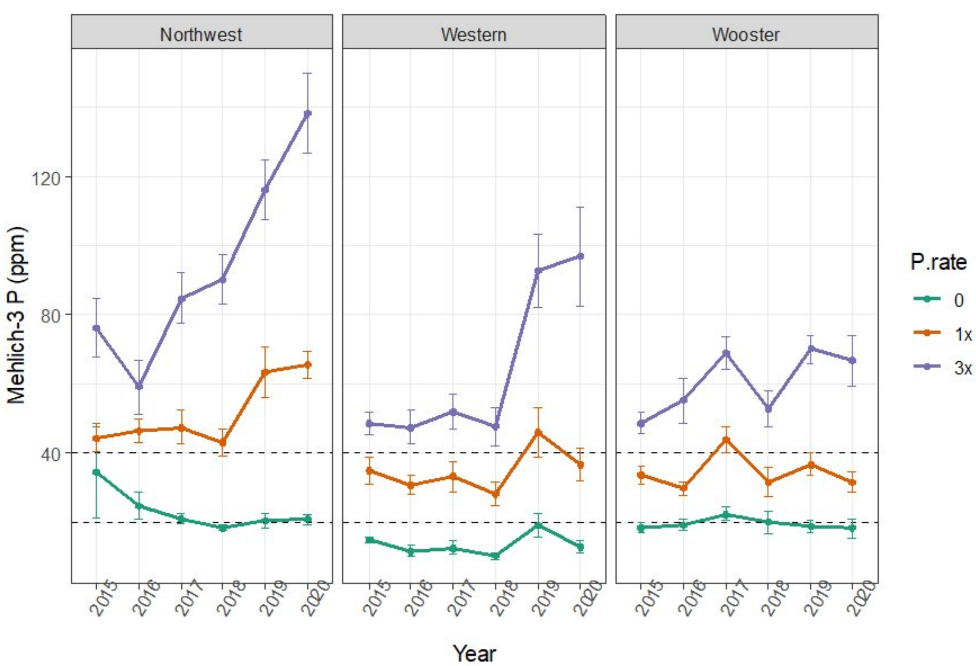

Fig. 1. Available soil P (Mehlich 3-P) under three different P management approaches (0x: no P, 1x: maintenance approach, 3x: build up) from 2015 to 2020 at three sites in Ohio.

Contrary to soil available P results, yield response was infrequent to P management. From 2015-2020 only 5 trials significantly responded to P application (4 corn and 1 soybean). The yield was higher in the buildup P management strategy than other P approaches. Significant corn yield differences were observed at the Northwest location in 2018 and 2019 and at the Wooster location in 2015 and 2016. Soybean yield differed among treatments in 2020 at the Western location (Table 1.). The difference in yield response ranged between 10-23% between the no P approach and the buildup approach at both Northwest and Wooster site.

Table 1. Average grain yield for corn and soybean from different P management approaches: no P application (0x), maintenance approach (1x) and build up approach (3x) from 2015 to 2020.

		2015	**2016**	**2017**	**2018**	**2019**	**2020**
Sites	P.Rate	Corn grain yield (bu/ac)					
Northwest	0X	117.23 (10.11)	145.71 (4.49)	149.77 (6.3)	186.26 (2.43)[b]	150.95 (3.84)[b]	104.32 (4.76)
	1X	106.65 (4.5)	154.61 (6.16)	151.42 (7.45)	199.64 (4.09)[a]	161.27 (4.18)[ab]	106.84 (8.3)
	3X	120.25 (2.3)	152.34 (5.32)	159.79 (1.39)	206.23 (5.61)[a]	180.04 (2.68)[a]	91.33 (9.75)
Western	0X	199.35 (6.83)	119.22 (32.38)	194.63 (6.58)	.	121.62 (17.19)	195.19 (45.78)
	1X	191.6 (6.69)	107.58 (24.69)	204.79 (7.54)	215.09 (13.17)	109.13 (15.92)	187.84 (6.86)
	3X	209.68 (7.33)	175.95 (13.23)	216.94 (4.54)	234.38 (1.35)	139.74 (6.37)	224.19 (7.1)
Wooster	0X	151.63 (6.54)[b]	95.08 (1.82)[b]	169.01 (16.05)	138.9 (8.86)	99.77 (2.85)	169.66 (1.9)
	1X	166.98 (10.53)[ab]	103.88 (3.5)[ab]	149.9 (30.69)	182.79 (12.41)	104.1 (2.81)	200.63 (9.77)
	3X	174.48 (5.64)[a]	117.6 (9.3)[b]	173.51 (11.32)	169.48 (4.75)	102.09 (3.01)	174.94 (9.39)
		Soybean grain yield (bu/ac)					
Northwest	0X	43.31 (2.31)	65.06 (1.51)	42.8 (2.76)	75.32 (1.31)	47.15 (2.21)	50.78 (1.51)
	1X	46.94 (2.62)	65.19 (3.12)	41.07 (1.09)	72.15 (1.36)	48.32 (2.72)	53.02 (1.13)
	3X	47.65 (2.16)	67.82 (0.99)	43.39 (4.64)	76.86 (0.52)	49.24 (2.35)	50.85 (1.5)
Western	0X	48.7 (3.26)	56.32 (5.18)	69.56 (3.17)	66.82 (4.64)	40.77 (0.28)	18.55 (1.74)[b]
	1X	47.33 (4.02)	48.58 (3)	80.48 (5.59)	61.29 (1.73)	44.13 (7.14)	23.35 (1.47)[ab]
	3X	53.1 (4.62)	58.29 (1.48)	85.03 (4.05)	65.78 (4.05)	53.17 (5.67)	28.39 (3.23)[a]
Wooster	0X	44.33 (1.59)	37.6 (2.21)	49.54 (1.29)	47.72 (1.07)	28.39 (2.99)	47.32 (3.2)
	1X	46.95 (0.63)	38.93 (1.53)	58.48 (6.87)	43.73 (1.35)	25.17 (1.27)	49.79 (2.98)
	3X	47.48 (2.18)	39.89 (0.59)	60.35 (3.93)	46.89 (2)	26.44 (2.52)	48.35 (3.6)

Crop P tissue data for both corn and soybean showed a positive, but weak relationship with soil P (R^2 of 0.077 for corn and R^2 = 0.023 for beans), whereas P concentration in the grain showed stronger relation to soil P (R^2 = 0.26 for corn and R^2 = 0.43 for beans). To further evaluate the most relevant factor that explains the crop yield, we tested the significance of organic matter, leaf tissue P and grain P concentration, soil P levels, P fertilizer rate, soil pH, and cation exchange capacity (CEC). Corn yield prediction was best explained by soil pH, CEC, organic matter, P fertilizer rate, soil P and leaf P concentration at R1. Soybean yield prediction was best explained by soil pH, organic matter, and leaf P concentration at R1.

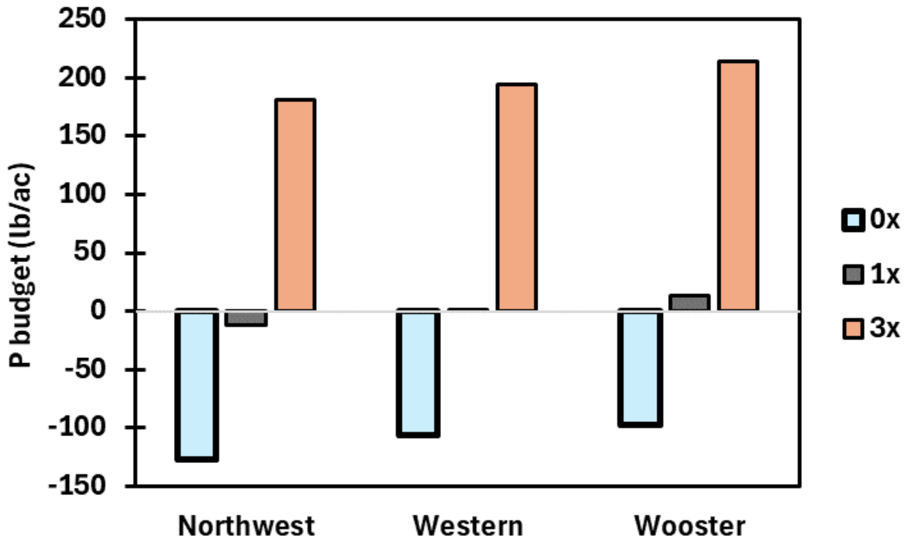

Fig. 2. Net P gain or loss from cropping system over six years due to different P management approaches at three locations in Ohio.

The P budget was affected by different P management approaches (Fig. 2). The 0x treatment showed negative P budgets at all three locations with a range of 97 to 127 lb P removed per ac over six years. It is interesting to note that even though crops removed P (106 lb/ac at Wooster and 97 lb/ac at Western) out of the system, the soil P levels of 0x treatment remained relatively similar at Western and Wooster over six-year period (Fig. 1). The P budget was slightly negative at Wooster, near zero at Western, and slightly positive at Wooster for maintenance approach. As expected, the buildup approach added 181 to 214 lb of P/ac to P net budget across sites.

Overall, our results indicate that different P management approaches can significantly affect the soil P levels and net P budget of a cropping system. To predict yield response, our study indicated that parameters such as soil pH and organic matter should be considered along with P fertilizer rate and soil P levels. The P budget findings revealed an interesting pattern of negative P budget under no P addition scenarios, yet no corresponding decline in available soil P levels were observed. Future studies should evaluate the contribution of other P pools and available soil P beyond routine soil sampling zone to explain the crop P uptake and yields.

REFERENCES

Brooker, A. P., Lindsey, L. E., Culman, S. W., Subburayalu, S. K., and Thomison, P. R. (2017). Low Soil Phosphorus and Potassium Limit Soybean Grain Yield in Ohio. *Crop, Forage & Turfgrass Management*, *3*(1), 1–5. https://doi.org/10.2134/cftm2016.12.0081

Culman, S., Fulford, A., LaBarge, G., Watters, H., Lindsey, L. E., Dorrance, A., and Deiss, L. (2023). Probability of crop response to phosphorus and potassium fertilizer: Lessons from 45 years of Ohio trials. *Soil Science Society of America Journal*, *87*(5), 1207–1220. https://doi.org/10.1002/saj2.20564

Culman, S., Fulford, A., Camberato, J., and Steinke, K. (2020). Tri-State Fertilizer Recommendations. Bulletin 974. College of Food, Agricultural, and Environmental Sciences. Columbus, OH: The Ohio State University

Dayton, E. A., Shrestha, R. K., Fulford, A. M., Love, K. R., W. Culman, S., & Lindsey, L. E. (2020). Soil test phosphorus and phosphorus balance trends: A county-level analysis in Ohio. *Agronomy Journal*, *112*(3), 1617–1624. https://doi.org/10.1002/agj2.20146

Fulford, A. M., and Culman, S. W. (2018). Over-Fertilization Does Not Build Soil Test Phosphorus and Potassium in Ohio. *Agronomy Journal*, *110*(1), 56–65. https://doi.org/10.2134/agronj2016.12.0701

Hanrahan, B. R., King, K. W., Williams, M. R., Duncan, E. W., Pease, L. A., and LaBarge, G. A. (2019). Nutrient balances influence hydrologic losses of nitrogen and phosphorus across agricultural fields in northwestern Ohio. *Nutrient Cycling in Agroecosystems*, *113*(3), 231–245. https://doi.org/10.1007/s10705-019-09981-4

Hebbali, A. (2024). olsrr: Tools for Building OLS Regression Models. 10.32614/CRAN.package.olsrr.

NCERA-13. (2015). Recommended chemical soil test for the North Central Region. North Central Region Research Publication. No. 221. Missouri Agricultural Experiment Station SB 1001. University of Missouri. https://hdl.handle.net/

Vitosh, M.L., J.W. Johnson, and D.B. Mengel. (1995). Tri-State fertilizer recommendations for corn, soybeans, wheat and alfalfa. Ext. Bull. E-2567. Michigan State Univ., East Lansing.

Wade, J., Culman, S. W., Sharma, S., Mann, M., Demyan, M. S., Mercer, K. L., and Basta, N. T. (2019). How Does Phosphorus Restriction Impact Soil Health Parameters in Midwestern Corn–Soybean Systems? *Agronomy Journal*, *111*(4), 1682–1692. https://doi.org/10.2134/agronj2018.11.0739