Why are Soil Test Potassium Levels so Variable over Time in the Corn Belt?

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1. Introduction

Perhaps one of the best uses of soil test information is tracking how levels change over time. Examining trends over years helps evaluate how nutrient management practices are performing. For instance, if soil test potassium (K) levels are high, a producer may decide to forego K fertilization and allow the crop to utilize the soil K already present. This practice would be expected to draw down soil K levels over time. Conversely, if a producer has low soil K supplies, he or she may want to build them to higher levels. As K is applied over time, a producer using a regular soil testing schedule can see if soil test levels are changing as desired. Although this use of soil test information is fundamental to nutrient management, many producers and their advisers have noticed that changes in soil test K can be quite variable and unpredictable over years. Consequently, some review is warranted of the factors that have been shown to cause such variability.

2. Time of Year

Studies have shown that soil test levels can vary with time of year (36, 37, 47). Figure 1 shows how soil test K levels can change over time. In this study, cores were taken every month where various K rates had been applied in March or April, prior to planting corn. The line at the bottom of the figure shows how soil test K levels changed where no K was applied. Levels were lowest in November, then rose during the winter, peaking in March. During the cropping season, K levels declined, again reaching their minimum. The upper graph shows similar trends, but K levels peaked in May, after the application of K, then declined to their lowest levels in September and October.

Figure 1. Seasonal variability in average soil test K levels in fertilized (+K) and unfertilized (-K) treatments. Fertilizer was applied in March or April. Monthly soil test levels are averaged over a 38 month period, starting in May 1980 and ending in July 1983. Error bars are ±1 standard deviation (37).
Higher soil test K levels in the spring, compared to the fall, have also been observed in other studies from the northern United States (36, 47). Maximum increases from fall to spring in these other studies ranged from 33-45 ppm, across various soil test K extractants. In some areas of the Corn Belt, crop advisers report that growers are requesting a shift to spring, rather than fall, soil sampling. This shift could cause soil test levels to increase above expectations when compared to samples from previous years’ fall samples.

Causes of seasonal variability in soil test K, like those shown in Figure 1, are numerous. Several possible factors are discussed below.

3. Nutrient Uptake and Removal by Crops

As crops grow during the season, they take up K from the soil. Much of the K in crops is in the vegetative portions of the plant. For example, some studies have shown that soybean has approximately 54% of its total K in the grain while for corn, it is 20-44% (21, 23, 28).

Figure 2 shows how K is partitioned among various soybean plant fractions (above-ground only) throughout the season (23). Leaves and petioles that fell during the season were collected and measured.

Figure 2. Potassium uptake and partitioning patterns for soybean (23).
Total K accumulation followed a pattern very similar to that of dry matter, with slow accumulation at early vegetative growth stages, and an almost constant, more rapid K accumulation at later vegetative and early to mid reproductive stages. After about growth stage R5 (beginning seed), K was rapidly lost from the leaves, petioles, and stems and repartitioned into the developing beans. Approximately half of the K in mature seeds came from these other plant fractions. At harvest, approximately 56% of the total K in the plant was in the mature seed. The K that had been rapidly taken up between growth stages V10 and R6 accounted for about 75 to 80% of the total K taken up in the above-ground soybean tissue.

Figure 3 demonstrates K uptake and partitioning patterns for corn (28). Plants were separated into 4 fractions: 1) lower leaves (below the ear), 2) upper leaves (above the ear), 3) stalk and tassel, and 4) ear and shank. The percent of the total K\textsubscript{2}O uptake attributable to each fraction was as follows: lower leaves (15%), upper leaves (14%), stalk and tassel (51%), and ear and shank (20%). Rate of K accumulation was most rapid during vegetative growth. Maximum rates of uptake during vegetative growth were: lower leaves (3-4 lb K\textsubscript{2}O/acre/day), upper leaves (8 lb K\textsubscript{2}O/acre/day), and stalk and tassel (11 lb K\textsubscript{2}O/acre/day). During grain fill, the ear and shank fraction took up less than 2 lb K\textsubscript{2}O/acre/day.

**Figure 3.** Potassium uptake and partitioning patterns for corn (28).
Table 1. Potassium uptake rates of several field crops, as reported by Midwest Extension publications.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Harvest unit</th>
<th>Uptake rate (lb K₂O/harvest unit)</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>ton</td>
<td>40-60</td>
<td>4, 5, 11, 18, 19, 24, 29, 30, 33, 35, 42, 45, 48, 52, 58, 63, 64</td>
</tr>
<tr>
<td>Corn</td>
<td>bu</td>
<td>1.25-1.50</td>
<td>6, 19, 48</td>
</tr>
<tr>
<td>Soybean</td>
<td>bu</td>
<td>2.4-2.4</td>
<td>19, 48</td>
</tr>
<tr>
<td>Wheat</td>
<td>bu</td>
<td>1.28-1.9</td>
<td>19, 48, 63</td>
</tr>
</tbody>
</table>

†M denotes that the mode was used; A signifies that the average was used when the mode could not be calculated (a value did not appear more than once in the list).

Table 2. Potassium removal rates of several field crops, as reported by Midwest Extension publications.

<table>
<thead>
<tr>
<th>Crop</th>
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<tr>
<td>Alfalfa</td>
<td>ton</td>
<td>40-60</td>
<td>4, 5, 11, 18, 19, 24, 29, 30, 33, 35, 42, 45, 48, 52, 58, 63, 64</td>
</tr>
<tr>
<td>Corn</td>
<td>bu</td>
<td>0.19-0.30</td>
<td>4, 5, 6, 18, 19, 24, 30, 34, 35, 42, 45, 48, 52, 58, 63</td>
</tr>
<tr>
<td>Soybean</td>
<td>bu</td>
<td>1.0-1.5</td>
<td>4, 5, 18, 19, 24, 30, 35, 42, 45, 48, 52, 58, 63, 64, 65</td>
</tr>
<tr>
<td>Wheat</td>
<td>bu</td>
<td>0.28-0.40</td>
<td>4, 5, 18, 19, 24, 35, 42, 45, 48, 52, 58, 63, 64, 66</td>
</tr>
</tbody>
</table>

According to Extension publications in the North Central region, average total uptake rates of K in the above-ground tissue of soybean and corn are approximately 2.3 and 1.37 lb K₂O/bu (Tables 1-2). Using the modal or average rates, we calculate:

soybean nutrient uptake = 50 bu/A x 2.4 lb K₂O/bu = 120 lb K₂O/A

corn nutrient uptake = 150 bu/A x 1.35 lb K₂O/bu = 203 lb K₂O/A.

Using average nutrient removal rates of 1.4 and 0.3 lb K₂O/bu for soybean and corn, respectively, we calculate:

soybean nutrient removal = 50 bu/A x 1.4 lb K₂O/bu = 70 lb K₂O/A

corn nutrient removal = 150 bu/A x 0.3 lb K₂O/bu = 45 lb K₂O/A.

To estimate how much K will be deposited to the soil after harvest, we subtract nutrient removal from nutrient uptake:

K deposited by soybean residue = 120 lb K₂O/A - 70 lb K₂O/A = 50 lb K₂O/A
K deposited by corn residue = 203 lb K$_2$O/A – 45 lb K$_2$O/A = 158 lb K$_2$O/A

So in 2 years of a corn soybean rotation, a total of 323 lb K$_2$O/A will be taken up by both crops, 115 lb K$_2$O/A will be removed, and 208 lb K$_2$O/A will be returned back to the soil as it is leached from the residue by precipitation.

Comparing the amount of K removed to the amount applied is often used as a way to predict the direction of soil test changes in the future. If more K is applied than removed, then a positive budget exists and levels are expected to increase. If application rates are less than removal rates, then soil test levels are expected to decline. How quickly and how much soil test levels will respond to budgets depends on the mineralogical properties of the soil, environmental conditions, and the magnitude of the K budget surplus or deficit. A rule of thumb in the Midwest is that a budget surplus of 8 lb K$_2$O/A are needed to raise the soil test K level 1 ppm (24). Obviously, actual amounts can vary widely.

How much K is leached from crop residues over time depends largely on the amount of precipitation that occurs. A Texas study (Figure 4) monitored K loss from corn residue placed in bags left at the soil surface (53). Bags were placed on field areas that received either rainfall and irrigation (by overland flow) or rainfall only. Regardless of moisture regime, K release was exponential. Release rates were greater with initial amounts of water than with later additions. In the irrigated treatment, K loss per unit of water added was less than the non-irrigated treatment.

Figure 4. Leaching of K from corn residue left at the soil surface under different moisture regimes imposed after harvest (53).

The reasons behind these differences are not currently known; however such relationships demonstrate that moisture additions are important for K release from plant tissue. Consequently, the timing and quantity of precipitation relative to harvest and sampling can affect the K levels measured by a soil test. Soil samples taken immediately after harvest would not detect much of the K contributions from the recently harvested crop’s residue. However, later sampling after more precipitation would be expected to capture more of the leached K. Leaching of K may be part of the cause of higher soil test K levels observed in the spring in Figure 1.
4. Soil Moisture

Many advisers have noticed that soil moisture at the time of sampling can greatly affect soil test K results. Most often, questions arise when test levels come back much lower than expected. The reasons behind these changes are not clear cut, but scientists have made some insights.

The influence of soil moisture upon soil test K levels has been attributed largely to the release of K from interlayer positions of certain clay minerals termed phyllosilicates.

Figure 5. Representation of adsorption positions for K\(^+\) in a mica-vermiculite interstratified mineral (50).

These minerals have a layered structure, with negative charges on planar and interlayer positions (54). Figure 5 shows how K\(^+\), a positively charged ion, or cation, is adsorbed to the planes, edges, wedges, and interlayer positions of these negatively-charged sheet-like minerals (50). The example shown is a mineral with both mica and vermiculate present in different layers (interstratified). Potassium held on the edge and planar positions is considered exchangeable and is measured by commercial soil tests. Planar positions always have a negative charge, but edge sites can change charge depending on pH. Edge sites are produced by the breaking of bonds at mineral edges. Generally, edge sites become more negative as soil pH increases (62). Potassium held in interlayer and wedge positions does not readily exchange with K\(^+\) in the soil solution. It is held very tightly and is often termed “fixed.” Fixed K\(^+\) can be released when exchangeable K\(^-\) is depleted or when environmental conditions change.

Minerals with the types of adsorption sites discussed above are kaolinite, mica, vermiculite, smectite, hydroxy-interlayered vermiculite and smectite, as well as interstratified combinations of these minerals. Not all minerals contain all sites, but all contain planar and edge positions. Only kaolinite does not contain interlayer positions (54).
When moisture levels change in soils, electrical and structural changes occur in clay minerals. In particular, the change in charge of iron (Fe) in phyllosilicate mineral structures has been shown to be important. Iron changes charge from +2 to +3 when soils are dried. For smectites, this results in less fixation of interlayer $K^+$ (8, 31, 60). However, for vermiculites and illite mica, more fixation can occur (2, 60). Consequently, how soil test K changes upon drying depends to a large extent on the mineralogical composition of the soil.

Many investigations took place in the mid 20th century examining the effects of soil moisture on soil test K levels (1, 7, 12, 13, 22, 38, 55, 56, 59). Generally, most of these researchers observed that when dried, soils low in K showed increases, while the same soils high in K exhibited decreases. Figure 6 shows such relationships for a Bedford soil.

**Figure 6.** Fixation and release of K by the same soil either low in K or enriched with K (12).

In this study (12), soils were dried and soil test levels monitored. Soils were studied either “as is” from the field or as they had been altered after incubations with nutrient solutions. A soil lower in K released K upon drying while the same soil with higher K fixed it as it dried. Not all soils in the study showed fixation or release. Some did not change much at all.

The release of K upon drying can be gradual or it can be exponential. An example of exponential release is shown in Figure 7. A Clarion loam and Harpster silty clay loam were air dried over a period of 24 hours, during which time sub-samples were taken at different intervals (38).

**Figure 7.** Changes in ammonium acetate extractable K as two soils (Clarion loam and a Harpster silty clay loam) were dried to different soil moisture contents (38).
Soil moisture content was measured, along with ammonium acetate extractable K. As samples dried, exponential releases in K occurred at moisture contents below about 10%. Releases of K below this moisture level have been observed in other studies (12, 55, 56). Rapid releases have been attributed to the soil mineral montmorillonite, while more gradual releases have been associated with vermiculite (12).

The importance of initial K levels to the directional change in soil test K with drying has been attributed to the presence of a chemical equilibrium of $K^+$ in soils. This theory, attributed by many to Bray and DeTurk (3), suggests that there is an equilibrium distribution of $K^+$ among the interlayers of minerals, the $K^+$ held on the surfaces and edges, and the $K^+$ in solution. Changes in the activity of $K^+$ in any one of these places affects the activity of $K^+$ in the others. In particular, low concentrations of exchangeable and solution $K^+$ can drive the release of fixed $K^+$ (57). Bray and DeTurk theorized that dry soils had lower activity of $K^+$ in solution, releasing $K^+$ according to this mechanism. Research on 6 soils in Kentucky suggested that average equilibrium exchangeable soil test K levels were approximately 0.45-0.50 meq/100 g or 176-195 ppm (9, 12). Below this range, soil test levels usually increased when soils were dried, while above this range, drying resulted in decreased levels. This average equilibrium range is also consistent with the results of similar investigations on Wisconsin soils (1). The notion, however, that drying simply hastens the attainment of equilibrium is challenged by more recent studies showing that drying changes the electronic and physical structure of clay minerals containing iron (14). One would expect that such changes would lead to new equilibrium conditions upon drying.

How long K levels can be sustained in dried soils once they are rewetted is also an important factor when examining soil test variability over time. In soils where K has been released with drying, increased K levels may continue for some time after soils are rewetted. Luebs et al. (38) rewet soils and kept them moist for several time increments. Out of the 13 soils studies, 9 were able to maintain higher levels for 147 days, the longest period of time measured. In soils where K levels declined as they were dried, continuously moist samples fixed much less K than those subjected to subsequent wetting.
and drying cycles (67). Consequently, the occurrence and number of wetting and drying cycles contributes to K release.

The extent to which wetting and drying cycles affect yearly variations in soil test levels under field conditions is not well defined. In one study in Iowa, it was found that soil test K levels varied inversely with soil moisture only in the top inch of soil (38). The fields studied had been plowed, and only the surface inch of soil dried to moisture contents low enough where K release occurred. Soil in lower depths retained sufficient moisture to keep K from being released.

There are practical implications of moisture relationships for soil testing and interpretation. Current practice in commercial laboratories is to dry received samples prior to grinding and chemical analysis. After air-drying, soil moisture contents are typically below 5% and have been reported as low as 0.7% (12, 38). The final moisture content of soils depends greatly on the relative humidity at which they are dried. Higher humidity results in higher moisture contents. Reported soil moisture contents after air-drying are well within the range where stark changes in soil test K have been reported. Consequently, on soils testing lower in K, lab results may overestimate K supply, while underestimations may occur in higher testing soils. These concepts may explain why K deficiencies are sometimes observed in soils with high K levels.

5. Freezing and Thawing

Freeze-thaw cycles affect soil test K in a manner similar to wetting and drying cycles, since freezing is a form of drying. In a study conducted on a variety of clay minerals and Wisconsin soils, freeze-thaw cycles increased ammonium acetate extractable K when initial soil test levels were at or below 235 ppm (16). Above this level, soil test K levels declined when frozen. The addition of lime alone either reduced the amount of K released or changed the reaction from release to fixation. As in the soil moisture studies discussed above, initial soil test levels were distributed across many different soils and mineralogical compositions. In the same study, smectites were shown to release K when frozen, whereas illite fixed K, similar to that observed by Stucki for wetting and drying cycles (60). Consequently, the release of K from freeze-thaw cycles probably contributes to increases in soil test K from fall to spring, like those shown in Figure 1. Like wetting and drying cycles, the directional change observed in soil test K levels with freezing and thawing will depend on soil mineralogy and initial K levels.

6. Microbial Activity

Some microbes in soils are capable of reducing Fe in clay minerals (changing the charge of iron from +3 to +2). In a study by Stucki et al., microbes indigenous to soils reduced 6.4-51% of Fe that was part of the clay mineral structure (61). The highest percentage was associated with montmorillonite and the lowest with nontronite. These changes have been shown to cause a collapsing of the clay layers in nontronite (32), a phenomenon associated with K fixation. Microbial activity may be responsible for some of the observed decreases in soil test levels from spring to fall sampling times.
7. Nutrient Stratification

7a. Depth Control when Sampling
7b. Numbers of Cores in a Sample
7c. Laboratory to Laboratory Variability

Nutrient stratification is a gradient of soil test levels with depth. In reduced tillage systems, levels of K can be several hundred ppm greater at the surface than just a few inches down (51, 20, 27). An example is shown in Figure 8. In this study (51), soil test K levels were measured on a Tama silt loam soil after 10 yr. of no-till corn production.

**Figure 8.** Stratification of soil test K after 10 years of no-till production (adapted from 51).

Potassium fertilizer had been broadcast at the surface each year as well as applied near the seed at planting. Soil test levels varied from 580 ppm to less than 160 ppm over a depth of 10 inches. In general, stratification results from surface applications of K, reduced tillage, nutrient uptake by crops, and leaching of K from crop residues left at the soil surface.

When fields with reduced tillage are fertilized with K, stratification occurs very quickly, due to the soluble nature of fertilizer materials. In a Minnesota study, broadcast applications of K produced significant stratification when measured 2-3 months after fertilization on a soil managed with no-till (43). After K was allowed a full year to react with the soils, the degree of stratification decreased; however, the upper 2 in. of soil were still higher in soil test K. Increased stratification after the first K application in recently adopted conservation tillage systems has also been observed in other studies (10, 15). In one of these studies (15), elevated K levels in the surface 2 in. of soil in conservation tillage systems accounted for most of the elevated levels observed in that layer after 5 years.

An important aspect of stratification is the shift in soil test levels not only at the soil surface but throughout the soil profile. Some studies have shown that, relative to more aggressive tillage systems such as moldboard plowing, reduced tillage systems have relatively higher levels near the surface but relatively lower levels deeper in the soil profile (10, 15, 27, 25). This has been attributed largely to the lack of incorporation of K applied to the surface in reduced tillage systems, coupled with plant uptake of K in lower
parts of the profile and the subsequent deposition of K by plant portions left at the surface.

7a. Depth Control during Sampling
Controlling sampling depth becomes more important as nutrient stratification increases. If samples are taken shallower than recommended, inaccurately high soil test K levels may result. If samples are taken too deeply, the opposite may occur. Using Figure 8 as an example, sampling to 8 in. would result in a core representing 160-580 ppm, while sampling only to 4 in. would capture only the upper end of this range. Strict depth control has fewer implications where nutrients are well mixed within the depth sampled.

7b. Number of Cores in a Sample
When analyzing a sample for K, a soil testing laboratory will use only a very small portion of the sample collected in the field - typically 2 g. (46). Therefore, a representative sample is critical for assessing soil nutrient status. Soil test K levels can be highly variable within a field, with reported coefficients of variation ranging from 39-157% (44). Causes of variability include differences in landscape position, erosion, and management history.

So how many cores should go into a sample? Traditional scientific guidance has been that 20 or more cores go into a sample that represents a fairly uniform, larger area, such as a field or an area within a field, while smaller numbers of cores, such as 8-12, may be adequate for more spatially intensive sampling methods (17, 26). On fields where K has been applied in a band, more cores, 20-50, may be needed when exact band positions from previous applications are unknown, as is usually the case (39, 49).

Taking a small number of cores results in reduced chances that the sample represents the average fertility of the area represented. Smaller core numbers lead to greater variability among samples taken from the same area. Consequently, taking too few cores per sample can contribute significantly to the observed year-to-year variability in soil test results, producing random increases or decreases.

7c. Laboratory to Laboratory Variability
A single sample sent to multiple laboratories will result in scattered results. In a recent assessment, variability in ammonium-acetate extractable K from laboratory to laboratory ranged from 6-22% across a range of soils used as standards (40). Variability in soil test K across laboratories is about 40% higher than variability within a given laboratory (41). Consequently, staying with the same laboratory for analyses is recommended, providing the laboratory has good quality control.

8. Summary

A number of factors have been discussed which may explain the variation in soil test K observed within and across years. Practically, advisers can manage only some of these factors. Some practical suggestions are:
• Sample at the same time of year. This helps take out some of the seasonal variability. Switching from fall to spring sampling can introduce significant changes from one sampling period to the next.
• Ensure samples are representative and composed of enough cores. This may require some strategizing. If areas of the field have been inexplicably variable from one year to the next, increasing the number of cores going into those samples may help stabilize some of the variation over time.
• Find a quality lab and stick with it. Staying with the same lab removes the lab to lab variability from the overall year to year variation.
• Find ways to control depth of sampling to ensure consistency. Adding stops to the probe or creating marks are possibilities.
• Keep track of nutrient additions and removals to calculate nutrient budgets. When additions exceed removals, soil test levels are expected to build. When removal exceeds additions, levels are expected to decline. If soils do not behave this way, other factors mentioned in this paper need to be examined.
• Consider setting up some monitoring areas. Places to start are on soils that have been changing in unpredictable ways. Samples of these areas should be taken every year to gain a better understanding of soil test K dynamics. Keeping additional information on these areas, such as moisture conditions at sampling and nutrient budgets, may provide some further insights into the primary causes of variability.
References


