Corn and soybean grain yield, phosphorus and potassium removal, and soil-test trend responses to long-term fertilization strategies

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Introduction

Maintaining desirable soil-test phosphorus (P) and potassium (K) values based on amounts removed with harvest is an essential part of profitable and environmentally sound management for these nutrients. Many Iowa fields have higher than optimum soil-test P and K levels because many farmers have applied higher fertilizer rates higher than needed. Given the prevailing low prices for grain, farmers need to watch closely soil-test level changes over time and prevailing yield levels of their fields in order to maximize the profitability of both fertilizer use and crop production.

Value of long-term field trials for phosphorus and potassium research

Agricultural research utilizes both short-term and long-term experiments. Short-term experiments provide useful information on how a system is affected at the time of management changes and evaluate short-term responses by the soil or crop. The initial or short-term response of a whole system or individual components may not necessarily indicate the direction or the magnitude of long-term changes. Long-term experiments include soil and crop measurements across years or decades and are critical for agronomic and environmental assessments of soil sustainability, productivity, and soil-environment interactions.

The prevailing P and K management and recommendation systems in Iowa and the north-central region are based on soil testing, response-based fertilization of low-testing soils, and removal-based fertilization to maintain desirable soil-test levels. Iowa State University (ISU) guidelines for P and K soil-tests interpretations and fertilization are in extension publication PM 1688 and were last updated in 2013 (Mallarino et al., 2013). Important issues for effective management and recommendations include use of appropriate soil-test methods and field calibrations to determine optimum soil-test levels and fertilization rates, knowledge of fertilization and cropping impacts on soil-test values over time, reliable estimates of P and K removal with harvest, and use of efficient fertilizer placement methods among others. Short-term experiments are very useful to correlate soil- or tissue test values with crop yield response, calibrate test methods by finding the nutrient rates needed to attain maximum yield or a percentage of the maximum yield and both the magnitude and probability of yield responses. Long-term P and K experiments also can provide some of this information, but most significantly add information about impacts of fertilization strategies on yield, nutrient uptake or removal, soil nutrient buildup or decline in topsoil and subsoil, and relationships between these measurements over time. This complementary information allows producers and nutrient management planners to make prudent management choices to profit from nutrient management while being mindful of soil sustainability and environmental impacts.

In Iowa and most soils of the north central region, moderate soil-test P and K buildup happens with the rates usually recommended for low-testing soils and large soil-test increases occur with larger application rates. This is explained by nutrient uptake by crops, recycling with residues, and properties in most soils that keep applied P and K in crop-available forms over time. On the other hand, high soil test levels of naturally high-testing soils or those with histories of fertilizer or manure application in excess of crop removal and loss from fields with erosion and surface runoff decrease gradually over time. Research has shown high short-term and long-term variability of soil-test values mainly due to variation in uptake and recycling processes highly affected by variation in rainfall amounts. Therefore, knowledge of long-term relationships between applied P or K, removal with harvest, and soil-test values is very useful for the management of these nutrients. As an example, the sections below summarizes results of three Iowa long-term projects.

Yield and soil-test P and K long-term trends and P by K interaction

An experiment established in the Iowa State University (ISU) northeast research farm has included measurements of grain yield of corn and soybean grown in rotations and soil-test values in the topsoil (6-inch depth) as affected by several combinations of P and K application rates. The soil at the site is Kenyon that initially tested high in P (28 ppm Bray-1) and K (213 ppm by the ammonium acetate method), and has been managed with tillage and broadcast fertilization. Identical adjacent trials were established to grow both crops of the corn-soybean rotation each year. Annual fertilizer treatments have been the combinations of 0, 46, and 92 lb P_2O_5/acre and 0, 72, or 144 lb K_2O/acre. Two other treatments are applied every other year to corn or soybean at rates of 92 lb P_2O_5/acre and 144 lb K_2O/acre. The study has provided very useful information about long-term trends in yield responses, interactions between P and K, and soil-test values even though the funding level never allowed for measurements of P and K removed with harvest or management effects on subsoil P and K levels.

Figure 1 shows that soil-test P (STP) and K (STK) values of non-fertilized plots decreased curvilinearly from the initial value of 28 ppm to an almost plateau at 10 ppm, and from 213 ppm to a plateau at 96 ppm. The low application rates slightly increased STP and maintained STK, while the high rates increased values curvilinearly with decreasing increments up to 120 ppm STP and 390 ppm STK.

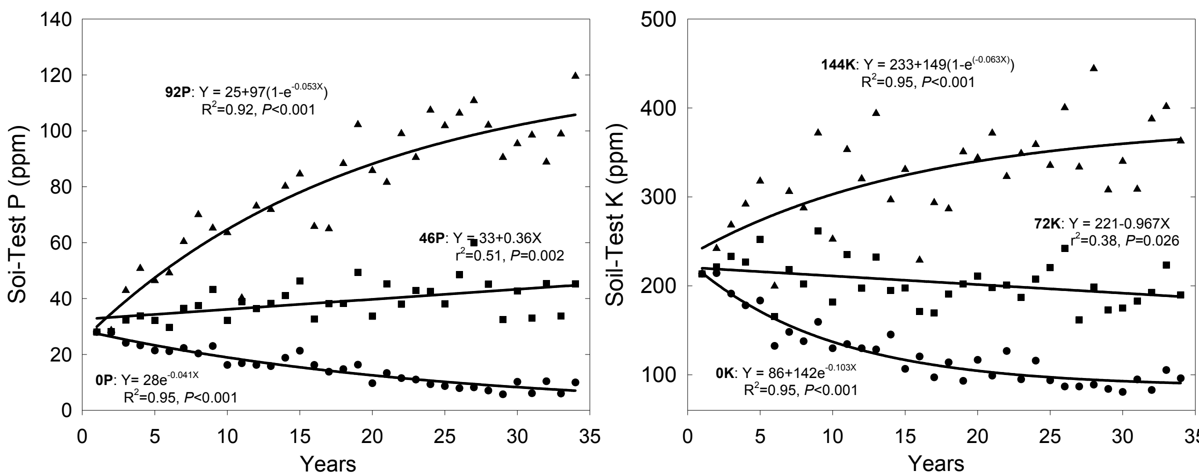

Figure 1. Soil-test P and K trends over time from a northeast Iowa long-term experiment with corn-soybean rotations that received 0, 46, and 92 lb P_2O_5/acre/year or 0, 72, and 144 lb K_2O/acre/year.

Graphs in Figure 2 show that statistically significant small and occasional yield responses began to be observed after seven years, but consistent responses were not observed until after 18 years. Moreover, results for show that in the last few years, the high annual K rate began to decrease soybean yield. The STK levels for this high rate have increased to about 300 ppm or higher in the last few years. These results confirmed that P or K deficiency can significantly limit crop yield, that P and K fertilization can be withheld for many years in high-testing soils, and that excessive K can decrease yield. The long time that high STP took to decrease to optimum levels shows that the impact of excessive P levels on P loss to water resources would last for many years.

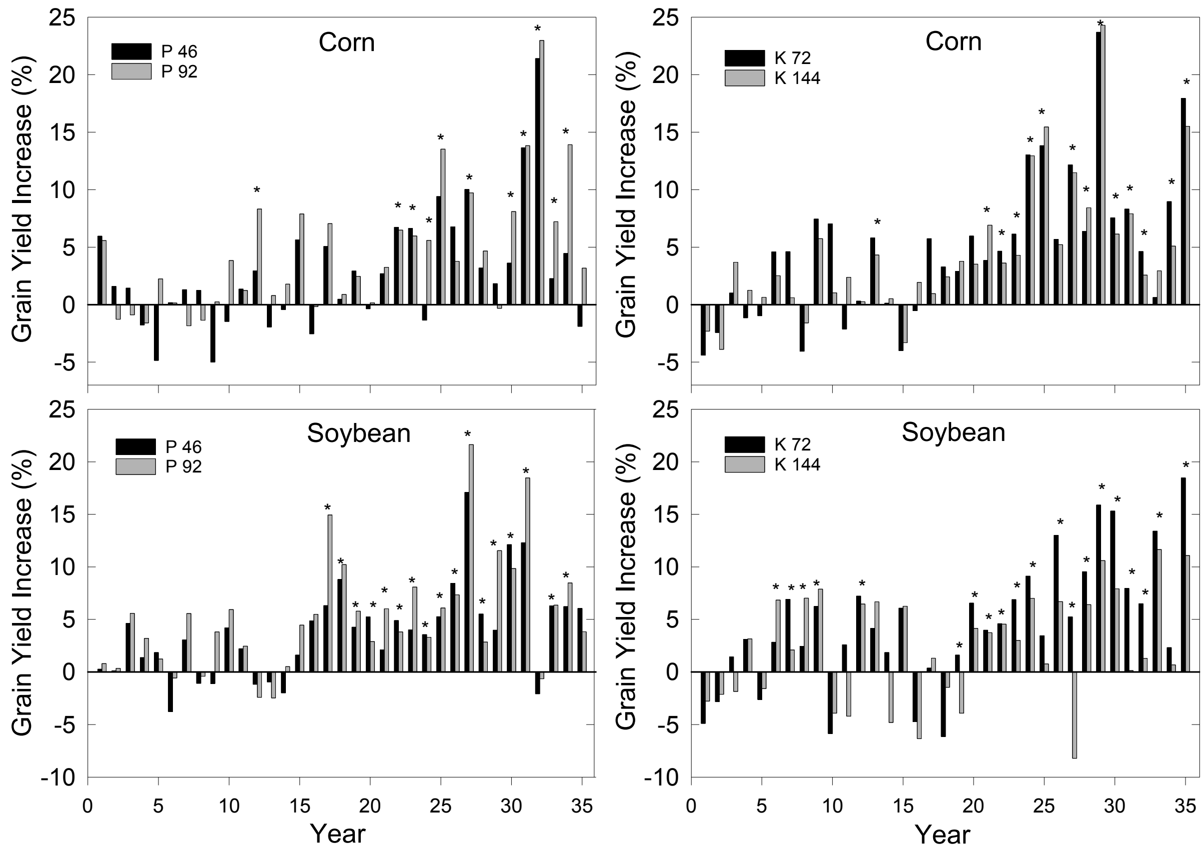

Figure 2. Corn and soybean grain yields from an Iowa long-term experiment that received 0, 46, and 92 lb P_2O_5/acre/year or 0, 72, and 144 lb K_2O/acre/year. Yields for each nutrient are averages across the two rates of the other. Asterisks indicate significant differences ($P \leq 0.05$).

The results of this study also are showing that a K deficiency also limits the relative yield response P fertilization. On average across the responsive years, there were no yield differences between the two annual application rates of each nutrient but there was an interaction between P by K fertilization. An interaction occurs when the relative response to application rates of one nutrient is affected by the application rates of another nutrient. Figure 3 shows that yield of both crops was higher for plots that received both P and K fertilizers than for plots that received either P or K alone. However, a lower P rate was needed to maximize yield of both crops when K was applied whereas the yield response to K was proportionally similar with or without P being applied. Figure 3 also clearly shows how the highest K rate decreased soybean yield compared with the lower K rate.

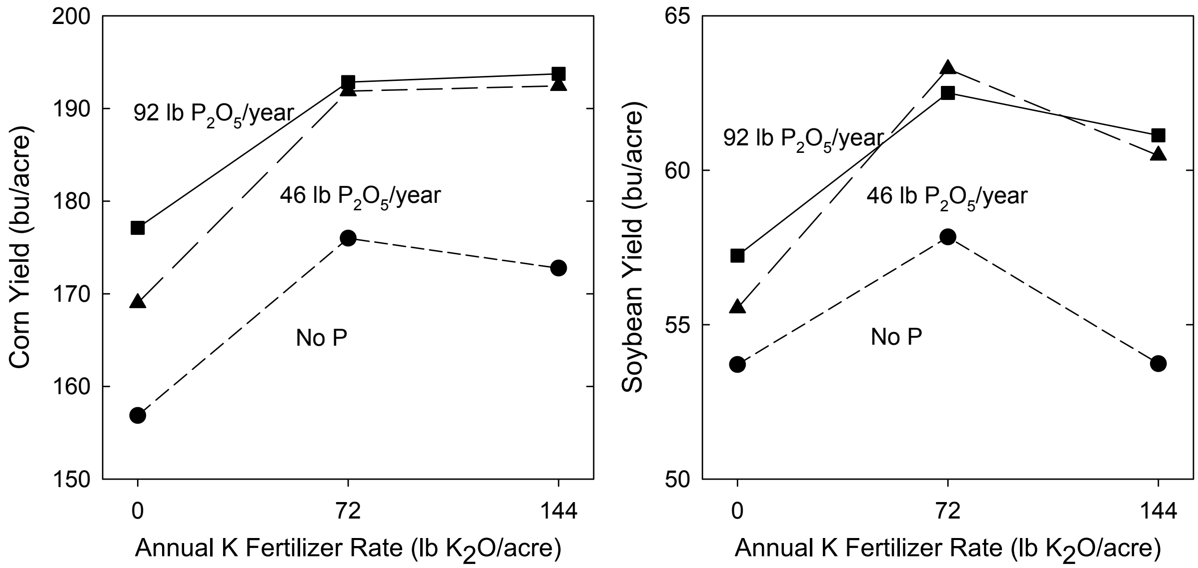

Figure 3. Average corn and soybean grain yields across 18 responsive years from an Iowa long-term northeast Iowa experiment that received 0, 46, and 92 lb P_2O_5/acre/year or 0, 72, and 144 lb K_2O/acre/year.

Long-term trends for P and K removed with harvest and soil-test values

The amounts of P and K removed with corn and soybean harvest could not be measured in the P-K study summarized above. However, P and K removal was measured in separate long-term studies for P and K have been conducted at the northern, northeast, northwest, southeast, and southwest (Armstrong) ISU research farms in fields that are representative of those regions. The treatments at each P or K trials consisted of different application rates and placement methods for granulated fertilizers for corn-soybean rotations managed with chisel-plow/disk tillage no-tillage. The P and K removal was measured only for the no-till plots and selected fertilization treatments. The application rates evaluated since the establishment of the trials have been 0, 28 and 56 lb P_2O_5/acre/year and 0, 35, and 70 lb K_2O/acre/year, and double the highest rates applied every other year before corn or soybean. The placement methods evaluated in all years have been broadcast in the fall and banded with the planter attachments 2 inches besides 2 inches below the seeds. Only the two lowest application rates were applied with the planter. Partial results concerning effects of placement methods and P or K rates on crop yield and soil-test values for each trial have been shared before, showed no consistent placement methods differences for any nutrient and crop, and will not be discussed here (Mallarino and Van Dee, 2011; Mallarino and Rueber, 2012; Mallarino and Sievers, 2016; Mallarino and Pecinovsky, 2017; Mallarino, et al., 2018). The yield response to P or K varied greatly across the five locations and years mainly as a result of differences in STP and rainfall. Sites initially testing high or very high in STP or STK according to ISU interpretations (Mallarino et al., 2013) showed very infrequent and small yield responses to P and K.

Figure 4 shows the long-term relationship between the cumulative P removed with harvested corn and soybean grain and STP (6-inch sampling depth) over 12 years for the non-fertilized plots at the five locations and for the average across the locations. The averages smoothed large variation at each location and there was a good general relationship between P removal and STP trends only over several years. On average across sites, removal of 37 lb P_2O_5/acre/year resulted in an average STP decrease of 0.78 ppm/year. These results imply an average removal of 47 lb P lb P_2O_5/acre/year to decrease 1 ppm STP/year. An equation (not shown) relating net P addition or removal and STP across fertilized and non-fertilized plots across all sites had a good fit for the drawdown portion but not for the buildup portion due to high variability in the data and relatively small P application rates. This equation showed that a net addition of 15 lb P_2O_5/acre increased STP by 1 ppm, which was a value only slightly lower than the average value reported for the Midwest (16 to 18 lb P_2O_5/acre).

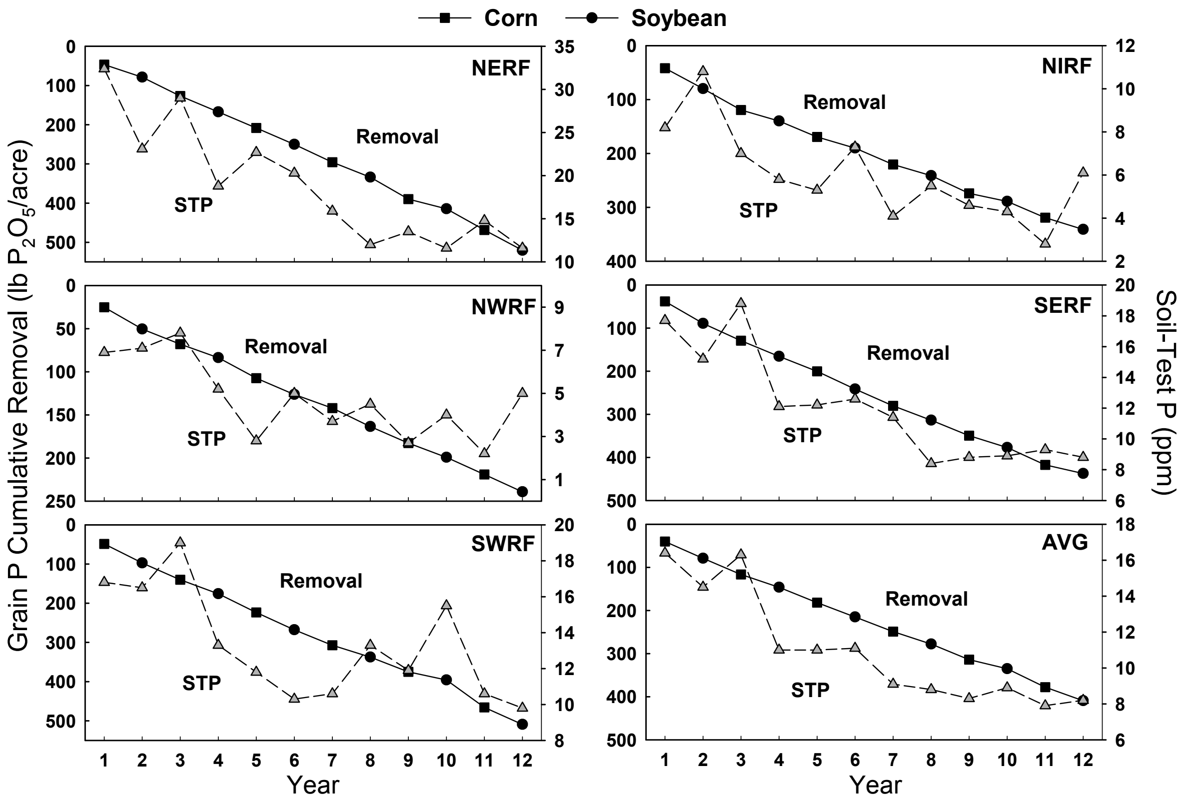

Figure 4. Phosphorus removal with grain harvest and soil-test P trends over time for corn-soybean rotations at five Iowa long-term experiments for plots that were not fertilized with P.

The graphs in Figure 5 show the long-term relationship between the cumulative K removed with harvested corn and soybean grain and STK (6-inch sampling depth) over 10 years for the non-fertilized plots at five locations and for the average across the locations. The relationship between K removal and STK over a long time is poorer than for P, but still there was a general long-term match between K removed and STK. Ongoing research is indicating that rainfall and soil moisture impacts on short-term nutrient recycling with crop residue and reactions between soil nutrient pools have a much higher impact on STK levels than on STP levels. In the long-term, and on average across all five locations, removal of 42 lb K_2O/acre/year resulted in an average STK decrease of 3.0 ppm/year. These results imply an average removal of 14 lb P lb K_2O/acre/year to decrease 1 ppm STK/year. In contrast to the P trials, the highest K rates applied resulted in little or no soil K buildup and much variability, so study of relationships when there is a K buildup is not possible.

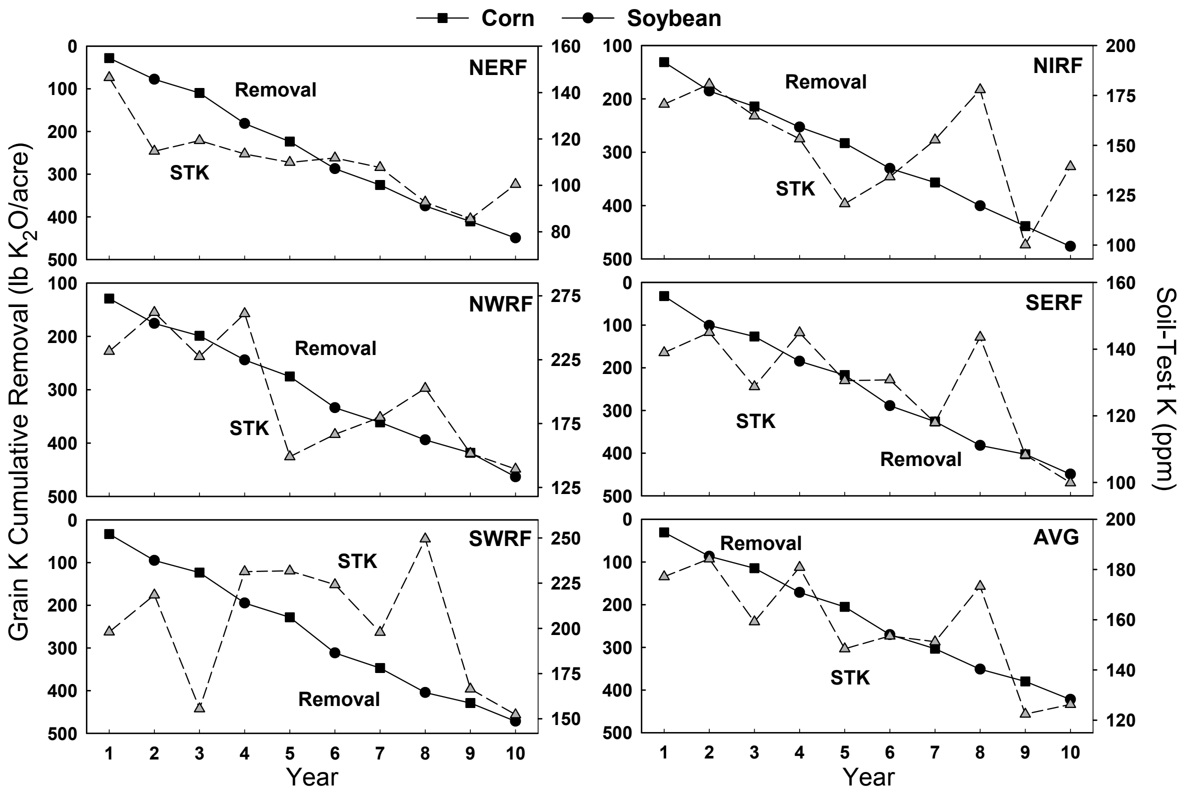

Figure 5. Potassium removal with grain harvest and soil-test K trends over time for corn-soybean rotations at five Iowa long-term experiments for plots that were not fertilized with K.

The data in Figure. 4 and 5 showed that the relationships between P or K removal and STP or STK were close over many years but not from year to year. This short-term large mismatch is more evident in the graphs of Figure 6. These graphs plot the actual amount of P or K removed each year by corn and soybean grown in rotation over time together with the soil-test P or K values measured after harvest of each year. The graphs show the P and K removal vary up and down over the years as affected by the yield level and amount of P and K removed by each crop. The graph for P shows that corn removed slightly higher amounts of P than soybean in most years, except in Year 4 and 10 when soybean P removal was very low because of lower yield. The graph for K shows that, in contrast, soybean removed much more K than corn did in most years. These figures make clear the very poor relationship between P or K removal and STP or STK from year to year, or even over 2 or 3 years. This is probably the result of variation in P recycling with crop residues and large temporal variation in the equilibrium of different soil P and K pools (Mallarino et al., 2011; Oltmans and Mallarino, 2011). These processes are known to be greatly influenced by rainfall, soil moisture, and temperature patterns.

The data shown demonstrate that P and K removal is closely related to soil-test trends over the long-term and that removal can be used as a criterion to decide maintenance fertilization when soil-test levels are optimum. Since P or K removal is not closely related to soil-tests values in the short term, producers should consider “prevailing” yield levels in a field and long-term soil-test trends when making decisions about STP or STK maintenance. Producers should not overreact to higher or lower than normal yield or soil-test value in a specific year because this may not reflect well what’s going on. Large changes in application based on one year information may not be the best thing to do for long-term profitability and will introduce more variability and confusion.

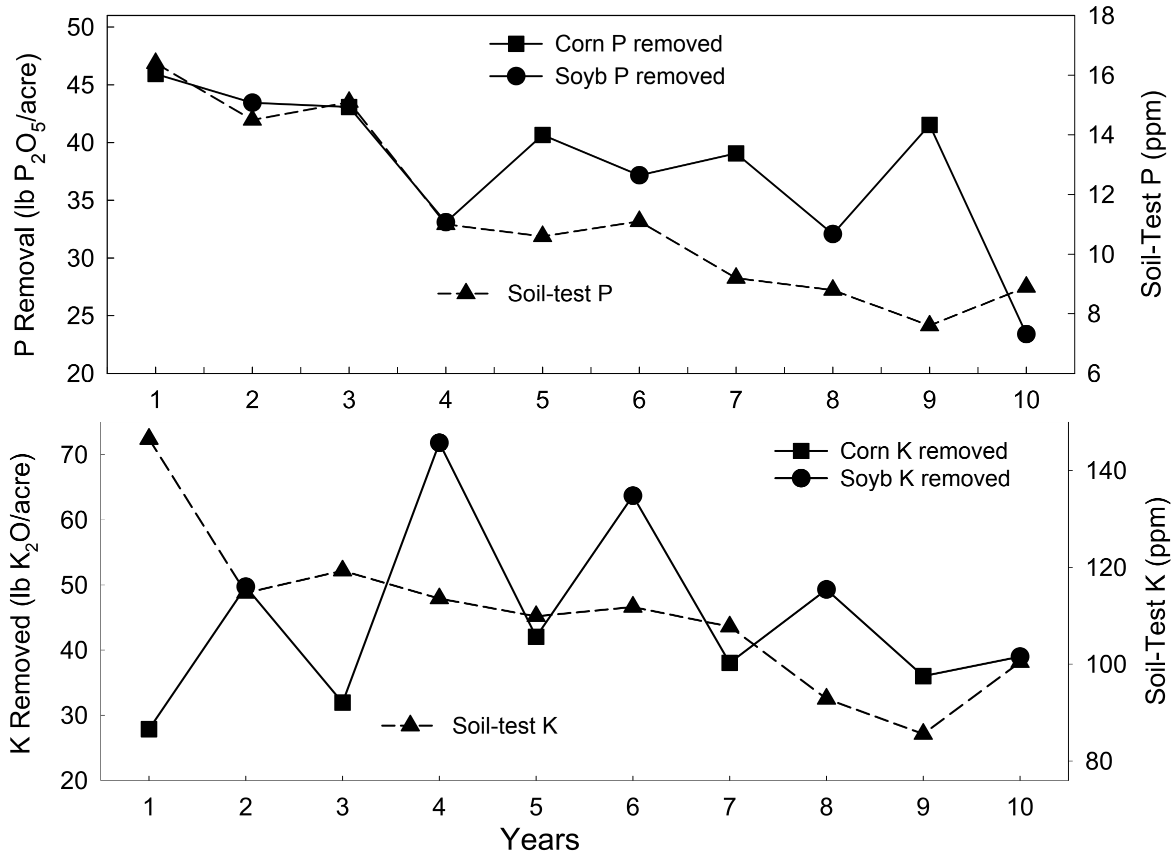

Figure 6. Annual phosphorus and potassium removed with grain harvest and soil-test K trends over time for non-fertilized corn-soybean rotations in separate trials for each nutrient conducted at one location.

The poor relationship between removal and soil-test values in the short term also justifies more frequent soil sampling than the usual 4-year interval. Sampling every two years for the corn-soybean rotation is reasonable, since the relative cost of soil sampling and testing have decreased over time compared to many crop production costs. Also, the more frequent sampling will provide more useful soil-test trends. At the time of making a fertilization decision, comparing the current yield and soil-tests values with trends over time will result in a better estimate of the amount of fertilizer to be applied.

References used

Mallarino, A.P., J. Jones, J. Hirniak, L. Thompson, D. Schaben, and J. Beckman. 2018. Yield of corn and soybean managed with tillage or no-tillage as affected by the phosphorus and potassium placement method. Farm Progress Reports: Vol. 2017, Issue 1, Article 17. Available at https://lib.dr.iastate.edu/farmprogressreports/vol2017/iss1/17.

Mallarino, A.P., and K. Pecinovsky. 2017. Phosphorus and potassium placement for corn and soybean managed with tillage or no-tillage. Farm Progress Reports: Vol. 2016, Issue 1, Article 76. Iowa State Univ., Ames. http://lib.dr.iastate.edu/farmprogressreports/vol2016/iss1/76.

Mallarino, A.P., and J. Sievers. 2016. Phosphorus and potassium placement and application rates for corn and soybean managed with no-till or tillage. Northwest Research Farm and Allee Demonstration Farm Annual Reports. ISRF15-29,31, RFR-A1563. Iowa State Univ., Ames.

Mallarino, A.P., Sawyer, J.E., and S.K. Barnhart. 2013. General guide for crop nutrient recommendations in Iowa. Publ. PM 1688 (Rev.). Iowa State. Univ. Extension.

Mallarino, A.P., and D. Rueber. 2012. Placement methods of phosphorus and potassium for corn and soybean managed with no-till and chisel-plow/disk tillage. Northern Research and Demonstration Farm Annual Reports. ISRF11-22. Iowa State Univ., Ames.

Mallarino, A.P., and K. Van Dee. 2011. Long-term study of phosphorus and potassium placement methods for corn and soybean managed with no-till or tillage. Southeast Research and Demonstration Farm Annual Reports. RFR-A1081, ISRF10-34. Iowa State Univ., Ames. http://www.ag.iastate.edu/farms/reports.html.

Mallarino, A.P., R.R. Oltmans, J.R. Prater, C.X. Villavicencio, and L.B. Thompson. 2011. Nutrient uptake by corn and soybean, removal, and recycling with crop residue. p. 103-113. In The Integrated Crop Management Conf. Proceedings. Nov. 30 - Dec. 1, 2011. Iowa State Univ. Extension.

Oltmans, R.R., and A.P. Mallarino. 2011. Phosphorus and potassium removal and leaching from residue in corn and soybean. p. 197-202. In North-Central Extension-Industry Soil Fertility Conf. Proceedings. Nov. 16-17. Vol. 27. Des Moines, IA.