Recalibration of Potassium Requirements for Corn in North Dakota

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ABSTRACT

The previous North Dakota potassium recommendations for corn were borrowed from central Corn Belt states, where the dry soil-based 1 M ammonium acetate extraction for soil test K was utilized with a critical K value of 150 ppm. This value was adequate before 2000 because corn production was limited to only a few counties in southeastern North Dakota, and soil test K values were commonly above 300 ppm. However, the intensification of corn production in these counties and an increasing acreage around the state with not only corn production but also soybean production has extracted much K from the soil. As a result, soil test K values in several southeastern ND counties are now below 200 ppm, and K deficiency symptoms in corn and even soybean are commonly observed in dry summers. A study was conducted from 2014 to 2016 on 30 sites in southeastern North Dakota. A randomized complete block design with 6 (7 in 2016) K treatments; check, 30, 60, 90, 120 and 150 pounds per acre K_2O as 0-0-60 (muriate of potash, KCl) (and an additional fallow check in 2016) was established at each site in the spring as preplant broadcast applications. A composite sample from the check plots of each site was analyzed for K-bearing mineral content (potassium-feldspar) and clay speciation. The results indicated that without consideration of clay species, the standard K test was only predictive of response at half of sites. Segregation of sites into those with a smectite/illite ratio greater or less than 3.5 resulted in greatly improved response prediction. Sites with a smectite/illite ratio greater than 3.5 indicate a critical soil test K level of 200 ppm, whereas those sites with a ratio less than 3.5 indicate a critical soil test K level of 150 ppm.

INTRODUCTION

Historically, soil test potassium (K) values have been high in North Dakota, with values from 1972 through 1981 in the Red River Valley reported to be greater than 300 ppm on 71% on acres, and another 19% of acres with K test values between 200 and 299 ppm (Dahnke et al., 1982). By 2010, the percentage of fields with K values less than 150 ppm in the same region had grown to 17%. North Dakota until recently had adopted the K soil test recommendations used by most central Corn Belt states of 150 ppm as a critical level (Dahnke et al., 1992; Vitosh et al., 1995), describing the soil test K value that separated those soils that would respond to K from those that would not most of the time. Since corn acreage in North Dakota has increased from about 200,000 acres in 1990 to over 3,000,000 acres consistently in the past 6 years, soybean acreage reached over 7,000,000 acres in 2017, and soil test K levels have declined as a result of net K removal in grain from corn growing counties, it was important to research corn K response seriously for the first time in North Dakota. The objective of the study was to determine the critical K level for corn production in North Dakota.

METHODS

From 2014 through the 2016 growing seasons, 29 field studies were established and taken to yield in farmer fields in Cass, Richland, Sargent and Barnes counties in North Dakota. Each site consisted of a randomized complete block design with 6 K rate treatments (0, 30, 60, 90, 120 and 150 lb K_2O/acre as 0-0-60 dry granular fertilizer) with 4 replications. In 2016, an additional treatment of a fallow check was added, thus totaling 7 K treatments in 2016. Each experimental unit (plot) was 10 feet wide and 30 feet long. Each site was screened through 0-6 inch soil sampling prior to establishing a trial to maximize the number of sites with low K levels and also to include at least one site per year with soil test K values greater than 200 ppm. Most sites had soil K levels less than 100 ppm, while a few had soil K levels above 200 ppm to establish soil test levels that would not support fertilization.

Once a site was identified, the corners of the site were flagged and georeferenced, with large steel washers buried below the expected spring tillage depth on conventional tilled sites. A blanket application of sulfur as 100 lb/acre gypsum (20% S) was applied to all sites. If N and P were required as a separate application because the cooperator was going to apply an N/P/K blend, N and P were applied to the site as urea and monoammonium phosphate (11-52-0) fertilizer. If zinc was required by the soil test and the cooperator did not plan to apply zinc, zinc was applied as 30 lb/acre zinc sulfate (36% Zn). At one site with initial pH 4.8, 2 ton/acre fine limestone powder was applied to the site, which increased the pH to 5.6 by early summer. Potassium rate treatments were pre-weighed in plastic bags and hand applied the same date as the foundational fertility applications.

The farmer-cooperators planted the sites when the rest of the field was planted using their own variety selection. The cooperators also applied herbicides to the study areas when they applied herbicide to the rest of the field. Any weed escapes were removed with hand-weeding through the growing season. Yield was obtained by removing all ears from an interior row of each experimental unit except the outer ear from each row end, shelling with an Almaco corn sheller, weighing, and taking moisture and test weight using a Dickey John GAC 500XT moisture-test weight instrument.

Soil samples obtained at experiment initiation were prepared for ‘dry’ extraction and ‘moist’ extraction using the methods of Gelderman and Mallarino (2012). The standard K soil test method used in the region is the ‘dry’ K soil test (Warncke and Brown, 2012), using 1 gram of air-dry soil with 1 M ammonium acetate at pH 7 as an extractant, a specific shaking time at a specific number of cycles per minute, filtering, then analysis on an atomic absorption spectrophotometer.

Iowa State University uses a ‘field-moist’ K soil test, with a similar extraction and analysis procedure (Warncke and Brown, 2012), but the method uses a field-moist soil sample directly rather than drying it prior to analysis. The sample weight is corrected for moisture content. Other soil test methods were investigated to try to capture nonexchangeable K release over time. These soil methods were the sodium tetraphenylboron extraction (Cox et al., 1999) using 5-min and 168-h extraction periods and a resin extractable K test using an ion-exchange resin capsule (UNIBEST Inc., Walla Walla, WA) over a 168-h period. The UNIBEST mixed-bed, cation- and anion-exchange resin capsule is based on the design of Skogley (1992). For the resin method, a 30 g air-dry equivalent mass of 2-mm sieved, field-moist soil was measured and incubated with a resin capsule and 30 mL deionized water for 168 h at constant 20 °C. After the incubation period, the resin capsule was washed with deionized water to remove attached soil and leached with 50 mL 2 M HCl using a manual slow-drip leaching apparatus (UNIBEST Inc., Walla Walla, WA). The resin capsule leachate was analyzed for resin extractable K using atomic absorption spectroscopy. A cation exchange method using base saturation of K as a critical response determinant was also investigated (Hefty, 2012). The results were fit to models relating soil test method values with relative corn yield.

Clay species and mineralogy related to potassium content were analyzed on a check sample from each K rate study and also from a spring 2017 sampling survey of two to three major soil groups within each North Dakota county. A total of 167 samples were analyzed from the K rate study and from 138 survey samples. The analysis was conducted on all samples by Activation Laboratories Ltd., Ancaster, Ontario, Canada. The sample preparation and analysis follows: A split of each sample was pulverized. A portion of each pulverized sample was mixed with corundum and packed into a standard holder. Corundum was added as an internal standard to determine the amount of X-ray amorphous and poorly crystalline material. For clay speciation analysis, a portion of each sample was dispersed in distilled water and clay minerals in the <2μm size fraction separated by gravity settling of particles in suspension. Oriented slides of the <2μm size fraction were prepared by placing a portion of the suspension onto a glass slide. To identify expandable clay minerals, the oriented slides were analyzed air-dry and after treatment with ethylene glycol.

The X-ray diffraction analysis was performed on a Panalytical X'Pert Pro (PANalytical, Nottingham, UK) diffractometer equipped with Cu X-ray source and an X'Celerator detector and operating at the following conditions: 40kV and 40 mA; range 5-70 deg 2θ for random specimens and 3-30 deg 2θ for oriented specimens; step size 0.017 deg 2θ;time per step 50.165 sec; fixed divergence slit, angle 0.5^o or 0.25^o; sample rotation 1 rev/sec. The X'Pert HighScore plus software along with the PDF4/Minerals ICDD (International Centre for Diffraction Data, Newtown Square, PA) for database were used for mineral identification. The quantities of the crystalline mineral phases were determined using the Rietveld method (Rietveld, 1967). The Rietveld method is based on the calculation of the full diffraction pattern from crystal structure data. The amounts of the crystalline minerals were recalculated based on a known percent of corundum and the remainder to 100% was considered poorly crystalline and X-ray amorphous material. The semi-quantitative amounts of clay minerals in the <2μm size fraction were calculated using relative ratios of basal-peak areas.

RESULTS AND DISCUSSION

The 2014 and 2015 growing seasons were relatively dry from mid-June through August. The 2016 growing season was characterized by moist but not excessively wet soil conditions through summer until physiological maturity. The initial analysis of soil test K methods from the 2015 and 2016 growing seasons showed a poor relationship with relative grain yield of check plots (Figure 1, Table 1). The dry K extractant had the best linear-plateau relationship with relative yield ($r^2 = 0.49$, $p = 0.017$ [relative yield = 31.5 + 0.664X, maximum 93%]). This indicates that only 49% of the data was represented by the best model. The relationship of relative yield to dry K soil test in 2014 was similar to the 2015-2016 results (Figure 2).

After the poor relationship between relative yield and soil test K was found in 2014, soil samples were analyzed for potassium-feldspar content of the mineral portion of soil and clay species was quantitatively analyzed within the clay fraction of each soil. The results from 2014 through 2016 are indicated in Table 2. The magnitude of corn yield increase at responsive site was never more than 25% greater than the check. This modest response may be due to the presence of potassium-feldspar in the mineral soil, which was usually greater than 5%. Although textbooks refer to potassium-feldspars as 'of little importance in agricultural soils' (Tisdale et al., 1985), Sparks and Jardine (1981) and Sparks and Huang (1985) indicated that potassium-feldspars reach equilibrium with soil solution in hours, not years as commonly assumed. The potassium-feldspar content of North Dakota soils appears in Figure 3.

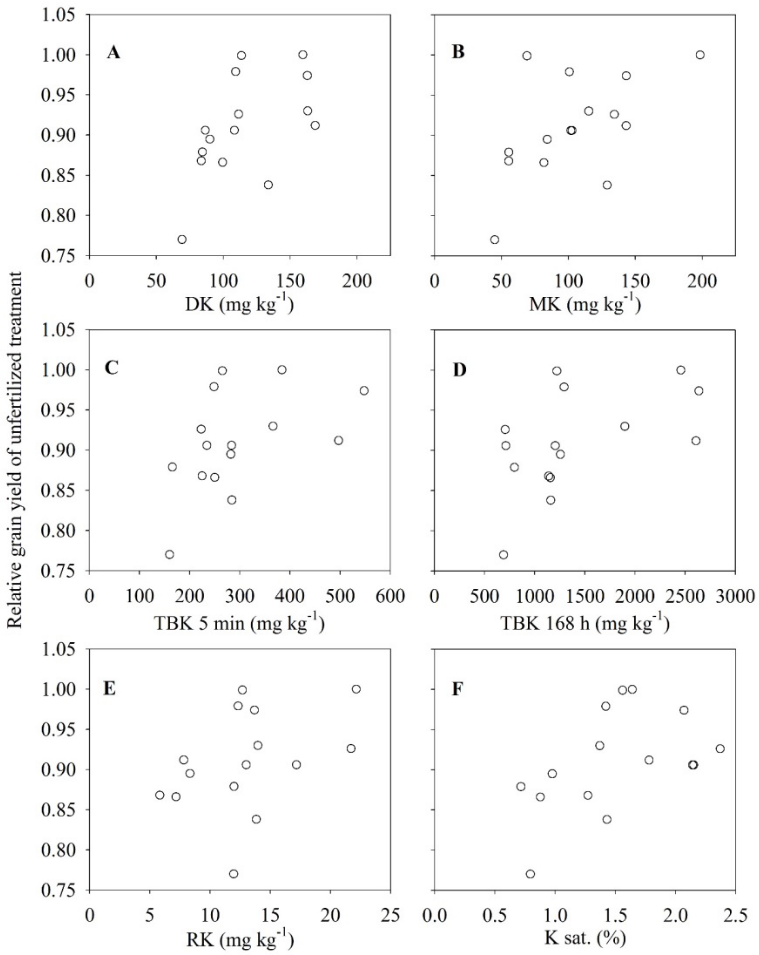

Figure 1. Relationship between relative yield of unfertilized corn and various soil test K methods: (A) DK and (B) MK, NH_4OAc extractable K on air-dry and field-moist soil, respectively; TBK, tetraphenylboron extractable K for (C) 5 min and (D) 168 h; (E) RK, resin extractable K; and (F) K sat., K saturation.

Table 1. Linear-plateau models of relative corn yield with plant available soil K extraction methods, 2015-16 site data.

Method*	Equation	X<	Maximum at plateau value	r^2	p>F
DK	31.5 + 0.664X	93	93	0.49	0.017
MK	32.6 + 0.998X	61	93	0.47	0.022
TBK 5 min	74.2 + 0.636X	333	95	0.33	0.090
TBK 168 h	81.9 + 0.00704X	2028	96	0.30	0.117
RK	84.2 + 0.528X	----	No plateau	0.16	0.140
K sat.	74.1 + 12.6X	1.56	94	0.42	0.037

***DK and MK are 1 M NH_4OAc extractable K on air-dry and field-moist soil, respectively; TBK is tetraphenylboron extractable K; RK is resin extractable K; K sat. is K saturation.**

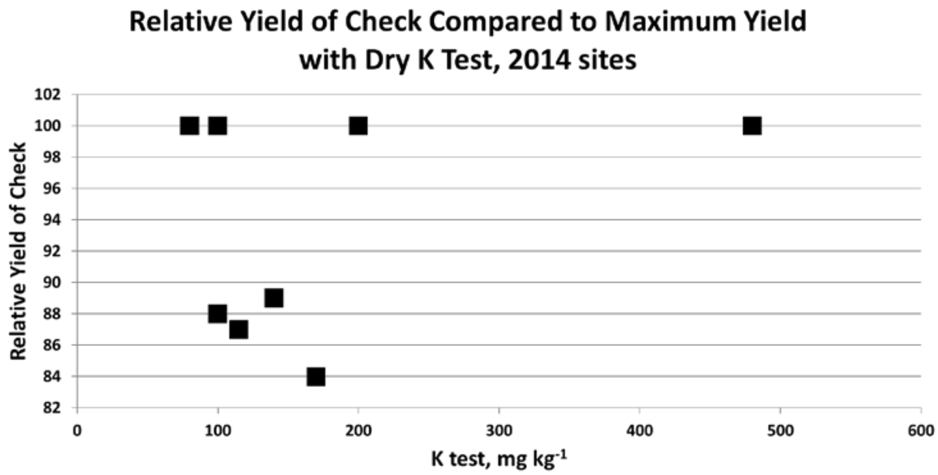

Figure 2. Relative yield of check in North Dakota K rate studies in 2014 and the relationship to soil test K.

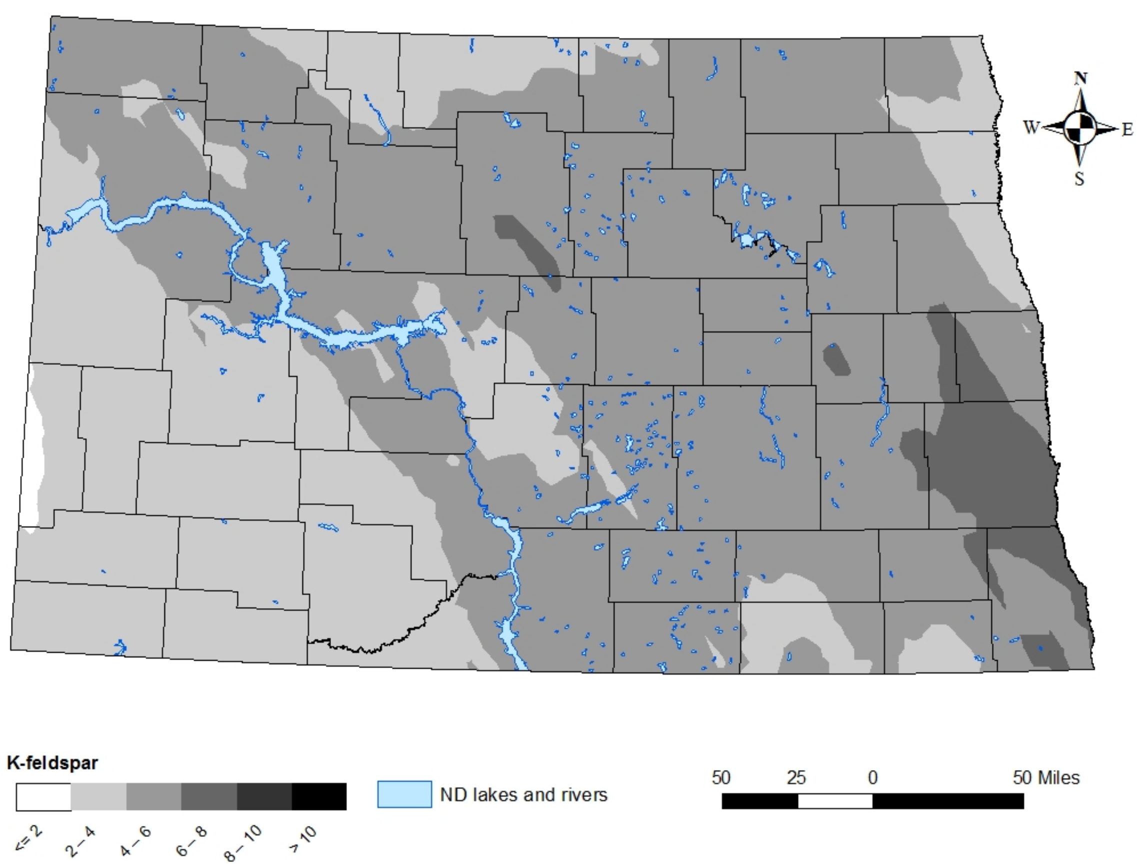

Figure 3. Potassium-feldspar concentration of total soil minerals in North Dakota.

Table 2 indicates that 9 of 23 sites either responded to K when the 150 ppm soil test indicated no response was probable or did not respond to K even though the intial soil test indicated a response was probable. The dominant clay species and potassium-feldspar content of the soil is also represented.

In addition, illite clays tend to release K regardless of whether they are wet or dry, whereas certain smectitic clays, particularly beidelite, draw in soil solution when drying, and 'fix' or retain K until the soil rewets. Although sources indicate that some smectites do not fix K (Borchardt, 1989), soils in the Red River Valley and, by extension, probably most soils in the region have significant beidelite in their smectite clay fractions, which has K fixation properties when dry (Badraoui et al., 1987). Soils with a dominance of these smectitic soils would conceivably require K at a higher level than soils with more illitic clays. A principle component analysis of data from 2015 and 2016 K rate trials indicated that in addition to dry K soil test, the illite and smectite content of the soil were related to relative yield and that the greater the smectite percentage, the lower the relative yield (Table 3).

Table 2. Data from 23 K rate studies in corn in North Dakota in the 2014 and 2015 dry-summer years, with clay mineralogy of the clay fraction and potassium-feldspar content of the mineral portion of the soil are indicated. Beginning preplant soil test K (1 M ammonium acetate on dry soil) is also indicated along with expected yield increase compared to the yield increase experienced.

Site, Year	K test, mg kg^{-1}	Expected Yield Increase	Actual Yield Increase	Potassium-feldspar-%	Smectite%-Illite %
Buffalo, 2014	100	**Y**	**N†**	7.1	85-11
Walcott E, 2014	100	Y	Y	5.8	84-13
Wyndmere, 2014	100	**Y**	**N**	6.1	72-22
Milnor, 2014	100	**Y**	**N**	11.7	35-57
Gardner, 2014	115	Y	Y	5.3	76-20
Fairmount, 2014	140	**Y**	**N**	8.0	80-14
Walcott W, 2014	80	**Y**	**N**	7.3	52-40
Arthur, 2014	170	**N**	**Y**	1.7	85-11
Valley City, 2014	485	N	N	9.0	70-23
Page, 2014	200	N	N	5.7	74-20
Absaraka, 2015	113	**Y**	**N**	9.9	84-14
Arthur, 2015	125	Y	Y	9.5	85-12
Barney, 2015	170	N	N	6.3	79-16
Casino, 2015	120	Y	Y	6.4	85-12
Dwight, 2015	110	Y	N	6	82-15
Fairmount1, 2015	188	**N**	**Y**	5.6	87-10
Fairmount2, 2015	118	**N**	**Y**	7.4	79-12
Leonard N, 2015	380	N	N	6.9	70-25
Leonard S, 2015	190	N	N	5.5	52-41
Milnor, 2015	118	Y	Y	8.6	74-20
Prosper, 2015	205	N	N	9.2	83-14
Valley City, 2015	200	N	N	5.6	65-30
Walcott, 2015	109	Y	Y	6.2	47-48
Absaraka, 2016	160	N	**Y**	5.6	70-25
Valley City, 2016	226	N	**Y**	5.5	81-16
Gardner, 2016	60	Y	Y	6.1	77-19
Lisbon, 2016	78	Y	Y	5.0	72-22
Mooreton, 2016	70	Y	**N**	4.8	78-18
Colfax, 2016	54	Y	Y	5.3	77-16

† Bold font denotes site where expected yield response or non-response was not recorded.

The sites were subjected to clustering analysis, and the results indicated that grouping sites into those with a smectite/illite ration greater than 3.5 had a critical K level of 200 ppm, while those sites with a smectite/illite ratio less than 3.5 had a critical K level of 150 ppm (Figure 4).

Table 3. Correlation matrix of possible factors relating to relative yield of 2015 and 2016 K rate trials in North Dakota from Table 2.

Factor	K test	K-feldspar	Illite	Smectite
K test	1.0			
K-feldspar	0.17	1.0		
Illite	-0.03	-0.32	1.0	
Smectite	0.05	0.33	-0.99	1.0
Relative yield	0.29	-0.0002	0.32	-0.25

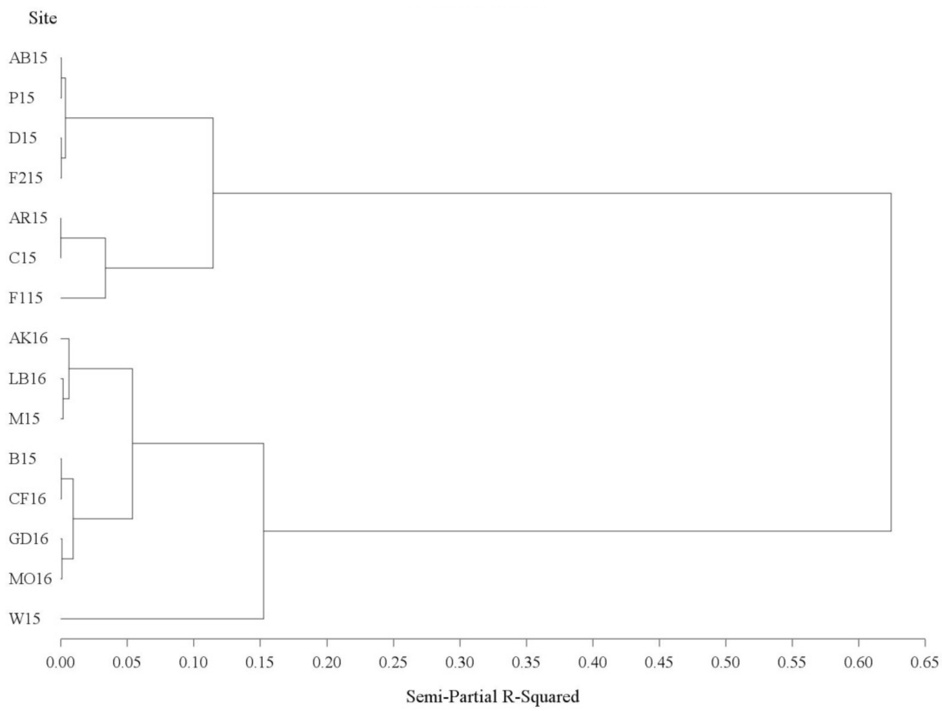

Figure 4. Cluster tree of 2015 and 2016 K trials by smectite/illite ratio using Ward's minimum variance cluster analysis.

Using the smectite/illite ratio of the sites (Table 2) and the cluster tree (Figure 4), a smectite/illite ratio of about 5 was found to separate the sites into two groups; one group consisting of K responses at higher K soil tests and the other with responses only at lower soil K values. A subsequent analysis of data including that from 2014 indicated that the smectite/illite ratio of 3.5 defined the separation required to maximize correct prediction of K response from soil test K values. Sites with a smectite/illite ratio greater than 3.5 defined a critical K value of 200 ppm, while sites with a ratio less than 3.5 defined a critical value of 150 ppm (Figure 5). To direct corn growers and their consultants to soils with their probable smectite/illite ratios, the smectite/illite ratio of North Dakota soils was mapped for areas with smectite/illite ratios greater or less than 3.5 (Figure 6).

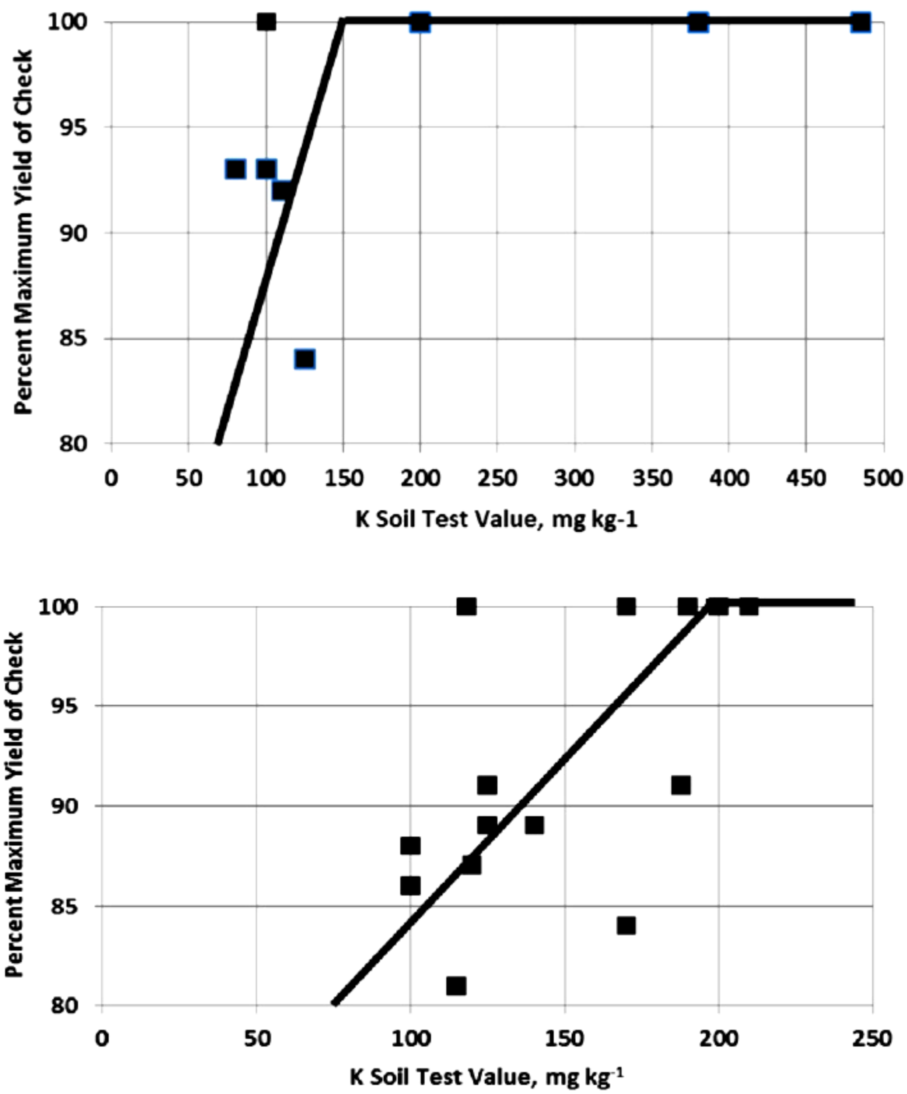

Figure 5. Percent maximum corn check yields in North Dakota K fertilizer rate studies at sites with smectite/illite ratio <3.5 (top) and smectite/illite ratio >3.5 (bottom).

Another phenomenon observed was that yield tended to decrease from maximum yield within an experiment when the K rate exceeded 120 lb K_2O/acre. A yield decrease with the 150 lb K_2O/acre rate was found at 12 of 29 sites. At only one site did yield continue to increase at the 150 lb K_2O/acre rate. Therefore, the rate of K to apply in any one year in North Dakota will be capped at 120 lb K_2O per acre. Plant stand was not affected by K rate in these studies.

An economic analysis of the data was conducted. The economic analysis considered that low rates of K (30 lb K_2O/acre) were not effective in increasing yield, whereas the yield increase within the studies were for rates from 60 lb K_2O/are to 120 lb K_2O per acre, and these formed 'shoulders' of a quadratic response within a site. The resulting recommendations can be found in Tables 4 through 7.

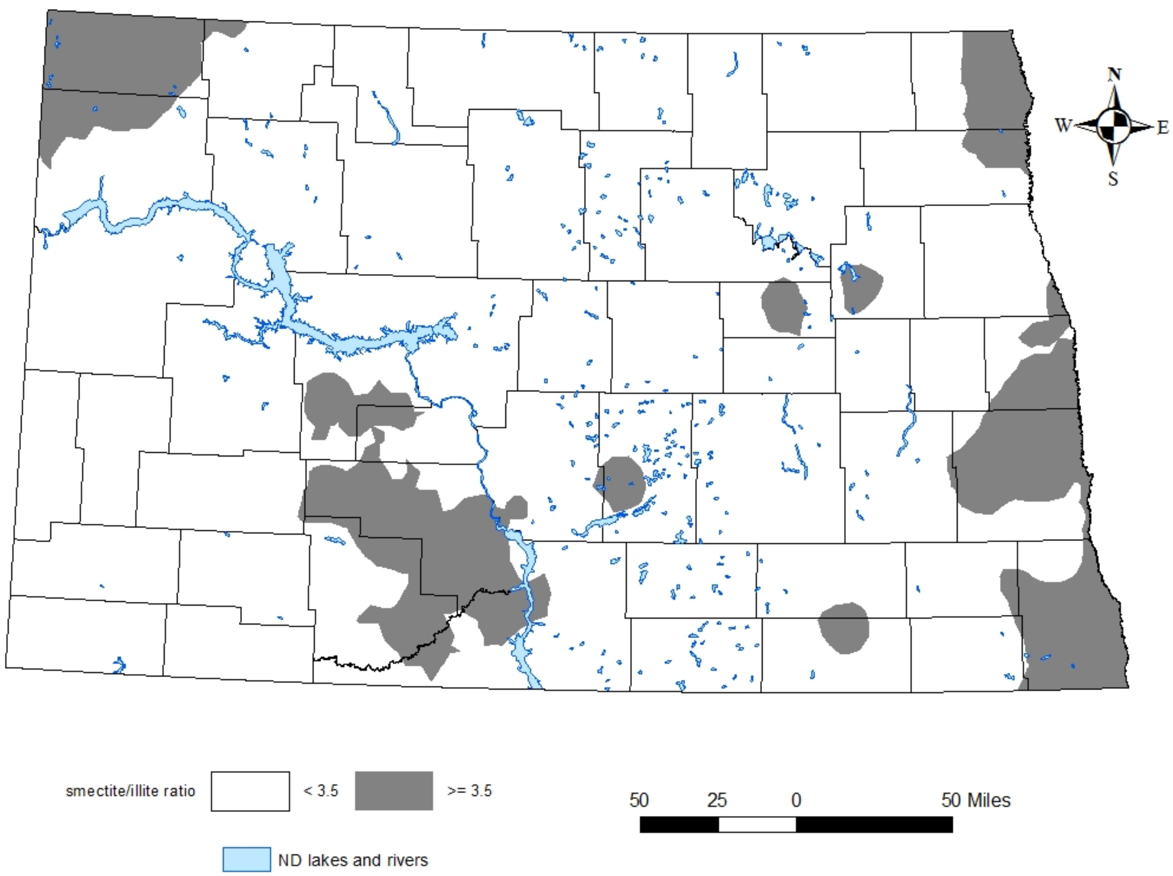

Figure 6. Smectite/illite ratio of the clay portion of soils in North Dakota, from a soil sampling of two to three major soil groups in each North Dakota county, spring, 2017.

Table 4. Potassium recommendations for corn in soils with clay chemistry having a smectite-to-illite ratio greater than 3.5 and soil test K levels 150 ppm or less.

Corn price, $ per bushel	Price per pound K_2O, $ per pound									
	0.125	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
	Recommended pounds K_2O per acre									
2	90	90	90	90	60	60	0	0	0	0
3	90	90	90	90	60	60	60	60	60	0
4	90	90	90	90	90	90	90	90	90	60
5	90	90	90	90	90	90	90	90	90	90
6	120	120	120	120	90	90	90	90	90	90
7	120	120	120	120	120	120	120	120	120	90
8	120	120	120	120	120	120	120	120	120	120
9	120	120	120	120	120	120	120	120	120	120
10	120	120	120	120	120	120	120	120	120	120

Table 5. Potassium recommendations for corn in soils with clay chemistry having a smectite-to-illite ratio greater than 3.5 and soil test K levels from 151 to 199 ppm.

Corn price, $ per bushel	Price per pound K_2O, $ per pound									
	0.125	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
	Recommended pounds K_2O per acre									
2	90	90	60	60	60	0	0	0	0	0
3	90	90	90	90	60	60	60	0	0	0
4	90	90	90	90	90	90	90	60	60	0
5	90	90	90	90	90	90	90	90	90	60
6	120	120	120	120	90	90	90	90	90	90
7	120	120	120	120	120	120	120	120	120	90
8	120	120	120	120	120	120	120	120	120	120
9	120	120	120	120	120	120	120	120	120	120
10	120	120	120	120	120	120	120	120	120	120

Table 6. Potassium recommendations for corn in soils with clay chemistry having a smectite-to-illite ratio less than 3.5 and soil test K levels 100 ppm or less.

Corn price, $ per bushel	Price per pound K_2O, $ per pound									
	0.125	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
	Recommended pounds K_2O per acre									
2	90	90	90	90	60	60	0	0	0	0
3	90	90	90	90	60	60	60	60	60	0
4	90	90	90	90	90	90	90	90	90	60
5	90	90	90	90	90	90	90	90	90	90
6	120	120	120	120	90	90	90	90	90	90
7	120	120	120	120	120	120	120	120	120	90
8	120	120	120	120	120	120	120	120	120	120
9	120	120	120	120	120	120	120	120	120	120
10	120	120	120	120	120	120	120	120	120	120

Table 7. Potassium recommendations for corn in soils with clay chemistry having a smectite-to-illite ratio less than 3.5 and soil test K levels from 101 to 149 ppm.

Corn price, $ per bushel	Price per pound K_2O, $ per pound									
	0.125	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
	Recommended pounds K_2O per acre									
2	90	90	60	60	60	0	0	0	0	0
3	90	90	90	90	60	60	60	0	0	0
4	90	90	90	90	90	90	90	60	60	0
5	90	90	90	90	90	90	90	90	90	60
6	120	120	120	120	90	90	90	90	90	90
7	120	120	120	120	120	120	120	120	120	90
8	120	120	120	120	120	120	120	120	120	120
9	120	120	120	120	120	120	120	120	120	120
10	120	120	120	120	120	120	120	120	120	120

CONCLUSIONS

The dry-soil 1 M ammonium acetate extraction for soil test K was the method that predicted yield response from K application better than other methods examined. Consideration of the smectite/illite ratio improved prediction of yield by separating sites into two groups; those with a smectite/illite ratio greater than 3.5 and the other with a smectite/illite ratio less than 3.5. The new North Dakota corn K recommendations also consider the economic return to K application modified by the base rate of K required for corn yield increase under deficient conditions and an upper limit to K rate based on the reduction of yield at rates greater than 120 lb/acre K_2O in many K rate experiments.

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