Fertilizing Corn in Minnesota

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In Minnesota, corn is grown on more acres than any other crop. Nationally, Minnesota ranks among the top five states in corn production. Average corn yields have improved steadily over the past several decades. While general fertilizer use contributed substantially to yield increases in the past, total fertilizer management which optimizes nutrient efficiency will be needed to increase future production and profitability.

Nitrogen guidelines

Minnesota corn growers receive substantial return for money invested in nitrogen (N) fertilizers. For many situations, the most profitable yield cannot be achieved unless N fertilizers are used.

There are many management decisions involved in the use of N fertilizers. The most important decision is the selection of a N rate that will produce maximum profit while limiting the potential for environmental degradation. The choice of an appropriate rate of fertilizer N is not easy because of the transient nature of N in soils.

Standard N guidelines

The consideration of soil productivity, price/value ratio, and previous crop are used to arrive at the fertilizer N guidelines for corn. This represents a significant change compared to previous approaches. This process has been in place since 2005 and is the product of a multi-state effort to use a similar philosophy/approach for determining N rate guidelines for corn.

Because of technology improvements in corn production practices such as weed and pest control, expected yield is not as important a factor in determining N rate as it has been in the past. Soil productivity has become a better indicator of N need. A majority of Minnesota soils are highly productive and have generally produced maximum economic corn yield with similar N rates over the last 15 years. Some soils have a reduced yield potential due to erosion, reduced water holding capacity caused by lower organic matter content, sandy soil texture, poor drainage, and restricted root growth. The fluctuation in fertilizer price affects the economic optimum N rate. To account for this change, the ratio of the price of N per pound to the value of a bushel of corn has been added to the N rate decision. An example calculation of the price/value ratio is if N fertilizer costs $0.40 per lb N (or $656 per ton of anhydrous ammonia), and corn is valued at $4.00 per bushel, the ratio would be 0.40/4.00 = 0.10.

The maximum return to N value (MRTN) shown in Table COR-1 is the N rate that maximizes profit to the producer based on the large number of Minnesota experiments supporting these guidelines. Once the soil productivity and price/value ratio have been determined, a producer's attitude towards risk must be factored into the process. A producer who is risk adverse and cannot tolerate risk associated with less-than-maximum yields in some years, even though economic return to N may not always be highly profitable, may want to use the N rates near the high end of the acceptable range shown in Table COR-1. On the other hand, if corn is grown on medium or fine textured soils considered to be of low or medium productivity and/or localized N response data support lower N rates, producers may choose N rates near the low end of the acceptable range in Table COR-1 if they are willing to accept the possibility of less-than-maximum yield in some years without sacrificing profit. The acceptable range gives producer flexibility in arriving at an acceptable and profitable N rate that is calculated as the rate +/- $1 from the MRTN rate.

Table COR-1. Guidelines for use of nitrogen fertilizer for corn grown following corn or soybean when supplemental irrigation is not used

Prior crop	N price/Crop value ratio	MRTN	Acceptable range	Prior crop	N price/Crop value ratio	MRTN	Acceptable range
Corn	0.075	190 lb N/acre	170-205 lb N/acre	**Soybeans**	0.075	150 lb N/acre	135-165 lb N/acre
Corn	0.100	175	160-190	**Soybeans**	0.100	140	130-150
Corn	0.125	165	150-175	**Soybeans**	0.125	135	125-145
Corn	0.150	155	145-165	**Soybeans**	0.150	130	120-140

The N rate guidelines in Table COR-1 are used if corn is grown in rotation with soybean or following corn when NOT irrigated. Corn grown on sandy soils deserves special consideration. If irrigated, the guidelines listed in Table COR-2 are appropriate when corn is grown in rotation with corn. If corn is grown following soybean on irrigated sandy soils, a credit of 30 lb of N per acre should be taken from the suggestions given in Table COR-2. For non-irrigated corn grown on soils with a loamy fine sand texture and less than 3% organic matter, use the guidelines provided in Table COR-3.

Table COR-2. Guidelines for use of N fertilizer for corn following corn when grown on irrigated sandy soils

N price/Crop value ratio	MRTN	Acceptable range
0.05	235 lb N/acre	210-255 lb N/acre
0.10	210	190-225
0.15	190	175-210
0.20	180	165-190

Table COR-3. Nitrogen guidelines for corn grown on non-irrigated loamy fine sands with less than 3% organic matter

N price/Crop value ratio	Corn/Corn	Corn/Soybean
0.05	100 lb N/acre	70 lb N/acre
0.10	90	60
0.15	80	50
0.20	70	40

Soils considered medium productivity in the past were given special consideration. More recent data has not shown strong support for a separate suggested application rate of N for medium productivity soils. The rate of N can be adjusted based on the acceptable range if a soil is considered to be medium productivity and has shown to be more or less responsive to fertilizer N.

Nitrogen management for first- and second-year corn following alfalfa

Alfalfa, which includes pure stands of alfalfa and alfalfa-grass mixtures with at least 50% alfalfa in the stand, can eliminate or greatly reduce the need for N from fertilizer or manure during the two subsequent years if corn is grown.

Past guidelines assigned N credits to corn based on alfalfa stand density, but analyses of field trials from across Minnesota and the Midwest indicate that the frequency and level of yield response to N in first- and second-year corn following alfalfa are more closely associated with soil texture, age of alfalfa at termination, alfalfa termination timing, and weather conditions.

It is well established that first-year corn following alfalfa rarely responds to N except on sandy soils, on fine-textured soils when there are prolonged wet early-season conditions, and on medium-textured soils when following very young alfalfa stands or in some cases when following spring-terminated alfalfa. In past field trials from across Minnesota and the Midwest, yield of second-year corn following alfalfa did not respond to N in half of the fields studied.

Suggested rates of N for first- and second-year corn following alfalfa are in Table COR 4. In some cases, the optimal rate of N can vary greatly due to weather-related variability in soil N mineralization. In such cases, limit the amount of N from fertilizer and manure that is applied prior to and near corn planting, and apply additional N to corn during the growing season if necessary based on weather and crop conditions.

Table COR-4. Nitrogen suggestions for first- and second-year corn following alfalfa[a]

Soil texture[b]	Irrigated or non-irrigated	Alfalfa stand age[c]	Alfalfa termination time	First-year corn following alfalfa	Second-year corn following alfalfa
Coarse	Irrigated	1 year	Fall or spring	140-170 lb N/acre	140-170[d] lb N/acre
Coarse	Irrigated	2 or more years	Fall or spring	70-150	70-150
Coarse	Non-irrigated	1 year	Fall or spring	40-80[d]	80-120[d]
Coarse	Non-irrigated	2 or more years	Fall or spring	0-20	0-80
Medium	Both	1 year	Fall or spring	40-80[d]	80-120[d]
Medium	Both	2 or more years	Fall	0-20	0-80
Medium	Both	2 or more years	Spring	0-40	0-80
Fine	Both	1 year	Fall or spring	40-80[d]	80-120[d]
Fine	Both	2 or more years	Fall	0-20[d]	0-80[d]
Fine	Both	2 or more years	Spring	0-40[d]	0-80[d]

[a] Includes pure stands of alfalfa and alfalfa-grass mixtures with at least 50% alfalfa in the stand.
[b] Coarse = sands and sandy loams; medium = loams and silt loams; fine = clays, clay loams, and silty clay loams.
[c] Alfalfa age at termination, including the establishment year if alfalfa was direct seeded without a small grain companion crop.
[d] An additional 30 to 40 lb N/acre can be applied to corn during the growing season if necessary based on the University of Minnesota supplemental N calculator (z.umn.edu/supplementalN)

Nitrogen credits from other previous crops

To arrive at a guideline following other crops, an adjustment (credit) is made to the corn following corn guidelines. The adjustments can be found in Table COR-5. In Table COR-5, several crops are divided into Group 1 and Group 2. The crops for each group are listed in Table COR-6.

Table COR-5. Nitrogen credits for different previous crops for first year

Previous crop	1st year N credit
Group 1 crops	75 lb N/acre
Group 2 crops	0
Edible bean	20
Field pea	20

Table COR-6. Crops in Group 1 and Group 2

Crop	Group number	Crop	Group number
Alsike clover	1	Grass/legume pasture	2
Birdsfoot trefoil	1	Oats	2
Grass/legume hay	1	Potatoes	2
Grass/legume pasture	1	Rye	2
Fallow	1	Sorghum-sudan	2
Red clover	1	Sugar beet	2
Barley	2	Sunflower	2
Buckwheat	2	Sweet corn	2
Canola	2	Vegetables	2
Corn	2	Wheat	2
Grass hay	2		

The N rates listed in Tables COR-1 and COR-2 define the total amount of fertilizer N that should be applied. All N applied should be accounted for in the calculation, including N in starter fertilizer, weed and feed program, DAP (di-ammonium phosphate) or MAP (mono-ammonium phosphate) applied late fall (after 4” average soil temperatures stabilize at 50ºF) on non-sandy soils or for all soil types in spring, and with sulfur.

It is generally accepted that legume crops provide N to the next crop in the rotation. Some forage legumes provide some N in the second year after the legume was grown. Red clover is the only crop other than alfalfa that may provide a second-year N credit. If red clover was grown two years before the current crop, 35 lb of N per acre should be subtracted from the N rate when corn follows the crops listed in Group 2, Table COR-5.

Using manure as a nitrogen source

The use of manure as a fertilizer source can raise questions about adequate nitrogen rates. The economics of manure application are not straightforward when on-farm sources are used in corn production. Manure also presents challenges as not all of the nutrients are 100% available to crops the first year of application. Plant available N (PAN) is a term used when applying manure to identify the amount of N applied that is plant available in any given year and may be less than the total N applied. Suggestions for N application when manure is the primary nutrient source are given in Table COR-7. If commercial fertilizer is used along with manure, the suggested rates in Table COR-7 should not be exceeded. Lower application rates similar to the 0.10 price ratio may be considered based on the productivity of the soils in your fields, economics, or environmental concerns.

Table COR-7. Nitrogen suggestions for corn when manure is used as a fertilizer source

Crop grown prior to corn	Crop 2 years prior to corn	Suggested PAN to apply
Corn	—	195 lb N/acre
Corn	Alfalfa (1 yr. old stand)	120
Corn	Alfalfa (>2 yr. old stand)	80
Soybean	—	150
Alfalfa (1 yr old stand)	—	80
Alfalfa (>2 yr old stand)	—	40

Use of a soil nitrate test encouraged

The pre-plant soil nitrate test (PPNT) can be a useful tool for assessing situations were residual soil nitrate can be credited to the corn crop. The PPNT should not be used when commercial fertilizer or manure was applied in the previous fall or in the spring prior to the sample being taken.

Western Minnesota

The use of the fall or spring PPNT is a key management tool for corn producers in western Minnesota. The suggestion that residual N in the fall can impact the need for nitrogen is contingent on the fact that evapotranspiration of water historically has exceeded precipitation in this area of the state. Use of the fall PPNT is appropriate in the maroon counties shown in Figure COR-1. The PPNT is particularly useful for conditions where elevated residual nitrate-N is suspected. Figure COR-2 is a decision tree that indicates situations where the nitrate-N soil test would be especially useful.

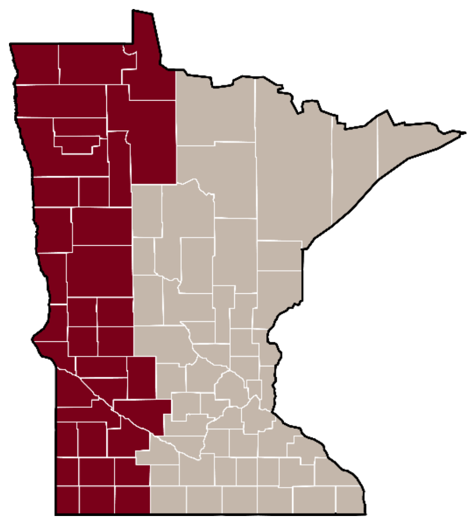

Figure COR-1. Use of the fall pre-plant nitrate test (PPNT) is appropriate in the maroon counties.

For the PPNT, soil should be collected from a depth of 6 to 24 inches in addition to the 0-to-6-inch sample that is used to test for pH, phosphorus, and potassium. Corn growers in western Minnesota also have the option of collecting soil from 0 to 24 inches and analyzing the sample for nitrate-nitrogen (NO_3^--N). This 0-to-24-inch sample should not be analyzed for pH, phosphorus, and potassium because the results cannot be used to predict lime needs or rates of phosphate and potash fertilizer needed.

When using the spring or fall PPNT, the amount of fertilizer N required is determined from the following equation:

NG = (Table COR-1 value for corn/corn) - (0.60 x STN(0-24in.))

- NG = Amount of fertilizer N needed (lb N/acre)
- Table COR-1 value = the amount of fertilizer needed adjusted for soil potential, value ratio, and risk
- STN(0-24 inch) = Amount of nitrate-N measured by using the fall PPNT (lb N/acre)

South-central, Southeastern, East-central Minnesota

Research has led to the inclusion of a spring PPNT to adjust fertilizer N guidelines in south-central, southeastern, and east-central Minnesota (gray counties in Figure COR-1). Soil nitrate-N, measured in the spring before planting from a two-foot sampling depth, is an option that can be used to estimate residual N. In implementing this test, the user should first evaluate whether conditions exist for residual N to accumulate. Factors such as previous crop, soil texture, manure history, and preceding rainfall can have a significant effect on accumulation of residual N.

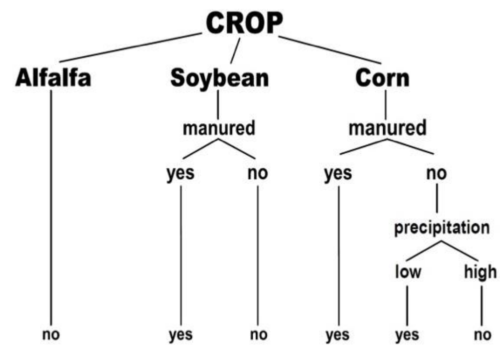

Figure COR-2. Flow chart decision-aid for determining probability of having significant residual nitrate-nitrogen in the soil following specific crop and situations where manure has been applied in a field within two to three cropping years prior to soil sample collection.

A crop rotation that has corn following corn generally provides the greatest potential for significant residual N accumulation. In contrast, when soybean is the previous crop, much less residual N has been measured. The PPNT should not be used following alfalfa.

The spring PPNT works best on medium- and fine-textured soils derived from loess or glacial till. The use of the soil N test on coarse-textured soils derived from glacial outwash is generally not worthwhile because these soils consistently have low amounts of residual nitrate-nitrogen.

The amount of residual nitrate-nitrogen in the soil is also dependent on the rainfall received the previous year. In a year following a widespread drought (2012 for example) a majority of fields will have significant residual nitrate. However, following relatively wet years, little residual nitrate can be expected.

Nitrogen fertilizer guidelines for corn can be made with or without the soil N test. The University of Minnesota's N guidelines (Table COR-1) are still the starting point. A five-step process is suggested when the soil nitrate-nitrogen test is considered.

1. Determine N rate guideline using Table COR-1 using soil productivity, price/value ratio, and previous crop for the specific field. The prescribed (rate assumes that best management practices (BMPs) will be followed for the specific conditions).

2. Determine whether conditions are such that residual nitrate-nitrogen may be appreciable. Figure 2, which includes factors such as previous crop, manure history, and previous fall rainfall can provide insight as to the applicability of testing for nitrate-nitrogen. If conditions are such that the probability of residual nitrate is small and soil testing for nitrate is not recommended, use the N guideline derived in Step 1.

3. If conditions suggest that a soil nitrate test is warranted, collect a pre-plant, 0-2 ft. soil sample taking enough soil cores from a field so that the sample is representative of the entire field. The sample should be sent to a laboratory and analyzed for nitrate-nitrogen.
4. Determine residual N credit based on the measured soil nitrate-nitrogen concentrations. Use Table COR-8 to determine this credit.
5. Calculate the final N rate by subtracting the residual N credit (Step 4) from the previously determined N guideline (Step 1). The resulting fertilizer N rate can then be applied either pre-plant and/or as a side-dress application.

Table COR-8. Residual N credit values based on the concentration of nitrate-N measured before planting in the spring from the top two feet of soil

Soil nitrate-N	Residual N credit
0.0-6.0 ppm	0 lb N/acre
6.1-9.0	35
9.1-12.0	65
12.1-15.0	95
15.1-18.0	125
>18.0	155

Best management practices for nitrogen

Because of the diversity of soils, climate, and crops in Minnesota, there are no uniform statewide guidelines for selection of a source of fertilizer N, placement of the N fertilizer, and use of a nitrification inhibitor. In order to accurately address this diversity, Minnesota has been divided into five regions and BMPs for N use in each region have been identified and described. The listing of these management practices for all regions is not appropriate for this publication, but they are available at the Minnesota Department of Agriculture (z.umn.edu/AgNitrogenBMPs). Currently, the use of these BMPs is voluntary. Corn growers should implement BMPs to optimize N use efficiency, profit, and protect against increased losses of nitrate-nitrogen to the environment.

Phosphate and potash guidelines

When needed, the use of phosphate and/or potash fertilizer can produce profitable increases in corn yields. Soil test categories represent the probability the soil will supply all the needed crop nutrients. Table COR-9 shows field research data summarizing the expected percent of time where a measurable response to P fertilizer will occur and the percentage of maximum yield produced when no fertilizer is applied. The chance of a yield response to P and the increase in yield is greatest when soil P tests Very Low and decreases as soil test P increases. Corn yield may still be increased by P at High and Very High soil test, but the net return to P may not be profitable.

Table COR-9. Corn grain yield response to applied P fertilizer based on soil test category

Bray-p1 or Olsen soil test P category	Expected time P fertilizer will increase corn grain yield	Expected yield without P fertilizer
Very Low	87%	87%
Low	83%	90%
Medium	27%	98%
High	13%	99%
Very High	7%	99%

Rate changes with placement

In general, the results of the Olsen test should be used if the soil pH is 7.4 or greater. There are some situations where the results of the Bray test are greater than the results of the Olsen test when soil pH values are greater than 7.4. For these cases, the amount of phosphate suggested should be based on the soil test value that is the higher of the two.

Measurement of P by the Mehlich III procedure is not suggested for use in Minnesota. However, some soil testing laboratories analyze P with this analytical test. For these situations, use the guidelines appropriate for the results of the Bray procedure. The definition of categories is the same for both the Bray and Mehlich III analytical procedures when P is determined colorimetrically. If the soil pH is greater than 7.4, use of the Mehlich III test is not suggested as the results may not correlate to the Olsen P test.

A combination of band and broadcast applications is suggested if the soil test for P is very low (0-5 ppm for Bray; 0-3 ppm for Olsen) (Table COR-10). For fields with very low P soil test values, plan on using the suggested band rate at planting then subtract the amount of P banded from the suggested broadcast P rate, then broadcast and incorporate the remainder of P before planting. Phosphate fertilizer can be applied as either a broadcast application or in a band fertilizer if the soil test value for P is in the low (6-10 ppm for Bray; 4-7 ppm for Olsen) or medium (11-15 ppm for Bray; 8-11 ppm for Olsen) ranges. Broadcast applications of phosphate fertilizer have a low probability of increasing corn yields when the soil test for P is in the high range (16-20 ppm for Bray; 12-15 ppm for Olsen). The use of phosphate in a banded fertilizer is suggested for these situations. No phosphate fertilizer is suggested for either broadcast or banded application if the soil test is greater than 25 ppm (Bray), or 20 ppm (Olsen), and conventional tillage systems are used.

As with phosphate, the suggested rates of potash vary with the soil test for potassium (K), expected yield, and placement (Table COR-11). A combination of broadcast and band applications is suggested when the soil test for K is in the range of 0-40 ppm. For fields with these values, plan on using the suggested rate in the band at planting, subtract this amount from the suggested broadcast rate, then broadcast and incorporate the remainder needed before planting. The grower has the choice of either broadcast or band placement if the soil test for K is in the low (41-80 ppm) or medium (81-120 ppm) range. The application of potash in a band is emphasized if the soil test for K is in the high range (121-160 ppm).

Table COR-10. Broadcast and band phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for corn production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm)*

Expected yield	Broadcast or band	0-5 ppm Bray 0-3 ppm Olsen	6-10 ppm Bray, 4-7 ppm Olsen	11-15 ppm Bray, 8-11 ppm Olsen	16-20 ppm Bray, 12-15 ppm Olsen	21+ ppm Bray, 16+ ppm Olsen
151-175 bu/acre	Broadcast	90 lb/acre	60 lb/acre	35 lb/acre	10 lb/acre	0 lb/acre
151-175	Band	45	35	25	10-15	10-15
176-200	Broadcast	110	75	45	15	0
176-200	Band	55	40	30	10-15	10-15
201-225	Broadcast	130	90	55	20	0
201-225	Band	65	45	30	10-15	10-15
226-250	Broadcast	145	100	60	20	0
226-250	Band	75	50	30	10-15	10-15
250+	Broadcast	160	115	70	25	0
250+	Band	80	60	35	10-15	10-15

* Use one of the following equations if a P_2O_5 guideline for a specific soil test value and a specific expected yield is desired.
$P_2O_{5 suggestions}$ = [0.700 - .035 (Bray P ppm)] (expected yield) | $P_2O_{5 suggestions}$ = [0.700 - (.044 (Olsen P ppm)] (expected yield)
No phosphate fertilizer is suggested if the soil test for P is greater than 25 ppm (Bray) or 20 ppm (Olsen).

Table COR-11. Broadcast and band potash guidelines (lb K_2O/acre) for corn production in Minnesota based on K soil test reported in parts per million*

Expected yield	Broadcast/band	0-50 ppm	51-100 ppm	101-150 ppm	151-200 ppm	200+ ppm
151-175 bu/acre	Broadcast	160 lb/acre	115 lb/acre	70 lb/acre	20 lb/acre	0 lb/acre
151-175	Band	75	60	45	10-15	10-15
176-200	Broadcast	185	135	80	25	0
176-200	Band	90	70	50	10-15	10-15
201-225	Broadcast	210	155	90	30	0
201-225	Band	105	80	55	10-15	10-15
226-250	Broadcast	235	165	100	35	0
226-250	Band	120	85	60	10-15	10-15
250+	Broadcast	255	180	110	40	0
250+	Band	130	90	65	15-20	10-15

* Use one of the following equations if a K_2O guideline for a specific soil test value and a specific expected yield is desired.
K_2Osuggested = [1.12 - 0.0056 (Soil Test K, ppm)] (expected yield)
No potash fertilizer is suggested if the soil test for K is 200 ppm or greater.

Maintenance-based P and K strategies

Many growers would prefer to maintain soil test values for P and K in the medium to high range to reduce the risk of yield loss due to insufficient P or K. This is especially true if they own, rather than rent, the land. There is justified concern that soil test levels for either P or K will drop substantially if low rates of phosphate or potash fertilizers are applied year after year and soils are not tested frequently enough to make adjustments for decreasing soil test values. In these circumstances, application of P and K based on crop removal may be warranted.

Median rates of P and K removed per bushel of corn grain are listed in Table COR-12. High rates of P or K applied for maintenance will typically result in a less return in crop value per pound of nutrient applied. The most economical use of P and K fertilizer is to only apply what is needed year to year. Recent research suggests that crop removal based on a **proven yield** (5-10 year yield average) can be economical for soils testing in the medium to high soil test categories. For very high testing soils, a small starter rate of P or K is typically sufficient to achieve maximum crop yield in situations where corn will respond to applied fertilizer. Application of 50% or less of crop removal is suggested for soils testing very high in available nutrients to allow soil tests to gradually draw down to the High STP classification.

Table COR-12. Expected removal of phosphate and potash in harvested corn grain at 15.5% moisture

Ingredient	Median	Range
Phosphate (P_2O_5)	0.28 lb/bu	0.25-0.33 lb/bu
Potash (K_2O)	0.19	0.18-0.22

Strict crop removal of P and K may not provide sufficient nutrients for soils that test Very Low or Low for either nutrient. Extra P can be applied to build some soils to the Medium or High soil test category. A general rule is that 16-18 lb P_2O_5 and 7-10 lb K_2O are required to increase the Bray-P1 or ammonium acetate K tests by 1 ppm, respectively. Rapid buildup of soil test P or K is not suggested. Research has shown that the rates of P suggested for the very low and low STP categories will slowly build STP to the medium classification for neutral to acid soils.

The amount of P or K needed to build the soil test greatly depends on soil chemical properties. For soils in western Minnesota where the Olsen P test is used, aggressively building soil test P values will not be cost effective due to the reaction of ortho-phosphate with calcium. Under these circumstances, applying only what the crop needs to maximize yield potential is suggested.

Excessive building of P can lead to increased risk for P loss to the environment. The strategy outlined in Table COR-13 shows the STP range which is Optimal for Maintenance within the Medium to High STP categories and suggests drawing STP down using P application based on partial crop removal in order to maintain STP in a more profitable zone. Soil test P ranges are not given for the Olsen P test as it may not be possible to build and maintain some high pH soils.

Table COR-13. Example P fertilizer suggestions for the use of crop removal when utilizing commercial P fertilizer sources (non-manure)

Bray-P1 test	Suggested rate ranges
0-10 (ppm)	See Table COR-9
10-20	100% (crop removal)
20-30	25-50%
30-40	0-20%
40-50	0-10%
50+	No P fertilizer suggested

The example in Table COR-13 could be used for K. However, research has demonstrated increased seasonal variability in the soil K test. Collecting samples at the same time is critical to best evaluate maintenance-based strategies for K.

Impact of cation exchange on corn K guidelines

Potassium fertilizer guidelines for corn were revised based on recent research on medium- and fine-textured soils in Minnesota. Currently, these guideline rates are not adjusted based on a soils' ability to hold potassium on cation exchange sites of clays. Coarse-textured soils, such as sands and loamy sands, have very little clay and low cation exchange capacity (CEC). Potassium can leach on low CEC soils, potentially wasting K fertilizer and reducing economic return to fertilizer.

Research in Minnesota is on-going to determine if K guidelines need to vary based on soil CEC. Recent research on sandy soils with a CEC around 5 meq per 100 grams showed sandy soils needed less potassium fertilizer than medium- and fine-textured soils with the same soil test K level and had a lower critical soil test level. Due to K leaching potential and a lower critical level of low CEC soils, it is not recommended to build soil test K greater than 120 ppm. Until more research data are available, K fertilizer could be applied on low CEC soils using the equation below. However, use of this equation will reduce K fertilizer application rates on low CEC soils and should be done on a trial basis to ensure K is not limiting yield on irrigated corn grown on low CEC sandy soils.

$K_2O_{suggested}$ = [1.08 - 0.0084 (Soil Test K, ppm)] (expected yield)

Special considerations

Because of the diversity of Minnesota's soils and climate, rental and lease arrangements for land, and goals of individual growers, the phosphate and potash suggestions listed in Tables COR-10 and COR-11 cannot be rigid across the entire state. There are some special situations where rates might be changed. Some, but not all, of these situations are described in the following paragraphs.

East-central Minnesota soils: This region of the state usually has high native levels of soil test P and strict interpretation of the guidelines suggests that no phosphate is needed in a fertilizer program. However, many corn growers have observed responses to phosphate when applied in a band at planting. Soils in this region are frequently cool and wet in the spring and these conditions can lead to a requirement for phosphate fertilizer early in the growing season. Therefore, a rate of 15-20 lb phosphate per acre is suggested for use in a banded fertilizer placed close to the seed at planting for corn production in these situations, regardless of soil test level for P.

Broadcasting low rates: Some of the suggested rates for phosphate and potash listed in Tables COR-10 and COR-11 are small and fertilizer spreaders cannot be adjusted to apply these low rates. The suggested broadcast rate of phosphate can be blended with the suggested broadcast rate of potash and the mixture could then be applied with available equipment. In other situations, broadcast applications of low rates of only phosphate or potash may be suggested. For these fields, it may be more practical to double the suggested broadcast rate and apply on alternate years.

Changes in P and K soil test values

Research in Minnesota has shown that soil test levels for P and K should not change rapidly with time. Yearly decreases have been small for situations where no phosphate or potash fertilizer has been applied but can vary from year to year depending on environmental conditions. Always use long-term soil test trends over 5 years when assessing changes in soil test values using maintenance-based strategies.

A small decrease in soil test levels for P and K can be expected when phosphate and potash are used repeatedly in a banded fertilizer. Likewise, some reduction can be expected when low rates of phosphate and potash are used year after year. When soil test values drop, broadcast applications of higher rates of phosphate and/or potash fertilizers are justified if profitability and cash flow is favorable and the grower wants to maintain soil test values in the medium or high range.

Unless long-term leases or rental arrangements are in place, the use of a banded placement for phosphate and/or potash may be the most profitable management system for rented land. It is difficult to economically justify the use of high rates of phosphate and/or potash to build soil test levels on rented acres.

Adjusting for manure use

Animal manure is an excellent source of plant nutrients. When using manure, first determine the amount of plant available nutrients it will provide in the first year (80% of P and 90% of K). Then, adjust the fertilizer program to make up the difference between what was applied and what is needed according to the fertilizer guidelines. Extension resources that describe in detail the use of manure are listed at the end of this publication.

Using a banded fertilizer

The use of a banded fertilizer at planting is an excellent management tool for corn production in Minnesota, especially when soils are cold and wet at planting. Yield increases are not always guaranteed with the use of a starter when soil test values are in the very high range or when recommended rates of broadcast P or K are applied.

The rate of fertilizer that can be applied in a band directly on the seed at planting varies by fertilizer source and soil texture. A summary of appropriate rates for banding fertilizer on the corn seed can be found in the publication “Banding fertilizer on the corn seed”. Application of fertilizer two inches beside and below the seed row presents a very low risk for reduced germination and higher rates of nutrients can be applied when there is one or more inches between fertilizer and seed placement. All nutrients applied in starter fertilizer should be accounted for in the total fertilizer program.

CAUTION! Do not apply urea, ammonium thiosulfate (12-0-0-26), potassium thiosulfate, or fertilizer containing boron in contact with the seed.

Sulfur guidelines

The addition of sulfur (S) to a fertilizer program for corn should be a major consideration based on soil texture, crop rotation, soil drainage, and soil organic matter concentration in the top six inches. Suggested sulfur application rates as sulfate-sulfur forms are given in Table COR-14.

Banding sulfur fertilizer can increase effectiveness and reduce the required application rate by as much as one half. Keep in mind that ammonium or potassium thiosulfate should not be placed in contact with the seed. Thiosulfate will not harm germination or emergence if there is at least 1 inch of soil between seed and fertilizer.

Table COR-14. Broadcast sulfate-sulfur guidelines (lb S/acre as SO_4-S) for corn grown in Minnesota with 0-6" soil organic matter concentration

Soil texture	Crop rotation	Drainage	0-2%	2-4%	4%+
Medium/fine	Soybean/wheat to corn	Well	10-25 lb/acre	10-15 lb/acre	0 lb/acre
Medium/fine	Soybean/wheat to corn	Poor	15-25	10-15	5-15
Medium/fine	Corn to corn	All	15-25	10-15	5-15
Coarse	All	—	25	25	15-25

Visual sulfur deficiency symptoms early in the growing season are common in Minnesota due to limited mineralization and uptake of S early in the growing season. Some of these symptoms may be temporary and will go away as the soil warms. If a deficiency of S is suspected, recent data have shown that fertilizer S can be applied when corn is 12 inches tall or less without a reduction in yield potential. Plant available sulfur in the sulfate form is an anion and is susceptible to leaching loss. Recent data suggests that sulfate can carry over from one year to the next. Total corn uptake of S can range from 20-25 lb of S per year. Application in excess of this amount will not result in increased grain yield but S not used by the current corn crop may be carried over to the next year, reducing the need for S application for the following crop.

There are several materials that can be used to supply S. Any fertilizer that supplies S in the sulfate (SO_4^{2-}S) form is preferred. Fertilizer sources containing elemental sulfur are commonly sold in Minnesota. Elemental sulfur must be oxidized to sulfate sulfur before it can be taken up by the plant. If elemental S is used, sulfate S may be required to ensure adequate availability of S early in the growing season and the application rate of elemental S should be 20 lb S per acre or greater, or double the amount of S suggested in Table COR-14.

Liquid S is commonly sold as thiosulfate products. The thiosulfate ion contains half of the S in sulfate and half in the elemental S form. Research has shown a greater availability of S from the elemental S fraction in thiosulfate fertilizers.

Magnesium guidelines

Most Minnesota soils are well-supplied with magnesium (Mg) and this nutrient is not usually needed in a fertilizer program. There are some exceptions. The very acidic soils of east-central Minnesota might need Mg.

There should be no need for the addition of Mg if dolomitic limestone has been applied for legume crops in the rotation or when soils are irrigated and the water source used contains a high concentration of Mg. Magnesium extracted with 1M ammonium acetate is used to predict the need for this nutrient. The suggestions for using Mg in a fertilizer program are summarized in Table COR-15.

Table COR-15. Guidelines for magnesium use for corn production

Magnesium soil test	Relative level	Row	Broadcast
0-50 ppm	Low	10-20 lb/acre	50-100 lb/acre
51-100	Medium	Trial*	0
101 +	Adequate	0	0

*Apply 10-20 lb Mg per acre in a band only if a Mg deficiency is suspected or if a deficiency has been confirmed by plant analysis.

Micronutrient needs

Plants take up less than one pound of micronutrients per acre, with only a few ounces required for optimal plant production. While micronutrients are needed for optimal plant growth, they may not need to be applied.

Zinc

Research trials conducted throughout Minnesota indicate that zinc (Zn) is the only micronutrient that may be needed in a fertilizer program for corn. This nutrient, however, is not needed in all fields. The DTPA soil test for Zn is very reliable and will accurately predict the needs for this essential nutrient. The suggestions for Zn are summarized in Table COR-16.

Table COR-16. Zinc guidelines for corn production in Minnesota

Zinc soil test*	Band	Broadcast
0.0-0.25 ppm	2 lb/acre	10 lb/acre
0.26-0.50	2	10
0.50-0.75	1	5
0.76-1.00	0	0
1.01+	0	0

* Zinc extracted by the DTPA procedure.

Because corn is the only agronomic crop that will consistently respond to Zn fertilization, the use of Zn in a banded fertilizer is suggested. However, carryover to succeeding years will be better with broadcast applications. There are several fertilizer products that can be used to supply Zn. Except for large particles of zinc oxide, all are equally effective. Cost should be a major consideration in product selection. Chelated zinc is commonly used when liquid starter fertilizer is applied directly on the corn seed. Chelated Zn can increase the availability of Zn by preventing the precipitation of low solubility Zn compounds, but these products typically cost more per lb of Zn applied. Zinc fully chelated with EDTA has been shown to provide the greatest stability of zinc across a range in soil pH values. Utilization of chelated Zn does not increase the potential for a yield response for soils testing 0.75 ppm or greater in soil test Zn and should be targeted to soils where a response to Zn is expected.

Boron

Recent research has shown that boron (B) is not likely to increase yield of corn across a variety of soils across Minnesota. Boron availability in soils is affected by soil organic matter concentration and soil moisture. There is a small chance of a response to B on sandy soils with SOM less than 1.0% and boron soil tests of 0.08 ppm or less. If a deficiency to boron is suspected, the application of boron should not exceed 1-2 lb per acre of B broadcast applied on a trial basis. There are no guidelines for foliar-applied boron as low rates of B applied to foliage do present a risk for boron toxicity.

Other micronutrients

The use of iron (Fe), copper (Cu), and manganese (Mn) is not suggested for corn fertilizer programs in Minnesota.

Additional resources

- University of Minnesota nutrient management (z.umn.edu/NutrientMGMT)
- Managing the rotation from alfalfa to corn (z.umn.edu/Rotation)
- Corn supplemental nitrogen rate calculator (z.umn.edu/supplementalN)
- Regional corn nitrogen rate calculator (z.umn.edu/Ncalculator)
- Using banded fertilizer for corn production (z.umn.edu/BandingCorn)
- University of Minnesota manure management (z.umn.edu/ManureApplication)
- Guidelines for manure application rates (z.umn.edu/ManureRates)
- MDA: Nitrogen Fertilizer BMPs for Agricultural Lands (z.umn.edu/AgNitrogenBMPs)

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