# Evaluating the Effect of Clay Mineralogy on Soil Test K Levels and K Fertilizer Recommendations for Corn

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## Core Ideas

- Clay minerals influence K fixation (trapping of K temporarily between clay layers) and K release.
- Smectite and illite clays are more dominant than kaolintic clays in eastern South Dakota.
- Soil test K levels decreased as the smectite:illite ratio decreased.
- There was a positive relationship between soil test K and pH for illitic and smectitic soils, but a negative relationship for highly smectitic soils.
- Soil test K is generally more variable (109-960 ppm) when the smectite:illite ratio is <4.5 and less variable when it is >4.5 (100-359 ppm).
- Grouping soils by smectite:illite ratio minimally changed the critical soil test K value where K fertilization is no longer expected to increase yield.
- The soil test K critical value will stay the same at 160 ppm for all soils.

## Background

Applications of organic and synthetic fertilizers are commonly applied to agricultural crop fields to help provide enough nutrients to optimize crop yield potential. For potassium (K), fertilizer applications are widely accepted as beneficial to improve corn yields when soil test K levels are below a critical soil test value, which is a threshold at which no additional yield is expected from fertilizer applications. Many Midwestern U.S. states including South Dakota use ammonium acetate extractable K to determine the K fertilizer recommendations. The soil test K levels for states which use ammonium acetate to extract K generally range from 50 to 300 ppm soil test K (Lyons et al., 2023). The variability in soil test K is attributed to a wide range of soil textures, clay contents, and precipitation differences across the U.S (Keeney et al., 2020). Further, there can be large spatial variations in available and slowly available soil K in different soils (Tan et al., 2012).

One challenge with only using soil test K to make K fertilizer recommendations is the sometimes-low variability in K responses (9 to 28%) that are explained by soil test K (Culman et al., 2023; Heckman et al., 2006). To help limit these K fertilizer recommendation errors North Dakota has included clay mineralogy information with soil test K (Breker et al., 2019).

## Clay Mineralogy's Influence on Available Soil K

Clay minerals are known to influence both soil K fixation, which is the process by which K cations are temporarily trapped between collapsing layers of certain 2:1 phyllosilicates under dehydrated conditions, and subsequent K release from those layers when hydrated (Florence et al., 2017; Rich, 1968) (Figure 1). For example, interlayer K found in 2:1 clay minerals (initially thought to be nonexchangeable) has been shown to be partially plant-available and thus important as a K reservoir in soil (Barré et al., 2008; Barré et al., 2007). This is the result of several processes, including root uptake, reduction of solution K concentration facilitating interlayer K release, and wetting-drying cycles that expansive 2:1 phyllosilicates like smectites undergo (Figure 1). Beyond interlayer K release in expansive

clays like smectite, K release can also occur in non-expansive clay minerals. For example, K release was observed to be higher in 2:1 illitic soils compared to 1:1 kaolinitic soils, both of which are non-expansive type clays (Darunsontaya et al., 2010). Other minerals such as vermiculites and/or interstratified mica-vermiculites in the silt and fine sand fractions of different soil parent materials can also contribute to a significant portion of K fixation capacity (Portela et al., 2019).

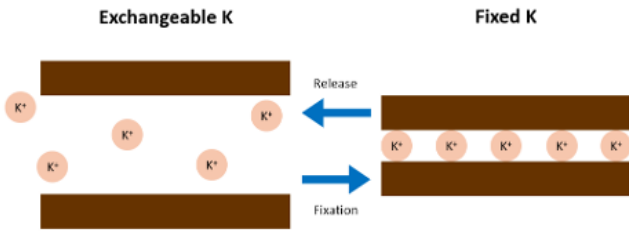



**Figure 1**. Schematic illustration of potassium (K) fixation and release in expansive 2:1 phyllosilicates like smectite. Under dehydrated conditions, clay mineral layers will collapse and temporarily render $K^+$ unavailable for plant uptake. When hydrated, the layers will expand and allow for cation exchange. Adapted from Moody & Bell (2006).

Potassium forms and clay content are also different based on whether soil was derived from kaolinitic or smectitic clays (Sharpley, 1989). Specifically, Sharpley (1989) noted that the exchangeability of nitric acid-extractable K was greater for soils dominant in 1:1 clay minerals (i.e., kaolinite) compared to soils dominant in 2:1 clay minerals (i.e., smectite). Intensive row crop agriculture (corn, soybean, wheat, sunflower) is heavily concentrated in the eastern half of South Dakota, which coincides with generally low relative amounts of kaolinite mapped in the A horizon of soil (Smith et al., 2014). Pockets of higher relative kaolinite concentrations are mainly restricted to the unglaciated areas west of the Missouri River, but those regions represent a fraction of the total row crop productivity in South Dakota. Rather, smectite and illite clays are dominant, yet variable, throughout eastern South Dakota.

In a recent study in central and eastern South Dakota soils were divided into three groups based on the smectite:illite ratio in the soil (<1 [illitic], ≥1 but ≤4.5 [smectitic], and >4.5 [highly smectitic]). The mean soil test K decreased as the smectite:illite ratio of the clay fraction increased, but the opposite trends occurred as mean pH and mean CECa values increased (Table 1). Linear correlation analysis also showed a strong negative relationship between soil test K and the smectite:illite ratio (-0.34). This negative relationship suggests a reduction of readily available soil K (solution and exchangeable) in soils with high proportions of smectite to illite clays.

**Table 1.** Means and standard deviations (**σ**) for various soil parameters based on the smectite:illite ratio: illitic (<1), smectitic (≥1 but ≤4.5), and highly smectitic (>4.5).

| Soil Parameter[a] (Units) | Illitic | | Smectitic | | Highly Smectitic | |
|---|---|---|---|---|---|---|
| | Mean | σ | Mean | σ | Mean | σ |
| STK (ppm) | 303a | 135 | 293a | 171 | 170b | 61 |
| Water-Soluble K (ppm) | 44a | 26 | 44a | 31 | 25b | 14 |
| pH | 6.2c | 0.8 | 6.7b | 0.9 | 7.1a | 0.8 |
| CECa (meq 100 g $^{-1}$) | 21.4b | 6.1 | 24.1a | 6.8 | 24.6a | 3.8 |
| SOM (%) | 4.0b | 0.9 | 4.4a | 0.8 | 4.3ab | 0.7 |
| Clay Content (%) | 30b | 9.1 | 33a | 7.9 | 29b | 7.0 |
| Smectite:Illite Ratio | 0.51c | 0.24 | 1.87b | 0.77 | 8.84a | 5.75 |

[a]STK, soil test potassium; CECa, apparent cation exchange capacity; SOM, soil organic matter.

Note: Within each row, means followed by different letters indicate significantly different groups using Fisher's least significant difference (LSD) test (α = 0.05).

The soil pH in South Dakota was found to have differing relationships with soil test K based on the smectite:illite ratio of the soil. There was a positive relationship between soil test K and pH for illitic and smectitic soils, but a negative relationship for highly smectitic soils (Figure 2). These results imply that there are notable variations in the relationships among soil K forms and pH at different levels of the smectite:illite ratio.

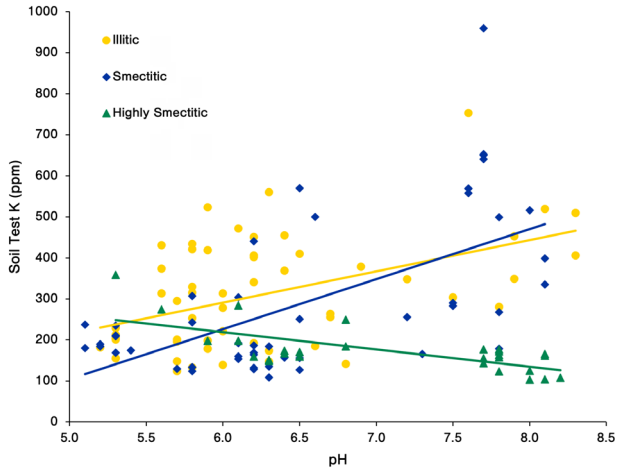



**Figure 2**. Soil test K (STK) as a function of pH for three different groups based on the smectite:illite ratio: illitic (<1), smectitic (≥1 but ≤4.5), and highly smectitic (>4.5).

## Using Mineralogy in K Recommendations

Figure 3 shows the relationship between soil test K and the smectite:illite ratio, where points were marked as above a smectite:illite ratio of 4.5 or below that value. Below 4.5 smectite:illite ratio, soil test K was observed to be highly variable, with a range of 109-960 ppm soil test K. At higher proportions of smectite (>4.5 smectite:illite); however, soil test K was predicted to be lower and less variable (range of 100-359 pm soil test K) compared to soils with a smectite:illite ratio below 4.5. These results demonstrate that soil test K can be highly variable among soils either dominant in illite or soils having up to 4.5 times more smectite than illite. However, soils that are highly smectitic (i.e., smectite:illite ratio >4.5) are likely to have relatively less soil test K. The lower potential availability of soil test K in highly smectitic soils is likely why research in North Dakota found it necessary to raise the soil test K critical value for corn fertilization when the smectite:illite ratio exceeded 3.5 (Breker et al. 2019).

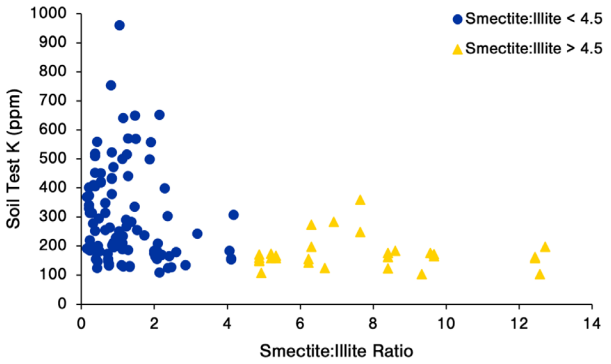



**Figure 3**. Soil test K (STK) as influenced by the smectite:illite ratio and partitioned into two clusters using k-means cluster analysis.

In evaluating the relationship between relative yield and soil test K in South Dakota to determine a critical soil test K value where above which K fertilization will no longer increase crop yield, we evaluated the data all together and divided into two smecitite:illite ratio groups (1, < 4.5; 2, > 4.5) (Figure 4). When evaluating all the data together the critical soil test K value was 172 ppm and when divided by smectite:illite ratio it was 186 ppm for the smectite:illite ratio < 4.5 and 171 ppm for the smectite:illite ratio > 4.5 (Table 2). Overall, the two groupings were only 15 ppm different and the root mean square error and $R^2$ values changed minimally when grouping sites by the smectite:illite ratio. This result was a much smaller difference compared to the studies in North Dakota that saw the critical soil test value increase to 200 ppm when the smectite:illite ratio was > 3.5 and remained near 160 ppm when the smectite:illite ratio was < 3.5. Machine learning algorithms were also used to determine if soil mineralogy data could improve corn K fertilizer recommendations. However, these modeling methods also showed no improvement in K fertilizer recommendations when including mineralogy information (unpublished data). The difference in our results compared to North Dakota may be the low number of sites with less than 140 ppm soil test K in this study, which likely resulted in an insufficient number of sites with relative yields below 90% that would have likely improved the relationships between relative yield and soil test K for all the sites combined and when divided into smectite:illite ratio groups. Further sites will need to be evaluated that have soil test K values below 140 to better understand these relationships and get better quality comparisons.

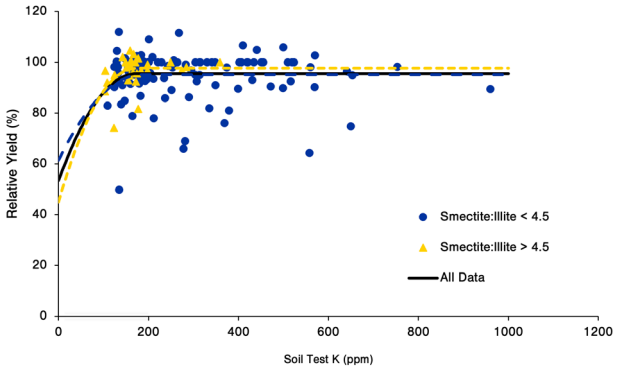



**Figure 4**. Relative corn yield response at varying soil test K levels (n = 134) for the 35 site-years in this study. Solid black line is the curve for all data, blue is for smectite:illite ratio < 4.5 and yellow is for smectite:illite ratio > 4.5.

**Table 2**. The K critical soil test value for all sites and sites divided into smectite:illite ratios of < 4.5 and >4.5 along with the root mean square error (RMSE) and $R^2$ values.

| Clay Mineralogy | K Critical Soil Test Value (ppm) | RMSE (%) | $R^2$ |
|---|---|---|---|
| All | 172 | 8.8 | 0.02 |
| S:I < 4.5 | 186 | 9.6 | 0.01 |
| S:I > 4.5 | 171 | 6.0 | 0.16 |

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