Soil Test Levels to Guide Nutrient Stewardship: Phosphorus and Potassium Focus for the North-Central Region

By John Jones, University of Wisconsin–Madison; Tom Bruulsema, Plant Nutrition Canada; and Saad Tarik and Quentin Rund, PAQ Interactive

While monitoring soil test levels for essential crop nutrients is most important on the field or subfield scale, assessing trends across broader geographies can indicate the direction of where past and current management practices are leading us. This article discusses the soil fertility status of the U.S., specifically the North-Central region, informed by the 2020 North American Soil Test Summary, and what can be interpreted to guide nutrient management decisions at different geographical scales. Earn 1 CEU in Nutrient Management by reading the article and taking the quiz at https://bit.ly/3aR26gE. View all CEUs online at https://web.sciencesocieties.org/Learning-Center/Courses.

In what is the most comprehensive assessment of soil fertility status of North America, the 2020 North American Soil Test Summary is the fifth summary conducted since 2001. The effort was initiated by the International Plant Nutrition Institute (previously Potash & Phosphate Institute) with the 2020 summary presented by The Fertilizer Institute, Foundation for Agronomic Research, Plant Nutrition Canada, and PAQ Interactive. Interactive exploration of the 2020 and past summaries can be done at https://soiltest.tfi.org/. This article discusses trends and relationships of soil test levels for phosphorus and potassium for the conterminous 48 states (CONUS) and the North-Central (NC) region of the U.S.

Soil Testing—A Nutrient Management Tool

Soil testing provides a foundation for nutrient management decisions. Those decisions are generally directed towards achieving agronomic, environmental, and economic outcomes within the framework of agricultural production and land management. Conceptually, Figure 1 displays how system metrics such as crop yield, losses with surface runoff, and the probability of an economic response to fertilization all relate to a given soil test P (STP) level. From these relationships, one can see that assessing trends in soil test levels (across wide geographies) can inform general discussions around crop production, environmental concerns, and economic resiliency. Agronomic objectives, specifically those related to crop nutrients, can be achieved through a well-planned, executed, and interpreted soil-testing program.

Methods for soil sample collection vary and have been well documented (Peck & Soltanpour, 1990). Laboratory analyses used for soil samples destined to inform nutrient management also vary greatly by region and are commonly developed and adopted to fit specific soil properties and wet chemistry that provides consistent results and recommendations (Melsted, 1967). Interpreting soil test results bring all of the field and laboratory work together to inform agronomists and farmers about how the results relate to predictable crop responses to fertilization, profitable economic fertilization strategies, and identification of soils that require specific management practices. Soil test interpretation methods vary greatly by state and represent considerable underlying investigation and resources to connect data with recommended practices.

Soil testing for agronomic deliverables represents one of, if not the, largest opportunity to relate nutrient management decisions to environmental outcomes. For example, many states that have

Abbreviations: CONUS, conterminous 48 states; NC, North-Central; SOM, soil organic matter; STK, soil test potassium; STP, soil test phosphorus. **Photo opposite page:** Courtesy of A. Larson.

DOI: 10.1002/crso.20152

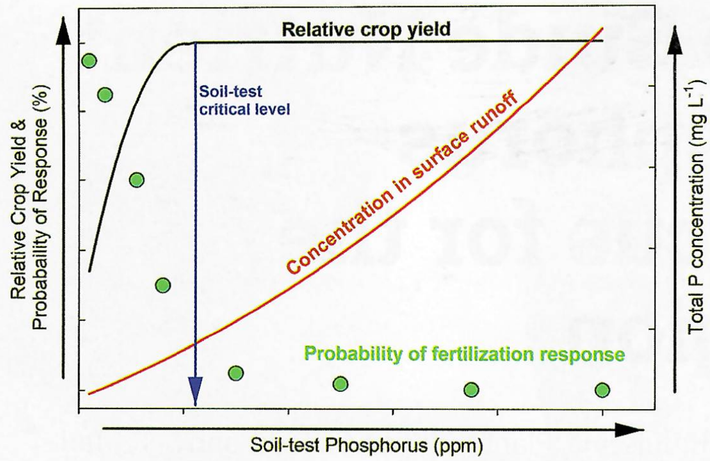

Figure 1. Conceptual relationship of soil test level, agronomic crop yield response, potential for losses, and the probability of an economic response to fertilization for nutrients commonly used in the soil test calibration process, such as phosphorus.

adopted a Phosphorus Index, designed to identify fields that would be susceptible to significant P losses, use agronomic-oriented sample depths and tests for use of the tools. It's been well established that agronomic soil tests can be used for environmental quality metrics (Sims, 1998) and certainly have value in monitoring beyond their purely agronomic benefit. The economic implications of soil testing are many; however, they primarily reside with decisions to amend or fertilize (Dahnke & Olson, 1990). Beyond nutrient recommendations, soil testing can inform other components of cropping systems such as planting densities, irrigation scheduling, and others that certainly affect the bottom line.

2020 Soil Test Summary

A similar protocol was used for the 2020 summary as was used for the previous efforts from 2001 to 2015 (TFI, 2021b). Forty-five private and public laboratories voluntarily submitted data for the 2020 summary. Soil test phosphorus (P), potassium (K), sulfur (S), magnesium (Mg), zinc (Zn), chloride (Cl^-), and soil acidity (pH) were included in the summary. Soil organic matter (SOM) was included for the first time in 2020. The data contributed to the summary were solely production farm soil samples, reported at the state level, with an identification for manured vs. non-manured and grid/zone vs. whole-field samples. For the purpose of this article, we will focus on P and K.

Soil Test Level Trends

Phosphorus and K are two macronutrients for which fertility recommendations largely rely on soil test levels. Not surprisingly, these nutrients have also been largely the focus of soil test correlation and calibration work to create specific recommendations for a given geography. *The nature of both P and K in the bulk soil and rhizosphere and their diffusive nature in moving through different media drive the ability for the soil test to be useful for nutrient management.* The 2020 summary included 7.3 million samples for P and 6.9 million samples for K representing the U.S. (Table 1.). While all P data are discussed as Bray-P1 equivalent values, it's important to acknowledge that the use of specific soil P tests does vary by region. Regarding P, the Mehlich-3 test determined with inductively coupled plasma spectroscopy (ICP) was the most frequently reported test at 56% of the total P samples, followed by Bray-P1 (24%), Olsen (9%), Mehlich-1 (6%), and Mehlich-3 determined colorimetrically (4%). While a diversity of K tests certainly exist, the majority of samples reported (86%) were either Mehlich-3 or ammonium acetate.

Table 1 shows the number of soil samples represented by the 2001–2020 summaries for the CONUS, NC region, and its states included. Summed across the five summaries, about 23.7, 22.7, and 22.8 million samples represent P, K, and soil pH. Sample volume in the NC region mirrors CONUS trends. Sample volume between states in the NC region varies greatly and largely reflects row crop acres for each specific state. Significantly large increases in sample volume from each NC State occurred from 2001 to 2002 with the largest amount of samples for P, K, pH, and SOM submitted from Iowa, which showed more than 1 million samples for P, K, and pH. These data help to communicate just how large the farming and agronomy community investment has been in soil sampling as a tool used by farmers and agronomists.

The NC region of the U.S. as discussed here includes Iowa, Illinois, Indiana, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. This scaled-down, regional focus allowed for analysis of areas where similar dominant crops are grown, cropping systems share similar characteristics, and soil-test-based recommendation systems are widely used. The NC region also has made up about two-thirds of the U.S. soil samples submitted to the Soil Test Summary from 2001 to 2020 (Table 1.).

National data in Table 2 display median P, K, pH, and SOM for the CONUS, NC region, and its included states individually from 2001 to 2020. It is important to note the differences in sample volume representation between each summary year (previously discussed and shown in Table 1.) when interpreting changes in median values for a given region. Median STP for the CONUS has fluctuated from 2001 to 2020 with a general decreasing trend. From 2001 to 2020, the CONUS median STP dropped from 27 to 23 ppm P. Median soil test K (STK) changed from 154 in 2001 to 141 ppm K in 2020 and peaked in 2005 at 155 ppm K. Soil pH showed no change when median values across the entire CONUS are assessed (Table 2). The large diversity of regions across the CONUS makes changes across the broad geography

TABLE 1. Sample number[a] included in Soil Test Summaries for soil test phosphorus, potassium, soil pH, and soil organic matter levels for the U.S. and the North-Central region and its states from 2001 to 2020.

Year	CONUS[b]	North Central	IL	IN	IA	KS	MI	MN	MO	NE	ND	OH	SD	WI	NC of CONUS
							Phosphorus								%
2001	1.91	1.26	0.14	0.14	0.38	0.05	0.07	0.09	0.08	0.14	0.04	0.07	0.02	0.04	66
2005	3.06	1.95	0.53	0.16	0.36	0.07	0.10	0.11	0.10	0.20	0.07	0.09	0.03	0.13	64
2010	4.11	2.93	0.22	0.42	0.78	0.08	0.19	0.22	0.15	0.36	0.08	0.25	0.08	0.10	71
2015	7.24	4.96	0.73	0.59	0.99	0.25	0.27	0.59	0.26	0.53	0.10	0.33	0.16	0.15	68
2020	7.39	4.90	0.47	0.54	1.14	0.30	0.31	0.57	0.29	0.66	0.08	0.27	0.14	0.13	66
							Potassium								%
2001	1.84	1.19	0.14	0.14	0.33	0.05	0.07	0.09	0.07	0.14	0.04	0.07	0.02	0.04	65
2005	3.03	1.92	0.51	0.16	0.37	0.07	0.10	0.10	0.10	0.19	0.07	0.09	0.03	0.13	63
2010	3.93	2.77	0.23	0.42	0.72	0.09	0.19	0.19	0.14	0.32	0.07	0.25	0.07	0.10	71
2015	6.95	4.69	0.72	0.59	1.02	0.22	0.27	0.42	0.25	0.51	0.10	0.33	0.13	0.14	67
2020	6.90	4.49	0.46	0.54	1.01	0.29	0.30	0.43	0.27	0.59	0.08	0.27	0.12	0.12	65
							Soil pH								%
2001	1.80	1.17	0.14	0.14	0.32	0.05	0.07	0.09	0.08	0.12	0.04	0.07	0.02	0.04	65
2005	3.15	1.87	0.50	0.16	0.31	0.07	0.10	0.11	0.10	0.19	0.06	0.09	0.04	0.13	59
2010	4.00	2.84	0.23	0.44	0.72	0.09	0.20	0.19	0.13	0.33	0.07	0.25	0.07	0.11	71
2015	6.91	4.72	0.70	0.63	0.98	0.23	0.29	0.42	0.23	0.51	0.10	0.34	0.13	0.16	68
2020	6.89	4.45	0.46	0.54	1.00	0.29	0.30	0.43	0.25	0.59	0.08	0.27	0.12	0.13	65
							Soil organic matter								%
2020[c]	4.00	3.49	0.26	0.40	0.83	0.26	0.20	0.39	0.22	0.54	0.06	0.11	0.10	0.12	87

[a]Million samples.
[b]Conterminous 48 U.S. states.
[c]Soil organic matter was first included in the 2020 summary.

difficult to capture, and realistically, local changes in acidity and soil pH should be addressed on a finer scale such as that done in Montana (Jones et al., 2019). Soil organic matter was first included in the 2020 summary, and so no trend assessment can be done yet, but as an important soil test measurement, it is worth noting the median SOM for the CONUS in 2020 was 2.9%.

State-specific soil test levels varied greatly and reflect the diversity of both management and natural soil test level effects over time. Individual states also varied in their trends from 2001–2020 (Table 2). For example, Illinois, Michigan, and Wisconsin all saw reductions in median STP over 10 ppm P, and states such as North Dakota and South Dakota increased 3 and 5 ppm P, respectively. Median STP stayed relatively steady in Iowa, Kansas, and Nebraska throughout all five summaries from 2001–2020 even with large increases in sample volumes. Median STK did not change over time in the same way STP did for many states and the NC region. States that showed the largest decreases were Kansas, Nebraska, and South Dakota with reduction of median STP of 120, 88, and 66 ppm K, respectively. Median STK increased in Iowa the most with a change of 27 ppm K from 2001 to 2020 (Table 2). Regionally, soil pH showed little change over time. Most states did not see large changes in soil pH as well, except for Kansas and South Dakota, which reported reductions of 0.5 and 0.3 pH units from 2001 to 2020. Median SOM was 3.0% for the NC region in 2020. State-specific median SOM values reflect the range of local parent materials, moisture regimes, and degrees of weathering and soil formation in the region.

To break down what is represented by a median soil test value change, Figure 2 shows the data for the CONUS and NC region segregated into soil test ranges. The y-axis in Figure 2 represents the change in the percentage of all samples existing in each range. For example, a greater percentage of samples for STP tested in the 0–5, 6–10, 11–15, and 16–20 ppm P ranges in 2020 compared with 2001 for both the CONUS and NC region. Values below 0,

TABLE 2. Median soil test phosphorus, potassium, soil pH, and soil organic matter levels for the U.S. and the North-Central region and its states from 2001 to 2020.

Year	CONUS[a]	North Central	IL	IN	IA	KS	MI	MN	MO	NE	ND	OH	SD	WI
Phosphorus (Bray-1 equivalent, ppm)														
2001	27	26	36	33	25	20	50	16	17	21	10	28	11	41
2005	31	27	36	29	25	21	49	18	18	22	11	25	14	39
2010	24	22	26	26	22	18	42	18	16	18	11	24	13	26
2015	26	23	25	24	25	21	37	21	20	21	11	21	15	27
2020	23	21	23	23	24	18	37	21	18	21	13	19	16	28
Potassium (ammonium acetate equivalent, ppm)														
2001	154	161	150	130	153	331	129	159	147	373	275	151	279	111
2005	155	177	178	145	173	295	149	156	150	364	265	169	269	126
2010	152	164	179	130	161	274	131	160	144	340	236	145	247	133
2015	150	172	164	134	189	208	129	165	144	306	247	145	241	141
2020	141	155	155	131	180	211	125	166	131	285	247	134	213	117
Soil pH														
2001	7.0	6.6	6.3	6.3	6.4	6.8	6.5	6.9	6.2	6.3	7.5	6.3	6.9	6.6
2005	7.0	6.6	6.3	6.4	6.4	6.8	6.7	7.0	6.3	6.4	7.5	6.3	7.0	6.6
2010	7.0	6.6	6.4	6.3	6.5	6.7	6.7	6.7	6.3	6.4	7.5	6.3	6.8	6.6
2015	7.0	6.6	6.3	6.3	6.4	6.4	6.7	6.7	6.4	6.4	7.5	6.4	6.8	6.7
2020	7.0	6.5	6.4	6.4	6.3	6.3	6.7	6.7	6.3	6.2	7.5	6.4	6.6	6.7
Soil organic matter, %														
2020[b]	2.9	3.0	3.3	2.4	3.6	2.1	2.2	4.1	2.7	2.5	3.3	3.1	3.7	2.8

[a]Conterminous 48 U.S. states.
[b]Soil organic matter was first included in the 2020 summary.

such as the STP range of > 50 ppm P, indicate a lower percentage of samples being in that category in 2020 than 2001. For STP, the trend of more samples testing below 20 ppm P and fewer samples testing above 20 ppm P matches well with the slight decreases in median STP shown in Table 2. Interestingly as well is that below 16–20 ppm P is where most soils would be considered "suboptimal" related to maintain STP for optimized agronomic function below which yield responses to fertilization would be expected. Distribution of STP for both the CONUS and NC region showed similar patterns; however, STP in the NC region tested more frequently in the 11–20 ppm P range and less frequently in the > 50 ppm P range when compared with the national data (Figure 2).

Soil test K distributions for the CONUS and NC region differed much more than for STP (Figure 2). While across the CONUS, STK increased significantly in the 0–120 ppm K ranges, NC data suggested very small changes from 2001 to 2020 below 120 ppm K. The NC region saw an increase in the percent of samples between 121–280 ppm K and no change from 281–300 ppm K, whereas CONUS data suggested there was either no change or reductions in the percent between 161–320 ppm K. Both nationally and regionally, STK was less frequently above 320 ppm K. As native STK and soil characteristics such as mineralogy change greatly between NC region states and the rest of the U.S., these differences in STK distribution are reasonable.

Soil Test Levels and Nutrient Use Data

The next step in this analysis was to relate soil test changes with nutrient use data from the NuGIS (Nutrient Use Geographic Information System) effort (TFI, 2021a). NuGIS aggregates fertilizer, recoverable manure nutrients, and crop removal with harvest at the county level and HUC8 watershed level for the CONUS (https://nugis.tfi.org/). Investigating these relationships allows for some reasoning behind changing soil test level and for identifying how

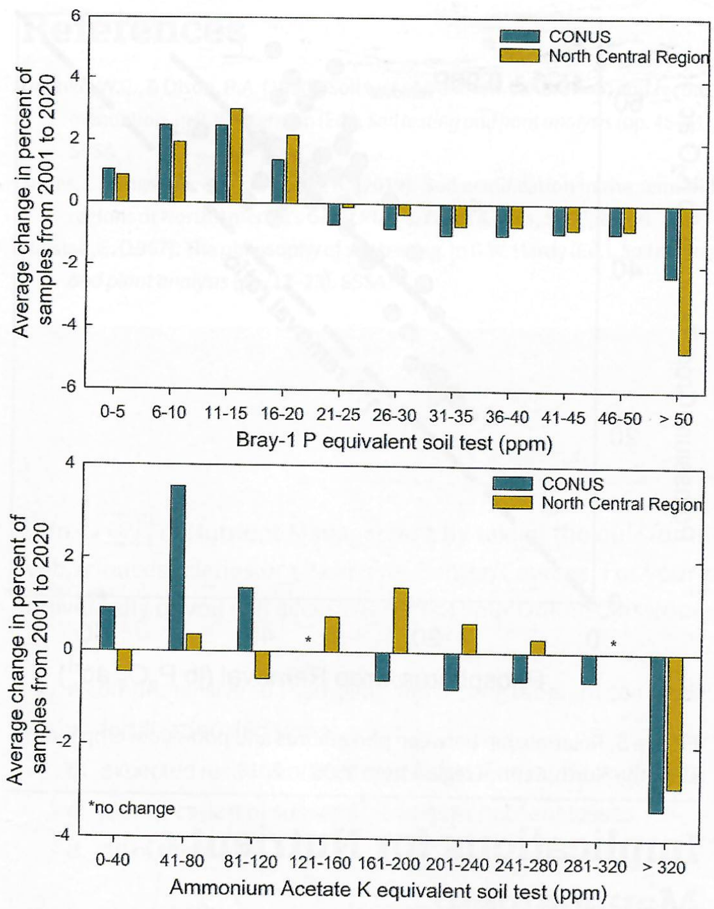

Figure 2. Changes in phosphorus (top) and potassium (bottom) relative frequencies over time for the North-Central region of the U.S.

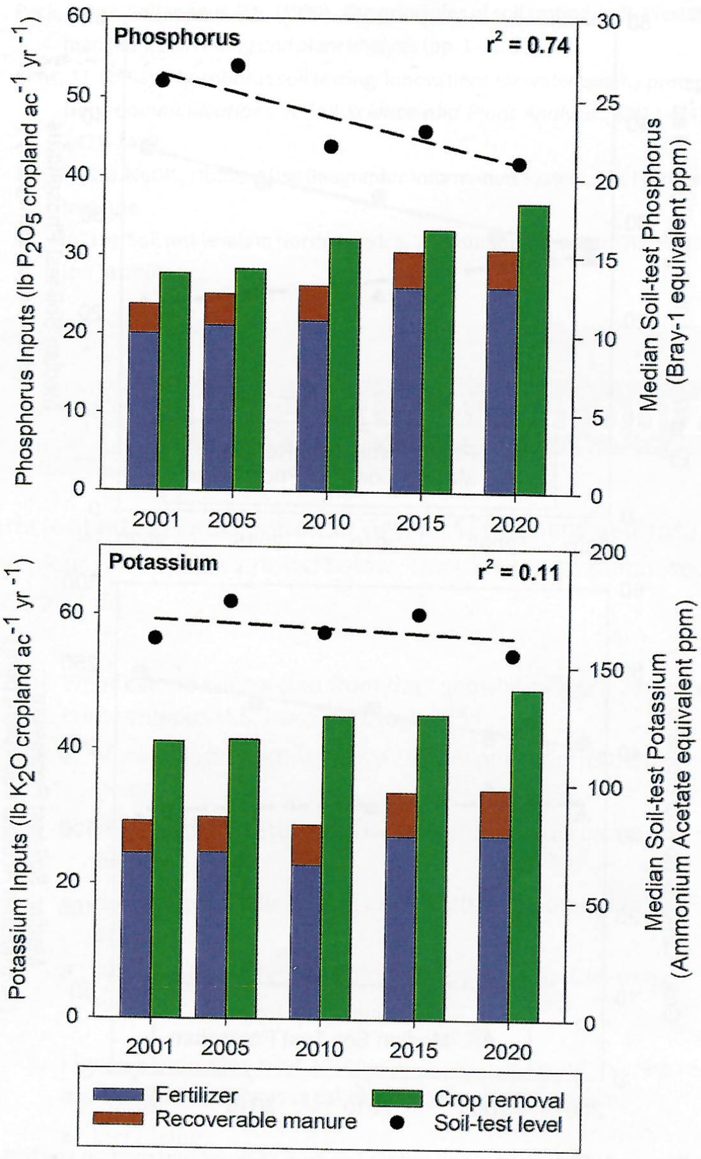

Figure 3. Phosphorus and potassium fertilizer, recoverable manure, crop removal, and soil test level for the North-Central region. Fertilizer, manure, and crop removal are presented in pounds per acre.

trends in nutrient use dynamics affect the soil fertility status. Data for each state, region, and the CONUS for four years prior to each Soil Test Summary was compared with the soil test level of a given year. In other words, the average fertilizer, manure, and crop removal per acre per year for a given state from 1996–2000 was paired with the 2001 summary data, the 2001–2004 nutrient use data was paired with the 2005 summary data, and so on. Figure 3 shows fertilizer, manure, crop removal, and median soil test levels for P and K in the entire NC region. The stacked blue and red bars indicate P and K inputs, and the green bar represents crop removal with harvest. The difference between the stacked inputs and crop removal equates to the nutrient balance per acre per year (expressed as P_2O_5 and K_2O) (Figure 3).

Nutrient balances for both P and K were negative for each year in the NC region, meaning more P and K was removed with the crop than applied with fertilizer and/or manure (Figure 3). The relationship between balance and soil test level was very different for P and K. Median STP showed a decreased trend from 2001 to 2020 and fit a linear decrease well. Potassium did not show a strong relationship with K_2O balance per acre, as median STK showed a slight decreasing trend, even though K balance was between 12 and 16 lb K_2O ac^{-1} yr^{-1}. Across such a large geography, relating the balance of nutrients to soil test level is difficult, and correlation should not be interpreted as causation. Median soil test levels for a single state at best can point to trends in soil fertility status over time if enough data is considered. What can be interpreted from Figure 3 is that at the same time negative P balances occurred, so too did the median STP decrease in the same region with paired data on the state level. Median STK did not correlate well with K balance, and as seen in Table 2, is much more difficult to assign a trend to than STP. The dynamic nature of K in soils and our cropping system could be the reasoning behind this.

Crop removal of nutrients with harvest informs many soil test recommendation systems for P and K across the county and specifically in the NC region. Increasing crop removal of P and K (Figure 4) from 1996 to 2016 is shown with trends in median STP

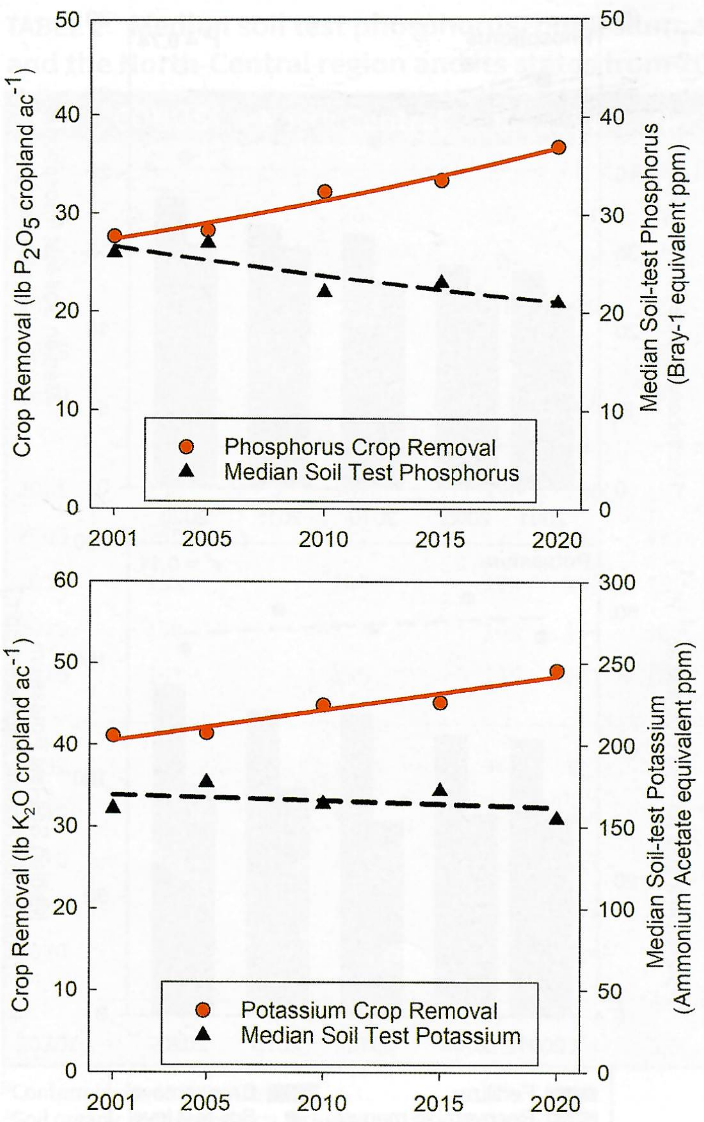

Figure 4. Phosphorus and potassium crop removal and median soil test level for the North-Central region over time.

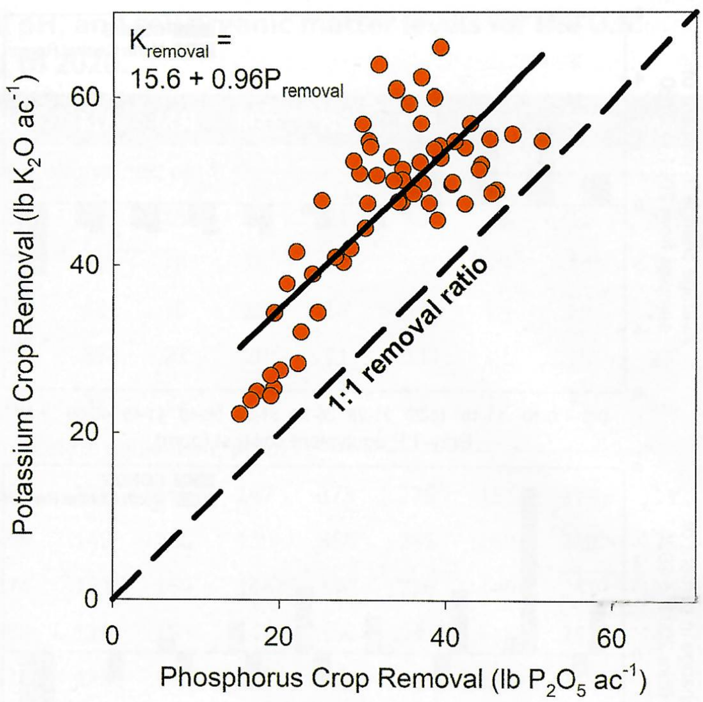

Figure 5. Relationship between phosphorus and potassium crop removal for the North-Central region from 1996 to 2016.

and STK. Though across a broad area, these trends are important to consider when fertilization decisions are being made, particularly if recent soil test data are not available. Increases of about 10 lb P_2O_5 and K_2O ac^{-1} yr^{-1} were observed from within two decades, eluding to changes in removal rates possibly due to higher yield levels in the region or shifts towards crops that remove greater amounts of nutrients. Commonly linked in conversations for soil testing the fertilization decisions, P and K are not necessarily being removed at the same rate every year. Crop removal coefficients (pounds of nutrient removed per harvest unit of crop) vary greatly between crops, and as seen in Figure 5, NC region crops across the whole area are removing much more K than P. With dominate crops like corn and soybean, this should come as to no surprise if you've had to calculate removal rates in the past. However, when seeing the data, it's a great reminder about the ratios of nutrients being removed from cropland acres on this large of a scale.

Implications for Nutrient Management

Soil test nutrient levels inform nutrient management and fertilization decisions across U.S. Though the above information is on a relatively large scale compared with how soil and crops are managed, the general trends can point to some important considerations.

- Observations of soil test levels via the North American Soil Test Summaries indicate shifts for P and K towards lower state median levels with a greater fraction of soil samples testing below state-specific agronomic critical levels.
- Increasing removal of P and K with harvested portions of the crops compared with inputs applied occurred at the same time of reduced medial STP and fluctuating median STK levels.
- The ratio of removed nutrients like P and K with harvest are not 1:1 and may be decreasing soil test levels at varying rates and considered from different perspectives.
- If instances of crop removal affecting soil test levels can be identified on large, regional scales, it is very important to monitor removal rates on the field or subfield level to identify accurate nutrient recommendations for crop production.

References

Dahnke, W.C., & Olson, R.A. (1990). Soil test correlation, calibration, and recommendation. In R. Westerman (Ed.), *Soil testing and pant analysis* (pp. 45–71). SSSA.

Jones, C., Engel, R., & Olson-Rutz, K. (2019). Soil acidification in the semiarid regions of North America's Great Plains. *Crops & Soils, 52*(2), 28–56.

Melsted, S. (1967). The philosophy of soil testing. In G.W. Hardy (Ed.), *Soil testing and plant analysis* (pp. 13–23). SSSA.

Peck, T.R., & Soltanpour, P.N. (1990). The principles of soil testing. In R. Westerman (Ed.), *Soil testing and plant analysis* (pp. 1–9). SSSA.

Sims, J.T. (1998). Phosphorus soil testing: Innovations for water quality protection. *Communications in Soil Science and Plant Analysis, 29*(11–14), 1471–1489.

TFI. (2021a). NuGIS, Nutrient Use Geographic Information System. The Fertilizer Institute.

TFI. (2021b). Soil test levels in North America, 2020 summary update. The Fertilizer Institute.

SELF-STUDY CEU QUIZ

Earn 1 CEU in Nutrient Management by taking the quiz for the article at https://bit.ly/3aR26gE. View all CEUs online at https://web.sciencesocieties.org/Learning-Center/Courses. For your convenience, the quiz is printed below. The CEU can be purchased individually or you can access as part of your Online Classroom Subscription.

1. A comprehensive soil sampling and testing program can guide

a. fertilization decisions.

b. expected responses from specific applied rates of nutrients.

c. identification of susceptible soils to nutrient losses.

d. All of the above.

2. ________ and ________ recommendations are largely soil test based due to their nature in soil.

a. Nitrogen and phosphorus

b. Nitrogen and potassium

c. Phosphorus and potassium

d. Phosphorus and sulfur

3. In the last two decades, the frequency of soil testing has

a. largely increased.

b. largely decreased

c. stayed constant.

d. None of the above.

4. What plant essential element is tested for the most in soil data reported in the 2020 Soil Test Summary?

a. Nitrogen.

b. Phosphorus.

c. Potassium.

d. Calcium.

5. What generally decreases as soil test levels greatly exceed an agronomic critical level for phosphorus or potassium?

a. Probability of yield responses to added nutrients.

b. Crop yield.

c. Potential for nutrient losses from crop fields.

d. Ability to determine application rates.

6. What is one benefit to evaluating large-scale soil test level trends?

a. The state median STP can be used for rate recommendations.

b. Nutrient losses from soils can be estimated.

c. Directions of trends allow general observations.

d. Nutrient application effectiveness can be indicated.

7. What can be interpreted from data shown in Figure 2 for the conterminous U.S. from 2001 to 2020?

a. More soils are testing above 25 ppm phosphorus than before.

b. More soils are testing below 21 ppm phosphorus than before.

c. No change in soils testing above 320 ppm potassium occurred.

d. Fewer soils are testing below 120 ppm potassium than before.

8. Figure 3 indicates that a general ________ trend in crop removal of phosphorus is taking place in the NC region.

a. increasing

b. decreasing

c. flat

d. None of the above

9. Phosphorus and potassium fertilizer application on a state level for all cropland are ________ compared with crop removal (Figure 3).

a. both higher

b. higher and lower, respectively,

c. lower and higher, respectively,

d. both lower

10. Across the NC region from 1996 to 2016, what was true about the relationship of phosphorus (P_2O_5) and potassium (K_2O) crop removal per acre?

a. They were equal.

b. Crops in the region removed more phosphorus.

c. Crops in the region removed more potassium.

d. There was a 2:1 phosphorus to potassium ratio.