SF722 (Revised)

Soil Fertility Recommendations for Corn

Corn has been a crop in North Dakota for at least 100 years.

However, the acres under corn grain production have been relatively small, compared with small-grain crops, until about 20 years ago. Today, corn acres are consistently above 3 million acres each year, with most North Dakota counties having significant acreage.

The surge in acreage has been the result of improved corn genetics supported by NDSU corn inbred research, combined with greater rainfall and the increase of long-term no-till acreage in western North Dakota.

Fertilizer recommendations for corn used until recently were published about 40 years ago and have been changed little since then. However, in the past 40 years, yield expectations have at least doubled from about 80 bushels per acre to more than 200 bushels per acre in many fields. Tillage practices and the hybrids planted have changed as well.

The changes from previous corn fertility recommendations in this publication are primarily the result of recent assessments of corn yield responses to nitrogen (N) and potassium (K) through field experiments using modern hybrids and conditions.

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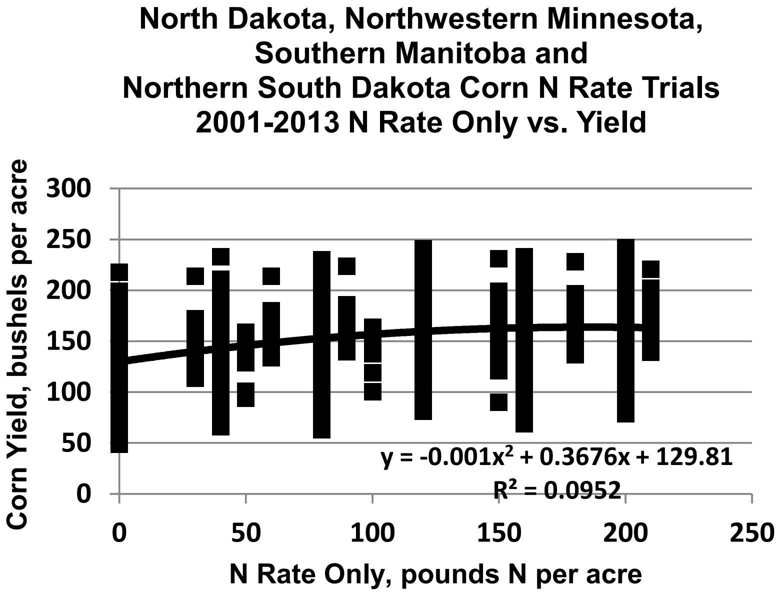
Nitrogen

The nitrogen (N) recommendations in this publication were developed from data accumulated from 2010 through 2013 on 77 North Dakota corn N rate trials. In addition, data from recent N rate studies in northwestern Minnesota, southern Manitoba and the northern tier of counties in South Dakota were used to augment the NDSU dataset.

A fall soil test to 2 feet in depth is a very important component of the N recommendation. **Figure 1** illustrates the poor predictive relationship between N applied and yield when the soil test nitrate-N results are not included in the analysis. Including the soil test nitrate-N results in a "law of diminishing returns" relationship of total known available N and yield.



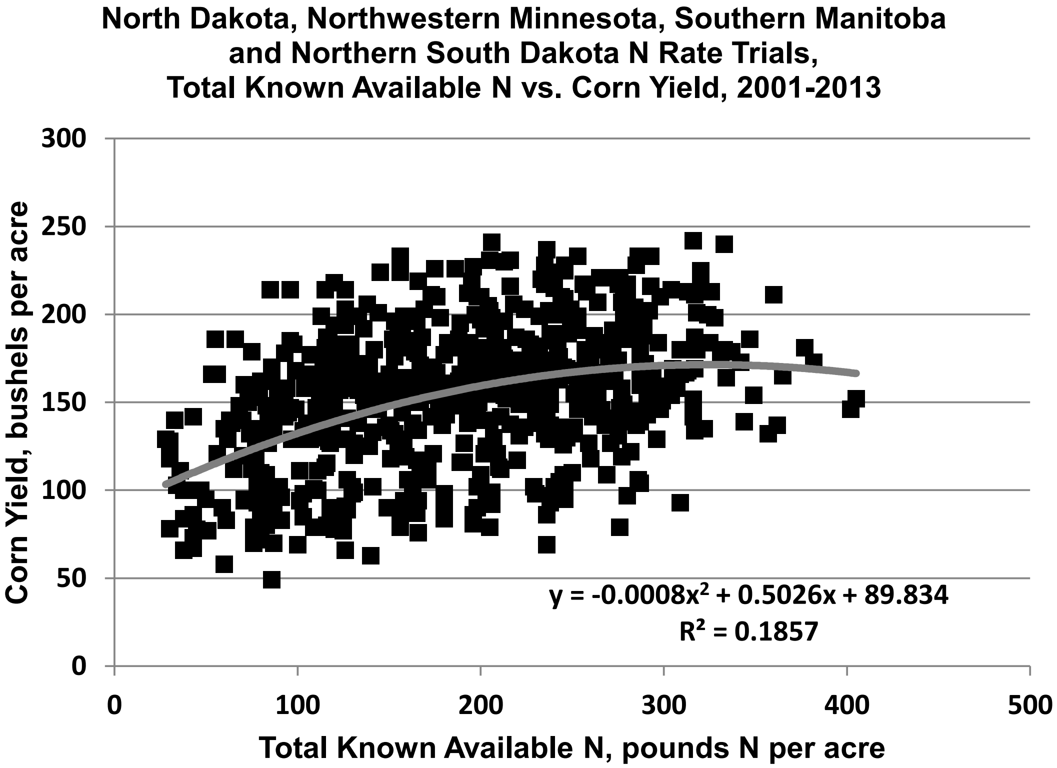


Figure 1. All data from North Dakota, Minnesota, Manitoba and South Dakota relating corn yield to N rate only (top) or N rate with soil nitrate analysis to 2 feet in depth (below).

A change from previous recommendations is that N recommendations are not linked directly to expected yield. N recommendation categories within high-clay soils and medium-texture soils are divided into those soils with a historic capability to produce more or less than 160 bushels per acre. However, within the higher-productivity categories, N rates have supported more than 240 bushels per acre in my experiments. Yields less than this were caused by too much water or not enough, but not by a deficiency of N.

Nitrogen recommendations are based on an economic production function that takes into account the yield response of corn to added N, less the cost of the N. This recommendation system is called the "Return to N" approach, as defined by Sawyer and Nafziger (2005).

In our work, we determined the formula that related the total available N to yield for each recommendation category. As available N increases, yield increases until the cost of another pound of N equals the income benefit for the fraction of a bushel of corn the N will produce.

At some rate of N, yield can decrease with added N. The yield decrease often is related to greater lodging, "green snap," which is caused by unusually rapid stalk elongation and poor stalk structure that results in stalk breakage during a high wind event, or other physiological factors.

The response of corn to N is different between west-river soils and soils east of the Missouri River. Part of this difference may be due to the tendency for productive corn acres west of the Missouri River to be in long-term no-till, but some is due to the soils and generally warmer and drier climate of the west-river region **(Table 1)**.

In eastern North Dakota, long-term no-till, defined as continuous no-till six years or longer, is segregated from conventional-tillage sites **(Table 2)**. This phenomenon also was seen in North Dakota spring wheat and durum research between 2005 and 2010, where a 50-pound-per-acre N credit was recommended in fields in long-term no-till.

In the corn N rate studies, the difference in N recommendation between long-term no-till and conventional-till soils was between 40 and 50 pounds less N per acre for long-term no-till soils. However, rather than incorporate a credit, a separate return to N analysis was prepared.

Within the conventional-till soils in eastern North Dakota, soils are divided into high-clay and medium textures. High clays include the textures of clay, clay loam and silty clay loam. Bearden, Fargo, Hegne and Viking soils are some of many soils in eastern North Dakota that would fall into this category. These soils have a high susceptibility for denitrification, which is a soil bacteria-led process in which nitrate is converted to nitrous oxide and nitrogen gas and is lost from the soil into the atmosphere.

Denitrification proceeds when soil pores are filled with water and soil oxygen levels are low. Denitrification can be found anytime that the soil is flooded, but in high-clay soils, significant denitrification occurs, even when the soil is muddy or saturated but not flooded.

Table 1. Corn N recommendation table for west-river soils, considering maximum return to N using corn N price and N cost.

	N cost, $/pound N								
Corn Price	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**
$/bushel									
2	150	120	37	0	0	0	0	0	0
3	150	150	149	94	38	0	0	0	0
4	150	150	150	150	121	79	38	0	0
5	150	150	150	150	150	138	105	71	38
6	150	150	150	150	150	150	149	121	94
7	150	150	150	150	150	150	150	150	133
8	150	150	150	150	150	150	150	150	150
9	150	150	150	150	150	150	150	150	150
10	150	150	150	150	150	150	150	150	150

Table 2. Corn N recommendation table for eastern long-term no-till soils, considering maximum return to N using corn N price and N cost.

	N cost, $/pound N								
Corn Price	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**
$/bushel									
2	200	168	137	106	75	43	12	0	0
3	220	200	179	158	137	116	95	75	55
4	232	216	199	185	169	154	137	119	107
5	239	226	213	200	187	176	163	150	137
6	243	232	220	211	201	190	179	169	158
7	246	237	226	217	209	200	191	183	173
8	247	241	232	223	215	207	200	192	184
9	249	243	235	228	220	213	207	200	194
10	252	244	239	232	225	218	212	206	200

Tiling or no tiling made little difference in our N rate plots on N efficiency in high-clay soils. Water takes a long time to percolate through high-clay soils. Some estimates of downward water movement are 0.015 inch per hour, or about ⅓ of an inch per day, in a Fargo soil.

High-clay soils are divided into those with historic yields exceeding 160 bushels per acre and those with historic yields of less than 160 bushels per acre. In the higher-productivity, high-clay soils, side-dress N is encouraged due to denitrification susceptibility; however, these soils have better internal drainage than those with lower yield capability, and growers might be able to achieve maximum economic yield with a greater portion of their total N applied preplant **(Table 3)**. The high-clay soils with lower productivity **(Table 4)** are likely to benefit from a side-dress N application.

The N rate from the recommendation table at a certain N cost and corn price is the maximum to apply preplant to these soils. To apply enough preplant N to these soils to support yields similar to those soils with higher historic yields would result in impractical N rates of more than 400 pounds per acre.

The answer to higher yield in these soils is not rate, but timing. Application of half or more of the recommended N at V6 to V8 would increase yield and N efficiency greatly in wetter years. Considering the tendency for high-clay soil to have sticky, mucky characteristics in wet conditions, the use of a coulter UAN (solution of urea and ammonium nitrate in water) side-dress applicator is recommended.

Medium-textured soils would include fine sandy loams, silt loams, loams, sandy loams, loamy sands and sands. The medium-textured soils with historic yield greater than 160 bushels per acre **(Table 5)** were the most

Table 3. Corn N recommendation table for eastern high-clay soils with historic yields greater than 160 bushels per acre, considering maximum return to N using corn N price and N cost.

	N cost, $/pound N								
Corn Price	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**
$/bushel									
2	242	214	186	159	131	103	75	47	19
3	260	242	222	205	186	169	149	131	113
4	270	257	243	229	213	200	186	172	158
5	276	265	254	243	232	220	208	196	184
6	280	270	260	250	240	230	220	210	200
7	285	274	263	252	243	235	226	218	212
8	285	277	270	264	257	251	243	236	229
9	286	280	274	267	261	255	249	243	237
10	287	283	276	270	266	260	254	248	242

Table 4. Corn N recommendation table for eastern high-clay soils with historic yields less than 160 bushels per acre, considering maximum return to N using corn N price and N cost.

The values in the table are the maximum to include in a preplant N application, followed by a side-dress N application, based on the difference between the value in this table compared with the corresponding N cost/corn price value in Table 3. The use of an active-optical sensor to direct side-dress N rate instead of the difference between the Table 3 rate and preplant rate from this table is encouraged.

	N cost, $/pound N								
Corn Price	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**
$/bushel									
2	150	150	150	117	67	17	0	0	0
3	150	150	150	150	150	133	100	67	34
4	150	150	150	150	150	150	150	143	118
5	150	150	150	150	150	150	150	150	150
6	150	150	150	150	150	150	150	150	150
7	150	150	150	150	150	150	150	150	150
8	150	150	150	150	150	150	150	150	150
9	150	150	150	150	150	150	150	150	150
10	150	150	150	150	150	150	150	150	150

Table 5. Corn N recommendation table for eastern medium-textured soils with historic yield greater than 160 bushels per acre, considering maximum return to N using corn N price and N cost.

	N cost, $/pound N								
Corn Price	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**
$/bushel									
2	222	201	180	160	139	118	97	76	55
3	235	222	208	194	180	166	152	138	124
4	236	234	223	213	202	192	181	171	161
5	249	241	243	223	215	206	198	190	182
6	252	245	238	231	223	216	209	202	195
7	254	248	242	236	230	222	217	211	205
8	255	250	245	240	234	229	223	218	213
9	256	252	247	243	238	233	229	223	218
10	257	253	248	244	239	234	230	224	219

productive and N-efficient soils in the conventional tillage category. These soils do not require N to be side-dressed to be N efficient.

However, the medium-textured soils with less than 160 bushels per acre were the most N-inefficient soils in our studies **(Table 6)**. These soils are highly susceptibility to leaching and would benefit greatly from side-dressing part of the N. Soils in this category usually are side-dressed using an anhydrous ammonia applicator, although a coulter UAN side-dress applicator also would work well.

For any subsurface-applied side-dress applicator, application may be made in every other row, rather than every row. An alternative side-dress application would be UAN streamed between each row. The efficiency of this alternative is high except in drier years, where surface dryness leads to greater N inefficiency.

A more risky application method would be to apply up to 100 pounds of urea (46 pounds of N per acre) broadcast over the whorl using a granular ground applicator or by air. The urea used in an over-the-top application should include a NBPT coating (such as Agrotain).

The N recommendations for irrigated corn are included in **Table 7**. These are the total N rates recommended through a Return to N model based on data collected in the Oakes area by Knighton, Derby and Albus in the 1990s.

The total N recommended should be divided into preplant, side-dress and the remaining N, which should be provided through the irrigation pivot up to tassel initiation. An additional 20 to 30 pounds of N could be applied if yield conditions are exceptional after pollination. No N is recommended through the pivot during pollination.

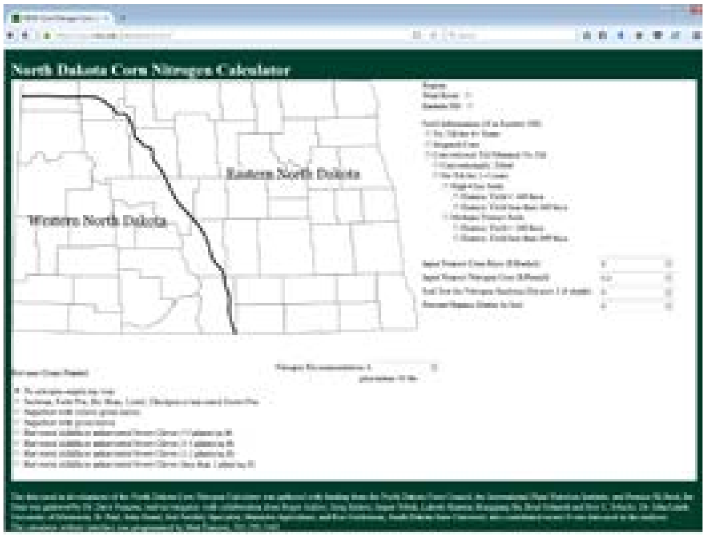
Table 6. Corn N recommendation table for eastern medium-textured soils with historic yields less than 160 bushels per acre, considering maximum return to N using corn N price and N cost.

The values in the table are the maximum to include in a preplant N application, followed by a side-dress N application, based on the difference between the value in this table compared with the corresponding N cost, corn price value in Table 5. The use of an active-optical sensor to direct side-dress N rate instead of the difference between the Table 5 rate and preplant rate from this table is encouraged.

	N cost, $/pound N								
Corn Price	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**
$/bushel									
2	150	150	124	0	0	0	0	0	0
3	150	150	150	150	124	41	0	0	0
4	150	150	150	150	150	150	124	62	0
5	150	150	150	150	150	150	150	150	124
6	150	150	150	150	150	150	150	150	150
7	150	150	150	150	150	150	150	150	150
8	150	150	150	150	150	150	150	150	150
9	150	150	150	150	150	150	150	150	150
10	150	150	150	150	150	150	150	150	150

Table 7. Corn N recommendation table for irrigated soils, considering maximum return to N using corn N price and N cost. This is the total amount for the season, which includes several split-N applications.

	N cost, $/pound N								
Corn Price	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**
$/bushel									
2	255	241	228	215	201	188	175	162	149
3	263	254	245	237	228	219	210	201	194
4	268	262	256	250	244	238	232	226	220
5	272	267	262	257	252	247	242	237	232
6	273	268	263	258	253	248	243	238	233
7	274	269	264	259	254	249	244	239	234
8	275	270	265	260	255	250	245	240	235
9	276	271	266	261	256	251	246	241	236
10	277	272	267	262	257	252	247	242	237



For the interactive North Dakota Corn Nitrogen Calculator, go to

www.ndsu.edu/pubweb/soils/corn

or

download it for IPhones and Android phones free of charge from your app store

Phosphorus

In states to the south and east of North Dakota, distinctions are made within states where banded phosphorus (P) would be expected to have a consistent positive yield response and areas where it might not. These distinctions are usually a point north or south of some line within the state.

In North Dakota, we are north of all of these lines; so in North Dakota, every corn acre would benefit in most years from an in-furrow or side-band P application. An example of the dramatic difference possible through banding P in some North Dakota soils is provided in **Table 8** from the Carrington Research and Extension Center.

The two most adopted at-seeding P banding strategies are in-furrow, also called "pop-up," and the 2 by 2 band, which is the starter band being placed 2 inches to the side and 2 inches from the depth of seed placement.

The in-furrow band, as seen in **Table 8**, is effective at placing fertilizer near the initial small rootlets. However, placing fertilizer in the 2 by 2 band eliminates the risk of seed damage from salt or ammonium concentration near the seed, which always results in lower stand with an in-furrow fertilizer placement.

The configuration of a 2 by 2 band in modern planters is not easy, but many growers use this configuration and they are able to apply N, P, potassium (K), sulfur (S) and zinc (Zn) easily with their starter with no reduction in stand.

Table 8. Corn yield with in-furrow application of 10-34-0, Hendrickson, 2007.

Rate of 10-34-0, gallons per acre	Corn yield, bushels per acre
0	101
2	121
4	125
6	150
8	156
10	153

In a 2 by 2 starter band, the N rate should be 50 pounds per acre or less to achieve a starter effect with any P in the band. Nitrogen rates higher than 50 pounds per acre in the starter band produce levels of free ammonia that are not penetrated by roots until later in the season, when the time for helpful early season effects of concentrated P are past.

Most of the P applied to corn is applied as broadcast P. Starter P sometimes can produce most of the yield benefit from a P application; however, corn grain contains about 0.4 pound P_2O_5 per bushel, so more P should be available to the crop than starter alone.

The P soil test used in the state should be the Olsen sodium bicarbonate extractant because it is diagnostic of relative soil P availability in acidic and basic soils. In one fertilization strategy utilized by most of the central U.S. Corn Belt states, buildup and maintenance, P anticipated to be removed is applied (maintenance) along with enough P to increase soil test levels through time (buildup).

A typical P application in Illinois, for example, that is necessary to increase soil test levels is about 9 pounds of P_2O_5 to increase the soil test 1 pound in the Bray P1 test. Experiments in Minnesota have indicated a range of P_2O_5 rates from 9 pounds to more than 40 pounds to achieve a similar soil test increase.

Most inorganic soil P is held by some soil mineral. No P fertilizer amendment effectively reduces the binding of P to soil minerals. In acid soils from below pH 5 to 6.8, the dominant P-binding element is iron. In alkaline soils with a pH above 7, the dominant P-binding ion is calcium.

In some of my experiments, yields approaching 200 bushels per acre were achieved in soils with P levels in the low range (less than 8 parts per million [ppm]). The corn obviously was taking up large quantities of P, even in soil test levels that were not optimum.

Some of the soil P available to crops is in organic form, which neither the Olsen nor the Bray test is very good at estimating. Recent studies in Minnesota have indicated that the current critical level for P should be closer to 20 ppm Olsen rather than 15 ppm.

North Dakota corn growers with very high yield potential might strive to achieve this higher soil test level if soil conservation methods and terrain were consistent with low wind and water erosion from their fields. General P recommendations for corn can be found in **Tables 9-1 to 9-3**.

Table 9-1. Corn P recommendations, West River, nonirrigated, pounds P_2O_5 per acre.

Olsen Soil Test Phosphorus, ppm				
VL 0-3	L 4-7	M 8-11	H 12-15	VH 16+
78	52	39	26	10

Table 9-2. Corn P recommendations, East River, nonirrigated, pounds P_2O_5 per acre.

Olsen Soil Test Phosphorus, ppm				
VL 0-3	L 4-7	M 8-11	H 12-15	VH 16+
104	78	52	39	10

Table 9-3. Corn P recommendations, irrigated, pounds P_2O_5 per acre.

Olsen Soil Test Phosphorus, ppm				
VL 0-3	L 4-7	M 8-11	H 12-15	VH 16+
156	104	78	52	26

Many state best management practices to reduce P pollution of surface waters are based on soil P particulate movement. However, studies in Manitoba indicate that the greatest source of P in surface water bodies in our relatively flat-terrain region is not from particulates but from soluble P in residues and other rotting organic sources, mostly released in early spring.

Corn is susceptible to a condition known as "fallow syndrome." Fallow syndrome is a stunting of corn, and often purpling leaves, and general P deficiency following a bare fallow, or following crops that do not support mycorrhizae. Mycorrhizae are a group of soil fungi that have a symbiotic relationship with many plant families, except for the Chenopodiaceae (lambsquarter family) and the Cruciferae (mustard family).

When corn follows canola (mustard family) or sugar beet (lambsquarter family), the likely result is fallow syndrome. Prevent plant acres generally have not resulted in fallow syndrome the following year, probably because in most cases, these acres are seeded to a cover crop (highly recommended) or weeds grow for a significant portion of the summer, which also promotes mycchorizal populations.

Work in South Dakota indicates that high rates of P fertilizer banded near the seed are necessary to offset the effects of fallow syndrome. A minimum P fertilizer rate in one study was 150 pounds 0-46-0 per acre in a 2 by 2 band. Simply increasing an in-furrow 10-34-0 rate from 3 gallons per acre to 6 gallons per acre does not eliminate fallow syndrome.

Potassium

Soil test potassium (K) values have been high for most soils in North Dakota until recently. With greater K removal with soybean and corn grain, soil test K levels have decreased in eastern North Dakota.

Recent K-rate research in North Dakota has shown that consideration of the clay chemistry in the soil is very important in predicting whether corn yield will increase with K if the soil test is lower than the critical level. The magnitude of yield increases in our K-rate studies probably was moderated by the amount of potassium feldspar as a portion of total minerals in the soil in the eastern part of North Dakota, where the studies were conducted **(Figure 2)**.

Three major clay chemistries in the clay-fraction of North Dakota soils influence K availability: smectite, illite, and kaolinite and other related clays. Smectite and illite are referred to as "2:1" clays; in addition to their small size, clay particles also have a specific crystalline structure. The 2:1 clays have two sheets of silicon oxide; one above one sheet of aluminum hydroxide and one below the sheet of aluminum hydroxide, like a sandwich.

In Illites, the three sheets are rather tightly held together with K+ ions. The edges of the illite can expand and contract with soil moisture differences, but most of the sheets are held together relatively tightly. Whether the soil is moist or dry, K+ ions are free to escape into the soil solution to maintain an equilibrium.

Smectite clays are also 2:1 clays, but the sheets are not held tightly by K+ ions; K+ ions are free to move in and out of the clay inter-layers. In moist soil conditions, K+ moves freely into the soil solution to maintain equilibrium, but when the soil dries, the clay layers collapse and draw K+ ions into the inter-layers, rendering them temporarily unavailable to plants.

Without using consideration of smectite and illite clays, the presently used dry K soil test only predicted corn yield response to K half of the time. If a smectite/illite ratio of 3.5 was used to separate sites, the dry K soil test predicted the K response in nearly all sites.

The new critical K soil test level for soils with a smectite-to-illite ratio greater

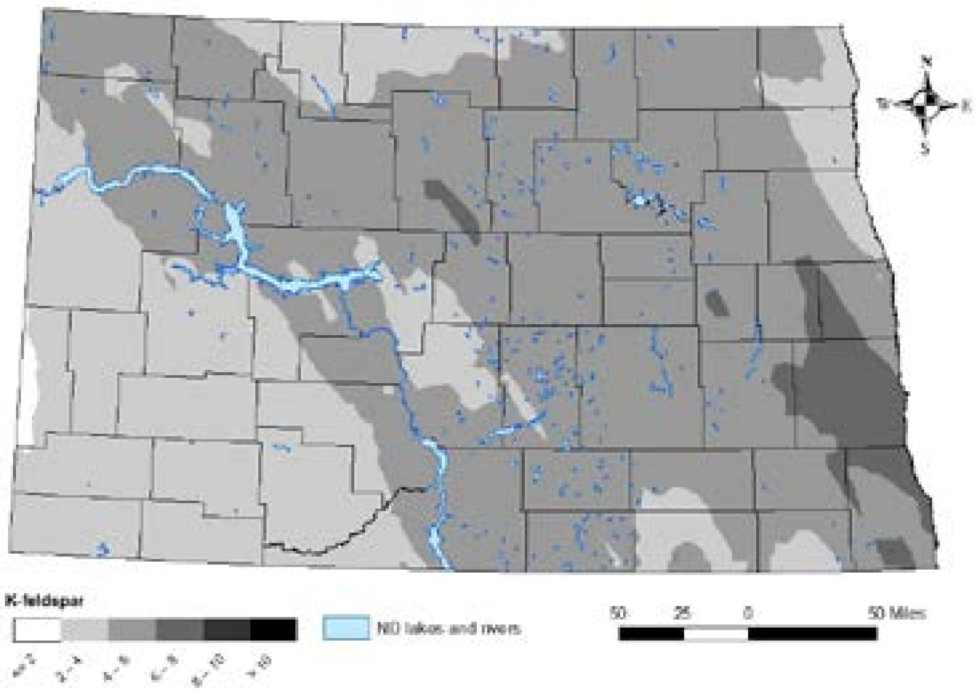


Figure 2. Potassium feldspar percentage of the total minerals in the surface soils in North Dakota. Based on a soil sampling of two to three major soil groups in each county, obtained in spring 2017.

than 3.5 is 200 ppm. The critical K soil test for soils with a smectite-to-illite ratio of less than 3.5 is 150 ppm. **Figure 3** is a map showing regions in North Dakota where the smectite-to-illite ratio of the clay fraction of soil is less than or greater than 3:5.

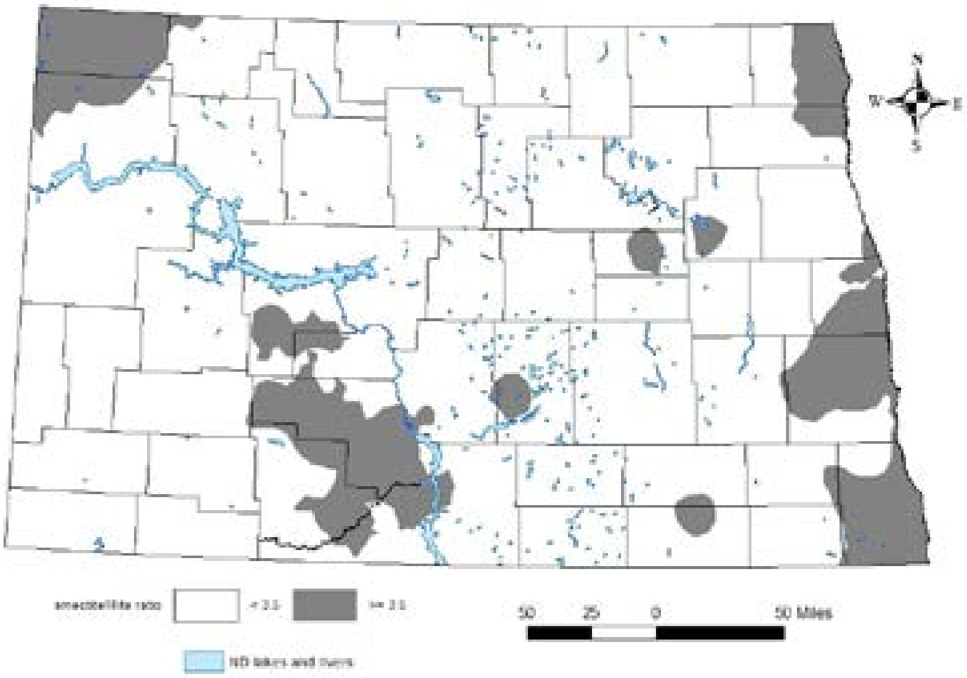


Figure 3. Smectite-to-illite ratio of surface soils in North Dakota from a soil sampling conducted in spring 2017. Dark gray regions are greater than 3.5. White areas are less than 3.5.

Table 10. 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.

	Price per pound K_2O, $ per pound									
Corn price	**0.125**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**
$ per bushel	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

The general recommendations for K fertilizer based on soil test for corn can be found in **Tables 10, 11, 12 and 13**. Our studies also found that rates of K_2O greater than 120 pounds per acre resulted in lower yield than rates of 90 and 120 pounds per acre K_2O; therefore, rates of K_2O recommended are capped at 120 pounds K_2O per acre.

Soybean harvest usually removes more K each year than corn, but corn is much more susceptible to K deficiency than soybean. Lower rates of K than those recommended in the tables will not result in the most economically achievable corn yield. Banding K in subsurface bands, such as those possible in strip-till shank applications, have been found beneficial in highly smectitic soils but not in soils with non-smectitic chemistry.

Potassium recommendations sometimes are given by sources other than NDSU based on the ratio of calcium and magnesium to potassium. These recommendations are based on poor soil fertility research and interpretation in Missouri and New Jersey in the late 1940s and early 1950s.

Despite the general soil fertility scientific community discarding these results, the concept of a "balanced soil" persists. Studies in several states indicate that the K extraction method, although not flawless, is a much better predictor of K requirement, compared with the balanced cation approach.

Growers should be aware that extraction of K in our soils often extracts calcium (Ca) and magnesium (Mg) from soluble salts and free lime in our soils, unrelated to Ca and Mg on the clay and organic matter particles. This will result in unreasonable cation-exchange capacity (CEC) values.

For example, a CEC test for a loam soil may be 30 millimhos per centimeter (mmhos/cm), where a true CEC value would be about 15 mmhos/cm. A very good review of the poor basis for the use of base exchange ratios for fertilization is available in Kopittke and Menzies (2007).

Sulfur

Sulfur deficiency has become an increasing problem for all North Dakota crops due to increased yield demand, increased rainfall compared with previous records, and decreased S in rainwater and erodible conventional till fields, decreasing organic matter levels and the thickness of the A horizon through time.

Table 11. 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.

	Price per pound K_2O, $ per pound									
Corn price	**0.125**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**
$ per bushel	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 12. 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.

	Price per pound K_2O, $ per pound									
Corn price	**0.125**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**
$ per bushel	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 13. 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.

	Price per pound K_2O, $ per pound									
Corn price	**0.125**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**
$ per bushel	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

The S soil test is nondiagnostic, and is available only because soil testing laboratory clients demand it, not because it is a reliable test. A better predictor of the need for S in a particular spring is to understand the soils and pay attention to rainfall and snow pack between the fall and spring planting season.

In soils with higher clay content and high organic matter levels, S is hardly ever a problem except in the most extraordinarily wet springs. In medium-textured or coarser soils (loams, sandy loams, loamy sands, sands) with lower organic matter levels (3 percent or less), particularly on hill/ridge tops and slopes, if rainfall/snowfall is normal or higher in the fall, winter or early spring, application of at least 10 pounds per acre of S as sulfate or thiosulfate is recommended.

These are spring fertilizers and should be applied in the spring. In coarser-textured soils, high rainfall after planting may require a second application.

Application of S as elemental S is not nearly as effective as sulfate or thiosulfate forms. Application of S as elemental S the fall before planting most often is not effective because any sulfate produced by very slow oxidation may be leached away by early spring rains, leaving only immediately unavailable elemental S near the soil surface.

Ammonium thiosulfate should not be applied as a row starter. Any ammonium sulfate applied is subject to similar rate restrictions of $N+K_2O$ as other row-placed fertilizers.

Sulfur deficiency appears in the spring as yellow upper leaves, with lower leaves remaining greener. The pattern of deficiency usually is related to landscape, with eroded areas, hilltops and slopes being particularly vulnerable, especially in medium- and coarser-textured soils.

Rescue with sulfate or thiosulfate sources such as ammonium sulfate, gypsum or ammonium thiosulfate are effective in correcting deficiencies, although a preplant application would result in the greatest yield improvement.

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Nitrogen Deficiency

Nitrogen deficiency symptoms can occur at any growth stage through ear development. Symptoms are yellowing lower leaves, starting at the leaf tip and following the midvein in a "V" pattern.

Nitrogen deficiency in corn. Note how the deficiency starts at the tip and moves down the midvein. The outer leaf edges are the last to turn yellow.

(NDSU photo)

Phosphorus Deficiency

Phosphorus deficiency symptoms are purpling of leaves, with the lowest leaves most affected.

Phosphorus deficiency symptoms. These symptoms also can be caused by soil or environmental factors that limit root growth, such as compaction, cold soils and excessive soil wetness.

(NDSU photo)

Potassium Deficiency Symptoms

Potassium deficiency symptoms are the result of low soil K, and they are intensified by dry soil conditions. The symptoms are yellowing of the leaf margins on older leaves. As the deficiency intensifies, the yellowing moves toward the leaf midvein, with the midvein the last leaf part to be affected.

Potassium deficiency symptoms in corn. Note the yellowing of lower leaf margins.

(Photo courtesy of Manbir Rakkar, University of Nebraska-Lincoln)

Sulfur Deficiency

Sulfur deficiency symptoms
are yellowing of upper leaves,
often with a striped appearance.

➤ **Sulfur deficiency symptoms on corn. Note upper leaves are most affected, with yellowing and striped appearance.**

(NDSU photo)

Zinc Deficiency Symptoms

Zinc deficiency symptoms
are stunted plants with
broad striping on upper leaves.

➤ **Zinc deficiency symptoms in corn.**

(NDSU photo)

Liquid solutions should be stream-applied between the rows or applied through an irrigation pivot to avoid serious leaf injury. Dry application on corn up to V4 is possible with little injury. Injury will increase as corn advances in maturity.

Zinc

Corn is one of four crops regularly grown in North Dakota that has shown yield increases from zinc application when soil levels are low. The critical level of soil test zinc, using the DTPA (diethylenetriaminepentaacetic acid) extraction method is 1 ppm.

Potential zinc deficiency may be avoided by a broadcast application of at least 30 pounds per acre of zinc sulfate 36 percent granules, or by adding a compatible zinc chelate of ammoniated zinc product to the starter fertilizer at planting. The broadcast zinc sulfate application will increase soil test zinc levels for more than 10 years, while the starter chelate application will be necessary each year that the field is planted to corn.

Zinc deficiency is expressed as yellow-striped newer leaves and stunting. The deficiency can be corrected by a zinc chelate application, although when detected, some yield decrease already has occurred.

Additional nutrient deficiencies in North Dakota have not been documented.

Corn Nutrient Deficiency Symptoms

A deficiency symptom is an indication that the crop is not well, but it is not a nutrient diagnosis by itself. For example, corn may show purpling of leaves early in the season, which can be a P deficiency symptom, but the purpling also can be any soil or environmental condition that reduces the rate of root growth, such as spring compaction, cold soils, very wet soil conditions and a tendency of purpling of certain hybrids. Therefore, a plant analysis, most often accompanied by a soil sample, except in the case of sulfur, from a “good” area and the “not-as-good” area most often will result in a diagnostic analysis.

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