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Low Soil Phosphorus and Potassium Limit Soybean Grain Yield in Ohio

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Abstract

A soil survey was conducted in Ohio with the following objectives: (i) to assess the status of soil fertility; (ii) to examine soybean grain yield in areas with fertility levels in the build-up range, where soil test levels were less than the critical level (CL); the maintenance range, where soil test levels were between the CL and maintenance limit (ML); and the drawdown range, where soil test levels were greater than the ML; and (iii) to determine if the soil test and yield data collected support the state-established fertility recommendations. Soil sampling was conducted from 2013 through 2015 resulting in 593 total samples. Soil P, K, Ca, Mg; pH; organic matter (OM); and cation exchange capacity (CEC) were measured. Soybean grain yield was also collected from the sampling areas. Twenty-one and 23% of the soil samples collected were within the build-up range for P and K, respectively. On average, grain yield was 7 bu/acre lower in sampling areas associated with soil P levels in the build-up range, whereas an average grain yield reduction of 4 bu/acre was associated with K levels in the build-up range. In sampling areas, there was no difference in grain yield associated with soil P and K levels within the maintenance range and drawdown range. Our data suggest that soil test levels within the build-up range were associated with lower soybean grain yields.

Previously Established Soil Fertility Guidelines for Ohio

The state-established soil fertility recommendations for Ohio are found in the Tri-State Soil Fertility Recommendations for Corn, Soybeans, Wheat, and Alfalfa which was published in 1995 (Vitosh et al., 1995). In Ohio, soybean grain yield increased by 32% between 1995 and 2015 (USDA-NASS, 2016). More than twenty years later, with growers achieving higher soybean yields, many question the validity of the state-established guidelines. The Tri-State Soil Fertility Recommendations are based on the scheme shown in Fig. 1, where the critical level is defined as the soil test level above which the soil can supply adequate quantities of a nutrient to support optimum yield, and ML is defined as the soil test level above which there is no agronomic reason to apply fertilizer. The CL and ML divide soil test levels into three ranges: build-up, maintenance, and drawdown. When soil test levels are within the build-up range, where soil test level is less than the CL, fertilizer application is recommended

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Core Ideas

- Twenty-one percent of the soil samples were within the build-up range for P.
- Twenty-three percent of the soil samples were within the build-up range for K.
- Soybean yield decreased when soil test P and K were within the build-up range.

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Abbreviations: CEC, cation exchange capacity; CL, critical level; IPNI, International Plant Nutrition Institute; ML, maintenance limit; OM, organic matter.

Conversions: For unit conversions relevant to this article, see Table A.

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Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
0.405	acre	hectare, ha
0.454	pound, lb	kilogram, kg
1.12	pound per acre, lb/acre	kilogram per hectare, kg/ha
1.12×10^{-1}	pound per acre, lb/acre	megagram per hectare, Mg/ha
2.54	inch	centimeter, cm (10–2 m)

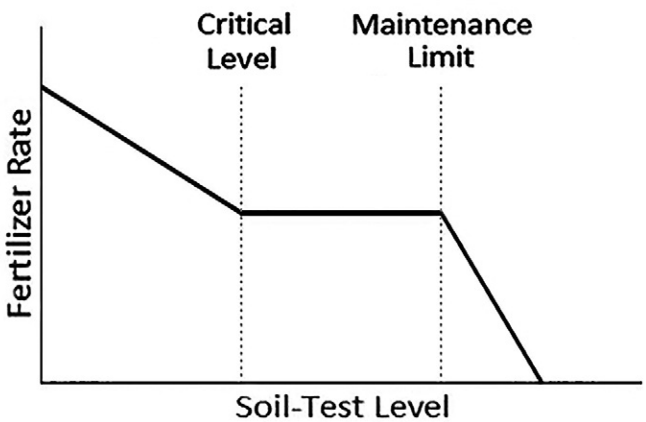

Fig. 1. Fertilization recommendation scheme used in the Tri-State Soil Fertility Recommendations (adapted from Vitosh et al., 1995). The critical level is defined as the soil test level above which the soil can supply adequate quantities of a nutrient to support optimum yield, and maintenance limit is defined as the soil test level above which there is no agronomic reason to apply fertilizer.

to supply additional nutrients and raise the soil test to the CL. When soil test levels are within the maintenance range, where soil test levels are between the CL and ML, fertilizer application is recommended to replace the nutrients lost each year through crop removal. In the drawdown range, where soil test level is greater than the ML, fertilizer application is quickly reduced to zero (Vitosh et al., 1995).

Using data from soil testing labs, the International Plant Nutrition Institute (IPNI) summarized the status of soil fertility throughout the United States and parts of Canada. In Ohio, the 2015 IPNI summary indicated that 33 and 32% of soil samples were within the build-up range for P and K, respectively (IPNI, 2015; Vitosh et al., 1995). Twenty-eight percent of soil samples had a pH less than 6.0, whereas 20% had a pH greater than 6.8 (IPNI, 2015).

The soil samples submitted to the soil testing labs and used in the IPNI summary were not collected with a uniform soil sampling procedure, and the IPNI summary did not examine the relationship between soil fertility status and soybean grain yield. In our survey, a uniform soil testing protocol was established with the following objectives: (i) to assess the status of soil fertility; (ii) to examine soybean grain yield in areas with fertility levels in the build-up range, where soil test levels were less than the CL; in the maintenance range, where soil test levels were between the CL and ML; and the drawdown range, where soil test levels were higher than the ML; and (iii) to determine if the soil test and yield data collected support the state-established fertility recommendations.

Assessing the Status of Soil Fertility in Ohio

In Ohio, a survey to assess the status of soil fertility and associated soybean grain yield was conducted annually from 2013 through 2015. Farmers volunteered to participate and selected fields that they manage to be used in the survey. Sixty-five fields were sampled in 2013, 75 in 2014, and 59 in 2015 by Ohio State University Extension educators and graduate students using a common protocol (Lindsey et al., 2014). Farmers could participate in more than 1 year, but the same fields were not sampled in subsequent years. All cultural practices were dependent on each farmer's decisions. Soil samples were collected from three sampling areas within each field and the GPS coordinates of each area recorded. One historically low-yielding area and two high-yielding areas were sampled the basis of the farmers' knowledge of the field and use of yield maps if available. There were 593 soil samples collected in total. Soil samples were collected in May through June of each year just prior to soybean planting. Each soil sample consisted of 10–15 homogenized 1-inch-diameter by 8-inch-deep soil cores collected in a zig-zag pattern within each sampling area as recommended by Vitosh et al. (1995).

Soil samples were air-dried and analyzed for Mehlich-3 extractable P, K, Ca, and Mg. Soil pH, organic matter (OM), and cation exchange capacity (CEC) were analyzed using the recommended soil test procedures for the north-central region (Nathan and Gelderman, 2012). The soil-test nutrient level from each sampling area was assigned to one of three categories: build-up range, maintenance range, or drawdown range (Vitosh et al., 1995). The build-up range, maintenance range, and drawdown range are shown in Table 1. Ranges originally outlined in the Tri-State Soil Fertility Recommendations are based on Bray P1 analysis for P and ammonium acetate for K but have been converted to Mehlich 3 values in

Table 1. Mehlich-3 extractable P, K, Ca, and Mg build-up range, P and K maintenance range, and P and K drawdown range.†

Soil nutrients‡	Build-up range	Maintenance range	Drawdown range
P (ppm)	<23	23–51	>51
K (ppm)			
CEC 5 meq/100 g	<88	88–140	>140
CEC 10 meq/100 g	<100	100–150	>150
CEC 20 meq/100 g	<125	125–175	>175
CEC 30 meq/100 g	<150	150–200	>200
Ca (ppm)§	<200		
Mg (ppm)	<50		

†Adapted from Vitosh et al., 1995.

‡Bray P values published in Vitosh et al., 1995, converted to Mehlich 3 P values using the equation: Mehlich 3 $P = 6.56 + (1.12 \times \text{Bray P})$. Ammonium acetate extraction values for K, Ca, and Mg were similar to Mehlich 3 extraction values, so no conversion was required (Culman, unpublished data, 2016). CEC, cation exchange capacity.

§There is no established maintenance or drawdown range for Ca and Mg.

Table 1. Ranges for K differ depending on the CEC. High-clay soils (associated with high CEC) often require higher K levels to support optimum yield compared to soils with low clay content (associated with low CEC; Vitosh et al., 1995).

Evaluating the Association between Soil Fertility and Soybean Grain Yield

In Ohio, soybean grain yield data were collected from the soil sampling areas using the recorded GPS coordinates by either (i) determining the weight of the grain harvested from the area using a weigh wagon or (ii) using calibrated yield monitors and calculating the grain yield from each sampling area using ArcGIS (Esri, Redlands, CA) or SMS (Ag Leader Technology, Ames, IA) mapping software. Yield was reported at 13% moisture content. Yield information was obtained from 35% of the sampling areas ($n = 219$).

For soil P and K two comparisons were made: (i) the average soybean grain yield from sampling areas with soil test values within the build-up range vs. above the build-up range (within the maintenance or drawdown range), and (ii) the average soybean yield from sampling areas with soil test values within the maintenance range vs. within the drawdown range. For soil pH, the average yield from sampling areas that were below the desired pH range (<6.0) and above the desired range (>6.8) were compared separately to the average yield of those that fell within the desired range (6.0–6.8). Mean comparison was conducted using the Proc TTEST procedure, using a grouped t test, in SAS 9.4 (SAS Institute Inc., Cary NC). Significance was determined at $\alpha = 0.05$. The TTEST procedure was used to determine the association between soybean grain yield and soil fertility factors, acknowledging that yield differences are limited to the study years and sampling areas.

Status of Soil Fertility in Ohio

In Ohio, 21 and 23% of the soil samples collected were within the build-up range for P and K, respectively. In the IPNI survey, 33% and 32% of samples were within the build-up range for P and K, respectively (IPNI, 2015). Thirty-five percent and 44% of the soil samples were within the drawdown range for P and K, respectively (Table 2). There were no soil samples within the build-up range for Ca and only three samples within the build-up range for Mg. Nineteen percent of the soil samples had a pH less than 6.0, 59% were within the recommended range for soybean production of 6.0–6.8, and 23% were higher than 6.8. In the IPNI survey, 28% of samples had a pH less than 6.0 and 20% of samples had a pH higher than 6.8 (IPNI, 2015). Organic matter levels ranged from 1.1 to 33.7%, with an average of 3.2%. The soil CEC ranged from 4.4 to 38.3 meq/100 g with a mean of 14.4 meq/100 g.

Of the fields sampled, 65% had at least one area of the field that had a soil P level within the build-up or maintenance range, for which fertilizer application would be recommended (Fig. 2). Fifty-eight percent of the fields had at least one area of the field where soil K level was within the build-up range or maintenance range, and for which fertilizer application would be recommended (Fig. 3). Nineteen percent of the soybean fields had at least one area with soil pH less than 6.0, for which lime application would be recommended (Fig. 4). These data indicate that many fields in Ohio have at least one area where P fertilizer, K fertilizer, or lime application would be recommended. Soil sampling and precise fertilization and soil amendment application may help reduce the risk of yield loss in specific areas of a field.

Association between Soil Fertility Factors and Soybean Grain Yield

Grain yield ranged from 22 to 82 bu/acre, and the average and median yield were both 56 bu/acre. Sixty-nine percent of the sampling areas with soil P in the build-up range were below the average yield. No sampling area had a yield greater than 63 bu/acre when soil P was within the build-up range. A grain yield reduction of 7.4 bu/acre was associated with soil P levels within the build-up range (Table 3). Sampling areas with soil P within the maintenance range yielded 56 bu/acre compared with those above the maintenance range, which yielded 59 bu/acre, but this difference was not statistically significant (results not shown).

Fifty-eight percent of the sampling areas with soil K in the build-up range were below the average yield. A grain yield reduction of 4.0 bu/acre was associated with K levels within the build-up range (Table 3). Sampling areas with soil K within the maintenance range yielded 56 bu/acre compared with those above the maintenance range, which yielded 57 bu/acre, but the difference was not statistically significant (results not shown).

Fifty-two percent of the sampling areas had below-average yields when the soil pH was less than 6.0 (results not shown.) However, there was no significant effect of low pH (<6.0) on

Table 2. Soil P, K, Ca, Mg, pH, organic matter, and cation exchange capacity (CEC) of samples collected in Ohio from 2013 through 2015.†

Properties	No. of samples	% of total	Minimum	Maximum	Mean	SD
Total P (ppm)	593		3	785	55	62
Build-up (<23.4 ppm)	126	21.3	3	23	17	4.3
Maintenance 23.4–51.4 ppm)	261	44.0	24	51	37	7.7
Drawdown (>51.4 ppm)	206	34.7	52	785	101	88
Extractable K (ppm)‡	593		23	633	177	75
Build-up	128	22.6	23	148	98	25
Maintenance	207	34.9	101	199	147	19
Drawdown	258	43.5	151	633	241	67
Extractable Ca (ppm)	591	100.0	391	5620	1816	835
Extractable Mg (ppm)	593		22	1267	282	148
Below CL (<0 ppm)§	3	0.5	22	42	32	10
Above CL (>50 ppm)	590	99.5	64	1267	283	148
Soil pH	593		4.9	8.0	6.5	0.6
Below 6.0	110	18.6	4.9	5.9	5.7	0.2
6.0–6.8	347	58.5	6.0	6.8	6.4	0.2
Above 6.8	136	22.9	6.8	8.0	7.2	0.3
Organic matter (%)	593		1.1	45	3.2	2.6
CEC (meq/100 g)	591		4.4	38	14	5.0

†Samples are categorized in build-up, maintenance, and drawdown ranges, or above/below the critical level (CL) for nutrients where these ranges are not established.

‡Build-up, maintenance, and drawdown ranges for K are dependent on the CEC.

§CL is defined as the soil test level above which the soil can supply adequate quantities of a nutrient to support optimum yield.

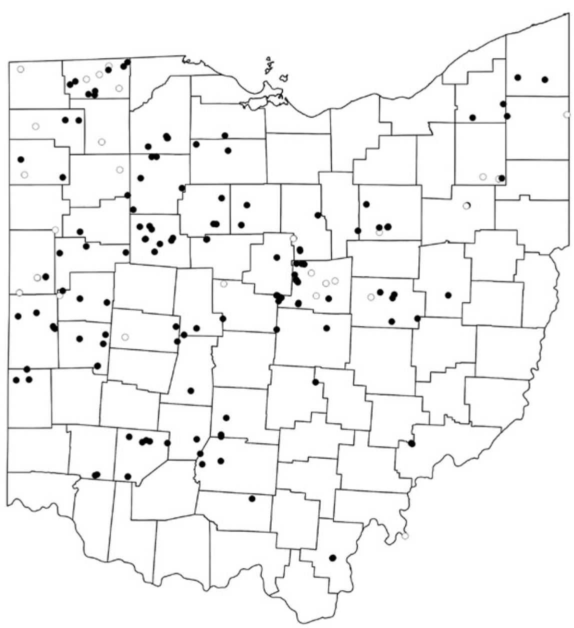

Fig. 2. Map of Ohio showing fields with at least one sampling area where P fertilizer is recommended (closed circles) and fields with all sampling areas above the maintenance range, where no P fertilizer is recommended (open circles).

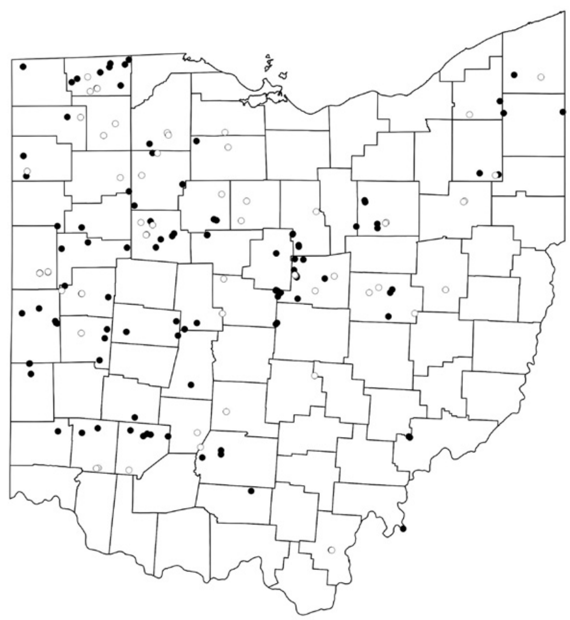

Fig. 3. Map of Ohio showing fields with at least one sampling area where K fertilizer is recommended (closed circles) and fields with all sampling areas above the maintenance range, where no K fertilizer is recommended (open circles).

yield when compared with the recommended range of 6.0–6.8 (Table 3). This result was probably due to a few samples having low enough pH to cause significant yield loss resulting from factors such as decreased nutrient availability and decreased N fixation. While the availability of nutrients declines below pH 6.0 (Barker et al., 2005), a resulting yield loss may not occur for samples slightly below pH 6.0. Also, N fixation by *Rhizobium* bacteria is not inhibited until the pH

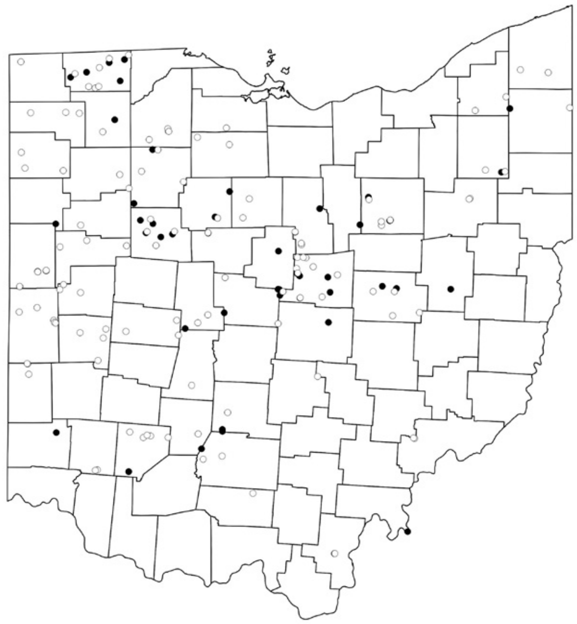

Fig. 4. Map of Ohio showing fields with at least one sampling area having a soil pH < 6.0 (closed circles) and fields with all sampling areas having a soil pH ≥ 6.0 (open circles).

Table 3. Effect of soil P, K, and pH on soybean grain yield in Ohio from 2013 through 2015.

	N	% of samples	Range	Mean	SD
			bu/acre		
P†					
Build-up	48	21.9	25.0–63.0	49.7	9.3
Above build-up	171	78.1	22.0–82.0	57.1*	11.6
K					
Build-up	53	24.2	25.0–77.3	52.4	11.6
Above build-up	166	75.8	22.0–82.0	56.4*	11.5
pH‡					
6.0–6.8	128	58.7	29.0–82.0	56.6	11.7
Below 6.0	54	24.8	25.0–81.4	54.7	10.8
Above 6.8	36	16.5	22.0–75.6	52.2*	11.4

*Statistically significant at $\alpha = 0.05$.

†For P and K, soybean grain yield from sampling areas with soil test levels within the build-up range was compared with grain yield from sampling areas with soil test levels above the state build-up range (within the maintenance or drawdown range).

‡For soil pH, soybean grain yield from areas with the recommended soil pH of 6.0–6.8 was compared with grain yield from areas with soil pH < 6.0 and > 6.8.

drops below 5.5, and it worsens as pH drops below 5.0 (Foy, 1984). Only six samples with associated yield data had pH levels below 5.0.

Forty-seven percent of the sampling areas had grain yield less than average when soil pH was higher than 6.8 (results not shown). Compared with the recommended range of 6.0–6.8, there was a 4 bu/acre decrease in yield for samples with high pH (>6.8). The yield reduction associated with a soil pH higher than 6.8 may be due to reduced nutrient availability (Barker et al., 2005).

Recommendations

There was a decrease in soybean grain yield when soil test P and K were within the build-up range. However, no increase in grain yield was associated with sampling areas within the drawdown range compared with the maintenance range. These data support the Tri-State Fertility Recommendations because yield reductions were associated with P and K levels within the build-up range and no yield increases were associated with soil P and K levels within the drawdown range. We recommend soil sampling and applying fertilizer to maintain soil test levels within the established state guidelines.

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