CONSIDERATION OF CLAY MINERALOGY FOR ENHANCED PREDICTION OF OPTIMAL CORN POTASSIUM FERTILIZER RATES

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ABSTRACT

Properly calibrated potassium (K) fertilizer recommendations (KFRs) are critical for improving crop yields and maintaining environmental stewardship. Recent innovations in soil and crop management suggest that certain soil factors, including clay mineralogy, can be used to predict optimal K requirements in corn. The objectives of this study include 1) correlate soil K levels to corn yield, 2) calibrate KFRs with clay mineralogy data, and 3) determine the relationships among clay mineralogy, K uptake, and fertilizer requirements. During the 2020-2021 growing seasons, 15 field trials were established across central and eastern South Dakota. The experimental design used was a randomized complete block design with four replications. Treatments of potash fertilizer were broadcast applied at 6 different rates: 0-150 lbs. K_2O ac.$^{-1}$ in 30 lb. increments. A linear plateau model correlating soil test potassium (STK) to relative yield suggested that South Dakota's K critical level could shift from 160 to 169 ppm. Calibrating K fertilizer rates to corn yield resulted in accurate prediction of optimal KFRs at 12 of the 15 sites. Initial results showed that including clay mineralogy in the calibration process could not confidently be used to predict corn yield response.

INTRODUCTION

Poorly managed potassium (K) fertilizer applications are costly. While under-applications of K fertilizer can reduce the ability of corn (*Zea mays* L.) to yield at optimal levels, over-applications of K fertilizer are just as inefficient, especially when soil test K (STK) levels are adequate. For example, applying K fertilizer in Ohio at twice the estimated crop removal rate was ineffective at building STK and resulted in infrequent corn yield responses over 9 years (Fulford and Culman, 2018). In Arkansas, correlation and calibration analyses conducted on K fertilizer recommendations found that corn yield responses to K fertilization gradually declined until reaching 0% at 140 ppm Mehlich-III K (Drescher et al., 2021). Furthermore, research by Oliver et al. (2022) concluded that the profit-maximizing fertilizer-K application rate is lower than the current agronomic recommendation for corn in Arkansas. These studies suggest that over-application of K fertilizer does not improve corn yields, fails to build STK, and is uneconomical. Moreover, they stress the need of thoroughly tested K fertilizer recommendations (KFRs).

One of the main difficulties in KFR research is addressing field-level variation, which has historically resulted in this research needing to be specific to a state or region. For example, K fertilizer rate verification research revealed the need for region-specific optimization of fertilizer recommendations to maximize economic yields and maintain sufficient STK levels, due to the fact that soils within the state of Tennessee differ considerably in yield potential, soil type, and nutrient supplying capacity (Singh et al., 2019). While traditional fertilizer recommendation and soil test correlation/calibration research has been conducted on a state-by-state basis, ongoing efforts to promote broad, multi-state collaborations for fertilizer recommendations are necessary and forthcoming (Lyons et al., 2021; Slaton et al., 2022; Zhang et al., 2021). Additionally, scientists are exploring the incorporation of additional soil measurements into fertilizer rate recommendation development. In Missouri, Svedin et al. (2022) offered insights for including soil health metrics into KFR development. In North Dakota, Breker et al. (2019) successfully improved corn yield response prediction when partitioning sample sites based on clay mineral content. These results provide evidence that incorporating other soil test parameters, notably clay mineralogy, into KFRs may improve their accuracy.

Current KFRs in South Dakota only incorporate STK and yield goals into the calculations. The current STK critical level is set to 160 ppm ammonium acetate-extractable K. Improvements in crop management practices over recent decades have led to higher yielding corn in South Dakota, which simultaneously suggests that more crop inputs are required. However, increasing K fertilizer rates to match the higher yielding demands of corn may not always be necessary. Research is needed to validate current KFRs in South Dakota. Therefore, the objectives of this project include 1) correlate STK levels to corn yield, 2) calibrate KFRs with clay mineralogy data, and 3) determine the relationships among clay mineralogy, K uptake, and fertilizer requirements.

MATERIALS AND METHODS

From 2020-2021, 15 field trials were conducted throughout central and eastern South Dakota (Table 1). Sites were conducted primarily on commercial operations, but also at three university research stations. Sites were chosen to encompass a broad range of soil types, climates, and management practices. The experimental design used within each site was a randomized complete block design with four replications. Six treatments (0 [control], 30, 60, 90, 120, and 150 lbs. K_2O ac.$^{-1}$) of potash fertilizer (0-0-60) were broadcast applied prior to corn emergence. Prior to treatment application, soil samples were collected within each replication at four depths: 0-4, 0-6, 6-12, and 12-24 in. Soil samples were dried and ground to pass through a 2 mm sieve, upon which they were sent to Ward Laboratories (Kearney, NE, USA) for fertility and health analysis, and Activation Laboratories (Ancaster, ON, Canada) for mineralogy analysis. Plots were harvested by hand or using a plot combine at physiological maturity. Statistical analyses were conducted using R. Yield data was transformed to percent of maximum yield, then correlated with STK using a linear plateau model. Quadratic plateau modeling was used to calibrate KFRs by plotting corn grain yield at responsive sites against K fertilizer treatments.

Table 1: Agronomic information for the 15 field trials in this study.

Site	Year	County	Soil Series	Soil Texture	Tillage	Previous Crop
1	2020	Tripp	Millboro	Silty Clay	No-Till	Wheat
2	2020	Tripp	Millboro	Silty Clay	No-Till	Wheat
3	2020	Potter	Agar	Silt Loam	No-Till	Wheat
4	2020	Kingsbury	Poinsett	Silty Clay Loam	No-Till	Soybean
5	2020	McCook	Clarno	Clay Loam	Reduced-Till	Soybean
6	2020	Clay	Egan	Silt Loam	No-Till	Soybean
7	2021	Yankton	Clarno	Clay Loam	No-Till	Wheat
8	2021	Roberts	Peever	Sandy Loam	Vertical-Till	Soybean
9	2021	Hutchinson	Hand	Loam	No-Till	Soybean
10	2021	Turner	Egan	Silty Clay Loam	Reduced-Till	Soybean
11	2021	Lincoln	Wentworth	Silty Clay Loam	Reduced-Till	Soybean
12	2021	Codington	Kranzburg	Silty Clay Loam	Conventional-Till	Soybean
13	2021	Minnehaha	Blendon	Sandy Loam	Conventional-Till	Corn
14	2021	Minnehaha	Moody	Silty Clay Loam	Conventional-Till	Corn
15	2021	Brookings	Brandt	Silty Clay Loam	Conventional-Till	Soybean

RESULTS AND DISCUSSION

Soil Test Potassium Correlations

Selected soil test parameters, including smectite and illite clay content, are reported in Table 2. Soil test K levels ranged from 132 to 735 ppm, with only sites 9, 10, and 12 reporting STK levels below 160 ppm. Figure 1 displays the linear plateau model for sites 5, 6, 9, 10, 12, 13, and 14, with STK ranging from 132 to 202 ppm. According to current KFRs in South Dakota, a yield response is unlikely to be observed in soils >160 ppm. In this study, the linear plateau model climbed past 160 ppm and plateaued at 169 ppm, suggesting that a higher percentage of maximum yield could be achieved by raising the K critical value to 169 ppm.

Potassium Fertilizer Recommendation Calibrations

Of the 15 field trials conducted, only two (sites 10 and 15) were observed to positively respond to K fertilizer treatments. To optimize corn yield, K fertilizer would need to be applied at rates of 60 and 37 lbs. K_2O ac.$^{-1}$ at sites 10 and 15, respectively. While the yield response was anticipated for site 10 (STK = 132 ppm), a yield response was not expected at site 15, where STK was exceptionally higher than the current 160 ppm K critical level (STK = 327 ppm). Although the agronomic optimum KFR was observed, neither site required K fertilizer to yield at economic optimal levels (assuming \$0.65 lb.$^{-1}$ K and \$6.00 bu.$^{-1}$ corn price), which is consistent with conclusions from Oliver et al. (2022).

Table 2: Select soil test data (0-6 in. sample depth) for the 15 field trials in this study.

	Soil Test Parameter†					
Site	pH	CEC	EC	K	Smectite	Illite
		meq 100 g^{-1}	mmhos cm^{-1}	ppm	--------- <2 μm fraction	---------
1	7.5	40.3	0.50	634	55.3	34.3
2	7.7	39.2	0.59	735	48.5	39.3
3	6.2	21.6	0.25	501	41.8	48.0
4	5.9	29.5	0.22	322	77.5	16.3
5	6.1	25.6	0.19	200	76.3	18.3
6	5.3	24.1	0.16	202	36.3	52.0
7	6.8	13.7	0.13	241	51.5	38.8
8	6.0	17.2	0.11	287	34.8	51.5
9	6.1	14.3	0.11	132	43.5	44.8
10	7.2	22.7	0.31	143	80.8	13.0
11	8.0	29.3	0.40	436	54.0	36.8
12	6.1	22.2	0.44	155	39.8	47.0
13	6.4	14.1	0.22	161	19.0	65.0
14	5.3	21.9	0.16	170	41.0	45.3
15	6.1	18.7	0.21	327	14.3	70.8

† pH, 1:1 soil water; CEC, cation exchange capacity; EC, electrical conductivity; K, potassium, ammonium acetate-extractable

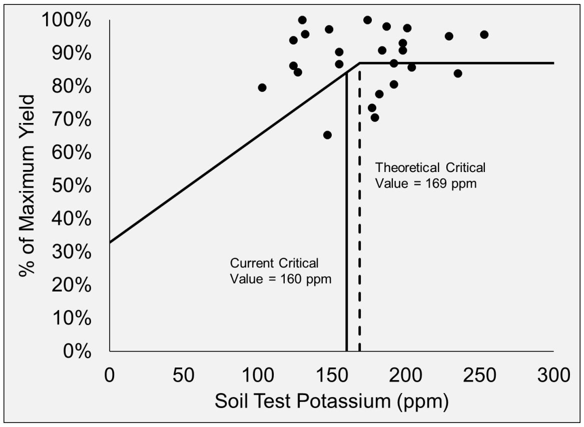

Figure 1: Linear plateau for correlation analysis.

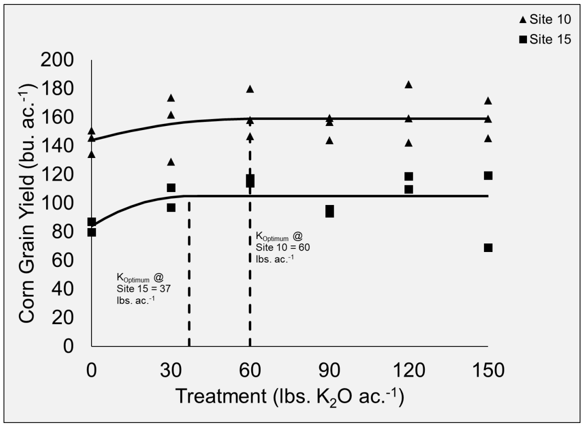

Figure 2: Quadratic plateau for calibration analysis.

Sites differed considerably in STK levels and mean maximum yields (MMY) (Table 3). However, only sites 10 and 15 showed positive yield responses to K fertilizer treatments. According to current South Dakota KFRs, using STK and MMY at each site, K fertilizer should be applied at 60 lbs. K_2O ac.$^{-1}$ at sites 9, 10, and 12 to optimize yield, while the remaining sites should not have any K fertilizer applied. Based on the observed yield responses, it was found that 60 lbs. K_2O ac.$^{-1}$ should be applied to site 10, and 37 lbs. K_2O ac.$^{-1}$ should be applied to site 15, while the remaining sites should have no K fertilizer applied. Therefore, when comparing current and optimum recommendations, KFRs were accurately predicted for 12 of the 15 sites. Over-applications of K fertilizer occurred at sites 9 and 12, while an under-application occurred at site 15.

Table 3: Soil test potassium, clay mineralogy, yields, and fertilizer recommendations.

Site	K	S:I†	MMY‡	Mean RY_0§	Yield Response⁋	Current KFR*	Optimum KFR††
			bu. ac.$^{-1}$	%		-------------lbs. K_2O ac.$^{-1}$-------------	
1	634	1.6	192	83	No	0	0
2	735	1.2	153	92	No	0	0
3	501	0.9	196	100	No	0	0
4	322	4.8	249	96	No	0	0
5	200	4.2	231	96	No	0	0
6	202	0.7	200	96	No	0	0
7	241	1.3	193	99	No	0	0
8	287	0.7	229	100	No	0	0
9	132	1.0	163	99	No	60	0
10	143	6.2	168	91	Yes	60	60
11	436	1.5	155	94	No	0	0
12	155	0.8	233	100	No	60	0
13	161	0.3	48	86	No	0	0
14	170	0.9	187	96	No	0	0
15	327	0.2	167	82	Yes	0	37

† S:I, smectite:illite ratio

‡ MMY, mean maximum yield, calculated as maximum yield from treatment means

§ Mean RY_0, mean relative yield from control treatment, calculated as yield of control plot divided by MMY

⁋ Significant quadratic plateau curve ($\alpha = 0.05$)

* Current South Dakota KFRs *Note*: 60 lbs. K_2O is minimum recommendation when STK <160 ppm

†† Theoretical optimum KFR obtained from quadratic plateau modeling

Integrating Clay Mineralogy

Clay mineralogy can impact the K fertilizer rate needed to optimize corn yield (Breker et al., 2019). It is theorized that a yield response to K fertilization may be observed, even if STK exceeds the soil test critical value, if there are more smectite than illite clays in the soil. Smectite clays are highly charged and exhibit shrink/swell dynamics, which hold onto K^+ ions tightly and temporarily fix K under dehydrated conditions. The K critical level in North Dakota was adjusted based on relative amounts of smectite and illite clays in the soil, in which soils containing 3.5 times or more smectites than illites increased the critical level to 200 ppm (Breker et al., 2019). Nitric acid-extractable K was found to be most exchangeable for kaolinitic soils, followed by mixed soils, and least exchangeable for smectitic soils (Sharpley, 1989). This finding may be a reason for observing a yield response to K at STK levels above the current critical soil test level, as demonstrated in Breker et al. (2019). In this study, the STK correlation findings demonstrated that the critical STK value for South Dakota may need to increase from 160 to 169 ppm (Figure 1). However, none of the sites in this study (1, 2, 4, 5, 7, and 11) that had STK levels >160 ppm and S:I >1.0 showed a yield response. While the STK level at site 15 was 327 ppm, the S:I value of 0.2 was the lowest of all sites, suggesting that clay mineralogy was not responsible for the yield response at that site. While clay mineralogy could not confidently be used as a prediction tool for KFRs in the first two years of this study, five additional field trials conducted in 2022 may provide further insights for this research.

REFERENCES

Breker, J. S., DeSutter, T., Rakkar, M. K., Chatterjee, A., Sharma, L., & Franzen, D. W. (2019). Potassium requirements for corn in North Dakota: Influence of clay mineralogy. *Soil Science Society of America Journal*, *83*(2), 429-436. https://doi.org/10.2136/sssaj2018.10.0376

Drescher, G. L., Slaton, N. A., Roberts, T. L., & Smartt, A. D. (2021). Corn yield response to phosphorus and potassium fertilization in Arkansas. *Crop, Forage & Turfgrass Management*, *7*(2), e20120. https://doi.org/10.1002/cft2.20120

Fulford, A. M., & Culman, S. W. (2018). Over-fertilization does not build soil test phosphorus and potassium in Ohio. *Agronomy Journal*, *110*(1), 56-65. https://doi.org/10.2134/agronj2016.12.0701

Lyons, S. E., Arthur, D. K., Slaton, N. A., Pearce, A. W., Spargo, J. T., Osmond, D. L., & Kleinman, P. J. (2021). Development of a soil test correlation and calibration database for the USA. *Agricultural & Environmental Letters*, *6*(4), e20058. https://doi.org/10.1002/ael2.20058

Oliver, K., Popp, M. P., Slaton, N. A., Drescher, G. L., & Roberts, T. L. (2022). Profit-maximizing potassium fertilizer recommendations for corn and cotton. *Agronomy Journal*, [accepted article]. https://doi.org/10.1002/agj2.21205

Sharpley, A. N. (1989). Relationship between soil potassium forms and mineralogy. *Soil Science Society of America Journal*, *53*(4), 1023-1028. https://doi.org/10.2136/sssaj1989.03615995005300040006x

Singh, S., Savoy, H. J., Yin, X., Schneider, L., & Jagadamma, S. (2019). Phosphorus and potassium fertilizer rate verification for a corn–wheat–soybean rotation system in Tennessee. *Agronomy Journal*, *111*(4), 2060-2068. https://doi.org/10.2134/agronj2018.12.0749

Slaton, N. A., Lyons, S. E., Osmond, D. L., Brouder, S. M., Culman, S. W., Drescher, G., Gatiboni, L. C., Hoben, J., Kleinman, P. J. A., McGrath, J. M., Miller, R. O., Pearce, A., Shober, A. L., Spargo, J. T., & Volenec, J. J. (2022). Minimum dataset and metadata guidelines for soil-test correlation and calibration research. *Soil Science Society of America Journal*, *86*(1), 19-33. https://doi.org/10.1002/saj2.20338

Svedin, J. D., Kitchen, N. R, Ransom, C. J., Veum, K. S., & Anderson, S. H. (2022). Can soil biology tests improve phosphorus and potassium corn fertilizer recommendations?. *Agronomy Journal*, [accepted article]. https://doi.org/10.1002/agj2.21180

Zhang, H., Antonangelo, J., Grove, J., Osmond, D., Slaton, N. A., Alford, S., Florence, R., Huluka, G., Hardy, D. H., Lessl, J., Maguire, R., Mylavarapu, R., Oldham, J. L., Pena-Yewtukhiw, E. M., Provin, T., Sonon, L., Sotomayor, D., & Wang, J. (2021). Variation in soil-test-based phosphorus and potassium rate recommendations across the southern USA. *Soil Science Society of America Journal*, *85*(4), 975-988. https://doi.org/10.1002/saj2.20280