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

Antonio P. Mallarino, professor, Agronomy, Iowa State University

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$_2$O$_5$/acre and 0, 72, or 144 lb K$_2$O/acre. Two other treatments are applied every other year to corn or soybean at rates of 92 lb P$_2$O$_5$/acre and 144 lb K$_2$O/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](image-url). Soil-test P (ppm) and STK (ppm) trends over time from a northeast Iowa long-term experiment with corn-soybean rotations that received 0, 46, and 92 lb P$_2$O$_5$/acre/year or 0, 72, and 144 lb K$_2$O/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 P₂O₅/acre/year or 0, 72, and 144 lb K₂O/acre/year. Yields for each nutrient are averages across the two rates of the other. Asterisks indicate significant differences (P ≤ 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.
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 P₂O₅/acre/year and 0, 35, and 70 lb K₂O/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 P₂O₅/acre/year resulted in an average STP decrease of 0.78 ppm/year. These results imply an average removal of 47 lb P lb P₂O₅/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 P₂O₅/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 P₂O₅/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 K₂O/acre/year resulted in an average STK decrease of 3.0 ppm/year. These results imply an average removal of 14 lb P lb K₂O/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.
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.
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


