University of Minnesota Extension

Fertilizer Guidelines for Agronomic Crops in Minnesota

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Understanding the Soil Test Report

Daniel E. Kaiser[1] and Keith Piotrowski [2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

The concept of soil sampling and analysis has been the basis of fertilizer recommendations used in crop production for many years. Regardless of the procedure used for the collection of the samples, the results of the laboratory analysis that reach the crop producer are frequently confusing. The units used to report the analytical results are not familiar.

There are several numbers on the analysis sheet and not all may be useful for making fertilizer recommendations. There is a relationship between the analytical results and fertilizer and lime recommendations. Some explanation of the information which appears on the analytical report would probably be helpful.

The reporting units

The numbers found on any soil test report are the result of some analytical measurement of the nutrients in the soil. Most soil testing laboratories report measurements in parts per million, abbreviated as ppm. This reporting unit is used for nutrients other than nitrogen. Some laboratories report measurements in terms of pounds per acre. There is a simple conversion factor for these two reporting systems. That conversion is: ppm x 2 = lb. per acre for a six-inch soil sample. When soil pH or buffer pH is measured, there are no units associated with the number that is reported.

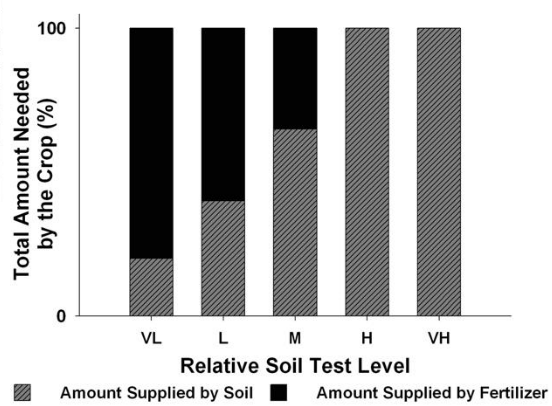
When soil samples are analyzed for nitrate-nitrogen (NO_3^--N, most laboratories will report the analytical results in two ways. Concentration is reported in terms of ppm. Then, depending on the depth from which the sample was collected, NO_3^--N concentration is converted into pounds of NO_3^--N per acre for each increment of depth that was sampled. For example, if soil was collected from depths of 0 to 6 inches and 6 to 24 inches, the amount of NO_3^--N at each depth is reported in terms of lb. per acre. The total for the 0-24 in. depth is calculated as the total that is found at 0-6 in. and 6-24 in. The sample calculations also apply to other depths that might be sampled.

There are a variety of reporting units for soil organic matter content. Some laboratories report the organic matter in relative terms for low, medium, and high. Others report the measured percentage.

The units chosen to report analytical results do not have any effect on fertilizer guidelines. It is important, however, to be aware of the difference between ppm and lb. per acre when reading the units associated with the numbers on the soil test report.

The procedures used

There are several analytical procedures that can be used to extract plant nutrients from soils. The procedures used in testing soils are not designed to measure the total amount of any nutrient present in the soil. The analytical procedure used to measure a specific nutrient is selected because it extracts the portion of the total amount of that nutrient that is best related to plant growth and yield. The selection of an analytical procedure is not arbitrary. The procedure selected has been developed from considerable research as the one which best predicts the amount of that nutrient in the soil that can be used by plants. The Bray and Kurtz #1 (Bray-P1) procedure (sometimes referred to as the weak Bray procedure) used for measuring phosphorus in acid soils is a good example. Results of considerable research have shown that the amount of phosphorus extracted by this method is the best predictor of the need for phosphate fertilizer for acid soils. Bray and Kurtz also developed an analytical procedure that uses a stronger acid. However, the amount of phosphorus extracted by the stronger acid was not related to crop growth. Therefore, the use of this strong Bray or Bray-P2 procedure has no value for making phosphate fertilizer guidelines in Minnesota.



Analytical procedures used in soil testing are usually standardized. Currently, most soil testing laboratories that operate in the North-Central states use the same analytical procedure when analyzing for a specific nutrient. These laboratories also participate in a quality control program that produces confidence in the analytical results coming from that laboratory.

Relative levels

The numbers listed on most soil test reports are usually followed by a letter such as VL, L, M, H, or VH. These letters are abbreviations for very low, low, medium, high, and very high, respectively. These letters designate the relative level of the nutrient measured and provide a good indication of the probability of measuring an economic increase in yield if fertilizer supplying the nutrient in question is applied. For example, if the relative level is classified as being very low, there is a high probability that crop yields will increase if fertilizer supplying the nutrient in question is applied. By contrast, no increase in yield from the application of the nutrient would be expected if the relative level in the soil is in the very high range. The relative proportion of nutrient needed from either soil or fertilizer at the various soil test levels is illustrated in the following figure.

The relative levels of the various immobile nutrients in soils have been defined in terms of concentration (ppm) measured by the appropriate extraction procedures.

Table I-1. Description of each relative level for the phosphorus (P), potassium (K), and zinc (Zn) extracted by the appropriate analytical procedure.

Relative Level	Phosphorus: Bray-P1 Test	Phosphorus: Olsen Test	Potassium – Most Crops	Potassium – Corn and Soybean	Zinc
Very low (VL)	0 to 5 ppm	0 to 3 ppm	0 to 40 ppm	0 to 50 ppm	0 to 0.25 ppm
Low (L)	6 to 11	4 to 7	41 to 80	51 to 100	0.26 to 0.50
Medium (M)	12 to 15	8 to 11	81 to 120	101 to 150	0.51 to 0.75
High (H)	16 to 20	12 to 15	121 to 160	151 to 200	0.76 to 1.00
Very high (VH)	21+	16+	161+	201+	1.01+

The range of values for each relative level shown in the above table is not used by all soil testing laboratories. A soil testing laboratory can use any range of values that it chooses. A difference in the range of values for each relative level is one source of confusion that adds to the difficulty of evaluating results from more than one soil testing laboratory.

It is important to understand that the number associated with any nutrient on a soil test report is an index value to be associated with one of the five relative levels. It is not the amount of a nutrient that is available for crop use. It is not the total amount of a nutrient present in the soil. The number listed is an index value only and when combined with an expected yield can be used to develop a fertilizer guideline.

Interesting, but not useful

The reports from some soil testing laboratories list the Cation Exchange Capacity (CEC) of a soil. This is a fixed soil property that varies with soil texture and organic matter content. This soil property, however, is not useful for making fertilizer guidelines.

The laboratories that measure CEC also usually report values of exchangeable potassium (K), calcium (Ca), and magnesium (Mg). This is interesting information, but this information is of little value for making fertilizer guidelines in Minnesota.

Don't be confused

The soil test report contains a substantial amount of information. At first glance, this report can be confusing. Hopefully, the information presented in the previous paragraphs can help to eliminate some of the confusion.

Funding for the development of this publication is provided by Minnesota's Agricultural Fertilizer Research and Education Council (AFREC).

University of Minnesota Extension

Fertilizing Alfalfa in Minnesota

Daniel E. Kaiser[1] and Keith Piotrowski[2]
[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

A well-managed fertilizer program is a key ingredient in the efficient and profitable production of this crop. When alfalfa production is considered, major emphasis should be devoted to 1) the proper use of lime and 2) application of appropriate rates of phosphate, potash, sulfur, and boron.

pH and liming guidelines

Profitable alfalfa production starts with a consideration of soil pH and lime needs. A pH of 6.5 or higher is desired for optimum alfalfa yields. When lime is used to raise the soil pH to this level and above, alfalfa growth is improved because there is a more favorable environment for the growth and development of rhizobia bacteria. These bacteria allow the alfalfa crop to manufacture the nitrogen (N) that it needs from the nitrogen in the atmosphere.

The availability of phosphorus (P) is also affected by soil pH. Liming to a pH of 6.5 increases the availability of both soil and fertilizer P to plants. Soils in Minnesota contain ample calcium (Ca) for crop growth. Liming materials are not used to supply Ca. Most soils have optimum amounts of magnesium for alfalfa production. If Mg is needed, the use of dolomitic lime will provide enough Mg for production.

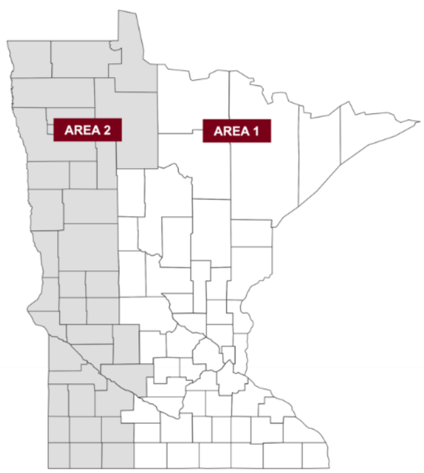


Figure ALF-1. In Area 1, most subsoils are acid. In Area 2, few subsoils are acid.

Determining the need for lime

The need for lime is not uniform across Minnesota and recommendations will vary. Analyzing a soil sample for pH and buffer pH is the only way to arrive at an accurate lime recommendation. Soils should be sampled to 6-8 inches. The recommendations will not be accurate if other sampling depths are used.

Lime recommendations for alfalfa production are summarized in Tables ALF-1 and ALF-2. The location of the field within the state must also be considered when the recommendations in Tables ALF-1 and ALF-2 are used (see Figure ALF-1). In Minnesota, lime recommendations are given in terms of pounds of ENP (Effective Neutralizing Power) per acre. The effectiveness of liming materials is reported as pounds of ENP per ton. To calculate the tons per acre of a liming material needed to raise the soil pH to 6.5 divide the recommended lb ENP per acre by the lb of

ENP per ton of material. A more detailed discussion of ENP and the variety of liming materials available is provided in Extension Fact Sheet AG-FS-5957.

The approximate recommendations for the use of Ag lime (crushed limestone) are also listed in Tables ALF-1 and ALF-2. These suggestions can be used when soil testing laboratories report lime recommendations in terms of tons per acre instead of lb ENP per acre. Lime should be applied several months before seeding for the best effect.

Table ALF-1. Lime suggestions for mineral soils when the soil pH is less than 6.0. The rates suggested should raise the pH to 6.5.

Buffer index	Area 1: ENP lb/acre	Area 1: Ag Lime* ton/acre	Area 2: ENP lb/acre	Area 2: Ag Lime* ton/acre
6.8	3000 lb/acre	3.0 ton/acre	2000 lb/acre	2.0 ton/acre
6.7	3500	3.5	2000	2.0
6.6	4000	4.0	2000	2.0
6.5	4500	4.5	2000	2.0
6.4	5000	5.0	2500	2.5
6.3	5500	5.5	2500	2.5
6.2	6000	6.0	3000	3.0
6.1	6500	6.5	3000	3.0
6.0	7000	7.0	3500	3.5
5.9	7500	7.5	3500	3.5
5.8	8000	8.0	4000	4.0
5.7	8500	8.5	4000	4.0
5.6	9000	9.0	4500	4.5

*These are approximate suggestions based on the average ENP value of Ag lime. An ENP of 1,000 lb per ton is an average value for Ag lime (crushed limestone) in Minnesota.

Table ALF-2. Lime suggestions for mineral soil when the SIKORA BUFFER TEST IS NOT USED (soil pH is 6.0 or higher). The rates suggested should raise the pH to 6.5.

Soil-water pH	Area 1: ENP	Area 1: Ag Lime*	Area 2: ENP	Area 2: Ag Lime*
6.5 pH	0 lb/acre	0 ton/acre	0 lb/acre	0 ton/acre
6.4	2000	2.0	0	0
6.3	2000	2.0	0	0
6.2	3000	3.0	0	0
6.1	3000	3.0	0	0
6.0	3000	3.0	2000	2.0

*These are approximate suggestions based on the average ENP value of Ag lime. An ENP of 1,000 lb per ton is an average value for Ag lime (crushed limestone) in Minnesota.

Phosphate guidelines

When needed, phosphate fertilizers can produce substantial increases in alfalfa yield. Phosphate fertilizer recommendations are based on a yield goal and the results of the analysis of a soil sample for phosphorus (P). These suggestions are summarized in Table ALF-3.

Table ALF-3. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for alfalfa production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected yield Bray P1	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm
Expected yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm
3 or less ton/acre	40 lb/acre	35 lb/acre	20 lb/acre	5 lb/acre
4	65	45	25	10
5	80	55	30	15
6	95	65	40	15
7	110	80	45	20
More than 7	125	90	55	25

*Use the following equations to calculate phosphate fertilizer suggestions for specific yield and specific soil test values for P:
$P_2O_{5 Suggested}$ = [18.57 - (0.93)(Bray P Test, ppm](Yield Goal) | $P_2O_{5 Suggested}$ = [18.57-(1.16)(Olsen P Test, ppm](Yield Goal)
No phosphate fertilizer is suggested if the soil test for P is greater than 20 ppm (Bray) or 15 ppm (Olsen).

Potash guidelines

Potassium (K) may be the most limiting nutrient for alfalfa production in central, east-central, and southeastern Minnesota. Potash fertilizer recommendations should be based on a realistic yield goal and the results of the analysis of a soil sample for K. The potash suggestions for alfalfa production in Minnesota are summarized in Table ALF-4.

Table ALF-4. Potash guidelines (lb K_2O/acre) for alfalfa production in Minnesota based on K soil test reported in parts per million*

Expected yield (ton/acre)	0-40 ppm	41-80 ppm	81-120 ppm	121-160 ppm
3 or less	145 lb/acre	100 lb/acre	55 lb/acre	10 lb/acre
4	190	130	70	10
5	240	165	90	15
6	290	195	105	15
7	335	230	125	20
More than 7	380	265	145	20

*Use the following equation to calculate potash fertilizer suggestions for specific yield goals and specific soil test values for K:
$K_2O_{Suggested}$ = [55.7 - (0.38)(Soil Test K, ppm)](Yield Goal)
No potash fertilizer is suggested if the soil test for K is 161 ppm or greater.

Phosphate and potash management

Annual applications of fertilizer, based on the results of a soil test, are suggested to produce high-yielding alfalfa. In the year of establishment, the suggested rates of phosphate and/or potash should be broadcast and incorporated before seeding. These suggested rates should be adequate for the seeding year. For the first full year of production, repeat the application that was used for the seeding year.

Soil samples should be collected again in the fall of the first full year of production. The amounts of phosphate and/or potash needed for the second and third production years can be based on the results of this test.

Needed fertilizer can be applied in either spring or fall if soils are not sandy. Spring applications are suggested when soils are sandy. Split applications can be used for alfalfa and are a good management practice. This is especially true if high rates of phosphate and/or potash fertilizer are needed. If split applications are used, the fertilizer should be applied in early spring and repeated after the 1st cutting. The split applications of K can also reduce the incidence of high K concentrations in the forage that can cause reduced forage quality for some classes of livestock.

Some of the rates for phosphate and potash use listed in Tables ALF-3 and ALF-4 are small. Most fertilizer spreaders cannot be adjusted to apply these low rates. In some situations, the recommended rate of phosphate can be blended with the recommended rate of potash and the mixture can then be spread 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.

Nitrogen guidelines

The use of nitrogen (N) fertilizer is not recommended when alfalfa is seeded in medium or fine-textured soils. In these situations, application of N fertilizer may reduce nodulation. Small amounts of a N fertilizer may enhance establishment when alfalfa is seeded in a coarse-textured soil. The N rate should be held to 25 lb/acre or less.

A small amount of N may be applied when alfalfa is seeded with a nurse or companion crop. This is especially true when soils are sandy. The suggested N rate for this planting situation is 30 lb/acre.

There is usually no benefit from topdressing fertilizer N to established stands unless there is firm evidence that nodulation is not present. Many times, weeds and grasses appear as the alfalfa stand ages. The application of fertilizer N or manure will stimulate the growth of both. This could accelerate the disappearance of alfalfa from the stand.

Sulfur guidelines

Several research trials have clearly demonstrated that the use of sulfur (S) in a fertilizer program will increase the production of alfalfa grown on sandy soils. Recent research in Northeast Iowa has shown positive yield responses to S on soils with organic matter concentrations of less than 3.0% in the top 6-8 inches. These soils can be heavier textured found on side slopes and eroded spots in fields.

In Minnesota, the soil test for S is only reliable for sandy soils. This soil test has no value for medium and fine textured soils. It is suggested that 15-25 lb S per acre should be applied to medium and fine textured soils with organic matter concentrations less than 3.0% if the producer suspects a sulfur deficiency. An application of 10-15 lb S per acre may be necessary under high yielding alfalfa production systems when organic matter concentration is greater than 3.0%.

Sulfur is mobile in soils, especially sandy soils. When needed, this essential nutrient should be applied each year in early spring. The annual applications of S fit easily with annual applications of phosphate and/or potash.

Table ALF-5. Sulfur suggestions for alfalfa production on sandy soils in Minnesota.

Soil test for S	Sulfur recommendation: S to apply
0-6 ppm	25 (annual) lb/acre
7-12	20-25 (annual)
More than 12	0

Micronutrient guidelines

In Minnesota, boron (B) is the only micronutrient that might be needed in a fertilizer program for alfalfa. Soils in Minnesota contain adequate amounts of copper (Cu), manganese (Mn), iron (Fe), and zinc (Zn) for optimum alfalfa production.

Soils that have either marginal or deficient levels of B are limited to the state's east-central and northeastern regions. A soil test for B is available, but this test is recommended for use only in the two areas just mentioned. The suggestions for use of B fertilizer are listed in Table ALF-6.

When needed, B fertilizers can be top-dressed to established stands. Because of the low rates of B needed, this nutrient should be broadcast with phosphate and/or potash fertilizers for best results.

Boron is also mobile in soils and should be applied each year. This nutrient should not be applied directly to actively growing green tissue because some serious plant injury could occur. Boron fertilizers should never be applied to germinating seed.

Table ALF-6. Boron suggestions for alfalfa production in Minnesota.

B Soil Test	Relative level	Boron to apply
Less than 1.0 ppm	Low	2-4 lb/acre
1.1-5.0 ppm	Adequate	0
More than 5.0 ppm	High	0

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Fertilizing Dry Edible Bean in Minnesota

Daniel E. Kaiser[1] and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

Edible bean production contributes substantially to farming enterprises in Minnesota. The term “edible bean” describes a variety of beans that are grown for human consumption. The guidelines and suggestions in this publication are intended to be used for the production of all edible beans. At this time, there are no data suggesting that one type of edible bean should be fertilized differently than another.

Nitrogen guidelines

Nitrogen (N) fertilizer guidelines can be based either on the results of the soil nitrate test or the consideration of yield goal, previous crop, and soil organic matter content. The soil nitrate test is appropriate for the fine-textured soils of western and northwestern Minnesota. It should not be used for soils that have a sand, loamy sand, or sandy loam texture. When the soil nitrate test is used, the fertilizer N guidelines are calculated below.

The nitrogen guidelines for the situations where the soil nitrate test is not used are listed in Table DEB-2.

Nitrogen management practices should be adjusted according to soil texture. Split applications are suggested for sandy soils (sands, loamy sands, sandy loams). Approximately one-half of the suggested nitrogen should be applied approximately two weeks after planting. The remainder of the amount needed can be applied two weeks later.

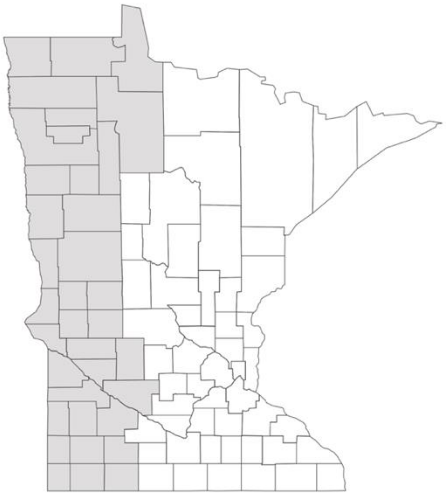

Figure DEB-1. The soil nitrate test should be used for nitrogen guidelines in the counties that are shaded.

Nitrogen fertilizer formula for dry edible bean plantings

Suggested N in lb/acre = [(.05) x YG] - STN(0-24 in.) - N_{PC}

Nitrogen formula variables

YG = yield goal, bu per acre

$STN_{(0\text{-}24\ in.)}$ = nitrate-nitrogen (NO_3^--N) measured to a depth of 2 feet, lb per acre.

N_{PC} = amount of N supplied by the previous crop, lb per acre (see Table DEB-1)

Table DEB-1. Suggested nitrogen credits for various crops that might precede dry edible beans in a crop rotation. Use these credits when the soil nitrate test is used

Previous Crop	First year N credit lb N/acre
Soybean	20
Edible Beans, Field Peas	10
Harvested Sweet Clover	10
Harvested Red Clover	35
Harvested Alfalfa[1] or non-Harvested Sweet Clover	
4-5 plants/ft^2	75
2-3 plants/ft^2	50
1-2 plants/ft^2	25
1 or fewer plants/ft^2	0
Sugar beet	
Yellow leaves at harvest	0
Light-green leaves at harvest	15-30
Dark-green leaves at harvest	60-80

[1]If 3rd or 4th cutting was not harvested, add 20 lb N/acre to the N credits listed.

Table DEB-2. Nitrogen guidelines for dry edible beans in situations when the soil NO_3^--N test is not used based on expected yield of the crop in lb per acre.

Crop grown last year	Organic matter level*	Below 1450 lb/acre	1451-1900 lb/acre	1901-2400 lb/acre	2400-2900 lb/acre	2900+ lb/acre
Alfalfa (4+ plants/ft^2)	Low	0 lb N/acre	0 lb N/acre	0 lb N/acre	0 lb N/acre	0 lb N/acre
Alfalfa (4+ plants/ft^2)	Medium/High	0	0	0	0	0
Alfalfa {2-3 plants/ft^2)	Low	0	0	20	40	60
Alfalfa (2-3 plants/ft^2)	Medium/High	0	0	0	10	30
Soybeans or Alfalfa (1 or less plants/ft^2)	Low	0	20	40	60	80
Soybeans or Alfalfa (1 or less plants/ft^2)	Medium/High	0	0	0	30	50
Edible beans, field peas, harvested sweet clover	Low	20	40	60	80	100
Edible beans, field peas, harvested sweet clover	Medium/High	0	0	30	50	70
Group 1 Crops (see below)	Low	0	0	0	25	45
Group 1 Crops	Medium/High	0	0	0	0	25
Group 2 Crops	Low	40	60	80	100	120
Group 2 Crops	Medium/High	10	30	50	70	90

*Low = less than 3.0%; Medium/High = 3.0% or more
Crops in Group 1: Alsike clover, birdsfoot trefoil, grass/legume hay, grass legume pasture, fallow, red clover.
Crops in Group 2: Alfalfa (0-1 plants/ft.^{2}), barley, buckwheat, canola, corn, flax, grass hay, grass pasture, oat, potato, rye, sorghum-sudan, sugarbeet, sunflower, sweet corn, triticale, vegetables, wheat.

Split applications are not needed if soils are not sandy. The nitrogen needed for these fields can be applied in the fall for western Minnesota, before planting, or as a side-dress treatment. Considering the late date of planting common with edible bean production, a spring pre-plant application followed by incorporation would be preferred. Do not apply any N in contact with the seed at planting.

There is no evidence to suggest that there is a superior source of nitrogen for edible bean production. If applied so as to prevent loss, all nitrogen fertilizers should have an equal effect on yield.

Phosphate and potash guidelines

Current phosphate guidelines are summarized in Table DEB-3. The guidelines for potash use are in Table DEB-4. The guidelines listed in these tables are suggested for either banded or broadcast applications. Do not apply any fertilizer in contact with the seed.

The soil tests are intended to be an index of crop response and not a direct measure of the amount of nutrient in the soil. The phosphorus (P) status of Minnesota soils is determined by using either the Bray or the Olsen analytical procedure. The Bray soil test uses a strong acid to extract P from the soil. In situations where carbonates are present in the soil, the acid in the Bray solution can be neutralized reducing the amount of P extracted and the effectiveness of the test. The Olsen test provides more accurate results if the soil pH is 7.4 or higher as it is not affected by carbonates in the soil. Both tests can be accurately used in situations where high soil pH is not an issue but values obtained from the Olsen tests will be lower for the same soil test classification range since the Bray and Olsen test extract P out of different pools of available P in the soil.

Table DEB-3. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for dry edible bean production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected Yield Bray-P1	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Expected Yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
Below 1401 lb/acre	30 lb/acre	20 lb/acre	15 lb/acre	0 lb/acre	0 lb/acre
1401-1900	35	25	15	0	0
1901-2400	45	30	20	10	0
2401-2900	55	40	25	10	0
2900+	60	45	25	10	0

*Use one of the following equations if a P_20_5 recommendation for a specific yield goal is desired.
P_20_5 Rec = [.0231-.0011 (Bray P, ppm)] (Yield Goal) | P_20_5 Rec = [.0231-.0014 (Olsen P, ppm)] (Yield Goal)

Table DEB-4. Potash fertilizer guidelines (lb of K_2O suggested to apply per acre) for dry edible bean production based on the ammonium acetate potassium (K) test reported in parts per million (ppm).*

Expected Yield	K: 0-40 ppm	K: 40-80 ppm	K: 80-120 ppm	K:120-160 ppm	K: 160+ ppm
Below 1401 lb/acre	35 lb/acre	15 lb/acre	0 lb/acre	0 lb/acre	0 lb/acre
1401-1900	45	15	0	0	0
1901-2400	55	20	0	0	0
2401-2900	65	25	0	0	0
2900+	75	30	0	0	0

* Use the following equation if a K2O recommendation for a specific soil test value and a specific yield goal is desired.
K_2ORec = [.0346-.00042 (K Soil Test, ppm)] (Yield Goal)

Other nutrient needs

Past research with edible beans has indicated that zinc is the only micronutrient that may be needed in a fertilizer program. Zinc suggestions for both starter and broadcast applications are listed in Table DEB-5.

Table DEB-5. Zinc application guidelines (lb/acre) for edible bean production

Zinc soil test	Starter	Broadcast
0.00-0.25 ppm	2 lb/acre	10 lb/acre
0.26-0.50	2	10
0.51-0.75	1	5
0.76-1.00	0	0

* Zinc extracted by the DTPA procedure

There is no research suggesting that other nutrients are needed in a fertilizer program for edible bean production.

CAUTION! Do not apply any fertilizer in contact with the seed at planting.

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Fertilizing Corn in Minnesota

Daniel E. Kaiser[1], Fabian Fernandez[1], Melissa Wilson[1], Jeffrey A. Coulter[2], and Keith Piotrowski [3]

[1]Extension nutrient management specialist [2] Extension corn agronomist [3]Director of Soil Testing Laboratory

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.

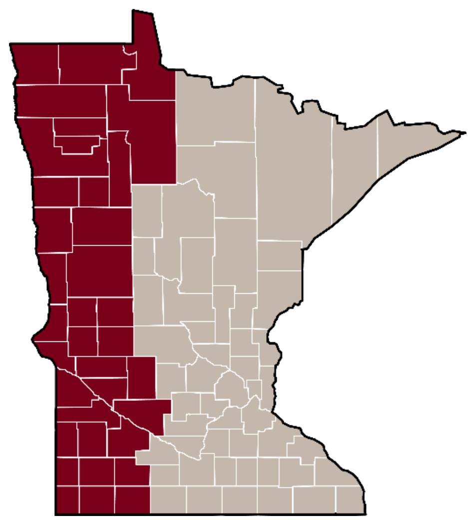

Figure COR-1. Use of the fall pre-plant nitrate test (PPNT) is appropriate in the maroon counties.

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.

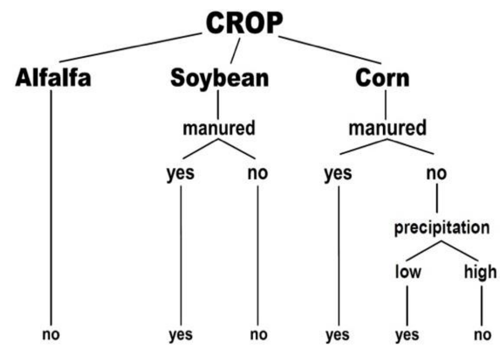

Figure COR-2. Flow chart decision-aid for determining probability of having significant residual nitrate-nitrogen in the soil following specific crop and situations where manure has been applied in a field within two to three cropping years prior to soil sample collection.

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.
$P_2O_{5suggestions}$ = [0.700 - .035 (Bray P ppm)] (expected yield) | $P_2O_{5suggestions}$ = [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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University of Minnesota Extension

Fertilizing Potato in Minnesota

Carl J. Rosen[1], Daniel E. Kaiser[1], and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of the Soil Testing Laboratory

Optimum potato growth depends on many management factors, including a sufficient supply of nutrients. Potatoes have a shallow root system and a relatively high demand for many nutrients (Table PO-1). A comprehensive nutrient management program is essential for maintaining a healthy potato crop, optimizing tuber yield and quality, and minimizing undesirable impacts on the environment.

Irrigated potatoes are usually grown on coarse-textured soils low in organic matter. Typically, these soils are sandy loams or loamy sands, low in native fertility, and quite acid. The crop's high nutrient demand coupled with low native fertility means that potatoes often have high fertilizer requirements. Over the years, however, continued fertilizer applications can build up the soil test levels of certain nutrients. Base your nutrient management program on soil test recommendations, plant tissue testing, variety, time of harvest, yield goal and the previous crop in the rotation.

Table PO-1. Uptake of soil nutrients by potato vines and tubers as a function of tuber yield.

Nutrient	Nutrient uptake from vines	Nutrient uptake tuber yield: 200 cwt/A	Nutrient uptake tuber yield: 300 cwt/A	Nutrient uptake tuber yield: 400 cwt/A	Nutrient uptake tuber yield: 500 cwt/A	Nutrient uptake tuber yield: 600 cwt/A
Nitrogen (N)	90 lb/acre	86 lb/acre	128 lb/acre	171 lb/acre	214 lb/acre	252 lb/acre
Phosphorus (P)	11	12	17	23	28	35
Potassium (K)	75	96	144	192	240	288
Calcium (Ca)	43	3.0	4.4	5.9	7.4	8.9
Magnesium (Mg)	25	5.9	8.9	11.8	14.7	17.6
Sulfur (S)	—	8.8	13.2	17.6	22.0	26.4
Zinc (Zn)	0.11	0.70	0.11	0.14	0.18	0.22
Manganese (Mn)	0.17	0.03	0.04	0.06	0.07	0.08
Iron (Fe)	2.21	0.53	0.79	1.06	1.32	1.58
Copper (Cu)	0.0	0.04	0.06	0.08	0.10	0.12
Boron (B)	0.14	0.03	0.04	0.05	0.06	0.07

Nutrient removal by the potato crop

The amount of nutrients removed by a potato crop is closely related to yield (Table PO-1). Twice the yield will usually result in twice the removal of nutrients. The vines take up a portion of the nutrients needed for production. The rest goes to the tubers and is removed from the field with harvest. The purpose of Table PO-1 is to provide relative uptake of essential elements for potato production. Do not use the table as a basis for fertilizer recommendations.

Soil testing

Fundamental to any effective nutrient management program is a reliable soil analysis and soil test interpretation. Take samples in the top six to eight inches, representative of the area you will fertilize. The soil test will help to determine whether the crop needs lime or nutrients and the rate of application. A typical soil analysis for potatoes should include pH, organic matter, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), and boron (B). Soil nitrate tests are not reliable for nitrogen (N) recommendations on irrigated sandy soils, because nitrate can move rapidly and fluctuate widely. We recommend nitrate testing for the finer textured soils and drier conditions of western Minnesota.

You can test sulfur (S) can on sandy soils if you suspect a problem, although the soil test for S on sandy soils is usually low. Copper (Cu) and manganese (Mn) soil tests are reliable only for organic soils in Minnesota. Iron (Fe) deficiencies are more related to soil pH than to soil test levels. Tissue analysis (see next section) is an alternative method of monitoring the adequacy of Cu, Fe, and Mn. These nutrients are not likely to be limiting on the acid, sandy soils commonly used for potato production, but may be deficient in alkaline soils.

Tissue analysis

You can use plant tissue analysis or tissue testing to: 1) diagnose a nutrient deficiency or toxicity, 2) help predict the need for additional nutrients (primarily nitrogen), and 3) monitor the effectiveness of a fertilizer program. Optimum nutrient ranges provide the basis behind tissue analysis (Table PO-2). If the level of a nutrient falls outside its sufficiency range, then take corrective measures.

Tissue test the petiole (leaf stem and midrib) of the fourth leaf from the shoot tip. Younger or older tissue will have different nutrient concentrations and can lead to erroneous interpretations. For sampling, collect approximately 40 leaves from randomly selected plants. Strip and discard the leaflets. Petioles are then sent to a laboratory for analysis. We base most diagnostic criteria for tissue analysis on a sample taken during the tuber bulking stage. Samples taken too early in the season or soon after a fertilizer application may not accurately reflect the nutritional status of the crop because the roots have not taken up applied fertilizer. In general, tissue analysis should begin about one week after final hilling and at least four days after a fertigation. Nitrogen is an exception to the rule because sufficiency ranges have also been developed for the vegetative and tuber maturation growth stages.

You can use whole leaves for analysis, but you'll need different diagnostic criteria for interpretations. Petioles are generally preferred as the tissue to use for predictive purposes, because they more accurately reflect the immediate nutritional status of the plants and whether they are currently taking up sufficient nutrients. Nutrients are ultimately transported from the petiole to the leaflets and the whole leaf provides a more integrated nutrient status since nutrients tend to accumulate in the leaflets. Therefore, leaves are better indicators of the cumulative nutritional status of plants and whether nutrient uptake has been adequate up to the present. Table PO-2 presents a comparison of nutrient sufficiency ranges for petioles vs. whole leaves. Note that K sufficiency levels are much higher for petioles compared to whole leaves. Also note that we use total N for whole leaves but nitrate-N for petioles. Most N in petioles is in the nitrate form and measurement of nitrate-N is a more straightforward procedure than total N. However, there is much less nitrate-N in leaflets and total N provides a more accurate measurement of N status for whole leaves.

Table PO-2. Suggested nutrient concentration sufficiency ranges in potato tissue collected from the 4th leaf from the top of the shoot during tuber bulking stage (3 growth stages for petiole nitrate-N)

Element	Petiole sampled	Whole leaf (leaflets + petiole) sampled
Total N	—	3.5-4.5%
Vegetative Nitrate-N	1.7-2.2%	—
Tuber bulking Nitrate-N	1.1-1.5%	—
Maturation Nitrate-N	0.6-0.9%	—
Phosphorus	0.22-0.40%	0.25-0.50%
Potassium	8.0-10.0%	4.0-6.0%
Calcium	0.6-1.0%	0.5-0.9%
Magnesium	0.30-0.55%	0.25-0.50%
Sulfur	0.20-0.35%	0.19-0.35%
Zinc	20-40 ppm	20-40 ppm
Boron	20-40 ppm	20-40 ppm
Manganese	30-300 ppm	20-450 ppm
Iron	50-200 ppm	30-150 ppm
Copper	4-20 ppm	5-20 ppm

Rather than sending samples into the lab for nitrate analysis, diagnostic criteria have been developed for nitrate analysis of the petiole sap. This provides a quick procedure to determine the N status of the plant without having to wait for results from a laboratory. Sap nitrate analysis is primarily used for irrigated potatoes because the water status of the plant is more uniform. It provides inconsistent readings in non-irrigated soils because sap nitrate concentrations can fluctuate with the water status of the plant. Table PO-3 provides petiole sap nitrate-N sufficiency ranges for Russet Burbank potatoes at different growth stages. Other potato varieties may differ slightly in their sufficiency ranges, but Table PO-3 is still a suitable starting point for determining the need for additional N.

Table PO-3. Petiole sap nitrate-N sufficiency levels for Russet Burbank potatoes

Time of season	Stage of growth	Sap NO_3^--N
Early	Vegetative/tuberization (June 15-June 30)	1200-1600 ppm
Mid	Tuber growth/bulking (July 1-July 15)	800-1100 ppm
Late	Tuber bulking/maturation (July 15-August 15)	400-700 ppm

Soil pH

One of the more important chemical properties affecting nutrient use is soil pH. Many soils used for potato production have become more acid over time due to use of ammonium fertilizers and leaching of cations from the root zone. Acid conditions are generally better for reducing common scab (*Strepotmyces scabies*), which is most widespread when soil pH is above 5.5. Use of liming amendments is often avoided to minimize scab. Controlling scab in this manner, however, can result in a soil pH that will cause nutrient imbalances. Once soil pH drops below 4.9, nutrient deficiencies and toxicities become more common. In particular, Mn and aluminum (Al) toxicity and P, K, Ca, and Mg deficiencies may occur in these low pH soils. The problem may not be prevalent through the entire field, but may occur in smaller areas where the soil consists of higher sand or lower organic matter content. In some cases, grid sampling a field for pH may be useful to identify areas that need correction. If you need to take corrective measures, lime the soil to a pH of 5.5 during a year in the rotation when potatoes are not grown. We also recommending using scab-resistant varieties to maintain desirable pH range. Irrigation water can be quite alkaline in Minnesota and may also help to slow down soil acidification processes.

Nutrient management suggestions

Potatoes have a relatively shallow root system with most roots located in the top 1.5 to 2 feet of soil. We recommend using banded fertilizer two to three inches below and two to three inches to the side of the tuber at planting to supply all or a portion of immobile nutrients, such as phosphorus and potassium. For most efficient fertilizer use, select a practical yield goal. Reasonable yield goals are usually set at 15-20 percent higher than a grower's average for the past 5 years. For potatoes, yield goal is associated with market class, growth habit (determinate or indeterminate) and the time of the season the vines are killed.

Nitrogen guidelines

Of all the essential elements, N is the one most often limiting for potato growth, particularly on soils with low organic matter. Ensuring adequate N is necessary to achieve high yields, but too much N can also cause problems. Excessive N can reduce both yield and tuber quality and has the potential to leach to groundwater on well-drained sandy soils.

Nitrogen rate

N application rate primarily depends on the cultivar and date of harvest, expected yield goal, amount of soil organic matter and the previous crop. Table PO-4 shows the effects of these factors on N recommendations for irrigated potato production. If using manure, include that in your estimate for meeting the total N recommendation. Irrigation water may contain significant amounts of nitrate-N. Include it as part of the N applied to the crop.

Different potato varieties and differences in harvest date will have a pronounced effect on yields and yield goals. Because of earlier harvest and lower yield, early maturing varieties generally require less N than later maturing varieties. We still use the yield goal concept to guide N recommendations for potatoes, with variety and harvest date, until a more complete measure of the N supplying capacity of the soil is available. Currently N recommendations are also adjusted for the amount of soil organic matter, with higher rates for low organic matter soils than for medium to high organic matter soils, which have a greater capacity to release plant-available N. We base yield goal on the total yield obtained rather than the marketable yield, but the two are generally well-correlated. An overestimation of the yield goal will result in excessive applications of N, which can potentially result in nitrate losses to groundwater.

High rates of N can also affect potato yields and tuber quality. Too high a rate of N will delay tuber initiation and maturity leading to excessive vine growth at the expense of tuber growth. Delayed maturity can result in tubers with lower specific gravity. Excess N can also increase brown center and the incidence of knobby, misshapen, and hollow tubers. High N will induce vigorous foliage, which can lead to an increase in vine rot diseases. On the other hand, lack of N can increase early blight infestations. Controlling early blight with proper use of fungicides will, in some years, reduce the N requirement. In other years, fungicides can increase yield potential. Hence, when blight is under control, the N requirement is the same or higher. Generalizations on foliar disease incidence and N requirement are difficult to make.

Previous crop can also affect N needs. Legumes in a crop rotation can supply significant N to subsequent crops, as shown by the recommendations in Table PO-4. Account for the N supplied by legumes to avoid a build-up of soil N, increase the potential for nitrate leaching and reduce tuber yield and quality.

Table PO-4. Nitrogen recommendations in pounds per acre (lb/acre) for irrigated potato production by previous crop and soil organic matter content (OM).

Yield goal[3] (cwt/acre)	Harvest[4]	Alfalfa[1]: Low[2] OM	Alfalfa Med-High[2] OM	Soybeans, field peas: Low OM	Soybeans, field peas: Med-High OM	Group 1 crop: Low OM	Group 1 crop: Med-High OM	Group 2 crop: Low OM	Group 2 crop: Med-High OM
<250	Early	0 lb/acre	0 lb/acre	80 lb/acre	60 lb/acre	60 lb/acre	40 lb/acre	100 lb/acre	80 lb/acre
250-299	Early	25	0	105	85	85	65	125	105
300-349	Early	50	30	130	110	110	90	150	130
350-399	Mid	75	55	155	135	135	115	175	155
400-449	Mid	100	80	180	160	160	140	200	180
450-499	Late	125	105	205	185	185	165	225	205
500+	Late	150	130	230	210	210	190	250	230

[1]Assumes good stand of alfalfa with 4 or more crowns per sq. ft.
[2]Low = less than 3.1% O.M.; medium to high = 3.1-19% O.M.
[3]Yield in this table refers to total yield, not marketable yield
[4]Early = vines killed or green dug before Aug. 1; Mid = vines killed or green dug Aug. 1-Aug. 31; Late = vines killed or green dug after Sept. 1
Crops in Group 1: Alfalfa (poor stand), Alsike clover, birdsfoot trefoil, grass/legume hay, grass legume pasture, fallow, red clover.
Crops in Group 2: Barley, buckwheat, canola, corn, edible beans, flax, grass hay, grass pasture, millet, mustard, oats, potato, rye, sorghum-sudan, sugar beet, sunflower, sweet corn, triticale, vegetables, wheat.

Application timing

Efficient use of N requires matching N applications with N demands by the crop. Nitrogen applications in the fall are very susceptible to leaching. Nitrogen applied early in the season when plants are not yet established is also susceptible to losses with late spring and early summer rains. Peak N demand and uptake for late season potatoes occurs between 20 and 60 days after emergence. Uptake is highest during the tuber bulking phase. Optimum potato production depends on having an adequate supply of N during this period.

Apply some N at planting for early plant growth. Then, apply the majority of the N in split applications beginning slightly before (by 10 days) the optimum uptake period. This assures that adequate N is available at the time the plants need it. Starter fertilizer should contain no more than 40 lb N/A for full season varieties. Split applications will encourage more N uptake compared to large applications applied before emergence. Incorporate any N applied through the hilling stage to maximize availability of the N to the potato root system.

Plan the majority of N inputs from 10 to 50 days after emergence. Late applications of N can delay maturity and lead to poor skin set. Just as N fertilizer applied too early in the season can potentially lead to nitrate losses, so can N fertilizer applied too late in the season. Nitrogen applied beyond 10 weeks after emergence is rarely beneficial and can lead to nitrate accumulation in the soil at the end of the season. This residual nitrate is then subject to leaching.

For determinate early harvested varieties like Red Norland, higher rates of N in the starter may be beneficial (up to 60 lb N/A). These varieties tend to respond to higher rates of N upfront, but the total amount of N required is generally lower because of early harvest and lower yield potential (Table PO-4). Late application will also tend to delay maturity and reduce yields, particularly if the goal is to sell for an early market. In many cases it is not possible to know when the exact harvest date will be because it depends on market demands and weather conditions during the season. Because of these unknowns it is important to have some flexibility in both rate and timing of N application.

We have seen increases in N use efficiency when some of the N is injected into the irrigation water after hilling (fertigation). Because the root system of the potato is largely confined to the row area during early growth, we do not recommend fertigation until plants are well established and potato roots have begun to explore the furrow area between rows. This is usually about three weeks after emergence. Post-hilling N applications are most beneficial in years with excessive rainfall pre-hilling. Base fertigation timing on petiole nitrate-N levels (Tables PO-2 and PO-3) as discussed in the Tissue analysis section. If you need N, inject 10 to 30 lb N/A per application for mid/late season varieties and up to 20 lb N/A for early season varieties. Application of late-season nitrogen can lead to misshapen tubers in some cultivars.

General guidelines for N application timing for mid/late season varieties are:

- Band starter N at planting
- Apply 1/3 to 1/2 of the recommended N at or around emergence
- If fertigation is not available, apply the remainder of the recommended N at final hilling
- If fertigation is available and final hilling is done 10-14 days after emergence, apply 1/3 of the recommended N at final hilling and fertigate the remainder based on petiole analysis
- If fertigation is available and final hilling is done at emergence, begin fertigating 14-21 days later and apply the remainder of the recommended N based on petiole analysis

General guidelines for N application timing for early season varieties are:

- Band starter N at planting
- Apply 1/3 to 2/3 of the recommended N at or around emergence
- Apply the remainder of the recommended N at final hilling

If fertigation is available, apply any additional N based on petiole analysis and anticipated harvest date.

Sources of N

Each fertilizer N source used for potatoes has advantages and disadvantages, depending on how they are managed. Because leaching rains often occur in the spring, avoid fertilizer sources containing nitrate (ammonium nitrate and urea-ammonium nitrate solutions) at or before planting. Ammonium sulfate, diammonium phosphate, monoammonium phosphate, and poly ammonium phosphate (10-34-0) are the preferred N sources for starter fertilizer. For sidedress applications, use urea, ammonium nitrate, urea-ammonium nitrate solutions, ammonium sulfate, or anhydrous ammonia. Because of its explosive nature, ammonium nitrate is not generally used for potato production in the upper Midwest. Urea-ammonium nitrate solutions are the main sources used for fertigation. Irrigation water may contain elevated nitrate levels and should be taken into account as a fertilizer N input if the nitrate-N concentration is greater than 10 ppm.

Take care not to band high amounts of ammonium fertilizer close to the seed, as ammonia toxicity may result, especially on high pH soils. Urea is the most common N source used for sidedressing. Urea is susceptible to ammonia volatilization if left on the soil surface. Therefore, it must be incorporated or irrigated in within 12 hours after application. Coating urea with a urease inhibitor, such as NBPT or NPPT, reduces the need for immediate incorporation.

Ammonium sulfate also provides sulfur and is the most acidifying N fertilizer. On a nitrogen basis, the cost of ammonium sulfate is double that of urea. However, if sulfur is also needed, then ammonium sulfate is an economical source to use. Anhydrous ammonia may be beneficial in delaying the potential for leaching losses. However, positional availability of the N in relation to the hill may be a problem with sidedress applications. Specialty N sources such as calcium nitrate can be effective, but are many times the cost of urea.

Reductions in nitrate leaching can occur under some conditions with slow-release N sources. Slow-release N sources include polymer coated urea that can be formulated to release N over various time intervals. These slow-release sources can also be applied earlier in the season without the fear of nitrate leaching losses. The main disadvantages of slow-release N fertilizer are delayed release to ammonium and nitrate when soil temperatures are cool and the higher cost of many of the products compared to conventional quick release N fertilizers. However, there are some newer slow-release fertilizers on the market that are more affordable. The cost savings of being able to make a single N fertilizer application is another factor to consider. Minnesota research with ESN, a relatively low cost slow-release N fertilizer, has shown promising results with a single ESN application at emergence compared to quick release urea applied using standard split application practices.

Dicyandiamide (DCD), a nitrification inhibitor, can also slow down the conversion of ammonium to nitrate, but limited research with potatoes has not shown a reduction in nitrate leaching relative to use of urea alone. Nitrapyrin is another nitrification inhibitor, but it is not registered for use on potatoes and should not be used for this crop.

Phosphorus guidelines

Phosphorus is important in enhancing early crop growth and promoting tuber maturity. Minnesota research has also found that P plays an important role in regulating tuber set with higher tuber numbers when P nutrition is high. We recommend banded P applications at planting, because P movement in the soil is limited. Placing P close to the seed piece is especially important early in the season when soil temperatures are cool and root systems are undeveloped. We have not seen benefits to in-season application of P on acid sandy soils in the upper Midwest. Soil pH affects P availability, which is reduced under both acid and alkaline conditions. Availability is highest at slightly acid to near neutral conditions, so the practice of growing potatoes at low pH to reduce scab can limit P uptake if it drops too low (see the Soil pH section).

Experiments conducted over a 6-year period in Minnesota revealed a consistent response to banded P fertilizer applied at rates of 100 to 150 lb P_2O_5/A in lower P testing soils (Bray P less than 25 ppm). We found inconsistent response to P fertilizer in high P testing soils (Bray P greater than 25 ppm). In about 50 percent of the studies, we found a positive response to P on high testing soils. In some cases, the positive response may have been due to low pH (5.3 or less), which tends to tie up P. In the other 50 percent, the P response was not significant. In addition, response to P fertilizer is cultivar dependent with some cultivars especially responsive to P fertilizer, even on very high testing soils. On average, some P fertilizer appears to be necessary for potatoes to reach maximum yields on the sandy soils of central Minnesota. Tuber yields affect P requirements due to greater P uptake with higher yields (Table PO-1). Table PO-5 presents phosphorus fertilizer recommendations for potato based on soil test levels and yield goal. Keep in mind that some cultivars can be highly responsive to P fertilizer even at lower yield goals.

Table PO-5. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for potato production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).[1]

Expected Yield Bray-P1	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21-25 ppm	26-30 ppm	31-50 ppm	51+ ppm
Expected Yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16-18 ppm	19-22 ppm	23-41 ppm	42+ ppm
less than 200 cwt/acre	75 lb/acre	50 lb/acre	25 lb/acre	—	—	—	—	—
200-299 cwt/acre	100	75	50	25	—	—	—	—
300-399 cwt/acre	125	100	75	50	50	50	50	50
400-499 cwt/acre	150	125	100	75	75	75	75	75
500 cwt/acre or more	175	150	125	100	100	100	100	75

[1]For acid irrigated sands, responses up to 150 lb/acre P_2O_5 have been observed on very high (41+ ppm) P soils. Yield in this table refers to total yield, not marketable yield. For most efficient application, apply phosphate fertilizer in a band 2-3 inches below and 2-3 inches to each side of the tuber at planting.

Common granular sources of P fertilizer include monoammonium phosphate or MAP (11-48 to 52-0) and diammonium phosphate or DAP (18-46-0). Research comparing these two P sources on potatoes in Minnesota found no difference between them in yield, although there are potential advantages and disadvantages to each. When MAP dissolves it initially results in an acid reaction in the soil, while DAP results in an alkaline reaction. For this reason MAP is often used on alkaline soils and DAP is often used on acid soils, although crop response to the two is usually similar. At equivalent P fertilizer rates, MAP has a lower N content than DAP. It is often the recommended P source to minimize early season N application on sandy soils vulnerable to nitrate leaching.

Ammonium polyphosphate (10-34-0) is the most commonly used liquid P fertilizer and is suitable for banded application in potatoes. A variety of related liquid products are available and suitable, although they have lower P contents. Orthophosphate P, as found in MAP and DAP, is the form of P taken up by plants. A large proportion of the P in liquid fertilizers is polyphosphate P. This should not be a factor in selecting a P source because polyphosphate is quickly converted to orthophosphate in the soil. The two forms of P have been found to have equal effects in numerous studies.

Potassium guidelines

Potatoes take up significant quantities of K (Table PO-1), a nutrient that plays important roles in tuber yield, size and quality. The plant needs high K to prevent blackspot bruising and shattering and attain good storage quality. However, you may reduce specific gravity if K fertilization is too high because it increases tuber water absorption. In-season K applications have a greater effect on lowering specific gravity than preplant or planting applications. Potassium chloride (0-0-60) can have more of an effect than potassium sulfate (0-0-50) at equivalent K rates. Potassium is a relatively immobile nutrient in medium- and fine-textured soils, but it does leach in sandy soils, particularly when they are acidic and low in organic matter. Excessive Mg fertilization can inhibit K uptake and induce a K deficiency, especially when soil K is low.

Soils tests are very useful in predicting K responsive soils. We base K recommendations for potato on a combination of soil test level and yield goal (Table PO-6). On low K testing soils, which require high K fertilizer application rates, we recommend both broadcast and banded applications. At least half of the K should be broadcast and incorporated before planting and the remainder banded at planting. On higher testing soils you can band all the K at planting. Because of concern over chloride (Cl-) leaching to groundwater, spring application of K is preferred over fall application to minimize leaching of Cl- and to some extent, K.

Table PO-6. Potash recommendations in pounds per acre (lb/acre) for irrigated potato production by yield goal and soil test K level (STK) reported in parts per million.[1]

Expected yield (cwt/acre)	0-40 ppm	41-80 ppm	81-120 ppm	121-160 ppm	161-200 ppm	201+ ppm
less than 200	150	75	50	25	--	--
200-299	200	100	75	50	25	20
300-399	300	200	100	75	50	25
400-499	400	300	200	100	75	50
500 or more	500	400	300	200	100	75

[1]Do not apply more than 200 lb/acre K_2O in the band at planting.

Potassium source generally has no effect on total yield. Potassium chloride is the most economical K source, but it has a high salt index and may cause salt problems if banded at rates higher than 200 lb K2O/A. Potassium sulfate has a lower salt index and may produce slightly higher percentages of large tubers, but is more expensive. It is more competitive if S is also required. Potassium-magnesium sulfate (0-0-22-18S-11Mg) is also more expensive than potassium chloride, but is a good option to supply at least part of the K when both S and Mg are required.

Deficiency symptoms

Symptoms of phosphorus deficiency are stunted growth and a dark green or purpling of the leaves. Potatoes may develop these symptoms in the early spring when soil temperatures are cool. Potassium deficiency symptoms include scorching of the margins of older leaves.

Calcium, Magnesium, and Sulfur Guidelines

Potato production on acid sandy soils low in organic matter may require addition of one or more of the secondary nutrients (Ca, Mg, and S) for optimum tuber yield and quality. However, keep in mind that groundwater and irrigation can contain substantial amounts of Ca, Mg and S and may be able to supply all or part of the requirements of these nutrients, depending on irrigation amounts used. Groundwater concentrations of Ca, Mg and S in Sherburne County in a recent study were 55.8,21.3 and 5.3 ppm, respectively.

Calcium

Calcium deficiency is rare in many agricultural soils, because they have high native Ca levels or are periodically limed to maintain soil pH. Sandy soils, however, do not maintain high Ca reserves. Plus, the practice of growing potatoes at low pH to reduce scab means that they are rarely limed (see the Soil pH section). Under these conditions soil Ca can fall to levels that reduce tuber quality and tuber yield.

Calcium plays an important role in maintaining tuber quality in storage and reducing internal tuber disorders like brown spot and hollow heart. Low Ca in tubers is often due to inadequate transport of Ca to the tuber caused by water or temperature stress. This may be a localized Ca deficiency with adequate Ca levels occurring in leaves and the soil testing high in Ca. We recommend adding Ca on high testing soils only if the potatoes you are storing have had storage problems in the past.

Table PO-7. Calcium recommendations for irrigated potato production.

Calcium soil test	Relative level	Calcium to apply
0-150 ppm	Low	200 lb/acre
151-299 ppm	Medium	100
300+ ppm	High	0

Table PO-7 provides Ca recommendation for potato based on a Ca soil test. Calcium sulfate (gypsum) and calcium nitrate are two Ca sources that can increase tuber calcium concentrations. You can apply gypsum at or before planting. Incorporate calcium nitrate into the hill as a sidedress application after emergence. Calcium nitrate is also the N source in this case, so application rates should not exceed the N requirement. If the recommended Ca rate is high, you may need additional Ca from another source. An additional alternative is to apply low rates of lime during a non-potato year in the rotation. Dolomitic lime will supply both Ca and Mg. Because transport of Ca from other parts of the plant to tubers is poor, be sure to place Ca in the zone of tuber formation. That way tuber or stolon roots can take it up directly from the soil.

Magnesium

Similar to Ca, inadequate Mg can occur on acid sandy soils that are not periodically limed. High rates of K fertilizer, which are often required for potatoes, can also induce Mg deficiencies since K and Mg compete for uptake. Table PO-8 gives Mg recommendations for potato based on a soil test. Magnesium sulfate or potassium-magnesium sulfate are the most common Mg sources available. They can be broadcast and incorporated prior to planting or banded in the row at planting.
As with Ca, another alternative is to apply low rates of lime during a non-potato year in the rotation. An application of 1000 lb dolomite/A will meet both the Mg and Ca recommendations for low testing soils.

Table PO-8. Magnesium recommendations for irrigated potato production (lb/acre).

Magnesium soil test	Relative level	Broadcast
0-49 ppm	Low	100 lb/acre
50-99 ppm	Medium	50
100+ ppm	High	0

Sulfur

On many soils, soil organic matter will be enough to meet S requirements. Rainwater and irrigation water contain some sulfate and can also provide a significant proportion of the S needed for growth. Sulfate readily leaches through sandy soils, so yield reductions from S deficiency are most common on sandy, low organic matter soils. Table PO-9 gives S recommendations for potato based on a soil test. The S soil test is only reliable for sandy soils. Sulfate-S is the form taken up by plants, so ammonium sulfate, potassium sulfate, magnesium sulfate, and calcium sulfate are common sources used to supply S. They can be broadcast and incorporated prior to planting or banded in the row at planting. With ammonium sulfate, be sure to account for the N it contains in meeting the crop N requirement. Elemental S is not an immediately available form. Soil bacteria must oxidize it to sulfate before plants can use it.
The oxidation to sulfate has an acidifying effect on the soil, but the effect is small at the rates required to meet S recommendations.

Table PO-9. Sulfur recommendations for irrigated potato production

Sulfur soil test	Relative level	Broadcast	Row
0-6 ppm	Low	20-30 lb/acre	10-15 lb/acre
7-12 ppm	Medium	trial only	trial only
12.1+ ppm	High	0	0

Micronutrients guidelines

Most soils contain sufficient amounts of zinc (Zn), boron (B), copper (Cu), manganese (Mn), iron (Fe), chlorine (Cl), molybdenum (Mo), and nickel (Ni) to meet plant needs. However, in some areas, micronutrient shortages occur and may limit yields. Calibrated soil tests for mineral soils are only available for Zn (Table PO-10) and B (Table PO-11). Soil tests for Cu and Mn are only reliable for organic soils. You can use tissue analysis to monitor micronutrient status (Table PO-2). Sandy soils are often low in B and Zn and muck or peat soils are often low in Cu and Mn.

A 5-year Minnesota study on irrigated sandy soil found increases in potato yields with B and Zn applications, but not with Mn or Cu applications. In acid soils, Fe, Mn, and Cu should be available in adequate amounts to meet crop needs. Pesticide sprays often contain enough Cu and Zn to meet plant demands for these nutrients. In extremely acid soils (pH less than 4.8), Mn toxicity may be a problem. Tissue Mn levels greater than 1,000 parts per million are often associated with stem streak necrosis. Potato responses to Mo and Cl have not been reported in Minnesota. Little research has been done on Ni, but required amounts are very low and soil deficiency is probably very uncommon.

If soil or tissue tests show the need for a micronutrient, you can use foliar applications during the growing season. However, with B, we recommend soil application because B applied to the foliage is not readily transported to the tuber. Excessive B applications can be toxic. You can band soil-applied micronutrients with the starter fertilizer.

Table PO-10. Boron application recommendations for irrigated potato production.

Boron soil test	Relative level	Boron to apply
0.0-0.4 ppm	Low	1 lb/acre broadcast 0.5 lb/acre banded
0.5-0.9 ppm	Medium	0
1.0+ ppm	High	0

Table PO-11. Zinc application recommendations for irrigated potato production.

Zinc soil test	Relative level	Broadcast	Row
0.0-0.5 ppm	Low	10 lb/acre	2 lb/acre
0.6-1.0 ppm	Medium	5	1
1.1+ ppm	High	0	0

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Fertilizing Soybean in Minnesota

Daniel E. Kaiser[1], Fabian Fernandez[1], Melissa Wilson[1], and Keith Piotrowski[2]
[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

Soybean is an important crop in Minnesota and provides a significant return for many farms. The fertilizer needs of the crop are often neglected while attention is mostly directed at fertilizing other crops in the rotation. Soybean crop yields will decrease when it lacks essential nutrients. Therefore, it's important to develop a profitable fertilizer program to maximize crop yields. This publication covers fertilizer guidelines that are a key component of profitable production.

Nitrogen guidelines

Soybean is a legume, and, if properly inoculated, can use the nitrogen gas (N_2) in the atmosphere for plant growth via fixation in the nodules. The amount of fixation that takes place is related to the amount of nitrate-nitrogen (NO_3^--N) in the soil. In general, the amount of N fixed increases as the amount of NO_3^--N in the soil decreases. When soil NO_3^--N is high, the amount of N fixed in the nodules is small. If soil NO_3^--N is low, N fixation quickly increases to meet the greater N demand.

Manure

Manure is an excellent source of phosphorus (P), potassium (K), all secondary nutrients, and micronutrients. However, producers have been concerned about the effect of N in the manure on nodule development. During the 1990s, research conducted at 10 sites throughout Minnesota evaluated the effect of manure application on soybean production. That research effort produced several conclusions about the use of manure for soybean. The soybean crop removed a greater amount of N when compared to corn, leading to the conclusion that the rate of manure applied should be limited to the amount of N removed by this crop. The results of the study also showed that if manure-N was applied at rates to supply less N than was removed, nodulation quickly resumed in mid-season and the final N removal was similar for both manured and non-manured fields.

The application of manure to soybean fields had a consistent positive effect on grain yield. This management practice also increased vegetative growth, which led to more lodging of some varieties. The increased vegetative growth also provided a more favorable environment for white mold growth and development. The effect of manure on production was the same for several soybean varieties. Therefore, decisions about variety selection should not be changed when manure is used.

In-season N

In recent years, some scientific speculation has questioned the ability of the soybean nodule to supply adequate amounts of N late in the growing season, a situation that could limit soybean yields. This speculation leads to suggestions, by some, for in-season fertilizer N application for the crop. Previously, University of Minnesota research was conducted at many locations throughout the state's soybean growing areas to evaluate the effect of in-season application of various N sources during the growing season on soybean yield. Results of the study were conclusive: In-season application of fertilizer-N had no effect on soybean yield.

The effect of nitrogen fertilizer use on soybean yield at one site is summarized in **Table SOY-1**. Foliar application of nitrogen during the growing season can decrease yields (see **Table SOY-2**). In-season application of fertilizer-N is **not recommended** for soybean production in Minnesota.

Table SOY-1. Soybean yield as affected by nitrogen source, time, and method of application (N rate = 75 lbs per acre)

Nitrogen source	Timing	Method	Yield
None	—	—	52.4 bu/acre
Ammonium sulfate	Pre-plant	Broadcast	54.2
Ammonium sulfate	Early bloom	Broadcast	54.3
Ammonium sulfate	Early bloom	Knife	52.5
Ammonium sulfate	Pod fill	Broadcast	53.2
Urea	Early bloom	Knife	51.5
Urea	Pod fill	Broadcast	52.4

Table SOY-2. Yield of irrigated soybean as affected by time and method of application of urea fertilizer (N rate = 75 lbs/acre)

Timing	Method	Yield
None	—	45.1 bu/acre
Early bloom	Broadcast	42.3
Early bloom	Foliar	42.4
Pod set	Foliar	31.8

N fertilizer in the Red River Valley

Nitrogen fertilizer use for soybean production in the Red River Valley deserves special consideration. Research in the region has shown that use of fertilizer N may increase yields where producers have (1) experienced problems getting good nodulation and (2) the amount of NO_3^--N to a depth of 24 inches is less than 75 lbs/acre. The use of some N in a fertilizer program (50 to 75 lbs/acre) could be beneficial for some soybean fields in the Red River Valley. Soybean growers in northwestern Minnesota are advised to measure carryover NO_3^--N before they decide to apply fertilizer N. In fields where iron deficiency chlorosis occurs, additional N may worsen the problem. In these cases, additional N is not recommended.

Phosphate and potash guidelines

The use of phosphate fertilizer can substantially increase soybean yield if soil test values for phosphorus are in the Low and Very Low ranges. The probability in which P application should increase the yield of soybean and the magnitude of the expected increase in grain yield is shown in Table SOY-3. The probability of a response to P fertilizer in the Low and Very Low ranges has been found to be less for soybean than corn. This difference can be attributed to the prevalence of iron deficiency chlorosis in sites summarized in Table SOY-3, which limited the potential for P fertilizer to increase yield. The reduction in soybean grain yield in the Very Low and Low soil P classes is such that P application is warranted despite the lower probability that a yield response will occur compared to corn. Phosphate fertilizer guidelines for soybean production are listed in Table SOY-4. The guidelines for potash use are listed in Table SOY-5.

Table SOY-3. Soybean grain yield response to applied P fertilizer based on soil test category

Bray-P1 or Olsen soil test P category	Probability P fertilizer will increase soybean grain yield	Expected yield without P fertilizer
Very Low	40%	90%
Low	49%	91%
Medium	23%	98%
High	23%	99%
Very High	15%	99%

Table SOY-4. Phosphate fertilizer guidelines (lbs of P_2O_5 suggested to apply per acre) for soybean production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm)

Expected Yield Bray-P1	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Expected Yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
less than 30 bu/acre	50 lbs/acre	30 lbs/acre	10 lbs/acre	0 lbs/acre	0 lbs/acre
30-39	60	40	15	0	0
40-49	70	50	20	0	0
50-59	80	60	25	0	0
60-69	90	70	30	0	0
70+	100	80	35	0	0

*Use the following equations to calculate phosphate fertilizer guidelines for specific yield and specific soil test values for P:

$P_2O_{5\ \text{Recommended}}$ = [1.752 - (0.0991) (Bray P, ppm)](Yield Goal)

$P_2O_{5\ \text{Recommended}}$ = [1.752 - (0.1321) (Olsen P, ppm)](Yield Goal)

No phosphate fertilizer is recommended if the soil test for P is greater than 10 ppm (Bray) or 7 ppm (Olsen).

Table SOY-5. Potash recommendations in pounds per acre (lbs/acre) for soybean production by yield goal and soil test K level (STK) reported in parts per million[1]

Expected yield (bu/acre)	0-50 ppm	51-100 ppm	101-150 ppm	151-200 ppm	200+ ppm
< 30 (bu/acre)	55 lbs/acre	35 lbs/acre	20 lbs/acre	15 lbs/acre	0 lbs/acre
30-39	65	50	30	20	0
40-49	80	60	40	25	0
50-59	100	75	50	30	0
60-69	110	85	60	35	0
70+	120	95	70	40	0

*Use the following equation to calculate potash fertilizer guidelines for specific yield goals and specific soil test values for K:

$K_2O_{\text{Recommended}}$ = [2.0 - (0.0088) (K Soil Test, ppm)](Yield Goal)

The recommended rates of phosphate and potash are not adjusted for placement. A summary of research in Minnesota and neighboring states leads to the conclusion that neither banded nor broadcast placement is consistently superior if adequate rates of phosphate and/or potash are applied. If moisture is adequate, soybean yields have usually been slightly higher if the recommended rates of phosphate and/or potash are broadcast and incorporated before planting.

Air seeding and fertilizing

The use of air seeders for planting soybean is increasing in popularity. There are several options for placement of seed and fertilizer with this seeding method. One option involves mixing fertilizer and soybean seed in the same band. The soybean seed is very sensitive to salt injury. Therefore, placement of fertilizer in contact with soybean seed is a risky practice. Results of trials have shown that placement of any fertilizer in contact with the seed when both are in a narrow band reduces stand establishment. Any method of application that places at least one inch of soil between fertilizer and seed is satisfactory.

No-till planting

No-till planting of soybean raises special questions with respect to phosphate and potash fertilization. Phosphorus and potassium are not mobile in soils. Therefore, broadcast applications in no-till systems can be questioned. A substitute would be to band phosphate and/or potash fertilizers below the soil surface, then plant on top of the band. Results of research conducted at the West-Central Research and Outreach Center in Morris show that yield responses to phosphate fertilization in no-till production systems are the same for both banded and broadcast applications. The fertilizer incorporation that takes place in the planting operation seems to be adequate in many no-till planting systems.

Removal-based management of P and K

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. Average removal of P and K for corn is listed in Table SOY-6.

Table SOY-6. Expected removal of phosphate and potash in harvested corn grain at 13% moisture

Fertilizer source	Median	Range
Phosphate (P_2O_5)	0.69 (lbs/bushel)	0.62 to 0.74 (lbs/bushel)
Potash (K_2O)	1.10	1.04 to 1.15

High rates of P or K applied for maintenance will commonly result in a lower 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.** It has not been shown that the build-and-maintain method is superior to the sufficiency approach for P and K management.

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 of thumb is that 16-18 lbs P_2O_5 and 7-10 lbs K_2O are required to increase the Bray-P1 or ammonium acetate K tests by 1 ppm, respectively. However, the exact amount of P or K needed to build the soil test greatly depends on soil chemical properties.

The rates of fertilizer suggested in Tables SOY-4 and SOY-5 should slowly build soils to the medium category beyond which removal rates of P or K can be used to maintain or slowly build soil test values to near critical soil test values.

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 recommended.

Excessive building of P increases the risk for P loss to the environment. The maintenance-based strategy for P application is outlined in Table SOY-7 indicated the STP range which is optimal for crop removal-based maintenance is within the Medium to High STP categories. This strategy suggests drawing STP down using P application based on partial crop removal in order to maintain STP in a more profitable, optimal 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. The example in Table SOY-7 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.

Table SOY-7. Example P fertilizer guidelines 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 4
10-20 ppm	100% crop removal
20-30 ppm	25-50% crop removal
30-40 ppm	0-20% crop removal
40+ ppm	No fertilizer P recommended

Yield data collected from combines equipped with yield monitors makes it easy to calculate nutrient removal by the crop on a yearly basis. Using the previous years' yield map to generate a P or K application map is not recommended due to potential high cost of fertilizer P and K, low probability of a profitable return on investment in Medium and High P testing soils, and general uncertainty as to the exact removal of nutrients per bushel of corn produced.

A long-term average yield should be used in these circumstances. Recent long-term research has shown that P and K will build over time in the top six inches of soil when exact removal of the nutrients was applied.

Soil tests will decrease over time when no fertilizer is applied. Research in Minnesota has shown that soil test levels for phosphorus and potassium do not decrease rapidly if no fertilizer is applied. Long-term trends indicate the Bray-P1 test will decrease by 1-2 ppm per year.

It is possible that soil test decreases can be greater due to extremely high starting P or K levels or due to some environmental factors. Having multiple sampling in the same area of a field over time is important when evaluating trends in soil test values over time.

P and K application timing

Timing of the phosphate application can be an important consideration when fertilizing soybean. Many farmers who wish to save on fertilizer application costs apply P or K for the soybean crop ahead of a preceding crop.

While it is okay to apply P or K directly ahead of the soybean crop, research has demonstrated that soybean is less sensitive to application timing within a two-year cropping system and will provide maximum yield as long at the rate of P or K applied to the preceding crop is sufficient for both crops in the rotation. An exception is situations where P can be quickly tied up. Soybean grown on soils with a pH of 8.0 or greater is more likely to respond to an application of P directly ahead of the soybean crop.

If phosphate is recommended and applied to soybean for fields having a pH of 7.4 or higher, the fertilizer should be applied in the spring before planting. This practice will reduce the time interval for contact between soil and fertilizer. This reduces tie-up of phosphorus and the soybean plant will make more efficient use of the applied phosphate.

For more acidic soils (pH <7.4) the timing of P application is less important for soybean and more important for corn. Application of P ahead of corn for a two-year corn-soybean rotation can be effective at maintaining high yield levels for both crops as long as the correct amount of fertilizer is applied.

Timing of K application and the Impact of chloride on soybean production

Potassium fertilizer is commonly applied as potassium chloride (KCl), which contains roughly 50% Cl- by weight. High levels of chloride in the soil are known to reduce soybean grain yield in the southern United States.

Recent research has shown a tendency to build chloride in some Minnesota soils, which can potentially reduce soybean grain yield. The potential for yield reductions due to Cl- is tied to seasonal rainfall with a reduced impact occurring in years with above-normal rainfall.

Soybean varieties can vary in tolerance to high Cl- in the soil but little is known about Cl- tolerance of northern soybean varieties. Research in Minnesota has found that soybean grain yield tends to be higher when KCl fertilizer is applied ahead of corn in areas of western Minnesota.

No long-term impact of K application timing in the rotation in central and eastern Minnesota has been found. However, small reductions in yield have been found in most areas of Minnesota on irrigated and non-irrigated soil when greater than 100 lbs of KCl were applied directly to the soybean crop.

If K is needed for soybean production particularly on soils where Cl- can build, no more than 100 lbs of KCl fertilizer should be applied per acre in the fall or spring directly ahead of the soybean crop, with the remainder of fertilizer applied ahead of a rotational crop like corn or hard red spring wheat.

Impact of cation exchange on soybean K guidelines

Potassium fertilizer guidelines for soybean were revised based on recent research on medium- and fine-textured soils in Minnesota. Currently, these guideline rates are not adjusted based on a soil's 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 the economic return on fertilizer costs. Research in Minnesota is ongoing 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 the K leaching potential and a lower critical level of low CEC soils, building soil test K greater than 120 ppm is not recommended. 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 soybean grown on low CEC sandy soils.

$$\mathbf{K_2O_{\text{Recommended}} = [2.0 - 0.0146\ (\text{Soil Test K, ppm})]\ (\text{expected yield})}$$

Sulfur guidelines

Several research studies have evaluated the use of sulfur (S) for soybean in Minnesota. Soybean may respond to sulfur application by increasing plant growth but yields were almost never increased and in some circumstances were decreased. Sulfur is only suggested under the following circumstances:

- Fields with a history of reduced yield for crops susceptible to deficiency such as alfalfa and corn, soil organic matter in the top six inches is 2.0% or less, and no or very low rates of sulfur were previously applied on the field for many years.
- Irrigated and very sandy soils where the amount of sulfate applied through the irrigation water is low.

Under these limited circumstances, an application of 10-15 lbs of S as sulfate may be warranted. In most cases, sulfate sulfur carried over from a previous application or mineralized from the soil will be enough for achieving maximum yield.

Application of sulfur in excess of soybean needs has been shown to increase sulfur containing amino acids cysteine and methionine but has not been shown to increase total protein concentration unless soybean grain yield is impacted by a deficiency of sulfur.

Iron deficiency chlorosis

Frequently, soybean grown on fields with a pH of 7.4 or greater turn yellow, and, in some cases, die. This condition is described as iron deficiency chlorosis (IDC). There is no deficiency or shortage of iron in the soil. Because of soil and/or environmental conditions, the soybean plant is not able to absorb or take up the amount of iron that is needed for normal growth and development.

There is no easy solution to the iron chlorosis problem. There are several management practices that can be used to reduce the severity.

Careful variety selection is of major importance. The University of Minnesota's Soybean Field Crop Variety Trials (varietytrials.umn.edu/soybean) have chlorosis scores for many varieties. Many of the companies that market soybean seed also provide chlorosis scores for their varieties.

Damage can be reduced if stress on the soybean plant is at a minimum. There are several factors that can stress soybean plants.

Some that are easy to identify are:

- use of some post-emergence herbicides,
- soils with a high "salt" content,
- root damage from excessively deep cultivation,
- soil compaction, and
- seedling diseases.

It is important to eliminate or manage, as much as possible, the factors that place stress on the soybean plant. In addition, nitrate carried over from previous crops has been found to increase the presence of chlorosis, especially in less tolerant varieties.

Current research has shown that application of EDDHA-Fe chelates that contain most of the chelate in the ortho-ortho form may increase yields with an application of 1-3 lbs of active ingredient per acre directly on the soybean seed at planting. Additionally, an oat companion crop seeded prior to planting at a rate of 1.5 bushels per acre and killed at 10 inches height has been shown to benefit soybean by reducing IDC for severely affected field areas.

It is recommended that growers in IDC-affected areas: 1) plant a tolerant variety, and 2) consider using either or both in-furrow EDDHA-Fe and an oat companion crop. More information on this topic can be found at: Managing Iron Deficiency Chlorosis in Soybean (z.umn.edu/SoyIDC).

Other possible nutrient needs

Research has shown a link between glyphosate-tolerant soybean and possible deficiencies of manganese and other micronutrients. Research trials conducted at several locations in Minnesota have shown that the soybean crop does not respond to the application of magnesium, zinc, or copper. Therefore, additions of these nutrients to a fertilizer program are not recommended.

Boron

In recent years, plant tissue analysis has been used to identify hidden nutrient deficiencies and help decide whether to apply in-season foliar nutrients. One nutrient consistently noted as potentially deficient in crops is boron (B). Soybean has a low tolerance to boron application and toxicity symptoms can show up with broadcast application rates as low as two lbs B per acre. Research has not shown a positive benefit to boron applied to soybean. In fact, boron is more likely to reduce yield in soybean if application rates are too high.

Manganese

Soybean has been shown to respond to manganese (Mn) application in some areas of the U.S. where soils have been traditionally low in Mn. In Minnesota, research has not demonstrated a widespread need for Mn application. Recent data has indicated that soybean may respond to Mn when grown on soils with a pH greater than 7.4 and a DTPA soil Mn test, from a 0-6" soil depth, of 10 ppm or less. In these cases, an application of 10 lbs Mn broadcast per acre may be warranted. Foliar application of Mn has not been tested and should be done on a trial basis. Research on more acidic soils with DTPA Mn soil tests of 10 ppm or less did not show a consistent benefit to Mn application to soybean.

Additional information about nutrient management in all crops can be found in the related publications listed below.

Additional resources

- University of Minnesota nutrient management (z.umn.edu/NutrientMGMT)
- Soybean nutrient calculator (z.umn.edu/SoyCalculator)
- Managing Iron Deficiency Chlorosis in Soybean (z.umn.edu/SoyIDC)
- Soybean Field Crop Variety Trials (varietytrials.umn.edu/soybean)
- University of Minnesota manure management (z.umn.edu/ManureApplication)
- Guidelines for manure application rates (z.umn.edu/ManureRates)

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Fertilizing Sugarbeet in Minnesota

Daniel E. Kaiser[1], Lindsay Pease[1], John A. Lamb[1], and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of the Soil Testing Laboratory

The three grower-owned cooperatives in Minnesota and North Dakota vary in their payment programs. Some programs pay strictly on net sucrose quality, determined by sugarbeet root quantity and quality. Others incentivize higher quality sugarbeet roots. In both cases we determine quality by the concentration of sucrose and impurities in the root that need to be separated during the refining process. Optimum sugarbeet production in Minnesota and North Dakota relies on a sound soil fertility program to enhance sugarbeet quality.

Nitrogen guidelines

Nitrogen is the most important nutrient when planning a fertilizer program for sugarbeet production. Nitrogen status of the plant affects early growth and the quality of the sugarbeet at harvest. Early canopy closure allows the sugarbeet to make better use of sunlight and produce more sugar. Excess nitrogen at or near the end of the growing season reduces sugarbeet quality, increases impurities, and reduces sucrose concentration. The highest quality sugarbeet will have nitrogen deficiency late in the growing season (about six weeks before harvest). The nitrogen fertilizer guideline will depend on the growing location.

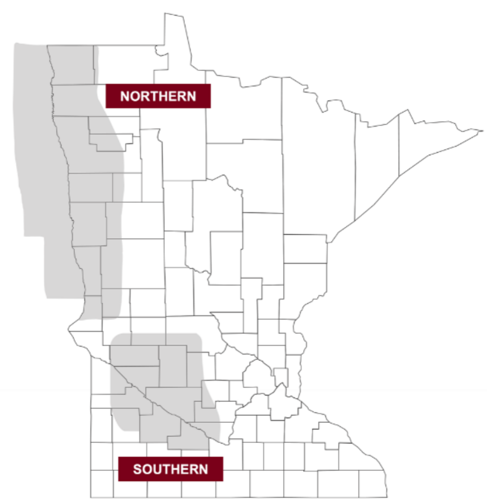

Figure SB-1. Sugarbeet growing regions in Minnesota.

Nitrogen Guidelines for Minn-Dak and American Crystal Northern growing regions

130 lb. N per acre – NO_3^--N in a 4 ft. soil sample

For a 2-foot soil sample: Target a rate of 100 pounds of total known available N per acre for the Minn-Dak and American Crystal growing regions.

Nitrogen Guidelines for Southern Minnesota Beet Sugar Cooperative

110-150 lb. N per acre – NO_3^--N in a 4 ft. soil sample, accounting for soil organic matter

For a 2-foot soil sample: Target a rate of 80-120 pounds of total known available N per acre for the Southern Minnesota Beet Sugar Cooperative growing region.

Soil testing for nitrate

The amount of nitrogen fertilizer application to a sugarbeet crop should be based on the total N recommendation minus the nitrate-N (NO_3^--N) from a soil test. The time of year at which the sample is taken is important. A soil sample for soil NO_3^--N should be taken when the soil temperature at a 6-inch depth has consistently dropped below 50 degrees Fahrenheit. Earlier sampling times will result in an inaccurate soil test value. The depth to which to take the required soil test depends on the previous history of nitrogen management. It is recommended to take a soil sample to a depth of 4 feet if little knowledge exists on levels of NO_3^--N below 2 feet. Research has indicated that soil samples for NO_3^--N should be taken from areas of 20 acres in size or less that are similar in landscape, soil type, or previous management.

Source of nitrogen

Field research shows that the source of the fertilizer does not matter if the source is applied in a way that will reduce loss. Nitrate fertilizer sources such as urea ammonium nitrate (28% or 32%) should not be applied in fall.

Split applications of nitrogen may improve fertilizer use efficiency for sugarbeets grown on sandy soils. Make sure your last application takes place before July 1. For soils that are not sandy, there is no need to split apply. Split nitrogen applications have not been shown to impact sugarbeet quality on medium- or fine-textured soils.

Sugarbeet stand loss following urea application

Current research has demonstrated that sugarbeet stand is reduced when urea is applied in spring. However, sugarbeet root size increased with the reduction in stand. The result was no loss in root yield. Fall application of urea did reduce the risk for stand loss. Nevertheless, root yield and recoverable sucrose were not affected by timing of urea application. The reduced stand loss from spring application is not expected to reduce yield. Fall urea application is not considered a better practice than application in spring.

Previous crop and rotation management

Nitrogen guidelines must be modified based on crop rotation and previous input management. The soil nitrate test is not accurate in situations where the previous crop is a legume (such as alfalfa) or manure applications have been made. It is strongly recommended not to grow sugarbeets following alfalfa or where manure has been applied the previous year because of the increase in nitrogen mineralized from organic N sources during the growing season can reduce sucrose concentration and recoverable sugar.

If a grower must use manure in the rotation, then it must be managed to take credit for the nitrogen mineralization that occurs from the manure. For more information on manure management, see our guidelines for manure application rates (z.umn.edu/ManureRates). This publication discusses nitrogen credits from different types and application methods of manure. The grower also must recognize the variability in the rate of nitrogen mineralization from the manure.

In the past it has been recommended not to grow sugarbeet after soybean but recent research in Southern Minnesota and Northwestern Minnesota indicate that if the diseases such as rhizoctonia can be controlled, a good sugarbeet crop can be grown following soybean. Research from the Southern Minnesota area indicates growing sugarbeet after corn resulted in the least extractable sucrose per acre in two of three years. Sugarbeet grown after spring wheat resulted in the greatest extractable sucrose. Intermediate results were found when growing sugarbeet after soybean. The previous crop did not affect the optimum N application.

Phosphorus guidelines

The sugarbeet plant uses phosphorus for energy compounds. Phosphorus increases root yields in soils that are low in phosphorus while not affecting quality. Since phosphorus is relatively immobile in the soil, recommendations are based on a soil sample to a depth of 6 to 8 inches. The phosphorus soil test does not measure the chemical form utilized by the plant as is the case with the nitrate test. The P soil test is only an index correlated to the crop response to P fertilizers in field trials.

The availability index (soil test) used for recommendations is dependent on the soil's pH. If the pH is less than 7.4, use a Bray P1 soil test. When the pH is 7.4 or greater, use the Olsen P soil test. Currently, the University of Minnesota and North Dakota State University do not support the Mehlich III soil test. The recommendations suggested in Table SB-1 are based on broadcast applications of P fertilizer in fall or spring.

Table SB-1. Phosphate application guidelines (in lb. of P_2O_5 per acre) for sugarbeet production based on soil test results in parts per million.

Rate to apply based on the Bray-P1 test	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Rate to apply based on the Olsen P test	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
P_2O_5 rate to apply	80 lb./acre	55 lb./acre	35 lb./acre	10 lb./acre	0 lb./acre

P fertilizer placement

Research at the University of Minnesota's Northwest Research and Outreach Center indicates that the use of a starter placement of fertilizer phosphorus with the sugarbeet seed is more efficient than a broadcast application (see Figure SB-2). Phosphate application rates can be reduced up to one-half of the broadcast application rates and still produce similar yields.

Greenhouse work in Minnesota and Nebraska indicates that early sugarbeet growth is enhanced with starter placement of phosphorus, but there is a difference in the placement of the starter band. Placement with the seed or two inches below the seed was superior to the more conventional placement of 2 inches to the side and 2 inches below the seed. If you choose to use the seed placement option, be cautious with how much you apply. **APPLYING GREATER THAN FIVE POUNDS PER ACRE OF N + K_2O IN CONTACT WITH THE SEED CAN REDUCE PLANT STAND EMERGENCE.** The amount of P in contact with the seed has not been detrimental to plant stands. The occurrence of stand reduction increases with decreasing soil moisture condition at the time of planting.

The source of starter fertilizer is not a factor in getting a yield response. Dry and liquid starter fertilizer sources will perform similarly. The only difference is the amount that can be applied in contact with the sugarbeet seed. Common phosphorus fertilizer sources that can be used and their maximum recommended application amounts are listed in Table SB-2.

Figure SB-2. The effect of broadcast phosphate fertilizer with and without 3 gallons of 10-34-0 starter fertilizer.

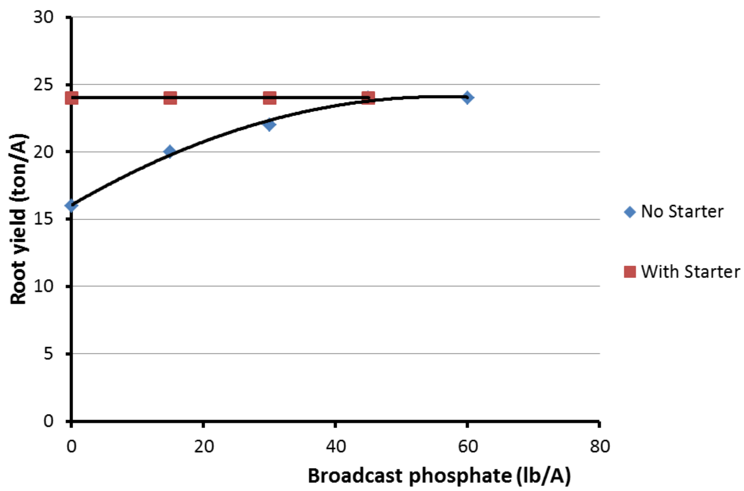

Table SB-2. Common starter phosphorus fertilizer sources and maximum amounts suggested for seed application.

Source	Name	Dry or liquid	Maximum amount to apply	Phosphate supplied
10-34-0	Ammonium polyphosphate	Liquid	4 gal/acre	16 lb./acre
18-46-0	Diammonium phosphate	Dry	28 lb./acre	13 lb./acre
11-52-0	Monoammonium phosphate	Dry	45 lb./acre	24 lb./acre
0-44-0	Triple super phosphate	Dry	No limit	N/A

Potassium guidelines

Potassium is essential to sugarbeet production and is not mobile in the soil. The soil test is based on an ammonium acetate extraction on a surface soil sample that is 6 to 8 inches deep (see Table SB-3). If the soil test is in the responsive range, placement can be similar to phosphorus except extreme caution should be exercised when placing in contact with the seed. Potassium is not a large concern in Minnesota because most of the soils where sugarbeet is grown are natively high in potassium. At this time, the use of a starter fertilizer with potassium is not recommended because there is little research on the effect these sources have on sugarbeet growth and only a small amount of the sugarbeet growing areas need potassium fertilization.

Table SB-3. Potash guidelines for sugarbeet production.

Ammonium Acetate soil test	K: 0-40 ppm	K: 40-80 ppm	K: 80-120 ppm	K:120-160 ppm	K: 160+ ppm
K_2O to apply	110 lb./acre	80 lb./acre	50 lb./acre	15 lb./acre	0 lb./acre

Other nutrients

Research has not demonstrated a widespread need for secondary macronutrients and micronutrients for sugarbeet production. Sulfur application has not been shown to increase root yield or effect recoverable sucrose on heavy textured soils with high organic matter. A response to sulfur is possible on sandy soils with soil organic matter concentrations of 2-3% or less. Research has not identified an optimal rate of sulfur to apply for sugarbeet grown on sandy soils. Applications of 10-25 pounds of sulfate sulfur can be made on a trial basis if a sulfur deficiency is suspected.

Boron (B) and manganese (Mn) are typically micronutrients of interest for sugarbeet production. Recent research in the southern growing region demonstrated the potential to reduce sugarbeet root yield with boron rates exceeding 3 pounds per acre. If a boron deficiency is suspected an application of boron can be made at a rate of 1 to 2 pounds of boron per acre as a pre-plant broadcast application or 0.15 to 0.25 pounds per acre as a foliar before mid-June. There currently is no calibrated soil test to determine where a response to boron may occur. Research on alfalfa has shown boron deficiencies are more likely on sandy soil with low organic matter concentrations when soil conditions are dry. If dry soils limit boron uptake, application of the nutrient may still not affect plant growth or yield even though boron concentration in leaf tissue is considered low.

Sugarbeet response to manganese has not been widely studied for sugarbeet in Minnesota and North Dakota. High pH soils can reduce the availability of manganese in the soil but research has seldom shown a benefit to manganese application in crops prone to a manganese deficiency. Treatment with fungicides for Cercospora leaf spot control may contain manganese, copper, and zinc which eliminates the need to apply separate applications of these nutrients for sugarbeet.

Deficiencies of magnesium, calcium, or sodium are not expected in the Minnesota and North Dakota sugarbeet growing areas.

Nutrient concerns for crops following sugarbeet

Work from North Dakota State University and the University of Minnesota's Northwest Research and Outreach Center indicate that nitrogen credits should be given for nitrogen in the sugarbeet tops for crops such as small grains and corn grown after the sugarbeet crop in rotation. If sugarbeet top growth is lush and green, the credit could be as great as 70 pounds N per acre. Research in southern Minnesota has not confirmed the N credit of sugarbeet tops for corn production following sugarbeet in the rotation.

If you are growing corn following sugarbeet in the rotation, you should consider using a starter application of 40 pounds phosphate per acre. If the EDTA zinc soil test is low, also include two pounds of zinc in the starter.

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Fertilizing Sweet Corn in Minnesota

Daniel E. Kaiser[1], Carl J. Rosen[1], and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

Sweet corn is an important processing crop grown in Minnesota and ranks 2nd in acreage for processing in the US. While acreage of sweet corn is less than dent corn in the state, fertilizer guidelines for sweet corn differ and therefore suggestions for dent corn should not be used.

Lime needs

Managing soil pH can be important for crops to ensure high availability of some nutrients. Lime is suggested for sweet corn in situations where soil water pH in the top six inches is less than 6.0. Lime suggestions are based on the location where the crop will be grown in the state and a buffer pH values. Specific suggestions for raising pH to 6.0 in Minnesota are summarized in the publication Lime Needs in Minnesota (chapter LN-1).

Nitrogen guidelines

Table SWC-1. Nitrogen recommendations in pounds per acre (lb/acre) for sweet corn by previous crop and soil organic matter content (OM).

Crop grown last year	Organic matter level*	Yield Goal: Less than 6 tons/acre	Yield Goal: 6-7 tons/acre	Yield Goal: 8-9 tons/acre	Yield Goal: 10+ tons/acre
Alfalfa (4+ plants/ft^2)	Low	10 lb N/acre	30 lb N/acre	50 lb N/acre	70 lb N/acre
Alfalfa (4+ plants/ft^2)	Medium/High	0	0	40	60
Soybeans or field peas	Low	100	120	140	160
Soybeans or field peas	Medium/High	70	90	110	130
Group 1 Crops	Low	90	110	130	150
Group 1 Crops	Medium/High	60	80	100	120
Group 2 Crops	Low	130	150	170	190
Group 2 Crops	Medium/High	100	120	150	160
Organic soil**		20	50	70	70

*Low = less than 3.0%; Medium/High = 3.0% or more
**Organic soil = more than 19% O.M.
Crops in Group 1: Alsike clover, birdsfoot trefoil, grass/legume hay, grass legume pasture, fallow, red clover.
Crops in Group 2: Alfalfa (0-1 plants/ft.^{2}), barley, buckwheat, canola, corn, flax, grass hay, grass pasture, oat, potato, rye, sorghum-sudan, sugarbeet, sunflower, sweet corn, triticale, vegetables, wheat.

Nitrogen is one of the most limiting nutrients for sweet corn production. Current nitrogen guidelines are based on the crop grown the previous year, soil organic matter level and the expected yield of the sweet corn crop grown. Nitrogen guidelines are summarized in Table SWC-1. Nitrogen can be applied as a single application in most situations in Minnesota where sweet corn is grown on Medium or Fine textured soils. For irrigated sandy soils, split N applications are recommended with 10-20 lb N per acre applied as a starter at or just before planting and the remainder of the suggested N applied in one or two split applications at the 4-6 leaf stage and the 10-12 leaf stage.

A soil nitrate test is available for sweet corn and can be taken in fall for areas west of highway 71 and in the spring before fertilizer application for central and southeastern Minnesota. The soil nitrate test is only calibrated for soil samples collected at a two-foot sampling depth. The amount of nitrate measured in the two-foot sample can be subtracted from the amount of N in Table SWC-2.

Because sweet corn is harvested earlier in the season and at an immature stare relative to dent corn, about one half of the nitrogen taken up is still in the stover, which also has a low carbon to nitrogen ratio. Use of a cover crop such as oats or winter rye is suggested to reduce nitrogen losses following harvest.

Table SWC-2. Nitrogen suggestions for sweet corn when a two-foot soil nitrate samples is used*

Expected Yield	Soil Nitrate N plus Fertilizer N
Less than 6 tons/acre	70 lb N/acre
6-7	130
8-9	165
10 or more	200

Phosphate and potash guidelines

Phosphate guidelines are summarized in Table SWC-2. Potash guidelines are summarized in Table SWC-3. Suggestions for phosphate and potash are adjusted based on how the nutrients are applied. It is suggested that rates of both nutrients can be reduced with band applications. Rate reductions with banded application are at the discretion of the grower. Past data suggests that rate reductions are greater for Very Low and Low soil tests.

Table SWC-3. Broadcast and band phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for sweet corn production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected yield Bray-P1 test	Broadcast/Row	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Expected yield Olsen test	Broadcast/Row	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
Less than 6 tons/acre	Broadcast	70 lb/acre	40 lb/acre	30 lb/acre	10 lb/acre	0 lb/acre
Less than 6	Band	40	25	20	10-15	10-15
6-7	Broadcast	80	50	30	10	0
6-7	Band	40	30	20	10-15	10-15
8-9	Broadcast	90	60	40	10	0
8-9	Band	40	35	25	10-15	10-15
10 or more	Broadcast	100	70	40	20	0
10 or more	Band	40	40	25	10-15	10-15

*Use one of the following equations if a broadcast phosphate guideline for a specific soil test and a specific expected yield is desired:
P_2O_5rec = [11.98 - (0.5627) (Bray P, ppm)] (Expected Yield)
P_2O_5rec = [11.63 - (0.7034) (Olsen P, ppm)] (Expected Yield)

Table SWC-4: Potassium recommendations (lb K_2O per acre) for sweet corn production based on K soil test results.

Expected yield (tons/acre)	Broadcast/Row	0-40 ppm	41-80 ppm	81-120 ppm	121-160 ppm	161+ ppm
Less than 6 tons/acre	Broadcast	120 lb/acre	60 lb/acre	40 lb/acre	40 lb/acre	0 lb/acre
Less than 6	Band	40	30	10-15	10-15	10-15
6-7	Broadcast	140	80	40	40	0
6-7	Band	40	30	10-15	10-15	10-15
8-9	Broadcast	160	100	60	40	0
8-9	Band	40	40	25	10-15	10-15
10 or more	Broadcast	180	120	80	60	0
10 or more	Band	40	40	30	25	10-15

*Use the following equation if a broadcast potash guideline for a specific soil test and a specific expected yield is desired.
K_2O rec = [20.21 - (0.1133) (Soil Test K, ppm)] (Expected Yield)

Using a banded fertilizer with the planter

The use of a banded fertilizer applied 2” below and to the side of the seed at planting is sometimes used to boost early season growth. Banding fertilizer directly on the seed can present a significant risk for reducing plant emergence. The rate of fertilizer that can be applied in a band directly on the seed at planting (popup) varies by fertilizer source and soil texture and has not been evaluated in Minnesota for sweet corn production; however, evidence suggests that stand may be reduced when popup rates for dent corn are used for sweet corn. Phosphorus is the main nutrient likely to enhance early plant growth and selecting a starter high in phosphorus and low in nitrogen and potassium can greatly reduce the risk for seedling damage. Research on crops has shown that increased early plant growth is largely cosmetic in Medium to High P testing soils and will likely not increase yield.

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

Other nutrients

Research has not demonstrated the need for calcium and magnesium applications to sweet corn in Minnesota. The need for calcium and magnesium can usually be met by using dolomitic lime to adjust soil pH. There may be a few rare situations where magnesium soil test is low. For those situations follow the guidelines in Table SWC-5. Questions on the application of sulfur have surfaced recently due to responses seen in dent corn fields. Sulfur responses in dent corn are more likely in situations with low organic matter and high leaching potential but have also occurred in poorly drained, high organic matter fields especially in high crop residue situations. Application of sulfur may be warranted for sweet corn under some circumstances at the rate of 10-25 lb S per acre. If groundwater is used for irrigation, up to half the sulfur requirements and all the magnesium requirements can be supplied with the irrigation water in most years.

Table SWC-5. Magnesium recommendations for sweet corn.

Magnesium soil test*	Relative level	Magnesium to apply: Broadcast	Magnesium to apply: Row
0-49 ppm	Low	100 lb/acre	20 lb/acre
50-99	Medium	50	10
100+	High	0	0

Table SWC-6. Zinc guidelines for sweet corn production in Minnesota

Zinc soil test*	Band	Broadcast
0.0-0.5 ppm	2 lb/acre	10 lb/acre
0.6-1.0	1	5
1.1 +	0	0

* Zinc extracted by the DTPA procedure.

The only micronutrient likely deficient in sweet corn production is zinc. Table SWC-6 summarizes the amount of zinc suggested in a band or broadcast application based on a 0-6" soil sample. Application of zinc directly to the seed is not suggested.

There is no evidence that the application of boron, copper, or manganese will increase the yield of sweet corn in Minnesota grown on mineral soils. When grown on organic soils with a pH greater than 5.7, manganese should be monitored for possible deficiency. If manganese deficiency has been identified in previous years, broadcast applications of 4-6 lb Mn/A are suggested when soil pH is greater than 5.7. Foliar applications of 0.2-0.3 Mn/A can be applied if deficiencies occur during the growing season.

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UNIVERSITY OF MINNESOTA EXTENSION

Fertilizing Wheat in Minnesota

Daniel E. Kaiser[1] and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

With 1.5 million acres planted annually, wheat is a fourth largest crop in Minnesota's agriculture. When diseases and other crop pests are not limiting, average yields continue to increase steadily. Adequate and efficient use of fertilizer is a major contributor to this increase.

Nitrogen guidelines

Nitrogen use generates the largest net return of any nutrient used in wheat production. It is important, however, to use this nutrient as efficiently as possible.

In Minnesota, fertilizer N suggestions are determined using two strategies, which depend on the area of the state in question. For the western portion of the state, where most of the wheat is grown, the soil nitrate test (soil samples collected to 2 feet) is the best and most accurate management tool for predicting the amount of fertilizer N to use. This soil test is recommended if wheat is grown in the shaded area of the state shown in Figure 1.

If the soil nitrate test is used, the amount of fertilizer N required to meet the yield goal is calculated from the following equation:

$$N_{Rec} = [(2.5) \times YG] - STN_{(0\text{-}24\ in.)} - N_{pc}$$

The following abbreviations are used in this equation.

YG = yield goal, bu per acre
STN = nitrate-nitrogen (NO_3^--N) measured to a depth of 2 feet, lb per acre.
N_{pc} = amount of N supplied by the previous crop, lb per acre (see Table WH-1)

If wheat is grown in the second year following any of the crops in Table WH-1 use the N credit listed in Table WH-2. For situations where the soil nitrate test is not used, suggestions for fertilizer N are based on a consideration of previous crop, yield goal, and soil organic matter content. The soil nitrate test is not used for making nitrogen fertilizer guidelines for wheat grown in eastern Minnesota (the area not shaded in Figure WH-1). Nitrogen fertilizer

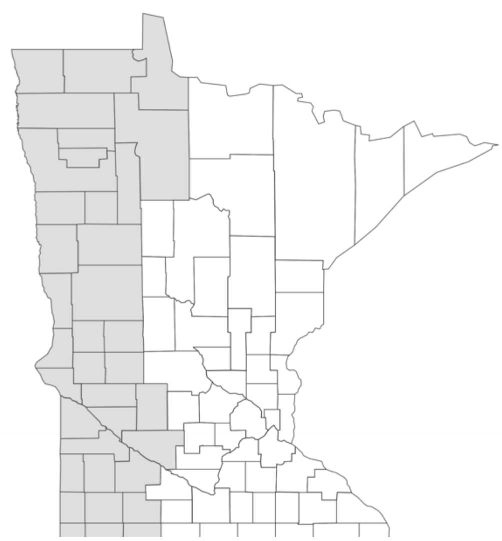

Figure WH-1. The soil nitrate test should be used for nitrogen guidelines in the counties that are shaded.

guidelines for these situations are summarized in Table WH-3. Use the fertilizer N guidelines for soils having a high organic matter content when wheat is grown in southeast Minnesota. This recommendation applies in Goodhue, Wabasha, Olmsted, Winona, Fillmore, and Houston Counties.

Table WH-1. Suggested nitrogen credits for various crops that might precede wheat in a crop rotation. Use these credits when the soil nitrate test is used.

Previous Crop	First year N credit
Soybean	20 lb N/acre
Edible Beans, Field Peas	10
Harvested Sweet Clover	10
Harvested red clover	35
Harvested Alfalfa[1] or non-Harvested Sweet Clover	
4-5 plants/ft^2	75
2-3 plants/ft^2	50
1-2 plants/ft^2	25
1 or fewer plants/ft^2	0
Sugar beet	
Yellow leaves at harvest	0
Light-green leaves at harvest	15-30
Dark-green leaves at harvest	60-80

[1]If 3rd or 4th cutting was not harvested, add 20 lb N/acre to the N credits listed.

Table WH-2. Suggested nitrogen credits when wheat is grown two years after a legume crop

Previous Legume Crop	Second year N credit
Alfalfa (4+ plants/ft^2), Non-harvested sweet clover	35 lb N/acre
Alfalfa (2-3 plants/ft^2), Birdsfoot trefoil	25
Red clover	20

The nitrogen supplied by legume crops can also be utilized by the wheat crop planted 2 years after the legume. The nitrogen credits for these situations are summarized in Table WH-2. Subtract these values from the N guidelines that are listed for crops in Group 2 (Table WH-3) when wheat is planted 2 years after a legume crop.

Nitrogen from the decomposing sugar beet tops can be used by the wheat crop following sugar beet. These N credits are based on the overall color of the sugar beet tops at harvest and are listed in Table WH-1. If the soil nitrate test is used for nitrogen guidelines, the value for the appropriate color should be used as the nitrogen credit from the previous crop (NPC) in the N recommendation equation. If the N guidelines are taken from Table WH-3, subtract the value for the appropriate leaf color in Table WH-1 from the appropriate N recommendation listed in Table WH-3.

Nitrogen guidelines, whether calculated from the equation or obtained from Table WH-3, should also be used for winter wheat production. For this crop, 15 to 30 lb N per acre should be applied in the fall either before or at the time of seeding. The remainder of the fertilizer N needed should be top-dressed early the following spring.

Managing nitrogen

Research has shown that the majority of the total amount of nutrients used by wheat is absorbed from the soil between the growth stages of tillering and heading. Therefore, it is important to have an adequate supply of all nutrients in the root zone early in the growing season.

Since N is mobile in soils and can move to the roots with soil moisture, there is considerable flexibility in the management of this nutrient. For wheat production in most of Minnesota, fertilizer N can be applied in the fall after soil temperatures have stabilized at or below 50˚F, or in the spring. In southeast, south-central, and central Minnesota, fertilizer N should be applied in the spring and incorporated before planting. Because of the potential for losses due to leaching, fertilizer N should be applied in the spring when soils are sandy. Split N applications are encouraged for very sandy soils. For these situations, the first application can be made before planting followed by the remainder between tillering and jointing.

In northwest and western Minnesota, N applications at tillering may be justified if loss of previously applied N from leaching or denitrification is suspected. Application of N at this time would also be appropriate where a yield goal established in the fall was conservative and projected weather plus available soil moisture suggests there is a good probability for a higher yield. For these situations, added N at tillering may also increase the protein content of hard red spring wheat.

Table WH-3. Nitrogen fertilizer suggestions for wheat where the soil nitrate test is not used.

Crop grown last year	Organic matter level*	Yield goal below 40 bu/acre	Yield goal 40-49 bu/acre	Yield goal 50-59 bu/acre	Yield goal 60-69 bu/acre	Yield goal 70-79 bu/acre	Yield goal 80+ bu/acre
Alfalfa (4+plants/ft^2), non-harvested sweet clover	Low	0 lb N/acre	0 lb N/acre	30 lb N/acre	55 lb N/acre	80 lb N/acre	95 lb N/acre
Alfalfa (4+plants/ft^2), non-harvested sweet clover	Medium/High	0	0	0	35	60	75
Soybeans	Low	35	60	85	110	135	150
Soybeans	Medium/High	0	40	65	90	115	130
Edible beans, field peas, harvested sweet clover	Low	45	70	95	120	145	160
Edible beans, field peas, harvested sweet clover	Medium/High	25	50	75	100	125	140
Any crop in Group 1	Low	0	30	55	80	105	120
Any crop in Group 1	Medium/High	0	0	35	60	85	100
Any crop in Group 2	Low	55	80	105	130	155	170
Any crop in Group 2	Medium/High	35	60	85	110	135	150
Organic soil		0	0	0	0	30	35

* Low = less than 3.0%; Medium (Med.) and High = 3.0% or more.
Crops in Group 1: Alfalfa (2-3 plants/ft^2), Alsike Clover, Birdsfoot Trefoil, Grass/legume hay, Grass/legume pasture, Fallow, Red Clover.
Crops in Group 2: Alfalfa (0-1 plants/ft^2), Millet, Rye, Sweet corn, Barley, Corn, Mustard, Sorgum-sudan. Triticale, Buckwheat, Flax, Oat, Sugar beet, Wheat, Canola, Grass/hay/pasture, Potato, Sunflower, Vegetables.

If applied properly, all of the common N fertilizers will have an equal effect on wheat yields. Some precautions in the application of some N sources are necessary. With anhydrous ammonia (82-0-0), there is concern for loss during application. If there is a strong ammonia odor emanating for the field, further application is discouraged since significant losses are likely occurring with application. There is also a potential for N loss if urea (46-0-0) or urea-ammonium nitrate (28-0-0) is broadcast on the soil surface without incorporation when soil pH is higher than 7.3, air temperatures are 50° or greater and there is residue on the soil surface. Shallow incorporation of urea or fertilizers containing urea within 48 hours of application is encouraged when these N sources are used for wheat production. Fall application of 28-0-0 or 32-0-0 UAN is strongly discouraged due to a portion of the N in the fertilizer already in the nitrate form at application.

Late season applications of 30 lb N/acre as Urea-ammonium nitrate solution (28-0-0) 2 to 5 days after anthesis (flowering) has been shown to increase hard red spring wheat grain protein 0.5 to 1.0%, 80% of the time. This rate will cause some leaf burn but will not harm grain yield. The economics of this application depend on the cost of the 28-0-0 and the protein premium of the wheat market. Figure 2 shows the economic decision guide. Do not apply during the heat of the day; instead apply either in early morning or evening application to limit the leaf burn by the 28-0-0. Do not tank mix N with any fungicides - wait 2 to 5 days after anthesis.

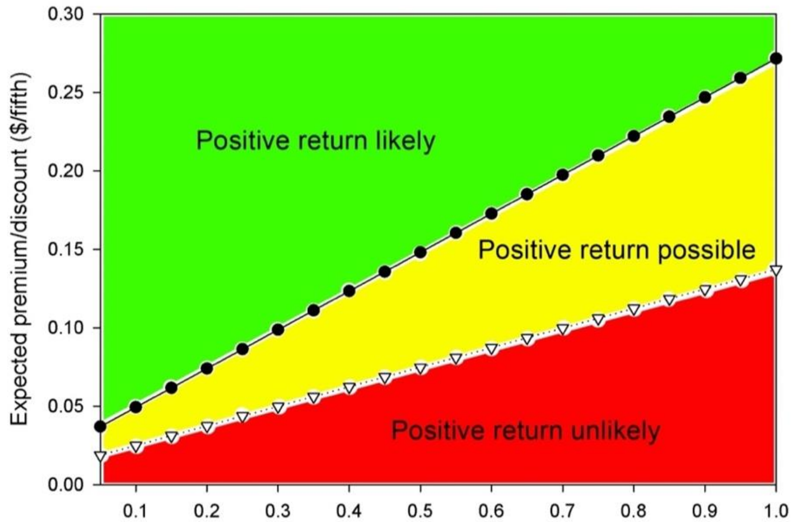

Figure 2. Decision guide for application of 28-0-0 (28% UAN) 2 to 5 days after flowering.

Phosphate guidelines

Suggestions for phosphate use are summarized in Table WH-4. The phosphorus (P) status of Minnesota soils is determined by using either the Bray or the Olsen analytical procedure. These tests are intended to be an index of crop response and not a direct measure of the amount of P in the soil. The Bray soil test uses a strong acid to extract P from the soil. In situations where carbonates are present in the soil, the acid in the Bray solution can be neutralized reducing the amount of P extracted and the effectiveness of the test. The Olsen test provides more accurate results if the soil pH is 7.4 or higher as it is not affected by carbonates in the soil. Both tests can be accurately used in situations where high soil pH is not an issue but values obtained from the Olsen tests will be lower for the same soil test classification range since the Bray and Olsen test extract P out of different pools of available P in the soil.

Table WH-4: Broadcast and drill phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for wheat production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected Yield Bray-P1	Broadcast/Drill	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Expected Yield Olsen	Broadcast/Drill	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
Less than 40 bu/acre	Broadcast	40 lb/acre	30 lb/acre	15 lb/acre	0 lb/acre	0 lb/acre
Less than 40	Drill	20	15	20	10-15	0
40-49	Broadcast	40	30	15	0	0
40-49	Drill	20	15	20	10-15	0
50-59	Broadcast	50	35	20	0	0
50-59	Drill	25	20	15	10-15	0
60-69	Broadcast	60	45	20	0	0
60-69	Drill	30	25	15	10-15	0
70-79	Broadcast	70	50	25	0	0
70-79	Drill	35	25	20	10-15	0
80 or more	Broadcast	80	55	25	0	0
80 or more	Drill	40	30	20	10-15	0

[1]Use one of the following equations if a phosphate recommendation for a specific soil test and a specific yield goal is desired.

P_2O_5 Rec = [1.071 - (.054) (Bray P, ppm)] (Yield goal)
= [1.071 - (.067) (Olsen P soil test, ppm)] (yield goal)

No phosphate fertilizer is suggested when the Bray P test is 21 ppm or higher or the Olsen P test is 16 ppm or higher.

The phosphate fertilizer suggestions change with soil test level and placement. At very low, low, and medium soil test levels, the needed phosphate can be broadcast and incorporated before planting or applied with the drill at planting in a narrow band near or with the seed Rates can be reduced by as much as 50% if the phosphate is applied with the drill.

No broadcast phosphate is suggested when the soil test for P is high (Bray P = 16 to 20 ppm; Olsen P = 12 to 15 ppm). A small amount of P_2O_5 applied with the seed is suggested for these situations. No phosphate will be needed when the soil test for P is in the very high range (Bray P = 21+ ppm; Olsen P = 16+ ppm) unless soils are cold and wet at planting time. On soils with high P fixing capacity such as soils with pH greater than 7.5, though soil test P is high or very high, some phosphate fertilizer (10 lb P_2O_5 per acre) placed in a band with or near the seed at planting may improve wheat yields.

Previous research has shown advantages to banding fertilizer in these situations as it reduces the amount of soil in contact with fertilizer which reduces the risk for fixation of P.

Potash guidelines

Suggestions for potash use are summarized in Table WH-5. As with phosphate, the soil test represents and index of availability and is not a direct measure of potassium in the soil. Suggestions vary with placement and soil test level for K. No broadcast potash will be needed when the soil test for K is 121 ppm or higher. No potash fertilizer (either drilled or broadcast) is suggested when the soil test for K is 161 ppm or higher.

It may not be practical to broadcast some of the low rates of suggested phosphate and potash. When low rates are suggested for a broadcast application, it is probably more practical to double the suggested broadcast rate and apply in alternate years if the grain drill or air seeder is not equipped to apply fertilizer with the seed.

Any phosphate and/or potash that is broadcast should be incorporated before seeding. These nutrients do not move in most soils and will have very little effect on production if they are top-dressed to an established stand. Application prior to a primary tillage operation is preferred.

Table WH-5: Broadcast and drill potash guidelines (lb K_2O/acre) for wheat production in Minnesota based on K soil test reported in parts per million*

Expected yield (bushels/acre)	Broadcast/band	0-40 ppm	41-80 ppm	81-120 ppm	121-160 ppm	161+ ppm
Less than 40	Broadcast	95 lb/acre	70 lb/acre	40 lb/acre	0 lb/acre	0 lb/acre
Less than 40	Drill	50	35	20	15-20	0
40-49	Broadcast	105	75	45	0	0
40-49	Drill	55	40	25	15-20	0
50-59	Broadcast	130	95	55	0	0
50-59	Drill	65	50	30	15-20	0
60-69	Broadcast	155	110	65	0	0
60-69	Drill	80	55	35	15-20	0
70-79	Broadcast	180	125	75	0	0
70-79	Drill	90	65	40	15-20	0

* Use one of the following equations if a potash guideline for a specific soil test value and a specific expected yield is desired.

$K_2O_{suggested}$ = [2.710 - .017 (K Soil Test, ppm)] (Yield Goal)

No potash fertilizer is suggested when the K test is 161 ppm or higher.

Fertilizer in contact with the seed

Since most of the wheat acreage in Minnesota is planted in early spring when soil conditions are cold and wet, the application of some fertilizer with the drill should be a routine management practice to increase nutrient availability in the root zone. However there is some need for caution when placing fertilizer with the seed!! Do not place ammonium thiosulfate (12-0-0-26) in direct contact with the seed. Do not place boron fertilizers in direct contact with the seed. Damage from nitrogen and urea (46-0-0) placed in contact with the seed is dependent on the moisture content of the soil at planting. Damage can be substantial if soils are dry at planting. If soils are dry at the time of planting, keep the amount of urea in contact with the seed to 10 lb N per acre or less. Higher rates can be used if the soil is wet at planting. The suggested rates for this use, however, are not well defined

High rates of potash in contact with the seed can cause problems if soils are dry at planting. Under typical moisture conditions, rates of K_2O up to 60 lb per acre in contact with the seed should not cause problems with emergence.

Phosphate has no negative effect on seed germination and seedling growth. Therefore, ample amounts of phosphate can be applied in contact with the seed.

Fertilizer applied with air seeders

The use of air seeders has increased in popularity in recent years. Many seeders are equipped to apply a mixture of seed and dry fertilizer at the time of planting. The amount of fertilizer that can safely be applied with the air seeder will depend on the seeder spacing, the spread width of the fertilizer and seed mixture, and soil texture. Less fertilizer can be safely applied when the fertilizer and seed are placed within a narrow band or when air seeders are used on coarse textured soils.

The amount of nitrogen that can be used with the air seeder is related to soil moisture content at planting. Recent trials showed that N rates in excess of 25 lb per acre as urea can reduce germination if applied with the wheat using an air seeder when soils are dry. By contrast, 75 lb N per acre as urea caused no emergence problems when soils were wet.

Urea fertilizer can present a significant risk of seedling damage when placed in contact with the seed. Data in Table WH-6 summarizes maximum rates of N that can be applied, assuming that soils are not dry at seeding. If soils are dry at planting, seeding rates should be reduced to decrease the risk of seeking damage.

Table WH-6. Maximum suggested nitrogen fertilizer rates with small grain seed at planting based on planter spacing, planter type, and seedbed utilization*

Planter spacing		6 inch	6 inch	7.5 inch	7.5 inch	10 inch	10 inch	12 inch	12 inch
Planter type	Seed spread	Seedbed Utilized	lb N/acre	Seedbed Utilized	lb N/acre	Seedbed Utilized	lb N/acre	Seedbed Utilized	lb N/acre
Double Disc	1 inch	17%	20-30	13%	19-28	10%	17-23	8%	15-20
Hoe	2	33%	32-44	27%	27-38	20%	23-31	17%	20-27
	3	50%	44-58	40%	37-48	30%	30-40	25%	26-34
Air Seeder	4	66%	56-72	53%	46-58	40%	37-48	33%	32-42
	5	83%	68-86	68%	56-68	50%	44-57	44%	38-49
	6	100%	80-100	80%	66-79	60%	51-55	50%	44-56
	7			94%	76-90	70%	58-74	58%	50-64
	8					80%	66-83	67%	56-71
	9					90%	73-92	75%	62-78
	10					100%	80-100	83%	68-86
	11							92%	74-93
	12							100%	80-100

* Table adapted from Deibert, E.J. 1994. Fertilizer Application with Small Grain Seed at Planting. N Dakota State Univ. Ext. Publ EB-62.

The maximum nitrogen rate applied with the air seeder also must be adjusted based on soil texture. Table WH-7. summarizes maximum suggested rates of N for soils with differing texture based on method of application. Loamy sands and sandy loams present the greatest risk for seedling damage as these soils contain less available water than clay loams and clays. Extreme care should be taken when applying fertilizer with the seed on sandy soils when fertilizer is banded in a narrow band with the seed.

Table WH-7. Maximum suggested nitrogen fertilizer rates (lb/acre) with small grain seed at planting based on soil texture and seedbed utilization*

Soil texture	Sand particle size	Silt particle size	Clay particle size	Seedbed utilization: 10-20%, Double disc, 1 inch	Seedbed utilization: 30-50%, Hoe, 1 inch	Seedbed utilization: 60-100%, Airseeder, 4-12 inch
Loamy sand	80%	10%	10%	5 lb/acre	10-20 lb/acre	25-40 lb/acre
Sandy loam	60	35	15	10	15-25	30-45
Sandy clay loam	55	15	30	15	20-30	35-50
Loam	40	40	20	20	25-35	40-55
Silt loam	20	65	15	25	30-40	45-60
Silty clay loam	10	55	35	30	35-45	50-70
Clay loam	30	30	40	35	40-50	55-80
Clay	20	20	60	40	45-55	60-100

* Table adapted from Deibert, E.J. 1994. Fertilizer Application with Small Grain Seed at Planting. N Dakota State Univ. Ext. Publ EB-62.

Recent trials have shown that rates of phosphate of 92 lb P_2O_5 per acre or less have not hindered germination if mixed with wheat seed planted with an air seeder. The amount of K_2O that can be applied in contact with the seed using an air seeder is not known at this time. If N and K are applied together, rates should be reduced of both nutrients.

Other nutrients needed

Major emphasis in wheat production should be directed to efficient and effective management of nitrogen, phosphate, and potash fertilizers. Sulfur (S) and copper (Cu) can be important in certain situations. These special cases are described in the paragraphs that follow.

Sulfur

Sulfur fertilization can increase wheat yields when the crop is grown on sandy soils. Research trials have shown that there is no need to add S to a fertilizer program for increasing grain yield and protein when wheat is grown on fine-textured soils in Minnesota. However, it is possible that in some years medium textured soils (loam and silt loam soils) with organic matter levels less than 3.0% may have limited S mineralization and may need small rates of sulfur to maximize yield. In these cases a smaller broadcast rate of 10-15 lb of S per acre may be applied on a trial basis.

The broadcast application of 25 lb S per acre in the sulfate form will be adequate for growing wheat on sandy soils. For more efficient applications, use 10 to 15 lb S per acre with the drill or air seeder at planting.

Copper

Copper (Cu) may be required in a fertilizer program when wheat is grown on organic soils. Suggestions for Cu use are summarized in Table WH-8. The suggestions in Table WH-8 are for organic (peat) soils only. The use of Cu in a fertilizer program is not currently suggested when wheat is grown on mineral soils.

Table WH-8. Guidelines for use of copper (lb/acre) for wheat grown on an organic soil

Copper, parts per million	Broadcast application, Copper	Broadcast application, Copper sulfate	Foliar spray application, Copper	Foliar spray Application, Copper sulfate
0-2.5 (low)	6-12 lb/acre	24-48 lb/acre	0.3 lb/acre	1.2 lb/acre
2.6-5.0 (marginal)	6	24	0.3	1.2
More than 5.0 (adequate)	0	0	0	0

Other micronutrients

Research from throughout Minnesota has shown that magnesium, calcium, iron, boron, zinc, and manganese are not needed in fertilizer programs. Most soils are able to supply ample amounts of these nutrients to a high-yielding wheat crop.

Additional resources

- University of Minnesota wheat nutrient management calculator (z.umn.edu/WheatCalculator)

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University of Minnesota Extension

Fertilizing Barley in Minnesota

Daniel E. Kaiser[1], Jochum J. Wiersma[2] and Keith Piotrowski[3]

[1]Extension nutrient management specialist [2]Small grains specialist [3]Director of Soil Testing Laboratory

In Minnesota, barley is grown for malting as well as a feed grain. Yields of this crop continue to increase and proper fertilizer use is key to continue this improvement.

The use of barley in the brewing industry is well known and, when sold for malting purposes, barley is a very stable crop in Minnesota's economy. The importance of barley as a feed grain is often overlooked. Yet, this crop can easily substitute for corn in feeding rations. This substitution is especially important where soils are sandy. These soils have a low water-holding capacity and drought frequently limits corn yields.

Nitrogen guidelines

The amount of nitrogen (N) fertilizer applied can have a major impact on yield as well as the protein percentage in the grain. For most crops, there is an advantage to having high protein content. High protein concentrations in the grain, however, are not desirable when barley is grown for malting purposes. The industry prefers a grain protein content of 12.5% or less. Therefore, special attention should be given to N management so that grain yield is maximized while maintaining a grain protein content below 12.5%.

There are two approaches to arriving at fertilizer N guidelines for barley. One approach is to base guidelines for fertilizer N on the results of the soil nitrate test. The soil nitrate test is recommended for western Minnesota (see Figure BA-1). When the soil nitrate test is used, the amount of fertilizer N needed to meet the yield goal is calculated from the following equations.

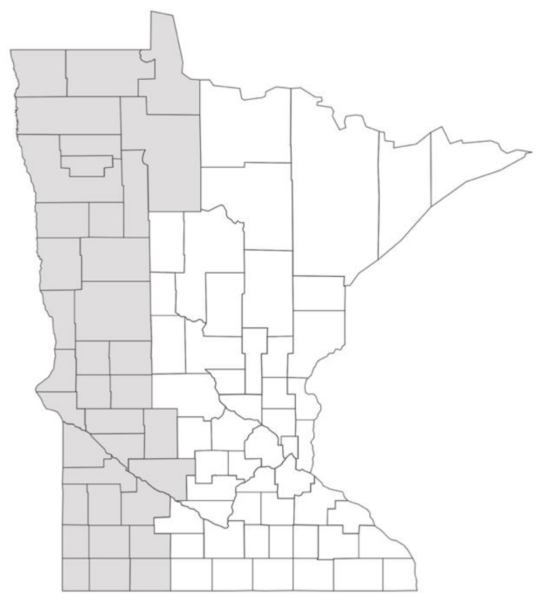

Figure BA-1. The soil nitrate test should be used for nitrogen guidelines in the counties that are shaded.

Nitrogen fertilizer formula for malting barley

Suggested N in lb/acre = [(1.5) x YG] - $STN_{(0\text{-}24\ in.)}$ - N_{PC}

Nitrogen fertilizer formula for feed grain barley

Suggested N in lb/acre = [(1.7) x YG] - $STN_{(0\text{-}24\ in.)}$ - N_{PC}

Nitrogen formula variables

YG = yield goal, bu per acre

$STN_{(0\text{-}24\ in.)}$ = nitrate-nitrogen (NO_3^--N) measured to a depth of 2 feet, lb per acre.

N_{PC} = amount of N supplied by the previous crop, lb per acre (see Table BA-1)

Table BA-1. Suggested nitrogen credits for various crops that might precede barley in a crop rotation. Use these credits when the soil nitrate test is used.

Previous Crop	First year N credit lb N/acre
Soybean	20
Edible Beans, Field Peas	10
Harvested Sweet Clover	10
Harvested Alfalfa[1] or non-Harvested Sweet Clover	
4-5 plants/ft^2	75
2-3 plants/ft^2	50
1-2 plants/ft^2	25
1 or fewer plants/ft^2	0
Harvested red clover	35
Sugar beet	
Yellow leaves at harvest	0
Light-green leaves at harvest	15-30
Dark-green leaves at harvest	60-80

[1]If 3rd or 4th cutting was not harvested, add 20 lb N/acre to the N credits listed.

Nitrogen credits should also be used when barley is grown in the second year after any of the legume crops listed above. For these situations, use of the N credit listed in Table BA-2.

Table BA-2. Suggested nitrogen credits when barley is grown 2 years after a legume crop.

Previous legume crop	2nd year N credit lb N/acre
Alfalfa (4+ plants/ft^2)	35
Non-harvested sweet clover	35
Alfalfa (2-3 plants/ft^2)	25
Birdsfoot trefoil	25
Red clover	20

The soil nitrate test is integral as a N management tool. The soil samples needed for measurement of carryover NO_3^--N can be collected in either fall or spring. It is usually easier to collect samples in early fall. If possible, delay sampling until soil temperature drops below 50˚ F.

The amount of fertilizer N needed can also be based on yield goal, previous crop, and soil organic matter content. These N suggestions are summarized in Table BA-3.

Nitrogen from the decomposing tops of a previous crop of sugar beet can be used by the barley crop when it follows in a rotation. These N credits are based on the overall color of the sugar beet tops at harvest and are listed in Table BA-1. If the soil nitrate test is used, the value for the appropriate color should be used as the nitrogen credit from the previous crop (NPC) in the N guideline equation. If the N suggestions are taken from Table BA-3, subtract the value for the appropriate color from the appropriate N suggestion listed in Table BA-1.

The nitrogen supplied by legume crops can also be utilized by the barley crop if it is planted two years after the legume. The nitrogen credits for these situations are summarized below. Subtract these values from the nitrogen suggestions that are listed for crops grown in Group 2 for the appropriate yield goal (see Table BA-3).

Table BA-3. Nitrogen guidelines for barley in situations when the soil NO_3^--N test is not used based on expected yield of the crop in bushels per acre.

Crop grown last year	Organic matter level*	Yield goal: <50 bu/acre	50-59 bu/acre	60-69 bu/acre	70-79 bu/acre	80-89 bu/acre	90-99 bu/acre	100+ bu/acre
Alfalfa (4+ plants/ft^2)	Low	0 lb N/acre	0 lb N/acre	10 lb N/acre	25 lb N/acre	40 lb N/acre	55 lb N/acre	70 lb N/acre
Alfalfa (4+ plants/ft^2)	Medium/High	0	0	0	0	20	35	50
Soybeans or Alfalfa (1 or less plants/ft^2)	Low	30	50	65	80	95	110	125
Soybeans or Alfalfa (1 or less plants/ft^2)	Medium/High	0	30	45	60	75	90	105
Edible beans, field peas	Low	40	60	75	90	105	120	135
Edible beans, field peas	Medium/High	0	40	55	70	85	100	115
Group 1 Crops	Low	0	20	35	50	65	80	95
Group 1 Crops	Medium/High	0	0	15	30	45	60	75
Group 2 Crops	Low	50	70	85	100	115	130	145
Group 2 Crops	Medium/High	30	50	65	80	95	110	125
Organic soil	—	0	0	0	0	30	40	50

*Low = less than 3.0%; Medium/High = 3.0% or more
Crops in Group 1: Alsike clover, birdsfoot trefoil, grass/legume hay, grass legume pasture, fallow, red clover.
Crops in Group 2: Alfalfa (0-1 plants/ft.^{2}), barley, buckwheat, canola, corn, flax, grass hay, grass pasture, oat, potato, rye, sorghum-sudan, sugar beet, sunflower, sweet corn, triticale, vegetables, wheat.

Managing nitrogen

Research has shown that most of the total amount of essential nutrients used by barley is absorbed from the soil between the tillering and heading growth stages. Therefore, it is important to have an adequate supply of all nutrients in the root zone early in the growing season.

Since N is mobile in soils and can move to the roots with soil water, there can be considerable flexibility in the management of this important nutrient. Fertilizer N can be applied in the fall for barley production in most of Minnesota. There are some exceptions. Fall application of fertilizer N is discouraged when soils are sandy. Split applications are encouraged for very sandy soils. For these situations, the first application can be made before planting. The remainder should be applied at or near tillering. In southeast Minnesota, fertilizer N should be applied in the spring and incorporated before planting. Fall application of fertilizer N is discouraged in the region.

Split N applications are strongly encouraged when irrigated barley is grown on sandy soils. For this production system, some N should be applied before planting and combined with a N application at the tillering to early boot stage. The ideal percentage of total N to use at each application has not been determined. It may be practical to apply ½ of the total N needed before planting and the remaining ½ at the tiller to early boot stage.

If applied properly, all common N fertilizer sources will have an equal effect on wheat yields. Some precautions in the application of some N sources are necessary. With anhydrous ammonia (82-0-0), there is concern for loss during application. If there is a strong ammonia odor emanating for the field, further application is discouraged since significant losses are likely occurring with application. There is also a potential for N loss if urea (46-0-0) or urea-ammonium nitrate (28-0-0) is broadcast on the soil surface without incorporation when soil pH is higher than 7.3, air temperatures are 50° F or higher and there is residue on the soil surface. Shallow incorporation of urea or fertilizers containing urea within 48 hours of application is encouraged when these N sources are used for wheat production. Fall application of 28 or 32% UAN is strongly discouraged due to a portion of the N in the fertilizer already in the nitrate form at application.

Urea-ammonium nitrate solution (28%) can be applied either before planting or post emergence. A foliar application may cause some leaf burning, but there will be no reduction in yields if reasonable rates up to 30 lb N per acre are used, unless the N is applied using streamer bars. Leaf burn may be excessive if foliar N rates exceed 60 lb N per acre.

Phosphate guidelines

Suggestions for phosphate use are summarized in Table BA-4. The phosphorus (P) status of Minnesota soils is determined by using either the Bray or the Olsen analytical procedure. These tests are intended to be an index of crop response and not a direct measure of the amount of P in the soil. The Bray soil test uses a strong acid to extract P from the soil. In situations where carbonates are present in the soil, the acid can be neutralized reducing the amount of P extracted and the effectiveness of the test. The Olsen test provides more accurate results if the soil pH is 7.4 or greater as it is not affected by carbonates in the soil. Both tests can be accurately used in situations where high soil pH is not an issue but values obtained from the Olsen tests will be lower for the same soil test classification range since the Bray and Olsen test extract P out of different pools of available P in the soil.

The phosphate suggestions change with soil test level and placement. At very low, low, and medium soil test levels, the needed phosphate can be broadcast and incorporated before planting or applied with the drill at planting. Rates can be reduced by 50% if the phosphate fertilizer is applied with the drill.

No broadcast phosphate is suggested when the soil test for P is high (Bray = 16-20 ppm P; Olsen = 12-15 ppm P). A small amount of phosphate applied with the drill is suggested for these situations. No phosphate fertilizer will be needed when the soil test for P is in the very high range (Bray = 21+ ppm P; Olsen = 16+ ppm P) unless soils are cold and wet at planting. In north-central Minnesota, soils may be cold and wet at planting time. Even though the soil test for P may be high, some phosphate fertilizer (10 lb P_2O_5/acre) placed in a band near the seed may improve barley yields on these soils.

Table BA-4. Broadcast and drill phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for barley production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected Yield	Broadcast or Drill	Bray 0-5 ppm	Bray 6-10 ppm	Bray 11-15 ppm	Bray 16-20 ppm	Bray 21+ ppm
		Olsen 0-3 ppm	Olsen 4-7 ppm	Olsen 8-11 ppm	Olsen 12-15 ppm	Olsen 16+ ppm
Less than 50 bu/acre	Broadcast	35 lb/acre	25 lb/acre	15 lb/acre	10 lb/acre	0 lb/acre
Less than 50 bu/acre	Drill	20	15	10	0	0
60-69	Broadcast	45	30	20	0	0
60-69	Drill	25	15	15	10-15	0
70-79	Broadcast	50	35	20	0	0
70-79	Drill	25	20	15	10-15	0
80-89	Broadcast	60	40	25	0	0
80-89	Drill	30	20	15	10-15	0
90-99	Broadcast	65	45	25	0	0
90-99	Drill	35	25	15	10-15	0
100+	Broadcast	70	50	30	0	0
100+	Drill	35	25	20	10-15	0

1/ Use one of the following equations if a phosphate recommendation for a specific soil test and a specific yield goal is desired.

P_2O_5Rec = [0.785 - (.039) (Bray P soil test), ppm] (yield goal)

[0.785 - (.050) (Olsen P soil test), ppm] (yield goal)

No phosphate fertilizer is suggested when the Bray P test is 21 ppm or higher or the Olsen P test is 16 ppm or greater.

Potash suggestions

Suggestions for the use of potash fertilizer are summarized in Table BA-5. As with phosphate, the soil test represents and index of availability and is not a direct measure of potassium in the soil. Suggestions vary with placement and soil test level for K. No broadcast potash will be needed when the soil test K is 121 ppm or greater. No potash (either banded or broadcast) is suggested when the soil test for K is 161 ppm or greater.

It may not be practical to broadcast low rates of phosphate and potash that are suggested. For these situations, it may be more practical to double the suggested broadcast rate and apply in alternate years if the grain drill is not equipped to apply fertilizer with the seed.

Any phosphate and/or potash that is broadcast should be incorporated before seeding. These nutrients do not move in most soils and will have very little effect on production if they are top-dressed to an established stand. Application before a primary tillage operation is preferred.

Fertilizer with the drill

Since most of the small grain acreage in Minnesota is planted in early spring when soil conditions are cold and wet, the application of fertilizer with the drill should be a standard management practice. Plant root growth tends to be slow under these circumstances which limit the uptake of immobile nutrients such as phosphorus and potassium. Placement near the seed ensures nutrient be readily available early in the growing season. CAUTION! Do not place ammonium thiosulfate (12-0-0-26) in direct contact with the seed. Do not place boron fertilizers in direct contact with the seed. Phosphate in fertilizer has no negative effect on seed germination and seedling growth. Therefore, ample amounts of phosphate can be placed in contact with the seed.

Table BA-5. Potash fertilizer suggestions for barley production in Minnesota.

Expected Yield	Broadcast/Drill	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Less than 50 bu/acre	Broadcast	50 lb/acre	40 lb/acre	20 lb/acre	0 lb/acre	0 lb/acre
Less than 50 bu/acre	Drill	25	20	15	0	0
60-69	Broadcast	70	50	30	0	0
60-69	Drill	35	25	20	10-15	0
70-79	Broadcast	85	60	35	0	0
70-79	Drill	40	30	25	10-15	0
80-89	Broadcast	95	65	40	0	0
80-89	Drill	50	35	25	10-15	0
90-99	Broadcast	105	75	45	0	0
90-99	Drill	55	40	30	10-15	0
100+	Broadcast	110	75	45	0	0
100+	Drill	55	40	35	10-15	0

1/ Use the following equation if a potash recommendation for a specific soil test and a specific yield goal is desired.

$K_2ORec =$ [1.286 - (.0085) (K soil test), ppm] (yield goal)

No potash fertilizer is suggested when the K test is 161 ppm or greater.

Fertilizer applied with air seeders

The use of air seeders has increased in popularity in recent years. Many seeders are equipped to apply a mixture of seed and dry fertilizer at the time of planting. There are, however, no firm guidelines for the amount of fertilizer that can be applied with the seed with this planting equipment.

The amount of fertilizer that can safely be applied with an air seeder depends on the row spacing and the amount of area the seed and fertilizer is spread over, and soil factors such as soil texture, cation exchange capacity, and pH. As row spacing increases the amount of fertilizer that can safely be applied decreases since the concentration in the band increases.

The amount of N + K_2O should be kept at a minimum and less than 30 lb per acre of N + K_2O combined as a general practice to minimize the risk of stand loss. However, these rates can vary based on many factors such as the soil type, soil moisture at planting, and the volume of soil the fertilizer is applied in. Rates should be reduced if soils are dry at planting. By contrast, high rates of P_2O_5 per acre generally do not hinder germination if mixed with wheat seed planted with an air seeder.

Fertilizer can present a significant risk of seedling damage when placed in contact with the seed. Table BA-6 summarizes maximum rates of N that can be applied, assuming that soils are not dry at planting adjusted for planter spacing and the amount of seedbed utilized for fertilizer application. If soils are dry at planting, rates should be reduced to the low end of the suggested range or less to decrease the risk of seedling damage.

The maximum nitrogen rate applied with the air seeder also must be adjusted based on soil texture. Table BA-7 summarizes maximum suggested rates of N for soils with differing texture based on method of application. Loamy sands and sandy loams present the greatest risk for seedling damage as these soils contain less available water than clay loams and clays. Extreme care should be taken when applying fertilizer with the seed on sandy soils when fertilizer is banded in a narrow band with the seed since this presents the highest potential for seedling damage.

It is important to remember that crops can differ in their tolerance to seed placed fertilizers, so the suggestions outlined should not substitute for sound judgment when making decisions on the amount fertilizer applied with the seed.

Table BA-6. Maximum suggested nitrogen fertilizer rates with small grain seed at planting based on planter spacing, planter type, and seedbed utilization (approximate volume of the seedbed the fertilizer is applied). *

Planter spacing		6 inch	6 inch	7.5 inch	7.5 inch	10 inch	10 inch	12 inch	12 inch
Planter type	Seed spread	Seedbed Utilized	lb N/acre	Seedbed Utilized	lb N/acre	Seedbed Utilized	lb N/acre	Seedbed Utilized	lb N/acre
Double Disc	1 inch	17%	20-30	13%	19-28	10%	17-23	8%	15-20
Hoe	2	33%	32-44	27%	27-38	20%	23-31	17%	20-27
	3	50%	44-58	40%	37-48	30%	30-40	25%	26-34
Air Seeder	4	66%	56-72	53%	46-58	40%	37-48	33%	32-42
	5	83%	68-86	68%	56-68	50%	44-57	44%	38-49
	6	100%	80-100	80%	66-79	60%	51-55	50%	44-56
	7			94%	76-90	70%	58-74	58%	50-64
	8					80%	66-83	67%	56-71
	9					90%	73-92	75%	62-78
	10					100%	80-100	83%	68-86
	11							92%	74-93
	12							100%	80-100

* Table adapted from Deibert, E.J. 1994. Fertilizer Application with Small Grain Seed at Planting. N Dakota State Univ. Ext. Publ EB-62.

Table BA-7. Maximum suggested nitrogen fertilizer rates (lb/acre) with small grain seed at planting based on soil texture (% sand, silt, or clay) and seedbed utilization (approximate volume of the seedbed the fertilizer is applied). *

Soil texture	Sand (%)	Silt (%)	Clay (%)	Seedbed utilization: 10-20%, Double disc, 1 inch	Seedbed utilization: 30-50%, Hoe, 1 inch	Seedbed utilization: 60-100%, Air seeder, 4-12 inch
Loamy sand	80%	10%	10%	5 lb/acre	10-20 lb/acre	25-40 lb/acre
Sandy loam	60	35	5	10	15-25	30-45
Sandy clay loam	55	15	30	15	20-30	35-50
Loam	40	40	20	20	25-35	40-55
Silt loam	20	65	15	25	30-40	45-60
Silty clay loam	10	55	35	30	35-45	50-70
Clay loam	30	30	40	35	40-50	55-80
Clay	20	20	60	40	45-55	60-100

* Table adapted from Deibert, E.J. 1994. Fertilizer Application with Small Grain Seed at Planting. N Dakota State Univ. Ext. Publ EB-62.

Other nutrients needed

Sulfur

Sulfur (S) can increase barley yields when the crop is grown on sandy soils. Research trials have shown no need to add S to a fertilizer program when barley is grown on fine-textured soils in Minnesota.

The broadcast application of 25 lb S per acre in the sulfate form will be adequate for growing barley when S is needed. For more efficient applications, use 10-15 lb S per acre with the drill at planting. The sulfate form is suggested for this method of application.

Copper

Copper (Cu) may be required in a fertilizer program when barley is grown on organic soils. Suggestions for Cu use are summarized in Table BA-8.

Table BA-8. Guidelines for use of copper (lb/acre) for barley grown on an organic soil.

Copper, parts per million	Broadcast application, Copper	Broadcast application, Copper sulfate	Foliar spray application, Copper	Foliar spray Application, Copper sulfate
0-2.5 (low)	6-12 lb/acre	24-48 lb/acre	0.3 lb/acre	1.2 lb/acre
2.6-5.0 (marginal)	6	24	0.3	1.2
More than 5.0 (adequate)	0	0	0	0

The suggestions in Table BA-8 are for organic (peat) soils only. The use of Cu in a fertilizer program is not currently suggested when barley is grown on mineral soils.

Other macro- and micronutrients

Research throughout Minnesota has shown magnesium (Mg), calcium (Ca), boron (B), zinc (Zn), iron (Fe), and manganese (Mn) are not needed in fertilizer programs for barley production. Minnesota's soils can supply ample amounts of these nutrients for crop production.

Funding for the development of this publication is provided by Minnesota's Agricultural Fertilizer Research and Education Council (AFREC).

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Fertilizing Buckwheat in Minnesota

Daniel E. Kaiser[1] and Keith Piotrowski[2]
[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

Nitrogen guidelines

Nitrogen (N) fertilization is an important management practice for optimum production of buckwheat. Nitrogen fertilizer guidelines can be based either on the results of the soil NO_3^--N test or the consideration of the combination of expected yield, previous crop, and soil organic matter content. The soil NO_3^--N test is appropriate for western Minnesota (see Figure BW-1). When the soil NO_3^--N test is used, the fertilizer N guidelines are calculated as follows:

Nitrogen fertilizer formula

Suggested N in lb/acre = (0.0458) (EY) - STN(0-24 in.) - N_{pc}

Nitrogen formula variables

- EY = expected yield (lb/acre)
- STN = nitrate-nitrogen (NO_3^--N) measured to a depth of 24 in. (lb/acre)
- N_{pc} = amount of N supplied by the previous legume crop (lb/acre)[1].

[1]These N credits are summarized in Table BW-2 and BW-3.

The N fertilizer guidelines for production situations where the 0-24 inch soil NO_3^--N test is not used are listed in Table BW-1. For most production situations, the N fertilizers should be broadcast and incorporated before planting. The N fertilizer can be applied in either dry or liquid form. There is no research to document that one form is superior to the other.

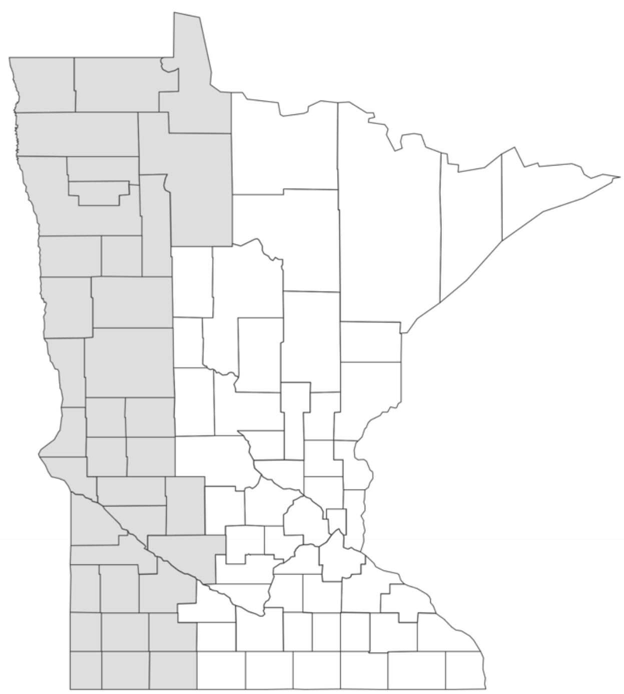

Figure BW-1. The soil nitrate test should be used for nitrogen guidelines in the counties that are shaded.

Table BW-1. Nitrogen guidelines for buckwheat in situations when the soil NO_3^--N test is not used based on expected yield of the crop in lb per acre.

Crop grown last year	Organic matter level*	1200-1450 lb/acre	1451-1700 lb/acre	1701-1950 lb/acre	1951-2200 lb/acre
Alfalfa (4+ plants/ft^2)	Low	0 lb N/acre	0 lb N/acre	0 lb N/acre	0 lb N/acre
Alfalfa (4+ plants/ft^2)	Medium/High	0	0	0	0
Soybeans or Alfalfa (1 or less plants/ft^2)	Low	0	10	20	30
Soybeans or Alfalfa (1 or less plants/ft^2)	Medium/High	0	0	0	0
Edible beans, field peas	Low	20	30	40	50
Edible beans, field peas	Medium/High	0	10	20	30
Group 1 Crops	Low	0	0	0	0
Group 1 Crops	Medium/High	0	0	0	0
Group 2 Crops	Low	40	50	60	70
Group 2 Crops	Medium/High	20	30	40	50

*low = less than 3.0%; medium and high = 3.0% or more
Crops in Group 1: Alsike clover, birdsfoot trefoil, grass/legume hay, grass legume pasture, fallow, red clover.
Crops in Group 2: Barley, buckwheat, canola, corn, grass hay, grass pasture, oat, potato, rye, sorghum-sudan, sugar beet, sunflower, sweet corn, triticale, wheat.

Table BW-2. Suggested nitrogen credits for various crops that might precede wheat in a crop rotation. Use these credits when the soil nitrate test is used

Previous crop	First year N credit lb N/acre
Soybean	20
Edible Beans, Field Peas	10
Harvested Sweet Clover	10
Harvested Alfalfa1 or non-Harvested Sweet Clover	
4-5 plants/ft2	75
2-3 plants/ft2	50
1-2 plants/ft2	25
1 or fewer plants/ft2	0
Harvested red clover	35
Sugar beet	
Yellow leaves at harvest	0
Light-green leaves at harvest	15-30
Dark-green leaves at harvest	60-80

[1]If 3rd or 4th cutting was not harvested, add 20 lb N/acre to the N credits listed.

Table BW-3. Suggested nitrogen credits when wheat is grown 2 years after a legume crop

Previous legume crop	Second year N credit lb N/acre
Alfalfa (4+ plants/ft2)	35
Non-harvested sweet clover	35
Alfalfa (2-3 plants/ft2)	25
Birdsfoot trefoil	25
Red clover	20

Phosphate and potash guidelines

The guidelines for the use of phosphate and potash are summarized in Tables BW-4 and BW-5. These fertilizers, when needed, should be broadcast and incorporated before planting. Special sources of phosphate and potash are not needed for buckwheat production. Phosphorus guidelines are given for the Bray-P1 and Olsen soil test methods. The Olsen soil test should be used in situations where soil pH is greater than 7.4.

Recommendations in Tables BW-4 and BW-5 suggest pounds of actual nutrient needed to be applied and do not reflect pounds of product that should be applied. Pounds of product to apply needs to be calculated based on the amount of nutrient suggested to be applied from Tables BW-4 and BW-5 divided by the percentage of P_2O_5 or K_2O per pound in the material to be applied. All commonly sold sources for each nutrient are equal. There is no research which suggests that nutrients other than N, P, and K are needed in a fertilizer program for buckwheat production in Minnesota**. CAUTION! Do not apply any fertilizer in contact with buckwheat seed at planting.**

Table BW-4. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for buckwheat production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected Yield Bray-P1	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Expected Yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
1200-1450 lb/acre	35 lb/acre	20 lb/acre	15 lb/acre	0 lb/acre	0 lb/acre
1200-1450 lb/acre	35	20	15	0	0
1451-1700 lb/acre	40	25	15	0	0
1701-1950 lb/acre	45	30	20	0	0
1951-2200 lb/acre	50	35	20	0	0

*Use one of the following equations if a phosphate guideline for a specific soil test and a specific expected yield is desired:

P_2O_5 rec = [0.0275 - (0.0014) (Bray P, ppm)] (Expected Yield)

P_2O_5 rec = [0.0275 - (0.0017) (Olsen P, ppm)] (Expected Yield)

Table BW-5. Potash fertilizer guidelines (lb of K_2O suggested to apply per acre) for buckwheat production based on the ammonium acetate potassium test reported in parts per million (ppm).*

Expected Yield	0-40 ppm	40-80 ppm	80-120 ppm	120-160 ppm	160+ ppm
1200-1450 lb/acre	45 lb/acre	35 lb/acre	20 lb/acre	0 lb/acre	0 lb/acre
1451-1700 lb/acre	55	40	25	0	0
1701-1950 lb/acre	60	45	25	10	0
1951-2200 lb/acre	70	50	30	10	0

*Use the following equation if a potash guideline for a specific soil test and a specific expected yield is desired.

K_2O rec = [0.0358 - (0.023) (Soil Test K, ppm)] (Expected Yield)

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NUTRIENT MANAGEMENT | CANOLA (CA) | REVISED 2023

Fertilizing Canola in Minnesota

Daniel E. Kaiser[1] and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

The canola crop has become an important part of the crop rotations in northern Minnesota. Yields have increased as improved management practices are adopted by growers. Improved fertilizer management is one major contributor to improved yields. The guidelines for improved canola production are described in the sections that follow.

Nitrogen guidelines

Nitrogen (N) fertilizer guidelines can be based either on the results of the soil NO_3^--N test or the consideration of expected yield, previous crop, and soil organic matter content. The soil NO_3^--N test is appropriate for western Minnesota (see Figure CA-2). When the soil NO_3^--N test is used, the N guidelines can be derived from the following equation:

Nitrogen fertilizer formula

Suggested N in lb/acre = (6.5) (EY) - $STN_{(0\text{-}24\ in.)}$ N_{pc}

Nitrogen formula variables

- EY = expected yield (lb/acre)
- STN = nitrate-nitrogen (NO_3^--N) measured to a depth of 24 in. (lb/acre)
- N_{pc} = amount of N supplied by the previous legume crop (lb/acre)[1].

[1]These N credits are summarized in Table CA-6.

The fertilizer guidelines for situations where the soil test is not used are listed in Table CA-1.

Phosphate and potash guidelines

The guidelines for the use of phosphate fertilizer are summarized in Table CA-2. The suggestions for potash use are in Table CA-3. The listed rates are suggested for a broadcast application.

Sulfur guidelines

The canola crop is very responsive to sulfur fertilization. When this crop is grown on heavy textured soils, a rate of 10 to 15 lb of sulfur per acre is suggested. The suggested rate increases to 20 to 30 lb of sulfur per acre when this crop is grown on sandy soils. Broadcast applications are appropriate for this crop.

Other nutrients

There is no research data to suggest that other nutrients are needed in a fertilizer program for canola production. Therefore, none are recommended. **CAUTION! Do not apply fertilizer in contact with the seed at planting.**

Table CA-1. Nitrogen guidelines for canola in situations when the soil NO_3^--N test is not used based on expected yield of the crop in lb per acre.

Crop grown last year	Organic matter level*	10-15 lb/acre yield	16-20 lb/acre yield	21-25 lb/acre yield	25+ lb/acre yield
Alfalfa (4+ plants/ft^2)	Low	0 lb N/acre	0 lb/ N/acre	0 lb N/acre	0 lb N/acre
Alfalfa (4+ plants/ft^2)	Medium/High	0	0	0	0
Alfalfa (23 plants/ft^2)	Low	0	0	0	0
Alfalfa (23 plants/ft^2)	Medium/High	0	0	0	0
Soybeans or Alfalfa (1 or less plants/ft^2)	Low	0	10	20	30
Soybeans or Alfalfa (1 or less plants/ft^2)	Medium/High	0	0	0	0
Group 1 Crops	Low	0	0	0	0
Group 1 Crops	Medium/High	0	0	0	0
Group 2 Crops	Low	40	50	60	70
Group 2 Crops	Medium/High	20	30	40	50

*low = less than 3.0%; medium/high = 3.0% or more. Crops in Group 1: Alsike clover, birdsfoot trefoil, grass/legume hay, grass legume pasture, fallow, red clover. Crops in Group 2: Barley, buckwheat, canola, corn, grass hay, grass pasture, oat, potato, rye, sorghum-sudan, sugar beet, sunflower, sweet corn, triticale, wheat.

Table CA-2. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for canola production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected Yield Bray-P1	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Expected Yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
1015 cwt./acre	40 lb/acre	25 lb/acre	15 lb/acre	0 lb/acre	0 lb/acre
1620 cwt./acre	55	40	25	0	0
2125 cwt./acre	75	50	30	10	0
25+ cwt./acre	80	55	35	10	0

*Use one of the following equations if a phosphate guideline for a specific soil test and a specific expected yield is desired:
P_2O_5 rec = [3.60 (0.17) (Bray P, ppm)] (Expected Yield) | P_2O_5 rec = [3.60 (0.22) (Olsen P, ppm)] (Expected Yield)

Table CA-3. Potash fertilizer guidelines (lb of K_2O suggested to apply per acre) for canola production based on the ammonium acetate potassium test reported in parts per million (ppm).*

Expected Yield	0-40 ppm	40-80 ppm	80-120 ppm	120-160 ppm	160+ ppm
1015 cwt./acre	60 lb/acre	40 lb/acre	25 lb/acre	0 lb/acre	0 lb/acre
1620 cwt./acre	85	60	35	10	0
2125 cwt./acre	110	80	45	15	0
25+ cwt./acre	115	85	50	15	0

*Use the following equation if a potash guideline for a specific soil test and a specific expected yield is desired.
K_2O rec = [0.0358 (0.023) (Soil Test K, ppm)] (Expected Yield)

Funding for the development of this publication is provided by Minnesota's Agricultural Fertilizer Research and Education Council (AFREC).

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Fertilizing Grass-Legume Mixtures in Minnesota

Daniel E. Kaiser[1] and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

A wide variety of grass legume mixtures are adapted to Minnesota growing conditions. These mixtures are also a special challenge for fertilizer management which should be focused on maintaining both components (grasses, legumes) of the mixture.

Nitrogen guidelines

Nitrogen fertilizer is important for maintaining the grass component of the mixture. Excessive nitrogen will stimulate the growth of grasses, which will crowd the legumes out of the mixture. Minimum rates may allow the legumes to crowd out the grasses. A rate of 60 pounds of nitrogen per acre is suggested for grass-legume mixtures. But a lesser rate or no nitrogen may be needed in some situations. Grass is more likely to need nitrogen in sandy soils or in shallow topsoil with low organic matter content in the top six inches. If nitrogen is required, it should be top-dressed to the established stands in early spring.

Phosphorus and potash guidelines

Fertilizers to supply phosphate and potash are necessary to maintain the legume component of the mixture. The suggestions for phosphate and potash use are listed in Tables GLM-1 and GLM-2. The suggested amounts should be top-dressed to established stands in early spring.

Table GLM-1. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for grass-legume mixtures production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected Yield Bray-P1	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Expected Yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
2 tons/acre	35 lb/acre	25 lb/acre	15 lb/acre	0 lb/acre	0 lb/acre
3 tons/acre	55	40	25	10	0
4 tons/acre	70	50	30	10	0
5 tons/acre	90	65	40	15	0

*Use one of the following equations if a P_20_5 recommendation for a specific yield goal is desired.

P_20_5 Rec = [20-(1.0)(Bray P, ppm)] (Yield Goal) | P_20_5 Rec = [20-(1.4)(Olsen P, ppm)] (Yield Goal)

Table GLM-2. Potash fertilizer guidelines (lb of K_2O suggested to apply per acre) for grass-legume mixtures production based on the ammonium acetate potassium (K) test reported in parts per million (ppm).*

Expected Yield	K: 0-40 ppm	K: 41-80 ppm	K: 81-120 ppm	K:121-160 ppm	K: 161+ ppm
2 tons/acre	95 lb/acre	65 lb/acre	40 lb/acre	15 lb/acre	0 lb/acre
3 tons/acre	140	100	60	20	0
4 tons/acre	185	135	80	25	0
5 tons/acre	230	165	100	35	0

* Use the following equation if a K_2O recommendation for a specific soil test value and a specific yield goal is desired.
K_2ORec = [51.2-0.299 (K Soil Test, ppm)] (Yield Goal).

Other nutrient needs

Sulfur is an important addition to a fertilizer program if alfalfa and red clover are the legumes included in the mixture. An annual application of 10-25 lb sulfur per acre is suggested if the legumes are grown on sandy soils. Use of other nutrients has not increased dry matter production of grasses and legumes used in the various mixtures. Therefore, the use of other nutrients is not suggested at this time.

Liming considerations

Maintaining a favorable soil pH is one key to maintaining legumes, especially alfalfa in the mixture. The suggested rate of lime should be broadcast and incorporated before the legumes are seeded. Use of lime will not maintain soil pH in the favorable range forever. When pH values drop into the acid range, alfalfa will probably disappear when it is mixed with grasses. Reseeding can be expensive and unless lime is incorporated, there is no way to reseed alfalfa to get a high yielding stand. Therefore, special attention to legumes other than alfalfa is suggested for soils where acid pH values are a problem. Some forage legumes are more tolerant than alfalfa to pH values in the acid range.

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Fertilizing Grasses for Hay/Pasture in Minnesota

Daniel E. Kaiser[1] and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

Several forage grasses and grass mixtures are adapted to Minnesota. As with other crops, adequate fertilizer programs are needed for optimum economic production. This is true for grasses grown for either hay or pasture.

Nitrogen guidelines

Grasses and grass mixtures, whether grown for hay or pasture, are perennial crops. Therefore, previous crop is not a consideration when making fertilizer guidelines. Nitrogen fertilizer guidelines are based on expected yield. The expected yield will vary with such factors as intended use, management intensity, and soil texture. The suggestions for each expected yield are listed in Table GHP-1. The recommendations in GHP-1 should not be used for situations where a legume is grown in combination with grass. Separate guidelines are available for grass/legume mixtures.

Table GHP-1. Nitrogen recommendations for grasses for hay and pastures.

Expected yield tons of dry matter/acre	N to apply
2 tons/acre	60 lb/acre
3 tons/acre	90
4 tons/acre	120
4+ tons/acre	150

Expected yields of 4 or more tons of dry matter per acre are reasonable for situations where soils have a good water holding capacity and intensive management practices such as the use of rotational grazing are used. Without irrigation, expected yields of 2 ton per acre are more reasonable when grasses are grown on sandy soils where moisture is usually limited. It’s not possible to assign a yield expectation for every situation in Minnesota where forage crops are grown. This is a decision for the individual managing the production of forage grasses.

The time of nitrogen fertilizer application should match the growth pattern of the forage grasses. With cool season grasses, the majority of the growth takes place in late spring and early summer. Therefore, early spring application of nitrogen is suggested for these grasses. Brome grass, orchard grass, and reed canary grass are three major cool season grasses grown in Minnesota.

Timing for warm season grasses should be different. These grasses thrive when temperatures are warm in mid-summer. Therefore, a late spring application of nitrogen is suggested. Switchgrass is an example of a warm season grass.

Split application of nitrogen fertilizer is an option for intensive management situations when expected yields are greater than 4 tons per acre. If the split application is an option, 3/4 of the nitrogen should be applied in early spring and 1/4 in late August.

Phosphorus and potash guidelines

The phosphate fertilizer guidelines are listed in Table GHP-2 while the potash fertilizer guidelines are listed in Table GHP-3. The listed rates are for all forage grasses and grass mixtures.
The needed fertilizer should be broadcast to established stands in early spring for cool season grasses, and late spring for the warm season grasses.

Table GHP-2. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for grasses for hay and pasture production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected Yield Bray-P1	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Expected Yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
2 tons/acre	40 lb/acre	30 lb/acre	20 lb/acre	10 lb/acre	0 lb/acre
3 tons/acre	50	40	30	20	0
4 tons/acre	60	50	40	30	0
4+ tons/acre	70	60	50	40	0

*Use one of the following equations if a P_20_5 recommendation for a specific yield goal is desired.
P_20_5 Rec = [19.12-(.723)(Bray P, ppm)] (Yield Goal) | P_20_5 Rec = [19.12-(1.012)(Olsen P, ppm)] (Yield Goal)

Table GLM-3. Potash fertilizer guidelines (lb of K_2O suggested to apply per acre) for hay and pastures production based on the ammonium acetate potassium (K) test reported in parts per million (ppm).*

Expected Yield	K: 0-40 ppm	K: 41-80 ppm	K: 81-120 ppm	K:121-160 ppm	K: 161+ ppm
2 tons/acre	90 lb/acre	60 lb/acre	30 lb/acre	0 lb/acre	0 lb/acre
3 tons/acre	100	70	40	10	0
4 tons/acre	110	80	50	20	0
4+ tons/acre	120	90	60	30	0

* Use the following equation if a K_2O recommendation for a specific soil test value and a specific yield goal is desired.
K_2ORec = [40.43-(.0286)(K Soil Test, ppm)] (Expected Yield Goal).

Other nutrient needs

Research trials in Minnesota have shown that forage grasses and grass mixtures have not responded to the application to other nutrients in a fertilizer program. Therefore, none are suggested.

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Fertilizing Millet in Minnesota

Daniel E. Kaiser[1] and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

Millet is important in some farm enterprises in Minnesota. Fertilizer is an important production input for optimum yields. Recommendations for nitrogen, phosphate, and potash are summarized in the tables that follow.

Nitrogen guidelines

Nitrogen (N) fertilizer guidelines can be based on the results of the soil NO_3^--N test or the consideration of the combination of expected yield, previous crop, and soil organic matter content. The soil nitrate test is appropriate for western Minnesota (see Figure MI-1).

When the soil nitrate test is used, the fertilizer N guidelines are calculated as follows.

Nitrogen fertilizer formula

Suggested N in lb/acre = (0.035) (EY) - $STN_{(0\text{-}24\ in.)}$ - N_{pc}

Nitrogen formula variables

- EY = expected yield (lb/acre)
- STN = nitrate-nitrogen (NO_3^--N) measured to a depth of 24 in. (lb/acre)
- N_{pc} = amount of N supplied by the previous legume crop (lb/acre)[1].

[1]These N credits are summarized in Table MI-2 and MI-3.

The N fertilizer guidelines for production situations where the 0-24 inch soil NO_3^--N test is not used are listed in Table MI-1. For most production situations, the N fertilizers should be broadcast and incorporated before planting. The N fertilizer can be applied in either dry or liquid form. There is no research to document that one form is superior to the other.

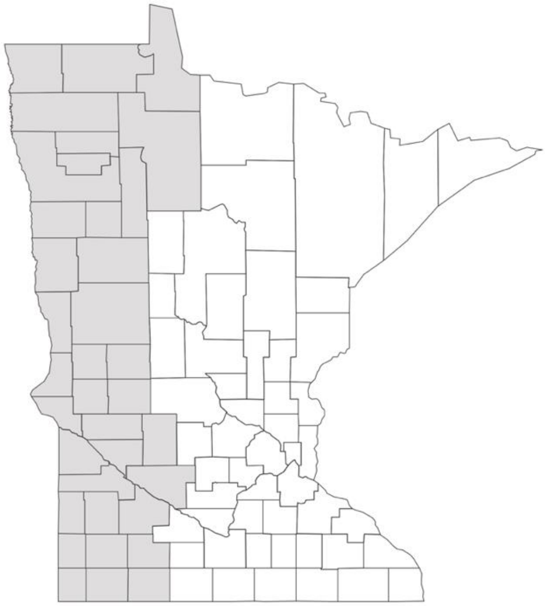

Figure MI-1. The soil nitrate test should be used for nitrogen guidelines in the counties that are shaded.

Table MI-1. Nitrogen guidelines for millet in situations when the soil NO_3^--N test is not used based on expected yield of the crop in lb per acre.

Crop grown last year	Organic matter level*	1500-1900 lb/acre	1901-2300 lb/acre	2301-2700 lb/acre	2701-3000 lb/acre	3000+ lb/acre
Alfalfa (4+ plants/ft^2)	Low	0 lb N/acre	0 lb N/acre	0 lb N/acre	0 lb N/acre	0 lb N/acre
Alfalfa (4+ plants/ft^2)	Medium/High	0	0	0	0	0
Alfalfa (2-3 plants/ft^2)	Medium/High	0	0	0	20	40
Alfalfa (2-3 plants/ft^2)	Medium/High	0	0	0	0	20
Soybeans or Alfalfa (1 or less plants/ft^2)	Low	0	10	20	40	60
Soybeans or Alfalfa (1 or less plants/ft^2)	Medium/High	0	0	0	20	40
Edible beans, field peas	Low	20	30	40	60	80
Edible beans, field peas	Medium/High	0	10	20	40	60
Group 1 Crops	Low	0	0	0	0	25
Group 1 Crops	Medium/High	0	0	0	0	0
Group 2 Crops	Low	40	50	60	80	100
Group 2 Crops	Medium/High	20	30	40	60	80

*low = less than 3.0%; medium and high = 3.0% or more. Crops in Group 1: Alsike clover, birdsfoot trefoil, grass/legume hay, grass legume pasture, fallow, red clover. Crops in Group 2: Barley, buckwheat, canola, corn, grass hay, grass pasture, oat, potato, rye, sorghum-sudan, sugar beet, sunflower, sweet corn, triticale, wheat.

Table MI-2. Suggested nitrogen credits for various crops that might precede millet in a crop rotation. Use these credits when the soil nitrate test is used

Previous crop	First year N credit
Soybean	20 lb N/acre
Edible Beans, Field Peas	10
Harvested Sweet Clover	10
Harvested Alfalfa1 or non-Harvested Sweet Clover	
4-5 plants/ft^2	75
2-3 plants/ft^2	50
1-2 plants/ft^2	25
1 or fewer plants/ft^2	0
Harvested red clover	35
Sugar beet	
Yellow leaves at harvest	0
Light-green leaves at harvest	15-30
Dark-green leaves at harvest	60-80

[1]If 3rd or 4th cutting was not harvested, add 20 lb N/acre to the N credits listed.

Table MI-3. Suggested nitrogen credits when millet is grown 2 years after a legume crop.

Previous legume crop	Second year N credit
Alfalfa (4+ plants/ft^2)	35 lb N/acre
Non-harvested sweet clover	35
Alfalfa (2-3 plants/ft^2)	25
Birdsfoot trefoil	25
Red clover	20

Phosphate and potash guidelines

Current phosphate guidelines are summarized in Table MI-4. Guidelines for potash are in Table MI-5. The guidelines listed in these tables are intended for broadcast application. The sensitivity of this crop to banded application of fertilizers is not known.

CAUTION! Do not apply N as urea (46-0-0) in contact with the seed at planting. Do not apply ammonium thiosulfate (12-0-0- 26) or boron in contact with the seed.

Table MI-4. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for millet production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected Yield Bray-P1	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Expected Yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
1500-1900 lb/acre	25 lb/acre	20 lb/acre	10 lb/acre	0 lb/acre	0 lb/acre
1901-2300 lb/acre	30	25	15	0	0
2301-2700 lb/acre	40	25	15	0	0
2701-3100 lb/acre	45	30	20	0	0
3100+ lb/acre	45	35	20	0	0

*Use one of the following equations if a phosphate guideline for a specific soil test and a specific expected yield is desired:

P_2O_5rec = [0.0171 - (0.0085) (Bray P, ppm)] (Expected Yield)

P_2O_5rec = [0.0171 - (0.00114) (Olsen P, ppm)] (Expected Yield)

Table MI-5. Potash fertilizer guidelines (lb of K_2O suggested to apply per acre) for millet production based on the ammonium acetate potassium test reported in parts per million (ppm).*

Expected Yield	0-40 ppm	41-80 ppm	81-120 ppm	121-160 ppm	160+ ppm
1500-1900 lb/acre	45 lb/acre	35 lb/acre	20 lb/acre	10 lb/acre	0 lb/acre
1901-2300 lb/acre	55	40	25	10	0
2301-2700 lb/acre	65	50	30	10	0
2701-3100 lb/acre	75	55	35	15	0
3100+ lb/acre	80	60	40	15	0

*Use the following equation if a potash guideline for a specific soil test and a specific expected yield is desired.

K_2O rec = [0.03 - (0.00018) (Soil Test K, ppm)] (Expected Yield)

Other nutrients

There is no research evidence which suggests that sulfur and micronutrients are needed for optimum production of millet. Therefore, there is no suggestion to add these nutrients to a fertilizer program.

Funding for the development of this publication is provided by Minnesota's Agricultural Fertilizer Research and Education Council (AFREC).

UNIVERSITY OF MINNESOTA EXTENSION

Fertilizing Oat in Minnesota

Daniel E. Kaiser[1] and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

In Minnesota, the oat crop is used for either grain and straw or as a nurse crop for seeding legumes. The recommendations in the tables that follow are intended for situations where the crop is grown for grain and straw.

Nitrogen guidelines

Nitrogen (N) fertilizer guidelines can be based on the results of the soil NO_3^--N test or the consideration of the combination of expected yield, previous crop, and soil organic matter content. The soil nitrate test is appropriate for western Minnesota (see Figure OAT-1).

When the soil nitrate test is used, the fertilizer N guidelines are calculated as follows.

Nitrogen fertilizer formula

Suggested N in lb/acre = (1.3) (EY) - $STN_{(0\text{-}24\ in.)}$ - N_{pc}

Nitrogen formula variables

- EY = expected yield (lb/acre)
- STN = nitrate-nitrogen (NO_3^--N) measured to a depth of 24 in. (lb/acre)
- N_{pc} = amount of N supplied by the previous legume crop (lb/acre)[1].

[1]These N credits are summarized in Table OAT-2 and OAT-3.

The N fertilizer guidelines for production situations where the 0-24 inch soil NO_3^--N test is not used are listed in Table OAT-1. Nitrogen, when needed, can be supplied from several sources. If applied in a way to prevent loss, all sources of nitrogen have an equal effect on yield. When using either dry or liquid sources, the fertilizer N can be broadcast and incorporated before planting. If anhydrous ammonia is the preferred source, this N fertilizer can be knifed in before planting.

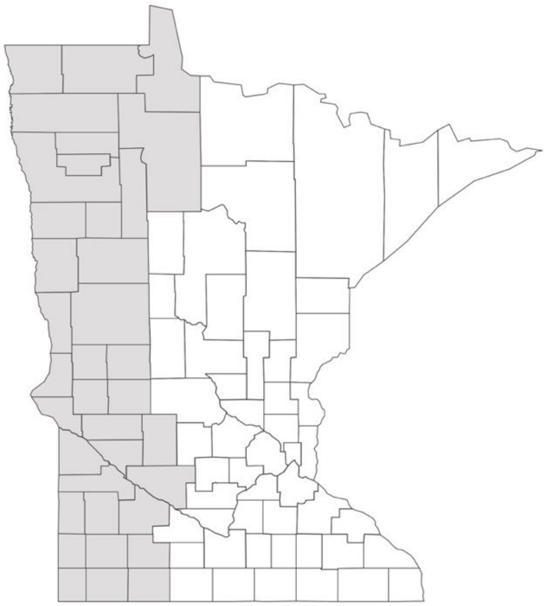

Figure OAT-1. The soil nitrate test should be used for nitrogen guidelines in the counties that are shaded.

Table OAT-1. Nitrogen guidelines for oat in situations when the soil NO_3^--N test is not used based on expected yield of the crop in bushels per acre.

Crop grown last year	Organic matter level*	40-60 by/acre	61-80 by/acre	81-100 by/acre	101-120 by/acre	120+ by/acre
Alfalfa (4+ plants/ft^2)	Low	0 lb N/acre	0 lb N/acre	0 lb N/acre	0 lb N/acre	0 lb N/acre
Alfalfa (4+ plants/ft^2)	Medium/High	0	0	0	0	0
Alfalfa (2-3 plants/ft^2)	Medium/High	0	0	20	40	60
Alfalfa (2-3 plants/ft^2)	Medium/High	0	0	10	30	50
Soybeans or Alfalfa (1 or less plants/ft^2)	Low	0	20	40	60	80
Soybeans or Alfalfa (1 or less plants/ft^2)	Medium/High	0	0	30	50	70
Edible beans, field peas	Low	20	40	60	80	100
Edible beans, field peas	Medium/High	10	30	50	70	90
Group 1 Crops	Low	0	0	0	25	45
Group 1 Crops	Medium/High	0	0	0	15	35
Group 2 Crops	Low	40	60	80	100	120
Group 2 Crops	Medium/High	30	50	70	90	110

*low = less than 3.0%; medium and high = 3.0% or more. Crops in Group 1: Alsike clover, birdsfoot trefoil, grass/legume hay, grass legume pasture, fallow, red clover. Crops in Group 2: Barley, buckwheat, canola, corn, grass hay, grass pasture, oat, potato, rye, sorghum-sudan, sugar beet, sunflower, sweet corn, triticale, wheat.

Table OAT-2. Suggested nitrogen credits for various crops that might precede wheat in a crop rotation. Use these credits when the soil nitrate test is used

Previous crop	First year N credit lb N/acre
Soybean	20
Edible Beans, Field Peas	10
Harvested Sweet Clover	10
Harvested Alfalfa1 or non-Harvested Sweet Clover	
4-5 plants/ft^2	75
2-3 plants/ft^2	50
1-2 plants/ft^2	25
1 or fewer plants/ft^2	0
Harvested red clover	35
Sugar beet	
Yellow leaves at harvest	0
Light-green leaves at harvest	15-30
Dark-green leaves at harvest	60-80

[1]If 3rd or 4th cutting was not harvested, add 20 lb N/acre to the N credits listed.

Table OAT-3. Suggested nitrogen credits when wheat is grown 2 years after a legume crop

Previous legume crop	Second year N credit lb N/acre
Alfalfa (4+ plants/ft^2)	35
Non-harvested sweet clover	35
Alfalfa (2-3 plants/ft^2)	25
Birdsfoot trefoil	25
Red clover	20

Phosphate and potash guidelines

Current phosphate guidelines are summarized in Table OAT-4. Guidelines for potash are in Table OAT-5. The rates listed are appropriate for both broadcast and banded (drill applied) application. There is no research evidence with this crop to suggest that the banded placement is more efficient than a broadcast application.

CAUTION! Do not apply more than 20 lb N per acre as urea (46-0-0) with the drill. Do not place ammonium thiosulfate (12-0-0- 26) in direct contact with the seed. Do not place fertilizers containing boron in direct contact with the seed.

Table OAT-4. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for oat production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected Yield Bray-P1	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Expected Yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
40-60 bu/acre	30 lb/acre	20 lb/acre	10 lb/acre	0 lb/acre	0 lb/acre
61-80 bu/acre	40	30	15	0	0
81-100 bu/acre	50	35	20	0	0
101-120 bu/acre	60	45	25	10	0
121+ bu/acre	70	50	30	10	0

*Use one of the following equations if a phosphate guideline for a specific soil test and a specific expected yield is desired:

P_2O_5 rec = [0.644 - (0.032) (Bray P, ppm)] (Expected Yield)

P_2O_5 rec = [0.644 - (0.041) (Olsen P, ppm)] (Expected Yield)

Table OAT-5. Potash fertilizer guidelines (lb of K_2O suggested to apply per acre) for oat production based on the ammonium acetate potassium test reported in parts per million (ppm).*

Expected Yield	0-40 ppm	41-80 ppm	81-120 ppm	121-160 ppm	160+ ppm
40-60 bu/acre	55 lb/acre	40 lb/acre	20 lb/acre	10 lb/acre	0 lb/acre
61-80 bu/acre	75	55	30	0	0
81-100 bu/acre	95	70	40	0	0
101-120 bu/acre	115	85	45	10	0
121+ bu/acre	130	90	50	10	0

*Use the following equation if a potash guideline for a specific soil test and a specific expected yield is desired.

K_2O rec = [1.277 - (0.00086) (Soil Test K, ppm)] (Expected Yield)

Other nutrients

Except for the need for sulfur (S) when this crop is grown on sandy soils, other nutrients are not needed in a fertilizer program. For production on sandy soils, either use 10-12 lb S/acre with the drill at planting or broadcast 25 lb S/acre and incorporate before planting.

Funding for the development of this publication is provided by Minnesota's Agricultural Fertilizer Research and Education Council (AFREC).

Fertilizing Processing Pea in Minnesota

Daniel E. Kaiser[1] Carl J. Rosen[1], and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

Lime needs

Managing pH can be important for legume crops that form symbiotic relationships with rhizobium bacteria that fix nitrogen for the plant. Lime is suggested for pea when the water pH of the soil is less than 6.0. The buffer index is used to determine how much limestone is required to raise the pH of the soil to 6.0. Liming recommendations to raise the soil pH to 6.0 are given at the end of this booklet in the chapter Lime Needs for Minnesota (LN).

Nitrogen guidelines

Pea grown for processing or canning purposes are primarily grown in the Southern part of Minnesota in areas where a pre-plant soil nitrate test is not suggested for use. Pea are a legume crop where nitrogen is supplied to the plant through a symbiotic relationship between rhizobium bacteria and the plant roots. Inoculation is suggested if the site has not had a history of pea production. Supplemental nitrogen should not be required in most cases. Nitrogen fertilizer needs are summarized in Table PEA-1 and are based on previous crop grown, soil organic matter concentration in the top six inches, and expected crop yield. A single application of nitrogen prior to planting is sufficient if conditions exist where a response to N is more likely.

Table PEA-1. Nitrogen guidelines for processing/canning pea in situations when the soil NO_3^--N test is not used based on expected yield of the crop in lb/acre.

Crop grown last year	Organic matter level*	<1000 lb/acre	1000-1999 lb/acre	2000-3999 lb/acre	>4000 lb/acre
Alfalfa (4+ plants/ft^2)	Low	0 lb N/acre	0 lb N/acre	0 lb N/acre	0 lb N/acre
Alfalfa (4+ plants/ft^2)	Medium/High	0	0	0	0
Soybeans or Field Pea (1 or less plants/ft^2)	Low	0	0	10	20
Soybeans or Field Pea (1 or less plants/ft^2)	Medium/High	0	0	0	0
Group 1 Crops	Low	0	0	0	10
Group 1 Crops	Medium/High	0	0	0	0
Group 2 Crops	Low	0	10	20	40
Group 2 Crops	Medium/High	0	0	10	20

*low = less than 3.1%; medium and high = 3.1% or more. Crops in Group 1: Alsike clover, birdsfoot trefoil, grass/legume hay, grass legume pasture, fallow, red clover. Crops in Group 2: Barley, buckwheat, canola, corn, grass hay, grass pasture, oat, potato, rye, sorghum-sudan, sugar beet, sunflower, sweet corn, triticale, wheat.

Phosphate and potash guidelines

When deficient, phosphorus and potassium can limit the yield of pea in Minnesota. Guidelines for broadcast applications of phosphorus and potassium are based on the soil test level for a six-inch soil sample and expected yield of the crop. Specific guidelines for phosphorus are given in Table PEA-2 based on two soil test methods. The Bray-P1 test is most accurate for situations where soil pH is 7.4 or less. If soil pH is 7.5 or greater then the Olsen P test should be utilized to determine fertilizer requirements. Potassium guidelines are given in Table PEA-3.

Table PEA-2. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for pea production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected Yield Bray-P1	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Expected Yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
0-999 lb/acre	25 lb/acre	15 lb/acre	0 lb/acre	0 lb/acre	0 lb/acre
1000-1999 lb/acre	50	25	15	0	0
2000-3999 lb/acre	75	50	25	15	0
4000 or more lb/acre	100	75	50	25	0

*Use one of the following equations if a phosphate guideline for a specific soil test and a specific expected yield is desired:

P_2O_5 rec = [0.034 - (0.0017) (Bray P, ppm)] (Expected Yield)

P_2O_5 rec = [0.033 - (0.0021) (Olsen P, ppm)] (Expected Yield)

Table PEA-3. Potash fertilizer guidelines (lb of K_2O suggested to apply per acre) for pea production based on the ammonium acetate potassium test reported in parts per million (ppm).*

Expected Yield	0-40 ppm	41-80 ppm	81-120 ppm	121-160 ppm	160+ ppm
0-999 lb/acre	25 lb/acre	15 lb/acre	0 lb/acre	0 lb/acre	0 lb/acre
1000-1999 lb/acre	50	25	15	0	0
2000-3999 lb/acre	75	50	25	15	0
4000 or more lb/acre	100	75	50	25	0

*Use the following equation if a potash guideline for a specific soil test and a specific expected yield is desired.

K_2O rec = [0.034 - (0.0002) (Soil Test K, ppm)] (Expected Yield)

Other nutrients

There has been no research demonstrating the need for the application of other secondary macronutrient fertilizers such as calcium, magnesium, or sulfur for pea production. Application of micronutrients such as boron, copper, iron, manganese, and zinc is not likely to increase pea yield in Minnesota.

Funding for the development of this publication is provided by Minnesota's Agricultural Fertilizer Research and Education Council (AFREC).

Fertilizing Red Clover, Alsike Clover and Birdsfoot Trefoil in Minnesota

Daniel E. Kaiser[1] and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

Nitrogen guidelines

These legume crops, if properly inoculated, can take needed nitrogen from the atmosphere and fertilizer N will not be needed after the crop is established. A small amount (less than 25 lb N/acre) may aid in establishment on sandy soils. Nitrogen fertilizer will not be needed for establishment on soils that are not sandy.

Lime requirements

These legumes will respond to the application of lime if the soil pH is less than 6.0. Lime suggestions for these crops have not been well defined. An application of 3,000 lb. ENP per acre is suggested for these legumes grown on acid soils. The lime should be broadcast and incorporated before seeding.

Phosphate and potash guidelines

The phosphate suggestions for these crops are summarized in Table CL-1. The potash guidelines are in Table CL-2. Phosphate and/or potash fertilizers can be top-dressed to established stands on an annual basis. The suggested rates of these two nutrients can also be broadcast and incorporated before seeding. This management practice may help in achieving a satisfactory stand.

Table CL-1. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for red clover, alsike clover and birdsfoot trefoil production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected Yield Bray-P1	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Expected Yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
2 tons/acre	35 lb/acre	25 lb/acre	15 lb/acre	0 lb/acre	0 lb/acre
3 tons/acre	55	40	25	10	0
4 tons/acre	70	50	30	10	0
5 tons/acre	90	65	40	15	0

*Use one of the following equations if a phosphate guideline for a specific soil test and a specific expected yield is desired:

P_2O_5 rec = [20 - (1.0) (Bray P, ppm)] (Expected Yield)

P_2O_5 rec = [20 - (1.4) (Olsen P, ppm)] (Expected Yield)

Table CL-2. Potash fertilizer guidelines (lb of K_2O suggested to apply per acre) for red clover, alsike clover and birdsfoot trefoil production based on the ammonium acetate potassium test reported in parts per million (ppm).*

Expected Yield	0-40 ppm	41-80 ppm	81-120 ppm	121-160 ppm	160+ ppm
2 tons/acre	95 lb/acre	65 lb/acre	40 lb/acre	15 lb/acre	0 lb/acre
3 tons/acre	140	100	60	20	0
4 tons/acre	185	135	80	25	0
5 tons/acre	230	165	100	35	0

*Use the following equation if a potash guideline for a specific soil test and a specific expected yield is desired.

K_2O rec = [52.38 - (0.333) (Soil Test K, ppm)] (Expected Yield)

Other nutrients

Except for the need for sulfur (S) when these crops are grown on sandy soils, other nutrients are not needed in a fertilizer program. Use an annual broadcast application of 25 lb S per acre when these crops are grown on sandy soils. An application of 10-15 lb of S may be needed when these crops are grown on medium to fine textured soils when the soil organic matter concentration in the top 6-8 inches is 3.0% or less.

Funding for the development of this publication is provided by Minnesota's Agricultural Fertilizer Research and Education Council (AFREC).

UNIVERSITY OF MINNESOTA EXTENSION

Fertilizing Rye in Minnesota

Daniel E. Kaiser[1] and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

Although the number of acres planted to this crop is not large, it remains a major component of some farm enterprises in Minnesota. This is a favorite crop used in rotation for those who farm sandy soils that are not irrigated. Fertilizer use is a major factor in attaining profitable yields.

Nitrogen guidelines

The majority of this crop is grown on sandy soils. Since the soil test for NO_3^--N is **NOT** suggested for use on sandy soils, guidelines for nitrogen use are based on a consideration of expected yield, previous crop, and soil organic matter content. Those guidelines are summarized in Table RYE-1.

The topdress application to established stands in early spring is suggested. There is no need for the use of split applications.

Table RYE-1. Nitrogen guidelines for rye in situations when the soil NO_3^--N test is not used based on expected yield of the crop in lb per acre.

Crop grown last year	Organic matter level*	40-49 bu/acre	50-59 bu/acre	60-69 bu/acre	70-79 bu/acre	80= bu/acre
Alfalfa (4+ plants/ft^2)	Low	0 lb N/acre	0 lb N/acre	0 lb N/acre	0 lb N/acre	0 lb N/acre
Alfalfa (4+ plants/ft^2)	Medium/High	0	0	0	40	75
Alfalfa (2-3 plants/ft^2)	Medium/High	0	0	40	65	90
Alfalfa (2-3 plants/ft^2)	Medium/High	0	0	20	45	70
Soybeans or Alfalfa (1 or less plants/ft^2)	Low	40	65	90	115	140
Soybeans or Alfalfa (1 or less plants/ft^2)	Medium/High	20	45	70	95	120
Edible beans, field peas	Low	50	75	100	125	150
Edible beans, field peas	Medium/High	30	55	80	105	130
Group 1 Crops	Low	0	35	60	85	110
Group 1 Crops	Medium/High	0	0	40	65	90
Group 2 Crops	Low	60	85	110	135	160
Group 2 Crops	Medium/High	40	65	90	115	140

*low = less than 3.0%; medium and high = 3.0% or more. Crops in Group 1: Alsike clover, birdsfoot trefoil, grass/legume hay, grass legume pasture, fallow, red clover. Crops in Group 2: Barley, buckwheat, canola, corn, grass hay, grass pasture, oat, potato, rye, sorghum-sudan, sugar beet, sunflower, sweet corn, triticale, wheat.

Phosphate and potash guidelines

Current phosphate guidelines are summarized in Table RYE-2. Guidelines for potash are in Table RYE-3. The suggested rates of phosphate and potash should be broadcast and incorporated before planting.

Table RYE-2. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for rye production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected Yield Bray-P1	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Expected Yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
40-49 bushels/acre	40 lb/acre	30 lb/acre	15 lb/acre	0 lb/acre	0 lb/acre
50-59 bushels/acre	50	35	20	0	0
60-69 bushels/acre	60	45	20	0	0
70-79 bushels/acre	70	50	25	0	0
80+ bushels/acre	80	55	25	0	0

*Use one of the following equations if a phosphate guideline for a specific soil test and a specific expected yield is desired:

P_2O_5rec = [1.071 - (0.054) (Bray P, ppm)] (Expected Yield)

P_2O_5rec = [1.071 - (0.087) (Olsen P, ppm)] (Expected Yield)

Table RYE-3. Potash fertilizer guidelines (lb of K_2O suggested to apply per acre) for rye production based on the ammonium acetate potassium test reported in parts per million (ppm).*

Expected Yield	0-40 ppm	41-80 ppm	81-120 ppm	121-160 ppm	160+ ppm
40-49 bushels/acre	100 lb/acre	75 lb/acre	45 lb/acre	0 lb/acre	0 lb/acre
50-59 bushels/acre	130	95	55	0	0
60-69 bushels/acre	155	110	65	0	0
70-79 bushels/acre	180	125	75	0	0
80+ bushels/acre	190	135	80	0	0

*Use the following equation if a potash guideline for a specific soil test and a specific expected yield is desired.

K_2O rec = [2.710 - (0.017) (Soil Test K, ppm)] (Expected Yield)

Other nutrients

Use of other nutrients in a fertilizer program has not increased rye yields in Minnesota. Therefore, use of other nutrients is not suggested at this time.

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University of Minnesota Extension

Fertilizing Sunflower in Minnesota

Daniel E. Kaiser[1] and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

Nitrogen guidelines

Sunflower is highly responsive to nitrogen (N) and rates of nitrogen should be adjusted for the type of sunflower grown. Suggested nitrogen fertilizer rates are no longer based on yield goals minus N fertilizer credits, as recent data has not shown a link between the yield of sunflower and N fertilizer requirements.

Table SF-1. Total known available N (lb/acre) for oilseed sunflower in situations based on N cost and sunflower harvest price. Total known available N includes soil test N to 2 feet, previous crop credit and fertilizer amendment N rate.

Sunflower Seed Price Per Pound Harvested	N use @ $.20/lb	N use @ $.30/lb	N use @ $.40/lb	N use @ $.50/lb	N use @ $.60/lb	N use @ $.70/lb	N use @ $.80/lb	N use @ $.90/lb	N use @ $1/lb
$0.09/lb	150 lb	135 lb	124 lb	111 lb	96 lb	84 lb	72 lb	59 lb	47 lb
$0.12	150	145	135	125	116	106	96	87	78
$0.15	150	150	143	135	127	119	112	104	96
$0.18	150	150	148	141	135	128	126	115	109
$0.21	150	150	150	146	141	135	129	124	118
$0.24	150	150	150	150	145	140	135	130	125
$0.27	150	150	150	150	148	144	139	135	131
$0.30	150	150	150	150	150	147	143	139	135
$0.33	150	150	150	150	150	150	150	150	138
$0.36	150	150	150	150	150	150	150	150	142
$0.39	150	150	150	150	150	150	150	150	144
$0.42	150	150	150	150	150	150	150	150	146
$0.45	150	150	150	150	150	150	150	150	148
$0.48	150	150	150	150	150	150	150	150	150
$0.51	150	150	150	150	150	150	150	150	150
$0.55	150	150	150	150	150	150	150	150	150
$0.60	150	150	150	150	150	150	150	150	150

* Chart adapted from NDSU Extension Publication SF713.

Table SF-2. Total known available N (lb/acre) for confection sunflower in situations based on N cost and sunflower harvest price. Total known available N includes soil test N to 2 feet, previous crop credit and fertilizer amendment N rate.

Sunflower Seed Price Per Pound Harvested	N use @ $.20/lb	N use @ $.30/lb	N use @ $.40/lb	N use @ $.50/lb	N use @ $.60/lb	N use @ $.70/lb	N use @ $.80/lb	N use @ $.90/lb	N use @ $1/lb
$0.09/lb	160 lb	107 lb	43 lb	0 lb	0 lb	0 lb	0 lb	0 lb	0 lb
$0.12	160	155	107	59	11	0	0	0	0
$0.15	160	160	145	107	69	30	0	0	0
$0.18	160	160	160	139	107	75	43	11	0
$0.21	160	160	160	160	134	107	79	52	25
$0.24	160	160	160	160	155	131	107	83	59
$0.27	160	160	160	160	160	149	128	107	86
$0.30	160	160	160	160	160	160	145	126	107
$0.33	160	160	160	160	160	160	160	142	139
$0.36	160	160	160	160	160	160	160	155	151
$0.39	160	160	160	160	160	160	160	160	160
$0.42	160	160	160	160	160	160	160	160	160
$0.45	160	160	160	160	160	160	160	160	160
$0.48	160	160	160	160	160	160	160	160	160
$0.51	160	160	160	160	160	160	160	160	160
$0.55	160	160	160	160	160	160	160	160	160
$0.60	160	160	160	160	160	160	160	160	160

* Chart adapted from NDSU Extension Publication SF713.

Recommended N Fertilizer Rates

Recommended rates of N should be based on the value of the sunflower seed in price per harvested pound and the unit price per lb of N applied. The suggested rate of N also varies based on the type of sunflower grown. Nitrogen suggestions for oilseed sunflower are given in Table SF-1. Suggestions for confection sunflower production are given in Table SF-2. These suggested guidelines are based on suggestions for sunflower grown under conventional tillage for Eastern North Dakota which has similar climate and soils as Northwest Minnesota.

The N rates suggested in Tables SF-1 and SF-2 include all known sources of N including the amount of Nitrate-N in a two-foot soil sample and any N credits from previous crops. Sampling for Nitrate-N is suggested, and samples can be collected in the fall after the previous crop has been harvested. Suggested first and second year N credits are listed in Tables SF-3 and SF-4.

An interactive version of the sunflower N calculator can be found at:
https://www.ndsu.edu/pubweb/soils/sunflower/

Table SF-3. Suggested nitrogen credits for various crops that might precede sunflower in a crop rotation. Use these credits when the soil nitrate test is used.

Previous crop	First year N credit lb N/acre
Soybean	20
Edible Beans, Field Peas	10
Harvested Sweet Clover	10
Harvested Alfalfa1 or Non-Harvested Sweet Clover	
4-5 plants/ft2	75
2-3 plants/ft2	50
1-2 plants/ft2	25
1 or fewer plants/ft2	0
Harvested Red Clover	35
Sugarbeet	
Yellow leaves at harvest	0
Light-green leaves at harvest	15-30
Dark-green leaves at harvest	60-80

[1]If 3rd or 4th cutting was not harvested, add 20 lb N/acre to the N credits listed.

Table SF-4. Suggested nitrogen credits when sunflower is grown 2 years after a legume crop.

Previous legume crop	Second year N credit lb N/acre
Alfalfa (4+ plants/ft2)	35
Non-harvested sweet clover	35
Alfalfa (2-3 plants/ft2)	25
Birdsfoot trefoil	25
Red clover	20

Phosphate and potash guidelines

Current phosphate guidelines are summarized in Table SF-5. Guidelines for potash are in Table SF-6.

Table SF-5. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for sunflower production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected Yield Bray-P1	0-5 ppm	6-10 ppm	11-15 ppm	16-20 ppm	21+ ppm
Expected Yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12-15 ppm	16+ ppm
1400-1900 lb/acre	55 lb/acre	35 lb/acre	15 lb/acre	0 lb/acre	0 lb/acre
1901-2400 lb/acre	65	45	20	0	0
2401-2900 lb/acre	75	55	25	0	0
2901-3300 lb/acre	85	65	25	10	0
3300+ lb/acre	90	70	30	10	0

*Use one of the following equations if a phosphate guideline for a specific soil test and a specific expected yield is desired:
$P_2O_5rec = [0.0225 - (0.0011) (\text{Bray P, ppm})] (\text{Expected Yield})$
$P_2O_5rec = [0.0225 - (0.0014) (\text{Olsen P, ppm})] (\text{Expected Yield})$

Table SF-6. Potash fertilizer guidelines (lb of K_2O suggested to apply per acre) for sunflower production based on the ammonium acetate potassium test reported in parts per million (ppm).*

Expected Yield	0-40 ppm	41-80 ppm	81-120 ppm	121-160 ppm	161+ ppm
1400-1900 lb/acre	55 lb/acre	40 lb/acre	20 lb/acre	10 lb/acre	0 lb/acre
1901-2400 lb/acre	75	50	30	15	0
2401-2900 lb/acre	90	65	35	20	0
2901-3300 lb/acre	110	75	40	25	0
3301+ lb/acre	115	80	45	25	0

*Use the following equation if a potash guideline for a specific soil test and a specific expected yield is desired.

K_2O rec = [0.0410 - (0.00027) (Soil Test K, ppm)] (Expected Yield)

CAUTION! Do not apply more than 10 lb N + K_2O per acre in contact with the seed for medium to fine textured soils. Starter fertilizer placed on the seed is not suggested for sandy textured soils.

Other nutrients

Research trials conducted in Minnesota have shown that most secondary macronutrients and micronutrients are not needed in a fertilizer program for sunflower production.

The need for sulfur (S) for sunflower has not been evaluated in Minnesota. The likelihood of sulfur deficiency on soils high in clay content (loam soils or heavier) is low if soil organic matter content is 2-3% or greater in the top six inches. The likelihood of a S deficiency is greater for sandy textured soils low in organic matter. If a sulfur deficiency is anticipated an application of 10 lb of S in the sulfate form at or before planting or post emergence before the R1 growth stage may be required. Application of a sulfate or thiosulfate form is suggested.

Do not place ammonium thiosulfate (12-0-0-26) in direct contact with the seed. Do not place fertilizers containing boron in direct contact with the seed.

Other Resources

NDSU Fertilizing Sunflower Guide:
z.umn.edu/NDSUsunflower

Funding for the development of this publication is provided by Minnesota's Agricultural Fertilizer Research and Education Council (AFREC).

Fertilizing Wild Rice in Minnesota

Daniel E. Kaiser[1] and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

Nitrogen guidelines

Wild rice paddies are very different from upland fields. Nitrate-N build up in groundwater caused by over fertilization is not a problem. Most N losses occur by the process of denitrification that produces N_2, which makes up 78% of the atmosphere.
Dry urea, liquid ammonium fertilizers, or anhydrous ammonia are appropriate sources of N. Nitrate fertilizers are ineffective because of denitrification upon flooding.

Basal N is often applied in the fall. To maximize carryover of N to the following spring, application of basal N should be followed by flooding within 2 or 3 days. Fall flooding prevents oxidation of the ammonium forms of N to nitrate and the subsequent losses caused by denitrification when flooding occurs. When fall application is desired, but flooding is not possible, application should be made when soil temperatures are well below 50ºF, preferably as close to freezing as possible.

Basal N can also be applied in the spring immediately before flooding. Both spring and fall N should be incorporated to minimize losses by the nitrification/denitrification process in the surface soil that can result in N losses. See Table WR-1 for N rates.

Table WR-1. Nitrogen applications for wild rice production, based on soil type.

Type of soil	Amount N to apply (lb/acre)
Organic soil	25-40 lb N/acre
Mineral soil	70-100 lb N/acre

A minimum of one top-dress application of 30-40 lb/ac of N as urea, applied by aircraft, is necessary for high yields. A second top-dress is typically needed to maximize yields. A third application may be needed if no basal N was applied or basal N was lost by nitrification followed by denitrification. Drainage of paddy water should not occur for about 5 days after N application.

Field testing in mid-June for soil ammonium N can be used to guide topdressing decisions. The SPAD chlorophyll meter or a color chart are also useful aids in determining the timing and number top-dress applications.

Phosphorus

Phosphorus in paddies can move into surface waters both in the soluble form and as part of soil particles (by soil erosion). When phosphorus is surface applied, it can dissolve in paddy waters causing algal blooms. Incorporation of P fertilizer is very highly recommended and erosion from ditches, etc. should be minimized to prevent phosphorus from entering drainage waters.

Phosphorus can be applied in the fall or spring. It must be incorporated by plow down or injection. The rate of application should be determined by soil testing. When the Bray P 1 test exceeds 16 ppm, do not apply P. See Table WR-2. If it is not possible to incorporate P it is best not to add any phosphorus fertilizer. The reserve P in the soil will normally be sufficient for good plant growth.

Table WR-2. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for wild rice production based on the Bray-P1 soil methods test reported in parts per million (ppm).*

Bray-P1 test results	0-7 ppm	8-15 ppm	16+ ppm
Organic or Mineral soils	40-50 lb/acre	20-30 lb/acre	0 lb/acre

Potassium

Potassium is required by wild rice both for high yield potential as well as helping in protection against some diseases. Potassium at the levels applied to wild rice paddies is not an environmental concern. Potassium can be applied in the fall or spring. Usually, it is applied with the phosphorus, but, unlike phosphorus, incorporation of K is a necessity. See Table WR-3 for rates. Application of potassium with the top-dress N is possible. This increases the late season uptake of K and might help prevent some diseases.

Table CA-3. Potash fertilizer guidelines (lb of K_2O suggested to apply per acre) for wild rice production based on the ammonium acetate potassium test reported in parts per million (ppm).*

Test results	0-50 ppm	51-100 ppm	101-150 ppm	151+ ppm
Organic soils	120 lb/acre	90 lb/acre	40 lb/acre	0 lb/acre
Mineral soils	80 lb/acre	50 lb/acre	30 lb/acre	0 lb/acre

Water drainage before harvest

Nitrogen in the water can be detected in wild rice fields for 3 to 5 days after fertilization but at drainage time most nutrients in the water have been consumed the plants. However, to avoid erosion of drainage ditches, the water should be released slowly during a one-to-two-week period before harvest. The soil particles from erosion can carry phosphorus, in addition to the any soluble P, into surface waters. Drainage ditches should be stabilized with grasses if possible.

Funding for the development of this publication is provided by Minnesota's Agricultural Fertilizer Research and Education Council (AFREC).

University of Minnesota Extension

Fertilizing Wildlife Food Plots in Minnesota

Daniel E. Kaiser[1] and Keith Piotrowski[2]

[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

Soil pH and liming guidelines

Maintaining an optimum soil pH can be critical for the growth and development of many crops. Legumes such as alfalfa and alsike clover require higher soil pH levels than other crops. Liming guidelines are given in Table WFP-1. Many soils where food plots are established have a history of forest vegetation. These soils tend to have low soil pH levels. In these cases, a soil test will typically indicate a need for lime application. Since liming a soil requires 2 to 3 tons of material per acre, consideration must be given to determine whether it is feasible to haul and apply lime to areas where food plots are established. Grasses and red clover will typically grow well when soil pH is less than 6.0. Selecting tolerant plant species is critical. Since most crops for wildlife food plots are not grown for maximum yield, liming rates could be reduced or eliminated. If equipment is available for lime application, lime should be applied prior to establishment when it can be incorporated. If lime can be applied, it is suggested that enough should be broadcasted to raise the pH of the soil to 6.0.

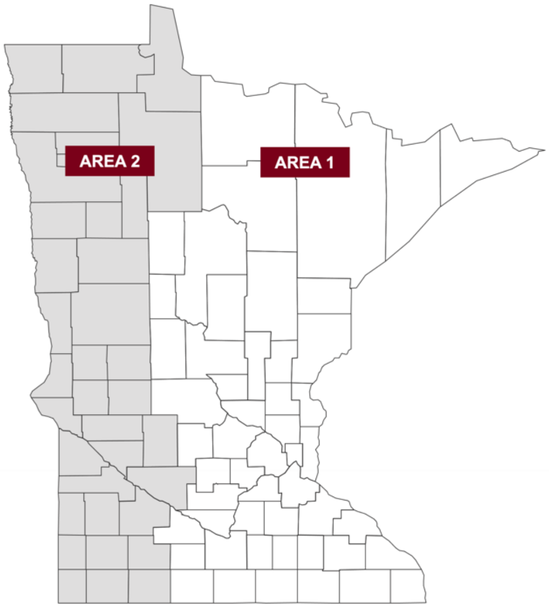

Figure ALF-1. In Area 1, most subsoils are acid. In Area 2, few subsoils are acid.

Table WFP-1. Lime suggestions for mineral soils when the soil pH is less than 6.0. The rates suggested should raise the pH to 6.0.

Buffer index	Area 1: ENP lb/acre	Area 1: Ag Lime* ton/acre	Area 2: ENP lb/acre	Area 2: Ag Lime* ton/acre
6.8	2000	2.0	0	0
6.7	2000	2.0	0	0
6.6	2000	2.0	0	0
6.5	2500	2.5	0	0
6.4	3000	3.0	2000	2.0
6.3	3500	3.5	2000	2.0
6.2	4000	4.0	2000	2.0
6.1	4500	4.5	2000	2.0
6.0	5000	5.0	2500	2.5

*These are approximate suggestions based on the average ENP value of Ag lime. An ENP of 1,000 lb per ton is an average value for Ag lime (crushed limestone) in Minnesota.

Nitrogen management

Optimum nitrogen management is critical not only to increase plant growth but also to maintain plant establishment on a year to year basis. Legumes, such as well nodulated alfalfa and clover, can produce enough nitrogen to satisfy the plants requirements. Plants such as grasses do not produce their own nitrogen, so fertilizer nitrogen should be applied under these circumstances. Nitrogen can be applied in a single surface application at or prior to rapid plant growth periods. The full recommended nitrogen rate may not be needed. The amount will depend on the time of planting and amount growth desired from the plants. For late plantings, nitrogen rates can be cut back considerably. A minimum rate of 30 lb of N is suggested for maintaining stand with a maximum application of no more than 60 lb of N.

Phosphorus and potassium

Current phosphate guidelines are listed in WFP-2 for separate food plot plant mixtures. Guidelines for potash use are in WFP-3. The rates listed are appropriate for broadcast application. Current research on P and K management in food plots is limited. However, if a crop is not harvested, P and K taken up by the plants will be recycled for the next season's use and therefore not lost through the removal of crop material. Current guidelines for individual crops consider maximum economic yield. For wildlife food plots, it is suggested that rates be reduced for individual crops since economic yield is not a consideration.

Table WFP-2. Phosphate fertilizer guidelines (lb of P_2O_5 suggested to apply per acre) for wildlife food plots production based on either the Bray-P1 or Olsen soil methods test reported in parts per million (ppm).*

Expected yield Bray P1	0-5 ppm	6-10 ppm	11-15 ppm	16+ ppm
Expected yield Olsen	0-3 ppm	4-7 ppm	8-11 ppm	12+ ppm
Corn/Forage Brassicas	25 lb/acre	20 lb/acre	15 lb/acre	0 lb/acre
Grass	25	20	15	0
Legume/Grass	35	25	15	0
Oat/wheat/rye	35	25	15	0
Soybean	30	15	0	0
Sugarbeet/Turnip	35	25	15	0

*No phosphate fertilizer is suggested if the soil test for P is greater than 16 ppm (Bray) or 12 ppm (Olsen).

Table WFP-2. Table ALF-4. Potash guidelines (lb K_2O/acre) for wildlife food plots production in Minnesota based on K soil test reported in parts per million.

K soil test result	0-40 ppm	41-80 ppm	81-120 ppm	121+ ppm
Corn/Forage Brassicas	60 lb/acre	40 lb/acre	25 lb/acre	0 lb/acre
Grass	40	30	20	0
Legume/Grass	40	30	20	0
Oat/wheat/rye	40	30	20	0
Soybean	60	40	25	0
Sugarbeet/Turnip	40	30	20	0

*No potash fertilizer is suggested if the soil test for K is 121 ppm or greater.

Secondary and micronutrients guidelines

For most crops grown in wildlife food plots secondary or micronutrients should not be needed for optimal growth. In sandy soils a small amount of sulfur may be needed for legume and grass mixtures. In these cases 10-15 lb sulfur per acre should be applied with the nitrogen application. Some nitrogen can be substituted with ammonium sulfate (21% N and 24% S) to provide sulfur for the plants. Gypsum can be surface applied to supply needed sulfur however gypsum DOES NOT have a liming effect on the soil.

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Lime Needs in Minnesota

Daniel E. Kaiser[1], Carl J. Rosen[1], and Keith Piotrowski[2]
[1]Extension nutrient management specialist [2]Director of Soil Testing Laboratory

The importance of lime

When needed, liming materials are major inputs for crop production enterprises in Minnesota. When soils are acid, there are many benefits from liming. Liming to a pH of 6.0 to 6.5 or higher provides an ideal environment for bacteria in soils. Some of these bacteria actively participate in the' breakdown of soil organic matter. Others form nodules on the roots of legumes. With this bacterial partnership, legumes can utilize the nitrogen in the air and no fertilizer nitrogen is needed.

The availability of phosphorus is also affected by soil pH. So, liming to a pH of 6.0 to 6.5 also increases the supply of soil phosphorus available to plants. Most soils in Minnesota contain ample calcium (Ca) for crop growth. Liming materials are generally not used to supply Ca, but depending on source, may be used to supply magnesium (Mg).

Determining the need for lime

The need for lime is not uniform across Minnesota and recommendations will vary. Analyzing a soil sample for pH and buffer pH is the only way to arrive at an accurate lime recommendation. Soils should be sampled to a depth of 6 to 8 inches for this test. The recommendations will not be accurate if other sampling depths are used.

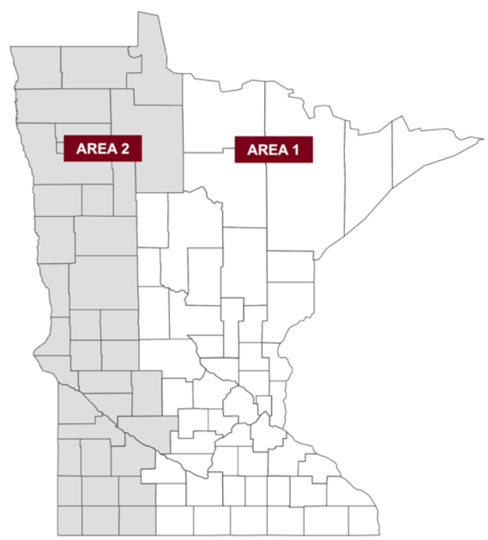

Figure LN-1. In Area 1, most subsoils are acid. In Area 2, few subsoils are acid.

After the soil sample reaches the laboratory and is dried, a pH reading is taken in a mixture of equal parts of soil and water. This value is referred to as the soil pH. If the soil pH reading is less than 6.0, a buffer solution is added to the soil/water mixture and another pH reading is taken. This second reading is referred to as the buffer pH and is used to determine the amount of lime to apply. The current buffer used at the University of Minnesota is called the Sikora Buffer. The pH of the buffer itself is 7.5. When it is added to an acid soil, the pH of the buffer will drop. The change in the pH of the buffer is directly related to the amount of lime needed.

The buffer pH is not determined on soils with a soil pH of 6.0 or higher. The relative error of using the buffer is too high in this soil pH range. For these soils, standard recommendations are used to raise the soil pH to 6.5. Lime guidelines for Minnesota are summarized in Tables LN-1 to LN-4. The area of the state must also be considered when these recommendations are used (see map Figure LN-1). The same pH is not required for optimum growth of all crops. Crops grown in Minnesota are divided into three groups. These groups are as follows:

Table LN-1. Lime suggestions for mineral soils when the soil pH is less than 6.0. The rates suggested should raise the pH to 6.0.

Sikora Buffer Index	Area 1 ENP	Area 1 Ag Lime*	Area 2 ENP	Area 2 Ag Lime*
6.8	2000 lb/acre	2.0 tons/acre	0 lb/acre	0 tons/acre
6.7	2000	2.0	0	0
6.6	2000	2.0	0	0
6.5	2500	2.5	0	0
6.4	3000	3.0	2000	2.0
6.3	3500	3.5	2000	2.0
6.2	4000	4.0	2000	2.0
6.1	4500	4.5	2000	2.0
6.0	5000	5.0	2500	2.5
5.9	5500	5.5	2500	2.5
5.8	6000	6.0	3000	3.0
5.7	6500	6.5	3000	3.0
5.6	7000	7.0	3500	3.5

**These are approximate suggestions based on the average ENP value of ag lime. An ENP of 1,000 lb per ton is an average value for ag lime (crushed limestone) in Minnesota.*

Table LN-2. Lime suggestions for mineral soils when the soil pH is less than 6.0. The rates suggested should raise the pH to 6.5.

Sikora Buffer Index	Area 1 ENP	Area 1 Ag Lime*	Area 2 ENP	Area 2 Ag Lime*
6.8	3000 lb/acre	3.0 tons/acre	2000 lb/acre	2 tons/acre
6.7	3500	3.5	2000	2.0
6.6	4000	4.0	2000	2.0
6.5	4500	4.5	2000	2.0
6.4	5000	5.0	2500	2.5
6.3	5500	5.5	2500	2.5
6.2	6000	6.0	3000	3.0
6.1	6500	6.5	3000	3.0
6.0	7000	7.0	3500	3.5
5.9	7500	7.5	3500	3.5
5.8	8000	8.0	4000	4.0
5.7	8500	8.5	4000	4.0
5.6	9000	9.0	4500	4.5

*These are approximate suggestions based on the average ENP value of ag lime. An ENP of 1,000 lb per ton is an average value for ag lime (crushed limestone) in Minnesota.

Table LN-3. Lime suggestions for mineral soils when the Sikora Buffer Test is NOT used (soil pH is 6.0 or greater). The rates suggested should raise the pH to 6.5.

Soil Water pH	Area 1 ENP	Area 1 Ag Lime*	Area 2 ENP	Area 2 Ag Lime*
6.5	0 lb/acre	0 tons/acre	0 lb/acre	0 tons/acre
6.4	2000	2.0	0	0
6.3	2000	2.0	0	0
6.2	3000	3.0	0	0
6.1	3000	3.0	0	0
6.0	3000	3.0	2000	2.0

*These are approximate suggestions based on the average ENP value of ag lime. An ENP of 1,000 lb per ton is an average value for ag lime (crushed limestone) in Minnesota.

Table LN-4. Lime suggestions for organic soils. The rates suggested should raise the pH to 5.5.

Soil Water pH	Area 1 ENP	Area 1 Ag Lime*	Area 2 ENP	Area 2 Ag Lime*
5.4	2000 lb/acre	2.0 tons/acre	2000 lb/acre	2.0 tons/acre
5.3	2000	2.0	2000	2.0
5.2	2000	2.0	2000	2.0
5.1	2000	2.0	2000	2.0
5.0	2000	2.0	2000	2.0
4.9	3000	3.0	3000	3.0
4.8	3500	3.5	3500	3.5
4.7	4000	4.0	4000	4.0
4.6	4500	4.5	4500	4.5
4.5 or less	5000	5.0	5000	5.0

*These are approximate suggestions based on the average ENP value of ag lime. An ENP of 1,000 lb per ton is an average value for ag lime (crushed limestone) in Minnesota.

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UMN Extension Nutrient Management

Events

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Editor

Daniel E. Kaiser, Soil and Plant Nutrient Management Extension Specialist. dekaiser@umn.edu

UMN Extension Nutrient Management

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