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Soil Fertility Recommendations for Corn

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

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However, the acres under corn grain production have been small compared with the acreage of small-grain crops, until about 25 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

The changes from previous corn fertility recommendations in this publication are primarily the result of continuing assessment of corn yield responses to nitrogen (N) 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 during 2010 through 2021 from 90 North Dakota corn N rate experiments. 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 for residual nitrate-N is a very important component of the N recommendation. There is a poor relationship between N rate and relative corn yield if soil test nitrate-N and previous crop N credits are not included in the analysis. Including soil test nitrate-N value of the 2-foot cores and previous crop N credits produces the “total known available N” relating available N to relative corn yield, with the resulting formula used to produce supplemental N recommendations.

Nitrogen recommendations are based on an economic production function which includes 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 these recommendations, the relationship between total available N to yield for each recommendation category (region, soil texture, tillage management) is considered. As available N increases, yield increases until the cost of an additional pound of N equals the income benefit for the fraction of a bushel of corn the additional N is expected to produce.

At some rate of N, yield can decrease with added N. The yield decrease 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.

N recommendation categories

Western region

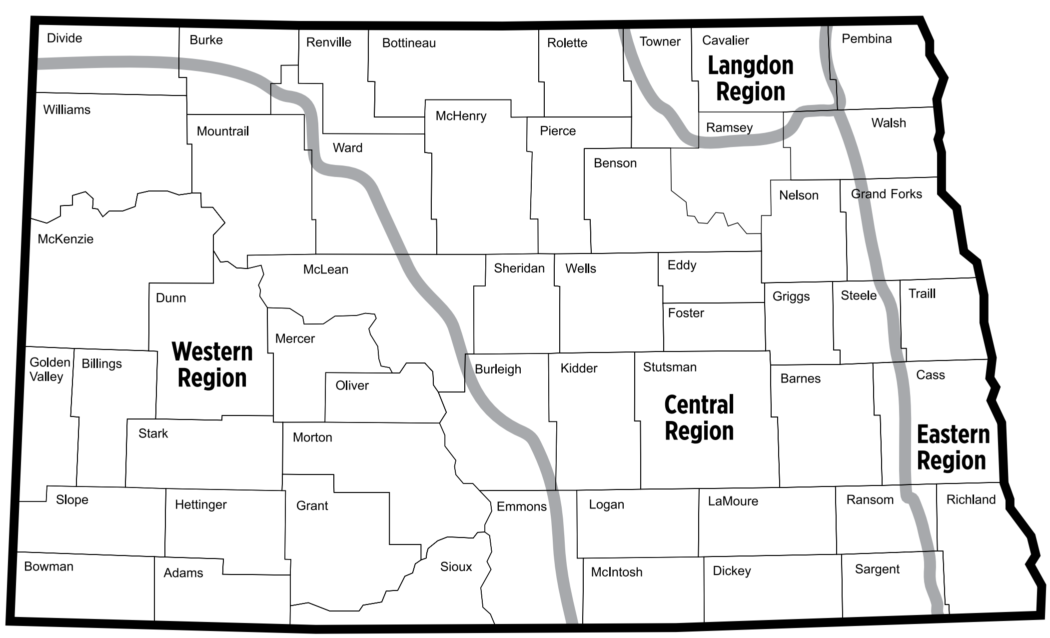
The response of corn to N is different between western region soils and soils east of the Missouri River. Part of this difference may be due to the tendency for productive corn acres west of the Missouri River to be in long-term no-till, but some is due to the soils and the warmer and drier climate of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

Central region and eastern region

This revision of recommendations differs from the previous publications (Franzen, 2017) because of the new “Central North Dakota” designation of a large eastern North Dakota region (**Table 3**). The central region has characteristics of the eastern region, but yield potential is not as great, and N loss from denitrification and leaching is not nearly as common, nor as severe as N losses in the eastern region. In the eastern region, certain fields with a history of lower yields are urged to incorporate side-dressing a portion of their N into their fertilization system, while in the central region, yield restriction is due not so much from N loss as from limitations of the soil and climate in that region, so side-dressing is neither encouraged nor discouraged.

Langdon region

Since corn is now commonly grown in the Langdon region, separate recommendations are included for Langdon region long-term no-till management and conventional-till fields (**Tables 4 and 5**). The Langdon region is different in N-supplying power from the rest of central/eastern North Dakota due to the abundance of ammonium-rich shale in this region. The Langdon region soils perform as a slow-release fertilizer to all crops.



Map of North Dakota showing the four important regions of the state relating to corn N recommendations.

Eastern region and central region long-term no-till

In eastern North Dakota and central North Dakota, long-term no-till, defined as continuous no-till six years or longer, is segregated from conventional-tillage sites (**Table 2**). The need to include a separate category for long-term no-till in these regions is also incorporated into the North Dakota spring wheat and durum recommendations and North Dakota sunflower recommendations, where research found that less N is required in long-term no-till compared to conventional-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.

Eastern region

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 high-clay category, with clay greater than 35% by weight of the total soil mineral material. 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. Tiling or no tiling made little difference in our N rate experiments regarding 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 1/3 of an inch per day, in a Fargo series soil.

High-clay soils in eastern North Dakota are divided into those at high or low risk to early season N loss (**Tables 6 and 7**). In lower loss risk high-clay soils, side-dress N is encouraged due to denitrification susceptibility; however, these soils have better internal drainage than those with higher risk, and growers might be able to achieve maximum economic yield with a greater portion of their total N applied preplant (Table 3). The high risk high-clay soils (Table 4) are likely to benefit most years from a side-dress N application.

The N rate specified in the high risk recommendation tables of high-clay soils at a certain N cost and corn price is the maximum to practically apply preplant to these soils. To apply enough preplant N in wet years to these soils to support yields similar to those soils with low loss risk would result in impractical N rates of more than 400 pounds N per acre, which is not economically or environmentally responsible.

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

Eastern medium-textured soils include fine sandy loams, silt loams, loams, sandy loams, loamy sands and sands. The medium-textured soils with low risk to early-season N losses (**Table 8**) were the most productive and N-efficient soils in the eastern North Dakota conventional tillage category. Soils with low risk of N loss do not require side-dress N to be N efficient.

However, the high loss risk medium-textured soils were the most N-inefficient soils in North Dakota studies (**Table 9**). These soils are highly susceptibility to leaching and would benefit greatly from side-dressing part of the N. Soils in this category can be side-dressed using an anhydrous ammonia applicator, although a coulter UAN side-dress applicator would also 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 riskier post-emergence N application method is application of 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 in Agrotain, Koch Industries, Inc., Wichita, Kansas).

The N recommendations for irrigated corn are included in Table 10. 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 for irrigated corn should be divided into preplant, side-dress and the remaining N, which should be applied through the irrigation pivot (fertigation) up until 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.

For the interactive North Dakota Corn Nitrogen Calculator, go to *https://www.ag.ndsu.edu/temp/cnc/*.

Table 1. Corn N recommendation table for western region soils, considering maximum return to N using corn N price and N cost.

Corn $ per bu	N cost $ per pound																		
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
	Nitrogen Recommended, pounds per acre																		
2	150	125	100	80	60	30	16	0	0	0	0	0	0	0	0	0	0	0	0
3	182	159	135	111	87	63	40	16	0	0	0	0	0	0	0	0	0	0	0
4	195	176	159	139	124	106	87	70	51	33	16	0	0	0	0	0	0	0	0
5	201	187	173	159	144	130	116	101	87	73	60	44	30	16	0	0	0	0	0
6	206	194	182	170	159	147	135	123	111	99	87	75	63	51	40	28	16	0	0
7	210	199	189	179	169	159	148	138	128	118	107	97	87	77	67	57	46	36	26
8	212	203	194	186	176	167	159	150	141	132	123	114	105	96	87	78	69	60	51
9	214	206	198	191	182	174	166	159	151	143	135	127	119	111	103	95	87	79	71
10	216	209	201	194	187	180	173	166	159	151	144	137	130	123	116	109	101	94	87
11	217	210	204	197	191	184	178	172	165	158	152	145	139	133	126	120	113	107	100
12	218	212	206	200	194	188	184	176	170	164	159	153	147	141	135	129	123	117	111

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

Corn $ per bu	N cost $ per pound																		
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
	Nitrogen Recommended, pounds per acre																		
2	173	147	121	95	70	42	17	0	0	0	0	0	0	0	0	0	0	0	0
3	190	172	155	136	120	102	85	68	50	33	16	0	0	0	0	0	0	0	0
4	200	187	1173	161	148	134	121	108	95	82	69	55	44	31	17	0	0	0	0
5	205	197	184	173	162	152	142	135	122	110	100	90	79	69	58	48	37	27	18
6	210	202	191	184	1731	163	156	147	138	131	121	112	103	96	87	78	70	61	52
7	212	204	197	190	182	173	165	158	151	143	136	128	121	113	106	99	91	84	77
8	214	206	201	194	188	181	174	167	161	154	147	141	135	127	121	114	108	102	95
9	215	209	203	195	192	183	181	173	167	162	157	151	145	138	133	128	122	116	110
10	217	210	205	198	195	188	184	179	174	169	163	158	152	147	142	137	131	126	121
11	218	212	207	203	198	193	189	184	178	174	169	164	160	154	149	144	140	135	130
12	218	213	209	204	201	196	191	187	183	179	173	169	164	161	156	151	147	143	138

Table 3. Corn N recommendation table for the central region of North Dakota, considering maximum return to N using corn N price and N cost.

Corn $ per bu	N cost $ per pound																		
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
	Nitrogen Recommended, pounds per acre																		
2	214	179	147	114	79	46	13	0	0	0	0	0	0	0	0	0	0	0	0
3	238	214	192	170	148	125	103	81	62	37	14	0	0	0	0	0	0	0	0
4	248	232	213	197	180	163	147	130	113	97	80	63	47	30	13	0	0	0	0
5	250	241	226	213	200	186	173	160	146	133	119	106	94	81	67	53	40	26	13
6	250	248	237	224	213	202	191	180	169	158	147	136	124	113	192	91	80	69	58
7	250	250	243	233	223	212	203	194	185	175	166	157	146	137	128	118	109	99	90
8	250	250	248	239	231	222	213	207	197	188	180	172	163	155	147	138	130	122	113
9	250	250	250	244	237	229	221	213	206	198	191	184	176	169	161	154	146	139	132
10	250	250	250	248	241	234	228	222	213	207	201	193	187	182	173	167	160	153	147
11	250	250	250	250	245	239	232	225	219	213	207	201	195	189	183	177	171	165	159
12	250	250	250	250	248	242	237	213	224	219	213	208	202	197	191	186	180	174	169

Table 4. Corn N recommendation table for the Langdon region of North Dakota, considering maximum return to N using corn N price and N cost.

Corn $ per bu	N cost $ per pound																		
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
	Nitrogen Recommended, pounds per acre																		
2	184	149	117	84	49	16	0	0	0	0	0	0	0	0	0	0	0	0	0
3	208	184	162	130	118	95	73	51	32	0	0	0	0	0	0	0	0	0	0
4	218	202	183	167	150	133	117	100	83	67	50	33	17	0	0	0	0	0	0
5	220	211	196	183	170	156	143	130	116	103	89	76	64	51	37	23	10	0	0
6	220	218	207	194	183	172	161	150	139	128	117	106	94	83	72	61	50	39	28
7	220	220	213	203	193	182	173	164	155	145	136	127	116	107	98	88	79	69	60
8	220	220	218	209	201	192	183	177	167	158	150	142	133	125	117	108	100	92	83
9	220	220	220	214	207	199	191	183	176	168	161	154	146	139	131	124	116	109	102
10	220	220	220	218	211	204	198	192	183	177	171	163	157	152	143	137	130	123	117
11	220	220	220	220	215	209	202	195	189	183	177	171	165	159	153	147	141	135	129
12	220	220	220	220	220	212	207	201	194	189	183	178	172	167	161	156	150	144	139

Table 5. Corn N recommendation table for long-term no-till fields in the Langdon region of North Dakota, considering maximum return to N using corn N price and N cost.

Corn $ per bu	N cost $ per pound																		
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
	Nitrogen Recommended, pounds per acre																		
2	144	109	77	44	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	168	144	122	90	78	55	33	11	0	0	0	0	0	0	0	0	0	0	0
4	178	162	143	127	110	93	77	60	43	27	10	0	0	0	0	0	0	0	0
5	180	171	156	143	120	116	103	90	76	63	49	36	24	11	0	0	0	0	0
6	180	178	167	154	143	132	121	110	99	88	77	66	54	43	32	21	10	0	0
7	180	180	173	163	153	142	133	124	115	105	96	87	76	67	58	48	39	29	20
8	180	180	178	169	161	152	143	137	127	118	110	102	93	85	77	68	60	52	43
9	180	180	180	174	167	159	151	143	136	128	121	114	106	99	91	84	76	69	62
10	180	180	180	178	171	164	158	152	143	137	131	123	117	112	103	97	90	83	77
11	180	180	180	180	175	169	162	155	149	143	137	131	125	119	113	107	101	95	89
12	180	180	180	180	180	172	167	161	154	149	143	138	132	127	121	116	110	104	99

Table 6. Corn N recommendation table for eastern high-clay soils with low risk of early-season N loss, considering maximum return to N using corn N price and N cost.

Corn $ per bu	N cost $ per pound																		
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
	Nitrogen Recommended, pounds per acre																		
2	250	223	196	168	140	124	85	57	29	0	0	0	0	0	0	0	0	0	0
3	250	234	206	187	169	150	132	113	95	75	58	39	21	0	0	0	0	0	0
4	250	250	226	211	197	183	169	155	141	127	113	99	86	72	58	44	30	16	0
5	250	250	250	224	213	202	191	180	169	158	147	136	124	113	102	91	80	69	58
6	250	250	250	235	224	215	206	197	187	178	169	160	150	141	132	124	113	104	95
7	250	250	250	241	233	224	217	209	201	193	185	177	169	161	153	145	137	129	121
8	250	250	250	246	239	232	224	217	210	204	197	190	183	176	169	162	155	148	141
9	250	250	250	250	244	238	232	224	218	212	206	200	194	187	181	175	169	163	157
10	250	250	250	250	250	242	237	231	224	219	213	208	202	197	191	186	180	174	169
11	250	250	250	250	250	246	241	236	230	224	219	214	209	204	199	194	189	184	179
12	250	250	250	250	250	250	244	239	235	230	224	220	215	211	206	201	197	192	187

Table 7. Corn N recommendation table for eastern high-clay soils with high risk of early-season N loss, considering maximum return to N using corn N price and N cost.

Corn $	N cost $ per pound																	
per bu	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
	Nitrogen Recommended, pounds per acre																		
2	150*	150	150	150	140	124	85	57	29	0	0	0	0	0	0	0	0	0	0
3	150	150	150	150	150	150	132	113	95	75	58	39	21	0	0	0	0	0	0
4	150	150	150	150	150	150	150	150	141	127	113	99	86	72	58	44	30	16	0
5	150	150	150	150	150	150	150	150	150	150	150	136	124	113	102	91	80	69	58
6	150	150	150	150	150	150	150	150	150	150	150	150	150	141	132	124	113	104	95
7	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	145	137	129	121
8	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	148	141
9	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
10	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
11	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
12	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150

*The 150 pound N per acre limit on N rate recognizes that increasing rate is not the way to achieve higher yields in these soils. When a split N application is used (side-dress), use Table 6 for the total rate of preplant plus side-dress.

Table 8. Corn N recommendation table for eastern medium-textured soils with low risk of early season N loss, considering maximum return to N using corn N price and N cost.

Corn $	N cost $ per pound																	
per bu	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
	Nitrogen Recommended, pounds per acre																		
2	231	226	161	126	92	57	22	0	0	0	0	0	0	0	0	0	0	0	0
3	250	232	207	184	161	138	115	92	68	45	22	0	0	0	0	0	0	0	0
4	250	250	232	213	196	178	161	144	126	111	92	74	57	41	22	0	0	0	0
5	250	250	245	232	216	203	189	175	161	147	133	119	106	92	78	64	50	36	22
6	250	250	250	243	232	219	207	196	184	173	161	150	138	126	115	103	92	80	69
7	250	250	250	250	241	232	221	211	201	191	181	171	161	151	141	131	121	111	102
8	250	250	250	250	250	241	232	222	213	204	196	187	178	170	161	152	144	135	126
9	250	250	250	250	250	250	239	232	223	215	207	200	192	184	176	169	161	153	146
10	250	250	250	250	250	250	245	238	232	226	217	210	203	196	189	182	175	168	161
11	250	250	250	250	250	250	250	244	238	232	226	218	212	207	199	193	186	180	174
12	250	250	250	250	250	250	250	250	243	237	232	226	219	213	207	202	196	190	184

Table 9. Corn N recommendation table for eastern medium-textured soils with high risk for early season N loss, considering maximum return to N using corn N price and N cost.

Corn $	N cost $ per pound																	
per bu	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
	Nitrogen Recommended, pounds per acre																		
2	150*	150	150	126	92	57	22	0	0	0	0	0	0	0	0	0	0	0	0
3	150	150	150	150	150	138	115	92	68	45	22	0	0	0	0	0	0	0	0
4	150	150	150	150	150	150	150	144	126	111	92	74	57	41	22	0	0	0	0
5	150	150	150	150	150	150	150	150	150	147	133	119	106	92	78	64	50	36	22
6	150	150	150	150	150	150	150	150	150	150	150	150	138	126	115	103	92	80	69
7	150	150	150	150	150	150	150	150	150	150	150	150	150	150	141	131	121	111	102
8	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	144	135	126
9	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	146
10	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
11	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
12	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150

*The 150 pound N per acre limit on N rate recognizes that increasing rate is not the way to achieve higher yields in these soils. When a split N application is used (side-dress), use Table 8 for the total rate of preplant plus side-dress.

Table 10. Corn N recommendation table for irrigated soils, considering maximum return to N using corn N price and N cost. This is the total N rate for the season, which includes several split-N applications.

Corn $	N cost $ per pound																		
per bu	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
	Nitrogen Recommended, pounds per acre																		
2	255	241	228	215	201	188	175	162	149	136	123	109	96	83	70	57	44	30	17
3	263	254	245	237	228	219	210	201	194	184	175	166	158	149	140	131	123	114	105
4	268	262	256	250	244	238	232	226	220	208	201	195	188	183	175	169	162	155	149
5	272	267	262	257	252	247	242	237	232	223	217	212	207	201	196	191	186	180	175
6	273	268	263	258	253	248	243	238	233	230	226	223	219	215	210	206	201	197	193
7	274	269	264	259	254	249	244	239	234	231	227	225	223	221	218	216	213	209	205
8	275	270	265	260	255	250	245	240	235	232	228	226	224	222	219	217	214	210	206
9	276	271	266	261	256	251	246	241	236	233	229	227	225	223	220	218	215	211	207
10	277	272	267	262	257	252	247	242	237	234	230	228	226	224	221	219	216	212	208
11	278	273	268	263	258	253	248	243	238	235	231	229	227	225	222	220	217	213	209
12	279	274	269	264	259	254	249	244	239	236	232	230	228	226	223	221	218	214	210

*The 150 pound N per acre limit on N rate recognizes that increasing rate is not the way to achieve higher yields in these soils. When a split N application is used (side-dress), use Table 6 for the total rate of preplant plus side-dress.

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; therefore, 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 11** with data from the Carrington Research Extension Center.

Table 11. 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

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 below the depth of seed placement.

The in-furrow band, as seen in Table 11, 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 in in-furrow fertilizer placement.

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

In a 2-by-2 starter band, the N rate should be limited to 50 pounds per acre to achieve a starter effect from the banded P. Nitrogen rates greater than 50 pounds per acre in the starter band can produce free ammonia concentrations 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 0.3 pound P_2O_5 per bushel, so more P should be made 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, called "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 NDSU 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] Olsen). 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 a 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 Table 12.

Table 12. Corn grain P suggested rates.

West River, non-irrigated, pounds P_2O_5 per acre.				
VL 0-3	L 4-7	M 8-11	H 23-15	VH 16+
78	52	39	26	10

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VL 0-3	L 4-7	M 8-11	H 23-15	VH 16+
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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 *Amaranthaceae* (lambsquarter/pigweed 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.

South Dakota experiments indicate that high rates of P fertilizer banded near the seed are necessary to offset the effects of fallow syndrome. A minimum P fertilizer rate to overcome fallow syndrome in one study was 150 pounds 0-46-0 per acre in a 2-by-2 band. However, recent NDSU experiments indicated that a higher rate of 10-34-0 (6 gallon per acre) was effective in overcoming most of the fallow syndrome effect.

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 1).

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 clay sheets are held rather tightly 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

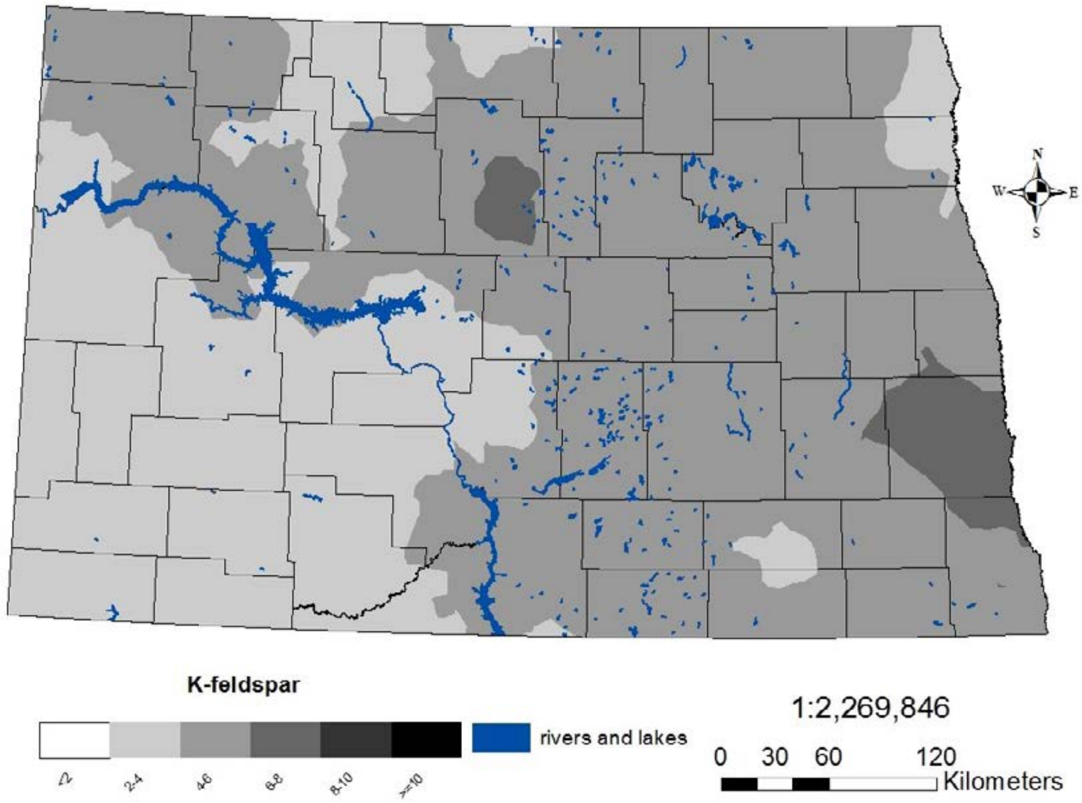

Figure 1. Potassium feldspar percentage of the total minerals in the surface soils in North Dakota. Based on a soil sampling of two to three major soil groups in each county, obtained in spring 2017.

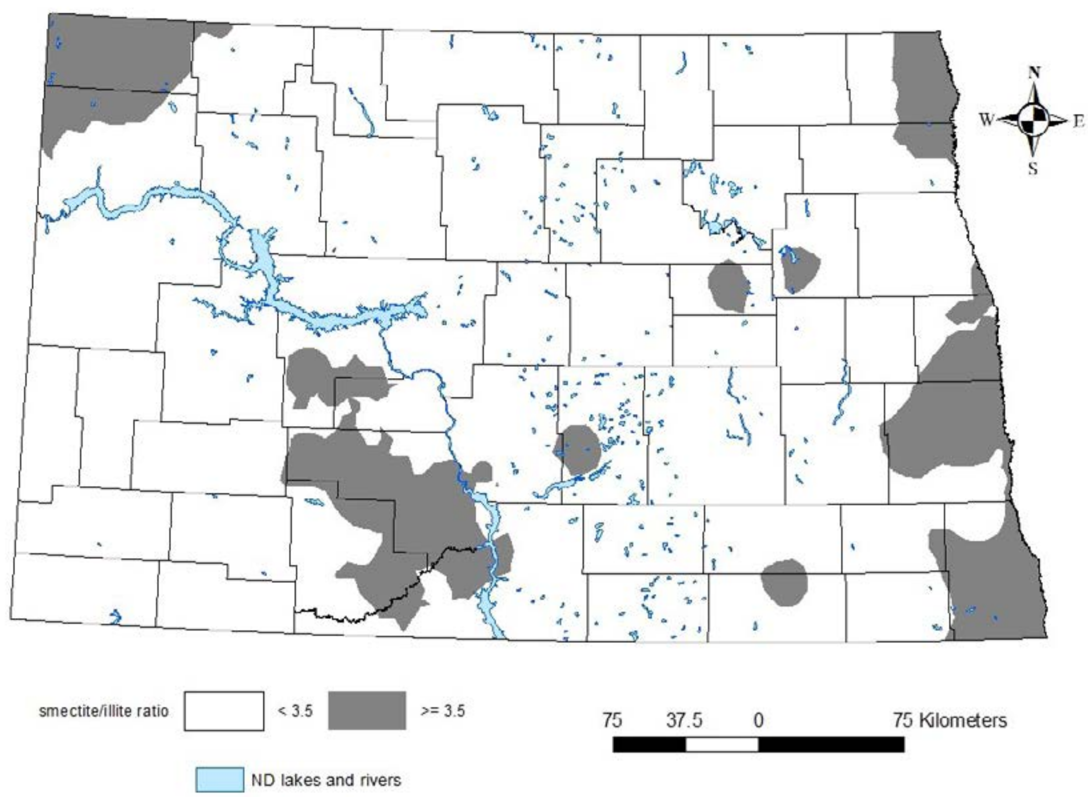

Figure 2. Smectite-to-illite ratio of surface soils in North Dakota from a soil sampling conducted in spring 2017. Dark gray regions are greater than 3:5. White areas are less than 3:5.

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 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 2** 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.

The general recommendations for K fertilizer based on soil test for corn can be found in **Tables 13, 14, 15 and 16**. 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).

Table 13. 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 14. 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 15. 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 16. 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

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.

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% 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.

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% 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.

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, Montana State University)

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)

References

Franzen, D. 2017. Soil Fertility Recommendations for Corn. NDSU Extension publication SF722.

Kopittke, P.M., and N.W. Menzies. 2007. A review of the use of the basic cation saturation ratio and the 'ideal' soil. Soil Science Society of America Journal 71:259-265.

Whitney, D.A. 1998. Micronutrients: zinc, iron, manganese and copper. In Recommended Chemical Soil Test Procedures for the North Central Region. North Central Regional Research Publication No. 221 (Revised).

1M-7-14; 1M-9-17; 1M-10-17; web-12-17; web-9-22