Nutrient Management for Commercial Fruit & Vegetable Crops in Minnesota

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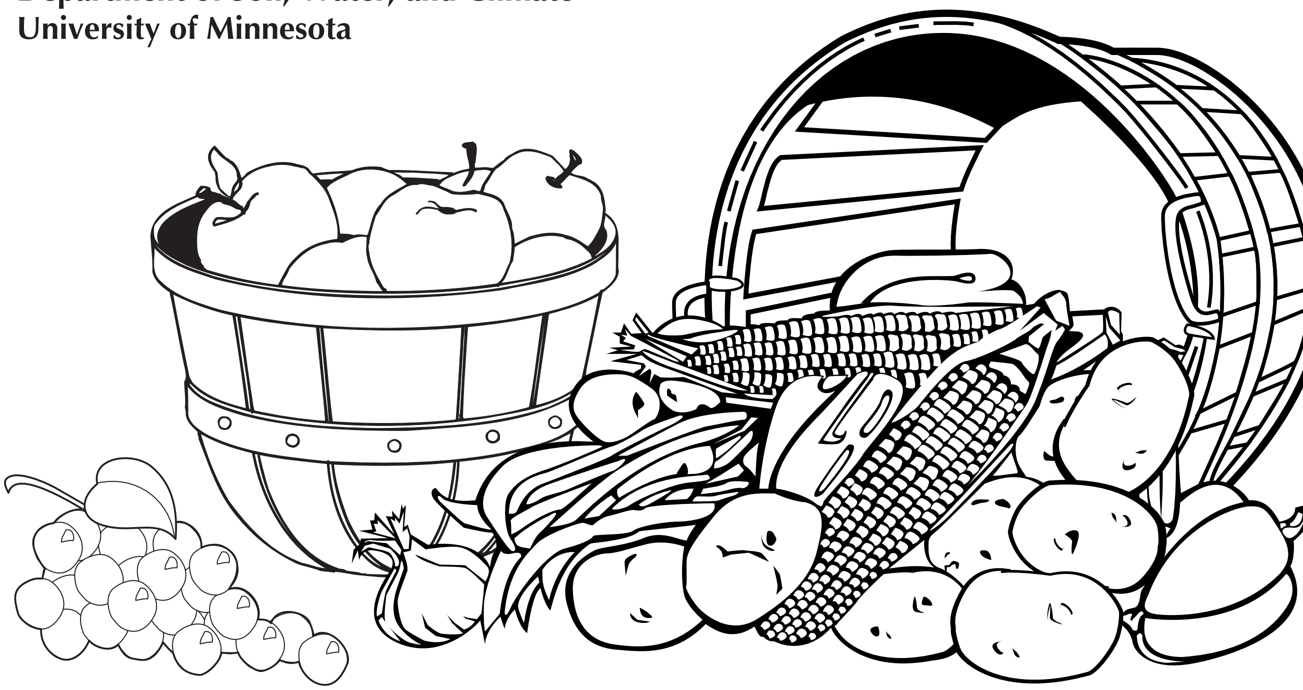

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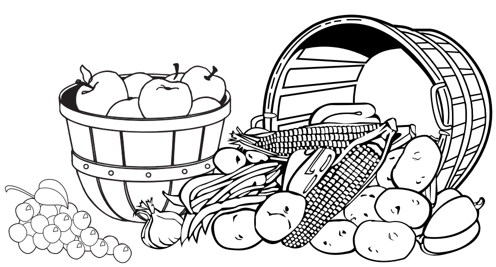
Introduction

There are 17 essential nutrients required for plant growth: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), chlorine (Cl) and nickel (Ni). Of these 17, all except carbon, hydrogen, and oxygen are derived from the soil. When the soil cannot supply the level of nutrient required for adequate growth, supplemental fertilizer applications become necessary.

Recommendations for fertilizing fruit and vegetable crops in Minnesota are based in part on soil test results. Soil testing provides information on lime and fertilizer needs prior to planting and is particularly well calibrated for nutrients such as phosphorus, potassium, magnesium, calcium, sulfur, zinc, and boron. Soil testing prior to planting takes the guesswork out of making fertilizer recommendations and leads to more efficient nutrient management. Fertilizer recommendations in this bulletin are intended for field-grown fruit and vegetable crops. For container-grown crops, such as transplants or vegetables grown in the greenhouse in pots, different soil tests should be used. Contact the University of Minnesota Soil Testing Laboratory (612-625-3101), for the appropriate form to fill out for container-grown crops or check online at http://soiltest.coafes.umn.edu/

For fertilizer requirements of established perennial crops and for fine-tuning fertilizer needs of annual crops, a combination of soil testing and tissue analysis should be used.



Taking a Soil Sample

Proper interpretation of soil test results for making fertilizer recommendations is dependent on collecting a representative sample. The procedure for taking a meaningful soil sample is summarized below.

Soil samples can be collected any time of the year, although spring and fall sampling are usually the most convenient. If soil test results from a given field are to be compared over the years, it is best that samples be collected at the same time of year.

Each field to be sampled should be divided into uniform areas. Each area should have the same soil texture and color, cropping history, and fertilizer, manure, and lime treatments. One sample should not represent more than 20 acres on a level uniform field, or 5 acres on hilly or rolling land. Samples are most easily collected using a soil tube, soil auger, or a garden spade. To take the soil sample, scrape off all surface residue and litter and take the sample to a depth of 6-8 inches for annual crops and 10-12 inches for perennial crops. Usually 15 to 20 subsamples (one core per subsample) should be collected from randomly selected areas in the field. The soil should be thoroughly mixed in a clean plastic pail and about 1 pint of this mixture should be placed in a sample bag or box.

Samples can be sent directly to the University of Minnesota Soil Testing Laboratory, 135 Crops Research Building, 1902 Dudley Ave., St. Paul, MN 55108. Sample submission forms and other soil testing information can be obtained from: http://soiltest.coafes.umn.edu/

A number of private laboratories also offer soil testing services. Contact your Regional Extension Office or fertilizer dealer for information about commercial laboratories in your area or look in the yellow pages of your phone book under "laboratories."

The nitrate test on a 0- to 2-foot soil sample can be used for nitrogen recommendations for selected crops grown in western Minnesota on nonirrigated soils. For more information on the nitrate test, refer to the section on nitrogen (**page 13**).

Interpreting a Soil Test

A soil test value for all nutrients except nitrate-nitrogen is an ***index*** of the availability of that nutrient to plants in the soil being tested. The University of Minnesota Soil Testing Laboratory reports soil test results as parts per million (ppm) and should be thought of as an index of the relative level. Older soil tests reported relative nutrient levels as lb/A; however, this unit was confusing since many incorrectly interpreted the result as actual lb of nutrient in the soil when in fact it only represented a small fraction of the total nutrient in the soil. To convert an older soil test reading of lb/A to ppm, divide lb/A by two.

The probability of response to applied fertilizer can conceptually be determined from relative soil test levels. As shown in **Table 1**, the higher the soil test level, the lower the probability of response to applied fertilizer. Conversely, a low soil test level would have a high probability of response to applied fertilizer.

Table 1. *Generalized relationship between relative soil test level and probability of response to applied fertilizer.*

Relative Soil Test Level	Probability of Response to Applied Fertilizer
low	greater than 90%
medium	60 to 90%
medium-high	30 to 60%
high	10 to 30%
very high	less than 10%

In contrast to the other nutrients, nitrate-nitrogen is expressed as lb/A when sampled to a 2-foot depth since it is a measure of the actual amount of nitrate-nitrogen present in the soil rooting zone at the time of sampling. Samples taken to other depths are reported as ppm and the nitrate test result is not then used in making the nitrogen recommendation.

Fertilizer Analyses and Calculating Fertilizer Rates

By convention, fertilizer phosphorus and potassium are expressed on the oxide basis, P_2O_5 and K_2O, respectively. In contrast, fertilizer nitrogen is expressed on the elemental basis, N. Minnesota state law requires that any material sold as fertilizer clearly shows the percent nitrogen expressed as N, percent phosphate expressed as P_2O_5, and percent potash expressed as K_2O on the bag. The percentages of each nutrient on the fertilizer label are referred to as the grade of fertilizer and are guaranteed by the manufacturer. All fertilizer recommendations are based on the amount of N, P_2O_5, and K_2O to apply per given area (usually per acre). Fertilizers can be sold as complete fertilizers, i.e., they contain all three primary nutrients—nitrogen, phosphorus, and potassium—such as 10-10-10, or they can be sold as single nutrient fertilizers such as 46-0-0 (only N), 0-0-60 (only K_2O), etc.

To determine the actual amount of nutrient in a given weight of fertilizer, multiply the percentage of nutrient by the weight of fertilizer and then divide by 100. For example, to determine the amount of actual nitrogen in 200 lb of urea (46-0-0): 200 X 46/100 = 92 lb of N. If 200 lb of 8-32-16 is applied per acre, then the total nutrients applied would be 16 lb N, 64 lb P_2O_5, and 32 lb K_2O.

If the fertilizer recommendation calls for a given amount of nutrient per acre, then to calculate the amount of fertilizer to apply, divide the recommended amount by the percent nutrient (fraction basis) in the fertilizer. For example, if the recommendation calls for 150 lb N per acre, and urea (46-0-0) is the fertilizer that will be used, the total amount of urea to apply per acre would be 150/0.46 = 326 lb urea per acre. If ammonium nitrate (33-0-0) is used, then 150/0.33 = 454 lb ammonium nitrate per acre would be required. Similar calculations can be made for phosphate and potash fertilizers.

Soil pH Modification

Soil pH is an important chemical property that affects nutrient availability and microbial activity. In general, the optimum pH for most fruit and vegetable crops is between 5.8 and 7.0 for mineral soils and 5.4 and 6.2 for organic soils (peats and mucks). Two exceptions are blueberries and potatoes. Blueberries are adapted to acid soil conditions and grow best at a soil pH between 4.5 and 5.2. Potatoes can tolerate a wide range in soil pH; however, potato scab can become more of a problem in scab-susceptible varieties as soil pH increases above 5.3.

Liming

Liming materials are used to increase the pH of soils. Not all soils in Minnesota need to be limed. In general, soils in the western part of the state were formed from limestone rocks and receive lower amounts of rainfall. Soils formed under these conditions have a high native pH. Many soils in eastern Minnesota were formed under conditions of higher rainfall and tend to be acidic. Intensive cropping and continuous use of manure and/or ammonium based fertilizers will acidify soils over time. In contrast, if high pH irrigation water is used on acid soils, soil pH may actually increase over time.

The need for lime is determined from a routine soil test. The pH value reported in a soil test indicates whether lime is needed, but cannot be used to determine how much lime is needed. The amount of lime to apply is dependent on reserve soil acidity, which is measured in the laboratory by the "buffer index" or SMP buffer test. The lower the buffer index, the more lime is required. In most cases, buffer index is related to soil texture and organic matter content. At the same soil pH value, soils with a high clay and organic matter content will require more lime than soils with a high sand and low organic matter content. The difference in lime application rates is determined by the SMP buffer index (**Table 2**). The SMP buffer test is not used if the soil pH is higher than 5.9 because of the high relative error above this level. The amount of lime recommended for mineral soils is that needed to raise the pH to 6.0 or 6.5. For peat and muck soils with a soil-water pH of 5.4 or less, lime is recommended to raise the pH to 5.5.

The amount of lime to apply is dependent on the type or quality of the liming material. The quality of a limestone is

Table 2. Lime recommendations expressed on an effective neutralizing power (ENP) and ag lime basis.

Where SMP buffer applies (soil-water pH values less than 6.0)	To raise pH to 6.0 for 6-inch plow depth[1]				To raise pH to 6.5 for 6-inch plow depth[1]			
	Area 1[2]		Area 2		Area 1[2]		Area 2	
Mineral Soils SMP buffer index	ENP[3] to apply (lb/A)	Ag lime[4] to apply (tons/A)	ENP to apply (lb/A)	Ag lime to apply (tons/A)	ENP to apply (lb/A)	Ag lime to apply (tons/A)	ENP to apply (lb/A)	Ag lime to apply (tons/A)
6.8	2000	2.0	0	0	3000	3.0	2000	2.0
6.7	2000	2.0	0	0	3000	3.0	2000	2.0
6.6	2000	2.0	0	0	4000	4.0	2000	2.0
6.5	2500	2.5	0	0	4500	4.5	2000	2.0
6.4	3000	3.0	2000	2.0	5000	5.0	2500	2.5
6.3	3500	3.5	2000	2.0	6000	5.5	2500	2.5
6.2	4000	4.0	2000	2.0	6500	6.5	3000	3.0
6.1	4500	4.5	2000	2.0	6500	6.5	3000	3.0
6.0	5000	5.0	2500	2.5	7000	7.0	3500	3.5
5.9	6000	6.0	2500	2.5	7500	7.5	3500	3.5
5.8	6500	6.5	3000	3.0	8000	8.0	4000	4.0
5.7	7000	7.0	3000	3.0	8500	8.5	4000	4.0
5.6	7500	7.5	3500	3.5	9000	9.0	4500	4.5
Where SMP buffer does not apply (soil-water pH values of 6.0 & higher)								
Mineral Soils **Soil-water pH**								
6.5					0	0	0	0
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

Organic Soils (peats and mucks)	To raise pH to 5.5 for 6-inch plow depth[1]			
Soil-water pH	Area 1[2]		Area 2	
5.4	2000	2.0	2000	2.0
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	3000	3.0	3000	3.0
4.7	4000	4.0	4000	4.0
4.6	4000	4.0	4000	4.0
4.5 or less	5000	5.0	5000	5.0

[1] *For 9 inch plow depth, multiply rates by 1.5.*

[2] *Refer to* **Figure 1**.

[3] *To obtain tons of liming material to apply per acre, divide the ENP value given in the table by the actual ENP analysis value provided by the ag lime dealer or lime producer.*

[4] *Ag lime recommendation is based on a liming material having a value of 1000 lb ENP per ton. This value is typical of that for lime from a Minnesota quarry.*

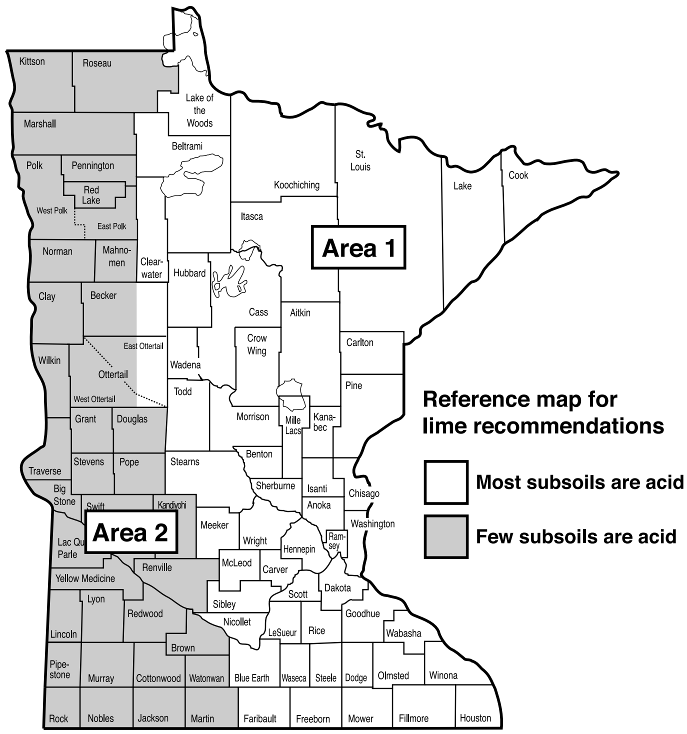


Figure 1. *Reference map for use in making lime recommendations.*

based on its calcium carbonate equivalent (CCE) and particle size. The higher the CCE, the greater the liming potential. The smaller the particle size, the faster it will react with the soil to raise pH. The effective neutralizing power (ENP) takes into account the fineness factor, CCE, and percent dry matter. The ENP can be thought of as a way to compare one lime source to another for effectiveness, similar to the way a comparison between fertilizers is made. For example, recommendations for nitrogen are based on the amount of actual N required and not on how much of a product like ammonium nitrate or urea is needed. There are many different liming materials sold in Minnesota; ENP simply provides a means to compare the effectiveness of these different sources.

By law, all liming materials sold in Minnesota must have the pounds of ENP per ton of lime provided by the ag lime dealer or lime producer at the time of purchase. Liming recommendations are based on the pounds of ENP to apply per acre. To determine how much of a particular liming material per acre is required, divide the ENP value given in the soil test report by the actual ENP analysis value provided by the ag lime dealer or lime producer. **Table 2** gives recommendations in both pounds of ENP per acre and tons of a typical ag lime per acre. Using the ENP method of calculating the rate of lime to apply will be more accurate than using the amount of typical ag lime to apply.

Agricultural limestone is the most common material used for liming. Limestone consists of either calcium carbonate (calcitic limestone) or calcium/magnesium carbonate (dolomitic limestone). In Minnesota, dolomitic limestone is usually the most economical form to apply and is particularly beneficial on low magnesium testing soils. Other liming sources include various waste products such as sugarbeet lime, water treatment lime, wood ash, and other industrial by-products. When considering the use of these sources, be sure that particle size and CCE (ENP), impurities, water content, and cost are taken into account. For further information on liming materials, see FS-05957, *Liming Materials for Minnesota Soils,* available online at: http://www.extension.umn.edu/distribution/cropsystems/DC5957.html.

Most agricultural lime takes several months to react with the soil and should be applied and incorporated to a depth of 6 inches, 6 months to 1 year before planting. Moisture is required for the neutralizing reaction with little change in pH occurring in a dry soil. An application of agricultural lime at recommended rates usually lasts 3 to 5 years. Fine lime (smaller than 60 mesh) takes only a few weeks to react with the soil and can be applied and incorporated the spring of planting. Fine lime is usually applied at lower rates, but has to be applied more often.

For apples and asparagus, lime is recommended to increase soil pH to 6.5 if the soil pH is 6.4 or less. For all other fruit and vegetable crops except blueberries and potatoes, lime applications are recommended to increase the soil pH to 6.0 if the soil pH is 5.7 or less.

When lime is recommended in western Minnesota (**Figure 1**) where subsoils tend to be very alkaline, the amount of lime to apply is half that recommended for a soil with the same SMP buffer test in eastern Minnesota.

Soil Acidification

Lowering soil pH is generally only practical and economical for blueberry production. Optimum soil pH for blueberries is 4.5-5.2. To lower soil pH to 4.5, use **Table 3** to determine the amount of finely ground elemental sulfur required. Elemental sulfur may take several months to react with the soil and

Table 3*.* *Rates of elemental sulfur required to lower soil pH to 4.5 for a 6 inch plow depth.*

	Amount of Elemental Sulfur to Apply			
Initial pH	**Sand, loamy sand, sandy loam[1]**		**loam, silt loam[1]**	
	lb/100 sq ft	lb/A	lb/100sq ft	lb/A
7.0	1.9	800	5.8	2500
6.5	1.5	650	4.6	2000
6.0	1.2	525	3.5	1500
5.5	0.8	350	2.4	1000
5.0	0.4	170	1.2	500

[1] *Sand, loamy sand, sandy loam = coarse-textured soil; loam, silt loam = medium-textured soil.*

Table 4. Relative soluble salt sensitivity levels.

mmhos/cm[1]	Description	Effect on crops
0 to 2	non-saline	none
2.1 to 4	very slightly saline	sensitive crops restricted
4.1 to 8	moderately saline	many crops restricted
8.1 to 16	strongly saline	most crops restricted
more than 16	very strongly saline	few plants tolerant

[1] *Based on saturated paste extract.*

therefore should be applied 1 year before planting. Test the pH of the soil 3 to 4 months after the initial application. If the soil pH is not in the desired range, reapply according to **Table 3**. In situations where irrigation water contains lime, additional annual applications of 300-400 lb/A elemental sulfur may be necessary to maintain pH in the desired range. Iron sulfate can also be used to acidify soils. This material reacts much faster than elemental sulfur, usually within 3 to 4 weeks. Multiply the rate of elemental sulfur recommended by 7 to determine the rate of iron sulfate needed. For high rates of iron sulfate, split applications are recommended. **Do not** apply more than 2 tons per acre of iron sulfate at a time. Use of ammonium sulfate as the nitrogen source will also help in maintaining a low soil pH. **Caution**—do not use more ammonium sulfate than that required for meeting the nitrogen requirements. Too much nitrogen can cause excessive vegetative growth, and may increase the potential for winter injury and reduce fruit quality. High lime soils with a pH greater than about 7.3 require higher rates of acidifying amendments and are not recommended for commercial blueberry production.

Soluble Salts (electrical conductivity)

The term *soluble salts* refers to the inorganic soil constituents (ions) that are dissolved in the soil water. Pure water is a very poor conductor of electric current, whereas water containing dissolved salts conducts current approximately in proportion to the amount of salt present. Thus, the measurement of the electrical conductivity of a soil extract gives an indication of the total concentration of salts. The electrical conductivity measurement is reported in millimhos per centimeter (mmhos/cm). Crops differ in their sensitivity to soluble salts. High soluble salts can restrict root growth, cause burning of the foliage, and limit crop yields. The relative values for soluble salt sensitivity levels are described in **Table 4.**

Most soils in Minnesota are nonsaline (0 to 2 mmhos/cm); however, a few soils in western Minnesota have formed under high sodium/alkaline conditions and may be high in soluble salts. Other conditions where soluble salts may limit plant growth are when fertilizers are overapplied or placed too close to the roots.

The relative salt tolerance of various fruit and vegetable crops is presented in **Table 5.**

Organic and Inorganic Fertilizers

Plant roots absorb the majority of their nutrients from the soil solution in the ionic (inorganic charged) form. Larger molecules can also be absorbed by roots, but their rate of absorption is slow. Thus, if a fertilizer (organic or inorganic) is applied, it must first be broken down to its simplest forms to be used efficiently by plants.

According to the Minnesota Department of Agriculture, a natural organic fertilizer has to be derived from either plant or animal materials containing one or more elements (other than carbon, oxygen, and hydrogen) that are essential for plant growth. Organic food production, however, allows for a broader definition that includes naturally occurring inorganic substances such as elemental sulfur and gypsum, and naturally occurring mineral materials that are not chemically modified.

Table 5. Soluble salt test[1] values and relative salt tolerance of fruit and vegetable crops.

0-2 mmhos/cm* Nontolerant	3-4 mmhos/cm* Slightly Tolerant	5-7 mmhos/cm* Moderately Tolerant	8-16 mmhos/cm* Tolerant
blueberries	apples	broccoli	asparagus
carrots	cabbage	beets, table	Swiss chard
green beans	celery	cucumbers	
onions	grapes	muskmelons	
radishes	lettuce	squash	
raspberries	peppers	tomatoes	
strawberries	potatoes	spinach	
	sweet corn		

[1] *Based on saturated paste extract.* *Plants can be successfully grown at these test levels or lower.

Table 6. *Approximate nutrient composition of various inorganic/chemical fertilizers. Fertilizers marked with an asterisk (*) are acceptable for organic fruit and vegetable production. Check with certifying agency for any restrictions.*

Nutrient	Fertilizer Material	Composition N	Composition P_2O_5	Composition K_2O
		%	%	%
	Ammonium nitrate	33	0	0
	Ammonium sulfate	21	0	0
	Ammonium thiosulfate	12	0	0
	Anhydrous ammonia	82	0	0
	Calcium nitrate	15.5	0	0
	Diammonium phosphate	18	46	0
	Mono-ammonium phosphate	11	48	0
	Potassium nitrate	13	0	44
	Sodium nitrate	16	0	0
	Urea	46	0	0
	Urea, polymer coated	40-44	0	0
	Urea-ammonium nitrate (UAN)	28-32	0	0
Phosphorus Sources				
	Diammonium phosphate	18	46	0
	Mono-ammonium phosphate	11	48	0
	*Rock phosphate	0	5	0
	Superphosphate	0	20	0
	Triple superphosphate	0	46	0
Potassium Sources				
	Potassium chloride	0	0	60
	*Potassium-magnesium sulfate	0	0	22
	Potassium nitrate	13	0	44
	*Potassium sulfate	0	0	50

Nutrient	Fertilizer Material	Composition
Calcium Sources		**% Ca**
	*Calcium sulfate (gypsum)	22
	Calcium nitrate	20
	Calcium chloride	36
	*Calcitic lime	30-40
	*Dolomite	22
	Calcium chelates	4-12
Magnesium Sources		**% Mg**
	Magnesium sulfate (Epsom salts)	10
	*Potassium-magnesium sulfate	11
	*Dolomite	11
Sulfur Sources		**% S**
	Ammonium thiosulfate	26
	Ammonium sulfate	24
	*Calcium sulfate (gypsum)	19
	*Elemental sulfur	90-100
	*Potassium-magnesium sulfate	18
	*Potassium sulfate	18
	Magnesium sulfate (Epsom salts)	13
Boron Sources		**% B**
	*Borax	11
	*Boric acid	17
	*Solubor	17-21
	Sodium pentaborate	18
	Sodium tetraborate	14-20
Copper Sources		**% Cu**
	Cupric chloride	47
	*Copper sulfate	25
	Copper chelates	8-13
Iron Sources		**% Fe**
	Iron sulfate	20
	Iron chelates	5-12
Manganese Sources		**% Mn**
	Manganese sulfate	27
	Manganese chelates	5-12
Molybdenum Sources		**% Mo**
	Ammonium molybdate	54
	Sodium molybdate	39
Zinc Sources		**% Zn**
	Zinc oxide	80
	Zinc sulfate·monohydrate	36
	Zinc chelate	14

National standards for organic crop production have recently been adopted (USDA National Organic Program). If you are unsure about a particular product, check with the Minnesota Department of Agriculture (MDA) (http://www.mda.state.mn.us/esap/organic/) or state certified agencies (available through the MDA website) about its suitability for organic farming before applying it to your field.

Characteristics of inorganic synthetic fertilizers are that they dissolve in water and are immediately available to the plant for uptake. When used according to recommendations, these types of fertilizers are safe for the environment and can supply the required nutrients for plant growth. However, excessive rates of these fertilizers can injure the roots of plants causing death and potentially lead to environmental degradation.

Organic fertilizers are made up of larger molecules and substances that take time to be broken down into forms usable by the plant. Compost made from animal manure and various plant residues is often used as an organic soil amendment and nutrient source. The composting process stabilizes available nitrogen into less available forms. Thus, compost and most organic fertilizers can be considered slow-release type fertilizers with a low salt index. Therefore, they can be applied in larger amounts at one time without causing injury to the plant root. For organic nitrogen sources (except urea), one application can be made without having to be concerned with losing all the nitrogen to leaching. However, even organic fertilizers applied at excessive rates can cause environmental degradation. Unless an animal operation is nearby, organic fertilizers are usually more expensive and bulkier than inorganic sources.

The nutrient composition of common inorganic/chemical fertilizer sources is provided in **Table 6.** The composition of selected organic fertilizers is provided in **Table 7**. More information about using organic fertilizers for vegetable and fruit production can be found at: http://www.extension.umn.edu/distribution/horticulture/M1191.html.

Using Animal Manure

The amount of plant nutrients in a fertilizer program can be reduced if manure is used. The nutrient content of manure varies with type of livestock and methods used in storage, handling, and application. As a general rule, the suggested rates of N, P_2O_5, and K_2O can be reduced by 5, 2, and 5 lb/A, respectively, for each wet ton or for each 250 gallons applied per acre. Some general analyses of different types of manure on a dry weight basis are provided in **Table 7**. To use these analyses effectively, the moisture content of the manure must be known. Many laboratories will measure the nutrient concentrations in manure. Manure analysis is strongly recommended if routine applications are made for crop production. The results of such an analysis will give a more precise measurement of the nutrient value of manure. Fresh manure is high in soluble forms of nitrogen, which can lead to salt build-up and leaching losses if overapplied. Fresh manure may contain high amounts of viable weed seeds, which can lead to weed problems. In addition, various intestinal pathogens such as *E. coli* may be present in fresh manure and can cause illness to individuals eating fresh produce unless proper precautions are taken. Apply and incorporate raw manure in fields where crops are intended for human consumption at least three months before the crop will be harvested. Allow four months between application and harvest of root and leaf crops that come in contact with the soil. Do not surface apply raw manure under orchard trees where fallen fruit will be harvested.

Heat generated during the composting process will kill most weed seeds and pathogens, provided temperatures are maintained at or above 131°F for 15 days or more (and the compost is turned so that all material is exposed to this temperature for a minimum of 3 days). The microbially mediated composting process will lower the amount of soluble nitrogen forms by stabilizing the nitrogen in larger organic, humus-like compounds. It is best to use well-composted manure for crops used for direct human consumption. Higher rates of composted manure will be needed because of

Table 7. *Approximate nutrient composition[1] of various organic fertilizers.*

Organic Materials	N	P_2O_5	K_2O
Manures	- - - - - - - -	% dry weight basis	- - - - - - - -
Beef	1.2	2.0	2.1
Dairy	2.1	3.2	3.0
Bat guano	6.0	5.0	3.0
Horse	2.1	3.2	2.0
Poultry	3.0	5.0	2.0
Sheep	1.6	1.2	2.0
Swine	2.5	2.1	1.0
Alfalfa hay	2.5	0.5	2.5
Blood meal	13.0	2.0	1.0
Bone meal, raw	3.0	22.0	0
Bone meal, steamed	1.0	15.0	0
Castor bean meal	5.5	2.0	1.0
Cotton seed meal	6.0	3.0	1.5
Fish meal	10.0	6.0	4.9
Kelp/seaweed	1.5	1.0	0
Peanut meal	7.0	1.5	1.2
Soybean meal	7.0	1.2	1.5
Tankage[2]	7.0	10.2	1.5

[1] *These are total concentrations and only slowly available over weeks, months, or years. Many materials will vary in composition due to moisture content and methods of handling.*

[2] *May contain high levels of chromium.*

lower nitrogen availability following the composting process. For more information on manure management and calculating rates to apply for vegetable and fruit crops refer to: http://www.extension.umn.edu/distribution/horticulture/M1192.html.

Sewage Sludge (Biosolids)

Although sewage sludge from municipal treatment plants can supply nutrients for crop growth, there is concern about elevated metal content and enteric diseases in some types of sewage sludge. While preventing metals from entering the sewer system and use of certain processing techniques can minimize these problems, use of sewage sludge for fertilizing fruit and vegetable crops is questionable. Sewage sludge is best used to provide nutrients (primarily nitrogen and phosphorus) for ornamental landscape plants and crops not directly used for human consumption.

Using Green Manures/Cover Crops

Crops that are incorporated into the soil while still green are referred to as green manures. Cover crops are similar to green manures, but are usually grown to protect soil from erosion during the non-growing season. Because topsoil is higher in organic matter and nutrient content than subsoil, controlling erosion is an important method of conserving soil nutrients. Green manures and cover crops are both used to supply nitrogen and increase soil organic matter. Legumes such as clover and alfalfa can fix between 100 and 200 lbs of nitrogen per acre in one year. The use of grasses such as rye or oats without a legume will not increase the nitrogen content of the soil. These crops are used for increasing soil organic matter content. They can also scavenge residual nitrogen from the previous crop and keep it from being lost by leaching. A mixture of both grasses and legumes can be used to obtain the advantages of each. Improved soil tilth from added organic matter improves root growth, which increases the capacity of a crop to take up available soil nutrients. The decision to plant a green manure should take into account the cost of cultural practices (planting, cultivation) and seed, as well as the lost opportunity cost if the green manure is grown instead of a cash crop.

Some green manure crops accumulate high levels of phosphorus and are thought to increase phosphorus availability to subsequent crops by returning it to the soil in organic form. For example, buckwheat and oilseed radish may solubilize phosphorus from relatively insoluble minerals like rock phosphate through the action of organic acids secreted by their roots. The benefit of these phosphorus accumulating crops will depend on the following crop and to what extent recycling of organic phosphorus increases phosphorus availability to them compared to inorganic soil phosphorus. There is little research information on phosphorus response of different crops following green manures like buckwheat and oilseed radish. More information on nutrient cycling and maintaining soil fertilization can be found at the following website: http://www.extension.umn.edu/distribution/horticulture/M1193.html.

Fertigation

Fertigation refers to the application of water soluble fertilizer through the irrigation water. Nutrients in a concentrated solution are injected in the irrigation water using an appropriate injection device. Providing nutrients through the irrigation system enables more flexibility in a fertilizer program. Several types of irrigation systems are available for use in crop production. For any system used, approved backflow control valves and interlock devices are necessary to prevent accidental contamination of the water source due to irrigation system failure or shutdown. Contact the Minnesota Department of Agriculture (http://www.mda.state.mn.us/) for Minnesota state regulations regarding application of fertilizer through irrigation systems. The type of system selected will depend on the crop being grown and resources available.

Overhead irrigation

Center pivot and solid set overhead irrigation systems provide the most uniform distribution of water. Center pivot systems are especially well suited for large acreage crops such as sweet corn and potatoes, while solid set systems are used for the smaller acreage. In most cases, nitrogen is the primary nutrient applied with an overhead irrigation system. Nitrogen solutions in the form of urea-ammonium nitrate (28-32% N) are the most common and economical sources to use. Generally, 20-40 lb N/A per application can be applied through the system to supplement crop needs. Other elements such as phosphorus, potassium, and micronutrients are more efficiently used if incorporated in the soil at or before planting.

For solid set systems a batch load of fertilizer is injected. That is, the area being irrigated is calculated and the amount of fertilizer required for that given area is then determined. In making these calculations with fertilizer solutions, the density or pounds of solution per gallon needs to be known. The density is usually provided on the fertilizer label or can be obtained from the fertilizer dealer. For solid set systems, the injection rate does not need to be precisely controlled. For center pivot systems, the movement of the system in acres per hour needs to be taken into account. For calibration of center pivot systems, refer to the manufacturer's irrigator operating manual. The timing of application should be based on crop demand and can be determined using tissue analyses. For potatoes, the demand for nitrogen is generally greatest between initial tuber growth and tuber enlargement (5 to 10 weeks after planting). For sweet corn, the demand for nitrogen is greatest between the 12-leaf stage and tasseling.

Drip Irrigation

Drip or trickle irrigation is a type of irrigation where water is supplied under low pressures directly to or near the plant's root zone. Water is carried through plastic tubing and emitted through small openings. Drip irrigation is often used in combination with plastic mulch. Advantages of using drip irrigation are better control of foliar diseases and more efficient water and fertilizer use. Water savings with drip irrigation can amount to as much as 50 percent compared with an overhead sprinkler system. This method of irrigation is particularly suited for high value crops such as tomatoes, peppers, blueberries, raspberries, strawberries, apples, vine crops, and cole crops.

As with overhead irrigation, nitrogen is the primary nutrient applied through the system. Nitrogen solutions are the most economical source of nitrogen to apply; potassium nitrate and ammonium sulfate are soluble and can also be used. Calcium nitrate is also water soluble but may precipitate if injected in high pH water. Drip irrigation, in combination with plastic mulch, allows for precise timing (spoon feeding) of nitrogen. Small amounts can be applied daily (1-2 lb N/A) or weekly (5-10 lb N/A) to meet the growth demands of the crop.

Potassium can also be injected without any precipitation problems, although in most Minnesota soils a broadcast and starter application can meet plant requirements. Phosphorus may precipitate with micronutrients or with calcium and magnesium in the irrigation water, resulting in clogging problems. Some micronutrients such as copper, iron, manganese, and zinc may also precipitate in high pH water. For most situations, phosphorus, and micronutrients, if needed, should be applied before planting. These elements can be injected alone in the drip system without precipitation problems. For phosphorus applications, phosphoric acid should be used. For micronutrients, chelated forms should be used. Clogging problems in drip lines can be corrected by injecting acids into the line to dissolve precipitates. If clogging is caused by bacteria or algae growth, then chlorine should be mixed with water. In all cases, the cause of clogging should be determined before treatment, and injection rates of chlorine or acid should be carefully monitored to avoid damaging the plants.

Calibration of fertilizer injection for drip irrigation is similar to that of a solid set sprinkler system in that a batch type injection is used. The area to be fertilized is first calculated and then the amount of fertilizer needed for that area is determined. In most cases, nutrients should be injected over a 15-20 minute period followed by a 15-20 minute flushing period.

Foliar Fertilization

For all fruit and vegetable crops, the major pathway for mineral nutrient uptake is via the roots. Nutrients applied to the leaves can be absorbed and utilized by the plant; however, for nitrogen, phosphorus, and potassium the quantity absorbed at any one time is small relative to the larger levels required for growth by the plant. Foliar application of these three nutrients cannot be expected to supply the total amount required for crop production.

An appropriate time to consider foliar fertilization would be when a shortage of a nutrient is evident as indicated by tissue analysis or visual symptoms. In these situations, foliar fertilization provides the quickest means to correct the problem. Certain soil conditions, such as high pH, excess moisture, or cool temperatures, may render a nutrient or nutrients unavailable to the plant root. If these conditions exist, the problem may be more effectively corrected by foliar applications compared with soil applications. For the macronutrients, foliar applications are a short-term solution. Refer to the potassium section **(page 15)** for suggestions on using potassium foliar sprays and **page 26** for using magnesium foliar sprays. Some crops have inefficient mechanisms for translocating calcium to fruits of young tissue. See the calcium section **(page 26)** for recommendations on using calcium foliar applications. For micronutrients, two to three applications may be all that are needed to meet crop demands. Even for micronutrients, the application is only effective during the year of application. Recommendations for rates of micronutrient foliar fertilizers to apply are provided in the micronutrient section **(pages 26-29)**.

Routine use of foliar fertilizers without a documented need is not recommended. Furthermore, foliar fertilization should not be used as a substitute for good soil fertility management. Have your soil tested and fertilize according to soil test recommendations.

Selecting a Yield Goal

Higher yielding crops generally require more nutrients than low yielding crops. For most fruit and vegetable crops listed in this bulletin, fertilizer recommendations are based on the yield obtained under optimum field conditions (i.e., water is not limiting and soil drainage is not a problem). If certain management practices such as plastic mulches, drip irrigation, row covers, or high tunnels are used, yield potential may be substantially higher than that reported in this bulletin. In those cases, an increase in fertilizer rates over those recommended may be warranted.

For the major processing crops (peas, sweet corn, snap beans, lima beans, and potatoes) where larger acreage is planted and soil conditions and water availability may not be as favorable as for the higher value fruit and vegetable crops, yield may vary as a function of the area in which the crop is grown as well as management practices. Selecting a realistic yield goal for these crops will improve fertilizer use efficiency. Reasonable yield goals are usually set at 15-20 percent higher than a grower's average yield for the past 5 years.

Primary Macronutrients

Nitrogen, phosphorus, and potassium are often referred to as the primary macronutrients because of the general probability of plants being deficient in these nutrients and the large quantities taken up from the soil relative to other essential nutrients.

Nitrogen

Of all the essential nutrients, nitrogen is the one most often limiting for crop growth. Many soils contain large amounts of nitrogen, but most of the nitrogen is tied up in the organic fraction and only slowly released. For most nonlegume crops, some nitrogen fertilizer is required for adequate yields. Nitrogen is available to the plant in two forms—ammonium (NH_4^+) and nitrate (NO_3^-). In most soils, ammonium is quickly converted to the nitrate form, a process called nitrification. This nitrate form is not tightly held on soil particles and is soluble in water. Consequently, nitrogen management is important both from a production and environmental standpoint. On sandy soils, nitrogen applied early in the season can be easily leached out of the root zone with heavy rainfall or excess irrigation. Nitrogen deficiency may result, as well as an increased potential for nitrate contamination of the groundwater. On irrigated sandy soils, nitrogen should be split applied—a small portion at planting and the remainder during the growing season after the crop has become established. The need for split applications on fine-textured or organic soils is not as critical as on irrigated sandy soils. In fine-textured clay soils, heavy rainfall may saturate the soil causing nitrogen to be converted to a gas and lost to the atmosphere, a process called denitrification.

Because of the mobility of nitrate in soils and the complex transformations from organic matter, soil tests for nitrogen are not reliable for predicting nitrogen fertilizer needs in the eastern half of Minnesota, particularly on sandy irrigated soils. The rate of nitrogen to apply, therefore, is based on yield goal, soil organic matter content, and previous crop.

The organic matter of the soil can be classified into categories for use in making fertilizer recommendations. The categories are: **Low** for soils with O.M. less than 3.1%, **medium** for soils with O.M. between 3.1% and 4.5%, **high** for soils with O.M. greater than 4.5%. The very high category is used for peats and mucks with O.M. greater than 19%.

The recommendations provided should be used as a general guide. For some crops, response to nitrogen will depend on the cultivar. In many cases too much nitrogen applied will result in excessive vegetative growth at the expense of fruit growth. Certain cultivars of tomato, potato, and many of the vine crops are susceptible to producing excessive vegetative growth with too much applied nitrogen. Nitrogen recommendations for organic soils are much lower due to the continual release of nitrogen from the organic matter during the growing season. For all crops except potatoes, sweet corn, peas, lima beans, and snap beans, only one yield goal is assumed. In western Minnesota, where rainfall is limited, the nitrate test is useful for determining initial levels of soil nitrogen. Research in western Minnesota has shown that more accurate nitrogen recommendations can be made for many crops (particularly potatoes) by determining the nitrate-nitrogen content in the top 2 feet of soil. Use of the nitrate test is strongly recommended for crops grown in the western part of the state (**Figure 2**). Refer to **Table 18** for potatoes and **Table 25** for sweet corn to determine nitrogen recommendations based on a nitrate test. For other vegetable crops, refer to **Table 28**. For fruit crops refer to **Tables 31** and **32**. Use the following formula:

$\mathbf{Fert_N = N\ Rec_{low\ O.M.} - Soil_{N\ 0\text{-}2\ ft}}$ **where:**

$Fert_N$ = Fertilizer N to Apply

$N\ Rec_{low\ O.M.}$ = N Recommendation at Low Organic Matter

$Soil_{N\ 0\text{-}2\ ft}$ = Soil Test Nitrate (0-2 feet)

As an example, if the nitrate test for the top 2 feet was 70 lb/A and carrots are to be planted, then the amount of fertilizer N to apply would be: 120 lb N/A - 70 lb N/A = 50 lb N/A.

In other areas of the state, nitrate tests will be run for those who desire it for monitoring purposes, but the results will not be used for making the nitrogen fertilizer recommendations. The nitrate soil test is not recommended for use on sandy soils.

Phosphorus

Phosphorus forms very insoluble complexes with aluminum and iron at low pH and calcium at high pH. Consequently, movement of phosphorus in soils is very low. For this reason, it is important to incorporate phosphate fertilizer into the soil rather than topdress. The form available to the plant is the

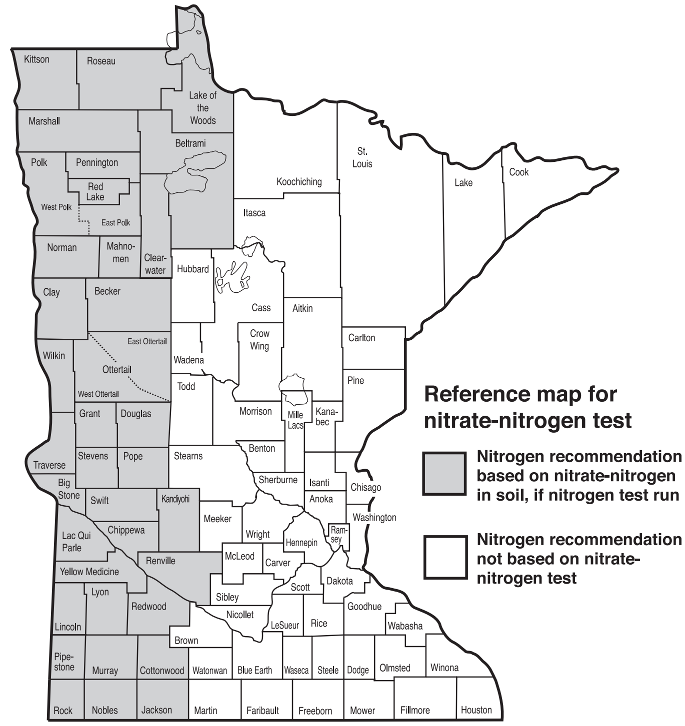


Figure 2. *Reference map for using the soil nitrate test.*

orthophosphate anion ($H_2PO_4^-$). Two different soil tests are used to determine available soil phosphorus. The Bray-P1 test is used when the soil pH is 7.4 or less and the Olsen-P test is used when the soil pH is greater than 7.4. It is important to note that interpretations for phosphorus fertilizer will change depending on which test is used. In other words, the extractable phosphorus using the Bray-P1 test is not equivalent to extractable phosphorus using the Olsen-P test.

Interpretations for relative phosphorus levels based on a soil test are presented in **Table 8** for lima beans, peas, snap beans, and sweet corn. Relative phosphorus levels for all other vegetable crops and fruit crops are presented in **Table 9**. The phosphorus measured does not represent all of the phosphorus that may be available for plant growth; i.e., some fraction of the organic phosphorus not measured may become available upon mineralization.

Response to phosphorus is most likely on low phosphorus testing soils and in the spring when soils are cool. Phosphorus recommendations are based on soil test phosphorus level, crop to be grown, and, for some crops, yield goal. For most seeded vegetable crops, banding a portion of the recommended phosphorus fertilizer 2-3 inches from the seed at planting will enhance root growth in cool soils in the spring compared with broadcast phosphorus. For high testing phosphorus soils, only banded phosphorus fertilizer is needed. For low phosphorus testing soils, a portion of the phosphorus fertilizer should be broadcast and incorporated.

Phosphorus is the primary nutrient associated with algal blooms in surface waters. Phosphorus can enter surface waters by runoff and wind erosion of soil particles. Runoff of phosphorus from decaying plant material and animal manure can also contribute to the problem. For these reasons it is important not to use excessive rates of manure or phosphorus fertilizers on sites vulnerable to runoff and erosion.

Table 8. Relative soil test levels of phosphorus for lima beans, peas, snap beans, and sweet corn.

Relative Level	Bray-P1	Olsen-P
	ppm	ppm
Low	0-5	0-3
Medium	6-10	4-7
Medium-high	11-15	8-11
High	16-20	12-15
Very high	21+	16+

Table 9. Relative soil test levels of phosphorus for fruit and vegetable crops not listed in Table 8.

Relative Level	Bray-P1	Olsen-P
	ppm	ppm
Low	0-10	0-7
Medium	11-20	8-15
Medium-high	21-30	16-25
High	31-40	26-33
Very high	41+	34+

Starter solutions high in phosphate are recommended for fruit and vegetable transplants to promote root growth. Follow the manufacturer's recommendations for the amount of fertilizer to mix with water. Typically, a high phosphate analysis starter solution such as 10-52-17 should be mixed at the rate of 3 pounds of material per 50 gallons of water. This solution should be applied at a rate of about $^1/_2$ pint per plant.

Potassium

Potassium is available to plants as the K^+ ion. Movement of potassium in soils is dependent on soil texture. As the clay content increases, movement of potassium decreases. For most soils, it is important that applied potassium be incorporated into the soil rather than topdressed. In sandy soils, potassium can actually leach out of the root zone. Consequently, sandy soils tend to be low in available potassium. As with phosphorus, a portion of the potassium can be banded 2-3 inches from the seed at planting. For high potassium testing soils, only banded potassium fertilizer application is necessary. For low testing potassium soils at least half of the potassium fertilizer should be broadcast. Interpretation for relative levels of potassium based on a soil test are presented in **Table 10**. Excessive magnesium fertilization can induce a potassium deficiency. Recommendations for fertilizer potassium are based on relative soil test level, crop to be grown, and, for some crops, yield goal. The most common source of potash fertilizer used for crop production is potassium chloride (0-0-60). Sulfate sources are also available, but the cost is higher. If sulfur or magnesium is also needed, potassium magnesium sulfate is the suggested fertilizer to use.

For apples grown in Minnesota, potassium deficiency is a common problem. While soil potash application is the preferred long-term solution to correct potassium deficiency, foliar application may be used to correct potassium deficiency during the season. Foliar sprays of potassium nitrate or sulfate at 6 to 10 lb per 100 gallons of water (200 gallons per acre) are suggested as a temporary measure to correct the problem.

Table 10. Relative soil test levels of potassium for fruit and vegetable crops.

Relative Level	K
	ppm
Low	0-40
Medium	41-80
Medium-high	81-120
High	121-160
Very high	161+

Lima Beans

Table 11. *Nitrogen recommendations for lima beans.*

Yield Goal	alfalfa (good stand) - O.M. -[2] low[3]	alfalfa (good stand) - O.M. -[2] medium to high	soybeans field peas - O.M. - low	soybeans field peas - O.M. - medium to high	any crop in Group 1[1] - O.M. - low	any crop in Group 1[1] - O.M. - medium to high	any crop in Group 2[1] - O.M.- low	any crop in Group 2[1] - O.M.- medium to high
	Previous Crop and Organic Matter (O.M.) Level							
lb/A	N to apply (lb/A)							
less than 2000	0	0	0	0	0	0	0	0
2000 - 2900	0	0	0	0	0	0	10	0
3000 - 3900	0	0	10	0	0	0	20	10
4000 - 4900	0	0	20	10	10	0	40	20
5000 or more	0	0	40	20	20	0	60	40

[1] Crops in Group 1

alfalfa (poor stand[4] or new seeding)
alsike clover or red clover
birdsfoot trefoil
fallow
grass-legume hay
grass-legume pasture

[1]Crops in Group 2

barley	grass-hay	sorghum-sudan
buckwheat	grass-pasture	sugarbeets
canola	millet	sunflowers
corn	mustard	sweet corn
edible beans	oats	triticale
flax	potatoes	wheat
	rye	vegetables

[2] *Low = less than 3.1% O.M., medium to high = 3.1-19% O.M.*
[3] *The well-drained silt loam soils in southeastern Minnesota with low O.M. receive the same N recommendation for soils with a medium to high O.M. content.*
[4] *Poor stand is less than 4 crowns per sq. ft.*

Table 12. *Phosphate recommendations for lima beans.*

Yield Goal	Soil Test P (ppm) Bray-P1 0-5 / Olsen-P 0-3	6-10 / 4-7	11-15 / 8-11	16-20 / 12-15	21+ / 16+
lb/A	P_2O_5 to apply (lb/A)				
less than 2000	25	15	0	0	0
2000 - 2900	50	25	15	0	0
3000 - 3900	75	50	25	15	0
4000 - 4900	100	75	50	25	0
5000 or more	125	100	75	50	0

Table 13. *Potash recommendations for lima beans.*

Yield Goal	Soil Test K (ppm) 0-40	41-80	81-120	121-160	161+
lb/A	K_2O to apply (lb/A)				
less than 2000	25	15	0	0	0
2000 - 2900	50	25	15	0	0
3000 - 3900	75	50	25	15	0
4000 - 4900	100	75	50	25	0
5000 or more	125	100	75	50	0

Peas

Table 14. Nitrogen recommendations for peas.

Yield Goal	alfalfa (good stand) - O.M. -[2] low[3]	alfalfa (good stand) - O.M. -[2] medium to high	soybeans field peas - O.M. - low	soybeans field peas - O.M. - medium to high	any crop in Group 1[1] - O.M. - low	any crop in Group 1[1] - O.M. - medium to high	any crop in Group 2[1] - O.M. - low	any crop in Group 2[1] - O.M. - medium to high
	Previous Crop and Organic Matter (O.M.) Level							
lb/A	N to apply (lb/A)							
less than 1000	0	0	0	0	0	0	0	0
1000 - 1900	0	0	0	0	0	0	10	0
2000 - 3900	0	0	10	0	0	0	20	10
4000 or more	0	0	20	0	10	0	40	20

[1]Crops in Group 1

alfalfa (poor stand[4] or new seeding)
alsike clover or red clover
birdsfoot trefoil
fallow
grass-legume hay
grass-legume pasture

[1]Crops in Group 2

barley
buckwheat
canola
corn
edible beans
flax
grass-hay
grass-pasture
millet
mustard
oats
potatoes
rye
sorghum-sudan
sugarbeets
sunflowers
sweet corn
triticale
wheat
vegetables

[2] *Low = less than 3.1% O.M., medium to high = 3.1-19% O.M.*

[3] *The well-drained silt loam soils in southeastern Minnesota with low O.M. receive the same N recommendation for soils with medium to high O.M. content.*

[4] *Poor stand is less than 4 crowns per sq. ft.*

Table 15. Phosphate recommendations for peas.

Yield Goal	Soil Test P (ppm) Bray-P1 0-5 / Olsen-P 0-3	Bray-P1 6-10 / Olsen-P 4-7	Bray-P1 11-15 / Olsen-P 8-11	Bray-P1 16-20 / Olsen-P 12-15	Bray-P1 21+ / Olsen-P 16+
lb/A	P_2O_5 to apply (lb/A)				
less than 1000	25	15	0	0	0
1000 - 1900	50	25	15	0	0
2000 - 3900	75	50	25	15	0
4000 or more	100	75	50	25	0

Table 16. Potash recommendations for peas.

Yield Goal	Soil Test K (ppm) 0-40	41-80	81-120	121-160	161+
lb/A	K_2O to apply (lb/A)				
less than 1000	25	15	0	0	0
1000 - 1900	50	25	15	0	0
2000 - 3900	75	50	25	15	0
4000 or more	100	75	50	25	0

Potatoes

Table 17. *Nitrogen recommendations for potatoes when the soil nitrate test is not used.*

Yield Goal	Previous Crop and Organic Matter (O.M.) Level: alfalfa (good stand) - O.M. -[2] low[4]	alfalfa (good stand) - O.M. -[2] medium to high	soybeans field peas - O.M. - low	soybeans field peas - O.M. - medium to high	any crop in Group 1[1] - O.M. - low	any crop in Group 1[1] - O.M. - medium to high	any crop in Group 2[1] - O.M. - low	any crop in Group 2[1] - O.M. - medium to high	Organic Soil[3]
cwt/A	N to apply (lb/A)[5]								
less than 200	0	0	55	35	35	15	75	55	0
200 - 249	0	0	80	60	60	40	100	80	0
250 - 299	25	0	105	85	85	65	125	105	30
300 - 349	50	30	130	110	110	90	150	130	30
350 - 399	75	55	155	135	135	115	175	155	30
400 - 449	100	80	180	160	160	140	200	180	40
450 - 499	125	105	205	185	185	165	225	205	40
500 or more	150	130	230	210	210	190	250	230	50

[1]Crops in Group 1

- alfalfa (poor stand[6] or new seeding)
- alsike clover or red clover
- birdsfoot trefoil
- fallow
- grass-legume hay
- grass-legume pasture

[1]Crops in Group 2

barley	grass-hay	sorghum-sudan
buckwheat	grass-pasture	sugarbeets
canola	millet	sunflowers
corn	mustard	sweet corn
edible beans	oats	triticale
flax	potatoes	wheat
	rye	vegetables

[2] *Low = less than 3.1% O.M., medium to high = 3.1-19% O.M.*
[3] *Organic soil = more than 19% O.M.*
[4] *The well-drained silt loam soils in southeastern Minnesota with low O.M. receive the same N recommendation for soils with a medium to high O.M. content.*
[5] *For irrigated sandy soils, split N applications are recommended: 1/5 at planting, 2/5 at emergence, and 2/5 at hilling. Application of nitrogen after hilling should be based on petiole analysis (refer to the section on tissue/petiole analysis, page 35).*
[6] *Poor stand is less than 4 crowns per sq. ft.*

Table 18. *Nitrogen recommendations for potatoes when the soil nitrate test is used.*

Yield Goal	Soil Nitrate-N (0-2 ft) + fertilizer N
cwt/A	lb/A
less than 200	60
200 - 249	80
250 - 299	100
300 - 349	120
350 - 399	140
400 - 450	160
451 or more	200

Table 19. *Phosphate recommendations for potatoes.[1]*

Yield Goal	Soil Test P Level (ppm): Bray-P1 0-5 / Olsen-P 0-3	6-10 / 4-7	11-15 / 8-11	16-20 / 12-15	21-25 / 16-18	26-30 / 19-22	31-50 / 23-41	51+ / 42+
cwt/A	P_2O_5 to apply (lb/A)[2]							
less than 200	75	50	25	0	0	0	0	0
200 - 299	100	75	50	25	0	0	0	0
300 - 399	125	100	75	50	50	50	50	50
400 - 499	150	125	100	75	75	75	75	75
500 or more	175	150	125	100	100	100	100	75

[1] *For acid irrigated sands, responses up to 150 lb/A P_2O_5 have been observed on very high (41+ ppm) P soils.*
[2] *For most efficient application, apply phosphate fertilizer in a band 2-3 inches below and to each side of the tuber planting.*

Table 20. Potash recommendations for potatoes.

Yield Goal	Soil Test K Level (ppm) 0-40	40-80	81-120	121-160	161-200	201+
cwt/A	K_2O to apply (lb/A)[1]					
less than 200	150	75	50	25	0	0
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	150	100	75

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

Snap Beans

Table 21. Nitrogen recommendations for snap beans.

Yield Goal	Previous Crop and Organic Matter (O.M.) Level: alfalfa (good stand) - O.M. -[2] low[3]	alfalfa (good stand) medium to high	soybeans field peas - O.M. - low	soybeans field peas medium to high	any crop in Group 1[1] - O.M. - low	any crop in Group 1[1] medium to high	any crop in Group 2[1] - O.M. - low	any crop in Group 2[1] medium to high
lb/A	N to apply (lb/A)							
less than 3000	0	0	0	0	0	0	0	0
3000 - 4900	0	0	0	0	0	0	10	0
5000 - 6900	0	0	10	0	0	0	20	10
7000 - 8900	0	0	20	10	10	0	40	20
9000 or more	0	0	40	20	20	0	60	40

[1]Crops in Group 1

alfalfa (poor stand[4] or new seeding)
alsike clover or red clover
birdsfoot trefoil
fallow
grass-legume hay
grass-legume pasture

[1]Crops in Group 2

barley	grass-hay	sorghum-sudan
buckwheat	grass-pasture	sugarbeets
canola	millet	sunflowers
corn	mustard	sweet corn
edible beans	oats	triticale
flax	potatoes	wheat
	rye	vegetables

[2] *Low = less than 3.1% O.M., medium to high = 3.1-19% O.M.*
[3] *The well-drained silt loam soils in southeastern Minnesota with low O.M. receive the same N recommendation for soils with a medium to high O.M. content.*
[4] *Poor stand is less than 4 crowns per sq. ft.*

Table 22. Phosphate recommendations for snap beans.

Yield Goal	Soil Test P (ppm) Bray-P1 0-5 / Olsen-P 0-3	6-10 / 4-7	11-15 / 8-11	16-20 / 12-15	21+ / 16+
lb/A	P_2O_5 to apply (lb/A)				
less than 3000	50	25	0	0	0
3000 - 4900	50	25	25	0	0
5000 - 6900	75	50	25	25	0
7000 - 8900	100	75	50	25	0
9000 or more	125	100	75	50	0

Table 23. Potassium recommendations for snap beans.

Yield Goal	Soil Test K (ppm) 0-40	41-80	81-120	121-160	161+
lb/A	K_2O to apply (lb/A)				
less than 3000	25	25	0	0	0
3000 - 4900	50	25	25	0	0
5000 - 6900	75	50	25	25	0
7000 - 8900	100	75	50	25	0
9000 or more	150	100	75	50	0

Sweet Corn

Table 24. Nitrogen recommendations for sweet corn.

Yield Goal	Previous Crop and Organic Matter (O.M.) Level: alfalfa (good stand) - O.M. -[2] low[4]	alfalfa (good stand) medium to high	soybeans field peas - O.M. - low	soybeans field peas medium to high	any crop in group 1[1] - O.M. - low	any crop in group 1[1] medium to high	any crop in group 2[1] - O.M. - low	any crop in group 2[1] medium to high	Organic Soil[3]
tons/A	N to apply (lb/A)[5]								
less than 6	10	0	80	50	70	40	110	80	10
6 - 7	30	0	100	70	90	60	130	100	30
8 - 9	50	20	120	90	110	80	150	120	50
10 or more	70	40	140	110	130	100	170	140	70

[1]Crops in Group 1

alfalfa (poor stand[6] or new seeding)
alsike clover or red clover
birdsfoot trefoil
fallow
grass-legume hay
grass-legume pasture

[1]Crops in Group 2

barley	grass-hay	sorghum-sudan
buckwheat	grass-pasture	sugarbeets
canola	millet	sunflowers
corn	mustard	sweet corn
edible beans	oats	triticale
flax	potatoes	wheat
	rye	vegetables

[2] *Low = less than 3.1% O.M. , medium to high = 3.1-19% O.M.*
[3] *Organic soil = more than 19% O.M.*
[4] *The well-drained silt loam soils in southeastern Minnesota with low O.M. receive the same N recommendation for soils with a medium to high O.M. content. All irrigated soils are included in the low O.M. category.*
[5] *For irrigated sandy soils, split N applications are recommended: 10-20 lb N/A in the starter and the remainder in one or two more applications at the 4-6 leaf stage and the 10-12 leaf stage.*
[6] *Poor stand is less than 4 crowns per sq. ft.*

Table 25. Nitrogen recommendations for sweet corn when the soil nitrate test is used.

Yield Goal	Soil Nitrate-N (0-2 ft) + fertilizer N
cwt/A	lb N/A
less than 6	70
6-7	110
8-9	145
10 or more	180

Table 26. Phosphate recommendations for sweet corn production.

Yield Goal	Soil Test P (ppm): Bray-P1 0-5, Olsen-P 0-3 Bcst	0-5 / 0-3 Row	6-10 / 4-7 Bcst	6-10 / 4-7 Row	11-15 / 8-11 Bcst	11-15 / 8-11 Row	16-20 / 12-15 Bcst	16-20 / 12-15 Row	21+ / 16+ Bcst	21+ / 16+ Row
tons/A	P_2O_5 to apply (lb/A)									
less than 6	70	40	40	25	30	20	10	10-15	0	10-15
6 - 7	80	40	50	30	30	20	10	10-15	0	10-15
8 - 9	90	40	60	35	40	25	10	10-15	0	10-15
10 or more	100	40	70	40	40	25	20	10-15	0	10-15

Table 27. Potassium recommendations for sweet corn production.

Yield Goal	Soil Test K (ppm): 0-40 Bcst	0-40 Row	41-80 Bcst	41-80 Row	81-120 Bcst	81-120 Row	121-160 Bcst	121-160 Row	161+ Bcst	161+ Row
tons/A	K_2O to apply (lb/A)									
less than 6	120	40	60	30	40	10-15	40	10-15	0	10-15
6-7	140	40	80	30	40	10-15	40	10-15	0	10-15
8-9	160	40	100	40	60	25	40	10-15	0	10-15
10 or more	180	40	120	40	80	30	60	25	0	10-15

Vegetable Crops

Table 28. *Nitrogen recommendations for vegetable crops.*

Crop	Approximate Yield Goal[2]	Soil Organic Matter Level (O.M.)[1] Low	Medium	High	Organic Soil	Suggested Method of Application[3,4,5]
	cwt/A	----------------N to apply (lb/A)------------------				
Asparagus (New Planting)	—	120	100	80	50	1/3 broadcast, 2/3 sidedress during cultivation
Asparagus (Est. Planting)	40	80	60	40	20	topdress before cutting starts or after harvest
Beets, table	200	100	80	60	30	1/2 broadcast, 1/2 sidedress 3-5 wks after planting
Broccoli	120	180	160	140	100	1/3 bcst, 1/3 sidedress 2 wks after planting, 1/3 sidedress 5 wks after planting
Brussels sprouts	175	140	120	100	70	1/3 bcst, 1/3 sidedress 2 wks after planting, 1/3 sidedress 5 wks after planting
Cabbage	400	180	160	140	100	1/3 bcst, 1/3 sidedress 2 wks after planting, 1/3 sidedress 5 wks after planting
Carrots	400	120	100	80	50	1/2 broadcast, 1/2 sidedress when plants are established
Cauliflower	150	180	160	140	100	1/3 bcst, 1/3 sidedress 2 wks after planting, 1/3 sidedress 5 wks after planting
Celery	600	180	160	140	100	1/3 bcst, 1/3 sidedress 2 wks after planting, 1/3 sidedress 5 wks after planting
Cucumber	250	100	80	60	30	1/2 broadcast, 1/2 sidedress when vines begin to run
Eggplant	250	120	100	80	50	1/2 broadcast, 1/2 sidedress when fruit appear
Endive	180	120	100	80	50	1/2 broadcast, 1/2 sidedress 3-5 wks after planting
Garlic	150	120	100	80	50	1/3 broadcast at planting (Sept./Oct.), 2/3 sidedress when shoots emerge in spring
Lettuce	300	120	100	80	50	1/2 broadcast, 1/2 sidedress 3-5 wks after planting
Mint	—	120	100	80	50	1/2 broadcast, 1/2 sidedress 3-5 wks after planting
Muskmelon	200	100	80	60	30	1/2 broadcast, 1/2 sidedress when vines begin to run
Onions (dry)	500	130	110	90	60	1/4 banded, 3/4 sidedress 4-5 wks after emergence
Onions (green)	150	80	60	40	20	1/4 bcst, 1/2 sidedress 4-5 wks after emergence, 1/4 sidedress 4 wks before hvst
Parsley	—	100	80	60	30	1/2 broadcast, 1/4 after first cutting, 1/4 after 2nd cutting
Parsnips	400	120	100	80	50	1/2 broadcast, 1/2 sidedress after plants are established
Peppers	200	140	120	100	70	1/2 broadcast, 1/2 sidedress after fruit appear
Pumpkins	400	70	50	30	20	1/2 broadcast, 1/2 sidedress after vines begin to run
Radishes	70	50	40	30	20	broadcast
Rhubarb (New Planting)	—	100	80	60	30	1/2 broadcast, 1/2 sidedress after plants are established
Rhubarb (Est. Planting)	200	80	60	40	20	1/2 broadcast in spring, 1/2 sidedress after last cutting
Rutabagas	400	100	80	60	30	1/2 broadcast, 1/2 sidedress when plants are 4-6 inches tall
Spinach	150	100	80	60	30	1/2 broadcast, 1/2 sidedress 4-5 weeks after planting
Squash	300	70	50	30	20	1/2 broadcast, 1/2 sidedress after vines begin to run
Swiss Chard	150	120	100	80	50	1/2 broadcast, 1/2 sidedress 3-5 wks after planting
Tomatoes	270	130	110	90	60	1/2 broadcast, 1/2 sidedress when fruit appear
Turnips	300	60	50	40	20	broadcast
Watermelon	300	100	80	60	30	1/2 broadcast, 1/2 sidedress when vines begin to run

[1] *Low = less than 3.1% O.M., medium = 3.1-4.5% O.M., high = 4.6-19% O.M., Organic soil = greater than 19% O.M.*
[2] *Recommendations are based on attaining approximate yield goals listed.*
[3] *Suggested methods of application are a general guide and can be modified when appropriate.*
[4] *On sandy soils, sidedress applications may be split 1-2 more times (not to exceed total recommended unless a need is indicated).*
[5] *Up to 30 lb N/A of the broadcast application can be banded if equipment is available.*

Nitrogen credits for previous crops:

Alfalfa (good stand)	:	70 lb N/A
Alfalfa (poor stand) Alsike clover Birdsfoot trefoil Grass-legume hay Grass-legume pasture Red clover	:	40 lb N/A
Snap beans Peas Soybeans	:	20 lb N/A
All other crops	:	0 lb N/A

Table 29. Phosphorus recommendations for vegetable crops.

Crop	Approximate Yield Goal[1]	Bray-P1 / Olsen-P	Soil Test P Level (ppm)					
		Bray-P1	0-10	11-20	21-30	31-40	41-50	51+
		Olsen-P	0-7	8-15	16-25	26-33	34-41	42+
	cwt/A		- - - - - - - - - -P_2O_5 to apply (lb/A)[2] - - - - - - - - - -					
Asparagus (New Planting)	—		200	150	100	50	25	25
Asparagus (Est. Planting)	40		75	50	25	0	0	0
Beets, table	200		150	100	75	50	25	0
Broccoli	120		150	100	75	50	25	0
Brussels Sprouts	175		150	100	75	50	25	0
Cabbage	400		150	100	75	50	25	0
Carrots	400		150	100	75	50	25	0
Cauliflower	150		150	100	75	50	25	0
Celery	600		200	150	100	50	25	0
Cucumber	250		150	100	75	50	25	0
Eggplant	250		150	100	75	50	25	0
Endive	180		150	100	75	50	25	0
Garlic	150		150	100	75	50	25	0
Lettuce	300		150	100	75	50	25	0
Mint	—		150	100	75	50	25	0
Muskmelon	200		150	100	75	50	25	0
Onions (dry)	500		200	100	100	50	25	0
Onions (green)	150		150	100	75	50	25	0
Parsley	—		100	100	75	50	25	0
Parsnips	400		150	100	75	50	25	0
Peppers	200		150	100	75	50	25	0
Pumpkins	400		150	100	75	50	25	0
Radishes	70		100	75	50	25	0	0
Rhubarb (New Planting)	—		200	150	100	50	25	25
Rhubarb (Est. Planting)	200		75	50	25	0	0	0
Rutabagas	400		150	100	75	50	25	0
Spinach	150		150	100	75	50	25	0
Squash	300		150	100	75	50	25	0
Swiss Chard	150		150	100	75	50	25	0
Tomatoes	270		150	100	75	50	25	0
Turnips	300		100	75	50	25	0	0
Watermelon	300		150	100	75	50	25	0

[1] *Recommendations are based on attaining approximate yield goals listed.*
[2] *Recommended rates are for total amount to apply: broadcast + starter. Up to 70 lb P_2O_5 can be banded at planting.*

Table 30. Potassium recommendations for vegetable crops.

Crop	Approximate Yield Goal[1]	Soil Test K Level (ppm) 0-40	41-80	81-120	121-160	161-200	201+
	cwt/A	K_2O to apply (lb/A)[2]					
Asparagus (New Planting)	—	250	200	150	100	50	0
Asparagus (Est. Planting)	40	100	75	50	25	0	0
Beets, table	200	200	150	100	75	50	0
Broccoli	120	250	200	150	100	50	0
Brussels Sprouts	175	250	200	150	100	50	0
Cabbage	400	250	200	150	100	50	0
Carrots	400	200	150	100	75	50	0
Cauliflower	150	250	200	150	100	50	0
Celery	600	250	200	150	100	50	0
Cucumber	250	200	150	100	75	50	0
Eggplant	250	200	150	100	75	50	0
Endive	180	200	150	100	75	50	0
Garlic	150	200	150	100	75	50	0
Lettuce	300	200	150	100	75	50	0
Mint	—	200	150	100	75	50	0
Muskmelon	200	200	150	100	75	50	0
Onions (dry)	500	250	200	150	100	50	0
Onions (green)	150	200	150	100	75	50	0
Parsley	—	200	150	100	75	50	0
Parsnips	400	200	150	100	75	50	0
Peppers	200	200	150	100	75	50	0
Pumpkins	400	200	150	100	75	50	0
Radishes	70	100	75	50	25	0	0
Rhubarb (New Planting)	—	250	200	150	100	50	0
Rhubarb (Est. Planting)	200	150	100	75	50	25	0
Rutabagas	400	200	150	100	75	50	0
Spinach	150	200	150	100	75	50	0
Squash	300	200	150	100	75	50	0
Swiss Chard	150	200	150	100	75	50	0
Tomatoes	270	250	200	150	100	50	0
Turnips	300	100	75	50	25	0	0
Watermelon	300	200	150	100	75	50	0

[1] *Recommendations are based on attaining approximate yield goals listed.*
[2] *Recommended rates are for total amount to apply: broadcast + starter. Up to 30 lb K_2O can be banded at planting.*

Fruit Crops

Table 31. Nitrogen recommendations for fruit crops—new plantings.

Crop	Soil Organic Matter (O.M.) Level[1] Low	Medium	High	Organic Soil	Suggested Method of Application[2,3]
	- - - - - - - - N to apply (lb/A) - - - - - - - - - - - - -				
Apples	60	45	30	20	1/2 broadcast, 1/2 sidedress in June
Blueberries	30	20	10	10	sidedress when 2nd flush of growth starts
Grapes	60	45	30	20	1/2 broadcast, 1/2 sidedress in June
Raspberries	60	50	40	25	1/2 broadcast, 1/2 sidedress in June
Strawberries	80	70	60	25	1/2 broadcast, 1/2 sidedress in August

[1] *Low = less than 3.1% O.M., medium = 3.1-4.5% O.M., high = 4.6-19% O.M., Organic soil = greater than 19% O.M.*
[2] *Suggested methods of application are a general guide and can be modified when appropriate.*
[3] *On sandy soils, sidedress applications may be split 1-2 more times (not to exceed total recommended unless a need is indicated).*

Nitrogen credits for previous crops:

Alfalfa (good stand)	:	70 lb N/A
Alfalfa (poor stand) Alsike clover Birdsfoot trefoil Grass-legume hay Grass-legume pasture Red clover	:	40 lb/N/A
Snap beans Peas Soybeans	:	20 lb N/A
All other crops	:	0 lb N/A

Table 32. Nitrogen recommendations for fruit crops—established plantings.[1]

Crop	Approximate Yield Goal[3]	Soil Organic Matter (O.M.) Level[2] Low	Medium	High	Organic Soil	Suggested Method of Application[4,5]
	cwt/A	- - - - - - - - - -N to apply (lb/A)- - - - - - - - - -				
Apples	140	30	20	10	0	sidedress in spring
Blueberries	50	50	35	20	10	sidedress in spring
Grapes	60	30	20	10	0	sidedress in spring
Raspberries	40	60	50	40	20	sidedress in spring
Strawberries	100	80	70	60	25	topdress after renovation

[1] *Leaf analysis should also be used to help determine nitrogen needs (see page 32).*
[2] *Low = less than 3.1% O.M., medium = 3.1-4.5% O.M., high = 4.6-19% O.M., Organic soil = greater than 19% O.M.*
[3] *Recommendations are based on attaining approximate yield goals listed.*
[4] *Suggested methods of application are a general guide and can be modified when appropriate.*
[5] *On sandy soils, sidedress applications may be split 1-2 more times (not to exceed total recommended unless a need is indicated).*

Table 33. Phosphorus recommendations for fruit crops—new plantings.

Crop		Soil Test P Level (ppm)					
	Bray-P1	**0-10**	**11-20**	**21-30**	**31-40**	**41-50**	**51+**
	Olsen-P	**0-7**	**8-15**	**16-25**	**26-33**	**34-41**	**42+**
		- - - - - - - - - - - - -P_2O_5 to apply (lb/A) - - - - - - - - - - - - -					
Apples		150	125	100	75	50	25
Blueberries		100	75	50	25	0	0
Grapes		150	125	100	75	50	25
Raspberries		100	75	50	25	0	0
Strawberries		150	125	100	75	50	25

Table 34. *Phosphorus recommendations for fruit crops—established plantings.*[1]

Crop	Approximate Yield Goal		Soil Test P Level (ppm)					
		Bray-P1	0-10	11-20	21-30	31-40	41-50	51+
		Olsen-P	0-7	8-15	16-25	26-33	34-41	42+
	cwt/A		P_2O_5 to apply (lb/A)					
Apples	140		100	75	50	0	0	0
Blueberries	50		75	50	25	0	0	0
Grapes	60		100	75	50	0	0	0
Raspberries	40		75	50	25	0	0	0
Strawberries	100		100	50	25	0	0	0

[1] *Leaf analysis should also be used to help determine phosphorus needs (see page 32).*

Table 35. *Potassium recommendations for fruit crops—new plantings.*

Crop	Soil Test K Level (ppm)					
	0-40	41-80	81-120	121-160	161-200	201+
	K_2O to apply (lb/A)					
Apples	300	250	200	100	50	0
Blueberries	200	150	100	50	25	0
Grapes	250	200	150	100	50	0
Raspberries	200	150	100	50	25	0
Strawberries	200	150	100	50	25	0

Table 36. *Potassium recommendations for fruit crops—established plantings.*[1]

Crop	Approximate Yield Goal	Soil Test K Level (ppm)					
		0-40	41-80	81-120	121-160	161-200	201+
	cwt/A	K_2O to apply (lb/A)					
Apples	140	200	150	100	50	0	0
Blueberries	50	150	100	50	25	0	0
Grapes	60	200	150	100	50	0	0
Raspberries	40	100	75	50	25	0	0
Strawberries	100	200	150	100	50	0	0

[1] *Leaf analysis should also be used to help determine potassium needs (see page 32).*

Secondary Macronutrients

The secondary macronutrients—calcium, magnesium, and sulfur—are generally not limiting to crop production in most Minnesota soils except under certain conditions.

Calcium

Calcium is available to plants as the Ca^{2+} ion. Calcium deficiency due to low soil calcium is rare, but may occur in acid sandy soils. Soils cropped to potatoes for many years may be low in calcium because liming is not recommended for this crop. Soil test results of less than 300 ppm calcium are considered low. For all crops except potatoes and blueberries, calcium needs can be met by liming according to soil pH. For potatoes where maintenance of acidity is desired, calcium needs can be met by applying low rates of lime (approximately 1000 lb/A) during the rotation year. An alternative is to apply calcium as gypsum (calcium sulfate—20% Ca) according to **Table 37**.

Some plants are susceptible to calcium deficiency even when adequate levels of calcium are present in the soil. For physiological disorders related to calcium deficiency (such as blossom end rot in tomatoes; tipburn in lettuce, cabbage, or cauliflower; black heart in celery; or bitter pit in apples) foliar calcium sprays may be beneficial. In soils where pH has been adjusted to 6.0 or above, additional soil applied calcium generally does not correct these physiological disorders. These disorders can often be related to cultivar, excessive ammonium fertilization, and/or excess or lack of water. For foliar sprays, apply 2-4 lb Ca/A. Calcium chloride at the rate of 5-10 lb per 100 gallons per acre or calcium nitrate at the rate of 10-15 lb per 100 gallons per acre should be applied directly to the sensitive tissue. Multiple applications are necessary to increase tissue calcium. Because of precipitation problems, do not mix calcium with sulfate or phosphate compounds.

Table 37. *Calcium recommendations for fruit and vegetable crops.*

Calcium Soil Test	Relative Level	Calcium to Apply
ppm		lb/A
0 - 150	low	200
151 - 299	medium	100
300 +	high	0

Magnesium

Magnesium is available to plants as the Mg^{2+} ion. Magnesium deficiency may occur in acid sandy soils. Soil tests less than 100 ppm magnesium are considered low. Deficiencies can be induced by high rates of potassium fertilizer on sandy soils low in magnesium. If magnesium deficiency is known or suspected, the use of dolomitic limestone is the best long-range approach. Apply low rates (approximately 1000 lb/A) if maintenance of soil acidity is desired. Other more immediately available sources of magnesium include potassium-magnesium sulfate (11% magnesium) or Epsom salts (10% magnesium). Recommended rates of magnesium based on a soil test are presented in **Table 38.** For in-season correction of magnesium deficiency, foliar sprays at the rate of 2-4 lb Mg/A are recommended (20-40 lbs of Epsom salts per acre). Two to three applications are required.

Table 38. *Magnesium recommendations for fruit and vegetable crops.*

Magnesium Soil Test	Relative Level	Magnesium to Apply Broadcast	Row
ppm		---------- lb/A	---------
0 - 49	low	100	20
50 - 99	medium	50	10
100 +	high	0	0

Sulfur

Sulfur is available to plants as the sulfate ion (SO_4^{2-}). Like nitrate, sulfate is susceptible to leaching on sandy soils. Sulfur deficiency is most common on sandy low organic matter soils. Soil tests for sulfur are only accurate for sandy soils. If deficiency is known or suspected, refer to **Table 39** for sulfur soil test recommendations. The sulfate form of sulfur is the preferred form to use as fertilizer.

Table 39. *Sulfur recommendations for fruit and vegetable crops.*

Sulfur Soil Test	Relative Level	Sulfur to Apply Broadcast	Row
ppm		----------- lb/A	-----------
0 - 6	low	20-30	10-15
7 - 12	medium	trial only	trial only
12.1 +	high	0	0

Micronutrients

Micronutrients, which include boron, chlorine, copper, iron, manganese, molybdenum, nickel, and zinc, are required in smaller amounts than the other essential nutrients. Generally, soils contain sufficient levels of micronutrients to meet crop demands; however, in some areas micronutrient shortages occur and may limit yields. Some crops have a higher demand for certain micronutrients than others and should be considered in determining whether a micronutrient fertilizer should be applied. The relative response of various fruit and vegetable crops to micronutrients is presented in **Table 40.**

Boron

Boron is taken up by plant roots as the neutral molecule H_3BO_3. Deficiency of boron is most likely on sandy soils low in organic matter. Excessive rainfall or irrigation may leach boron from sandy soils. A suspected boron deficiency should be confirmed by soil and plant analyses before a boron fertilizer is applied since excessive boron can be highly toxic to plants. Boron recommendations are presented in **Table 41**. For in-season correction of boron deficiency, foliar sprays at the rate of 0.2 to 0.4 lb B/A are recommended. Multiple applications are usually required.

Table 40. *Relative response of fruit and vegetable crops to micronutrients under soil conditions favorable to a deficiency.*[1]

	Relative Response					
Crop	**Zinc**	**Iron**	**Manganese**	**Molybdenum**	**Copper**	**Boron**
Apples	high	–	high	low	medium	high
Asparagus	low	medium	low	low	low	low
Beans, snap	high	high	high	low	low	low
Broccoli	–	high	medium	medium	medium	high
Blueberries	–	high	low	low	medium	low
Cabbage	low	medium	medium	medium	medium	medium
Carrots	low	–	medium	low	high	medium
Cauliflower	–	high	medium	high	medium	high
Celery	–	–	medium	low	medium	high
Cucumber	–	–	high	–	medium	low
Grapes	medium	high	high	low	low	medium
Lettuce	medium	–	high	high	high	medium
Onions	high	–	high	high	high	low
Parsnips	–	–	medium	–	medium	medium
Peas	low	–	high	medium	low	low
Potatoes	medium	–	high	low	low	low
Radishes	medium	–	high	medium	medium	medium
Raspberries	–	high	high	low	–	medium
Spinach	high	high	high	high	high	medium
Strawberries	–	high	high	–	medium	medium
Sweet corn	high	medium	medium	low	medium	low
Tomatoes	medium	high	medium	medium	medium	medium
Turnips	–	–	medium	medium	medium	high

[1] *From R. F. Lucas and B. D. Knezek. 1973.* Climatic and Soil Conditions Promoting Micronutrient Deficiencies in Plants. Micronutrients in Agriculture. *Soil Science Soc. of America.*

Table 41. *Boron recommendations for fruit and vegetable crops.*[1]

Boron Soil Test	**Relative Level**	**Group**[2]	**Boron to Apply**
ppm			lb/A
0.0 - 0.4	low	1	4
		2	2
		3	1
0.5 - 0.9	medium	1	2
		2	1
		3	0
1.0+	high	1	0
		2	0
		3	0

[1] *Rates suggested are for broadcast applications.*

[2] ***Group 1:*** *cauliflower, celery, broccoli, turnips, table beets, Brussels sprouts, rutabagas, apples*

Group 2: *cabbage, radishes, carrots, onions, tomatoes, spinach, eggplant, parsnips, strawberries, raspberries, grapes*

Group 3: *lettuce, peppers, asparagus, potatoes, squash, watermelon, muskmelon, parsley, mint, endive, rhubarb, green onions, blueberries*

No boron is recommended for fruits or vegetables not listed above.

Table 42. Copper recommendations for fruit and vegetable crops (organic soils only).

Copper Test	Relative Level	Group[1]	Copper to Apply
ppm			lb/A
0.0 - 2.5	low	1	10 broadcast 0.3 foliar[2]
		2	0
2.6 - 5.0	medium	1	6 broadcast 0.1 foliar[3]
		2	0
5.1+	high	1	0
		2	0

[1] **Group 1:** carrots, lettuce, spinach, onions, table beets, radishes, parsnips, turnips, celery, green onions
Group 2: asparagus, broccoli, Brussels sprouts, cabbage, cauliflower, mint, endive, parsley

[2] Some leaf burn may occur if foliar applications of copper exceed 0.15 lb Cu/A. Split the high rate recommended into two or more applications at weekly intervals.

[3] Two or three applications are usually required.

Chlorine

Chlorine is available to plants as the chloride ion (Cl^-) and is a major component of the potash fertilizer, 0-0-60. Actual plant requirements for chlorine are very low and adequate levels of chlorine to meet plant needs are believed to be present in all Minnesota soils. Excessive levels of chloride can cause salt burn. The need for using supplemental fertilizer applications to provide chlorine for fruit or vegetable crops in Minnesota has not been demonstrated.

Copper

Copper is available to plants as the Cu^{2+} ion. In Minnesota, copper deficiency is most likely on organic soils. Responses to copper by crops on mineral soils (loams, clay loams, etc.) have not been demonstrated; therefore, copper fertilizer is not recommended for crops grown on mineral soils. Soil tests for copper are reliable only for organic soils. Soil or foliar applied copper can be used to correct suspected deficiencies (**Table 42**). For soil application, apply copper sulfate and mix thoroughly in the top 6 inches before planting. Retest in three years.

Iron

The soil test for iron is not reliable for predicting iron requirements in Minnesota. Therefore, no recommendations based on a soil test are provided. Iron availability is related more to soil pH than it is to soil test iron levels. Alkaline soil conditions (pH greater than 7.2) can render iron unavailable to plant roots. Iron is usually present in the Fe^{3+} (ferric) form and must be converted to the Fe^{2+} (ferrous) form before it can be absorbed by plant roots. If soil pH is above 7.2 and interveinal chlorosis is apparent, then a foliar application of iron chelate may be beneficial. A general recommendation for foliar iron is 0.1 to 0.15 pounds actual iron per acre. Follow label instructions for specific crops and materials applied. Applications made during early stages of growth are more beneficial than later in the season. More than one foliar spray is usually required. Iron chlorosis in many crops can be minimized by selecting iron efficient varieties. Iron chlorosis can be corrected by soil applications of iron chelate, but the large amounts required make the practice uneconomical for most crops. For blueberries, soil pH should be lowered to 5.2 or less to correct iron chlorosis problems (see soil acidification section, **page 8**).

Table 43. Manganese recommendations for fruit and vegetable crops (organic soils only).

Soil pH	Group[1]	Manganese to Apply	
		Foliar[2]	Soil
		lb/A	
5.7 or less	1	0	0
	2	0	0
5.8 - 6.3	1	0.3	10
	2	0.2	4
6.4 or more	1	0.4	15
	2	0.3	6

[1] **Group 1:** lettuce, onions, potatoes, radishes, spinach, table beets, green onions, raspberries, strawberries, apples, grapes
Group 2: sweet corn, celery, broccoli, cauliflower, cabbage, Brussels sprouts, turnips, carrots, parsley, peppers, tomatoes
No manganese is recommended for crops not listed.

[2] Two or three applications are usually required. Apply with 50 to 100 gallons of water. Chelated manganese sources such as MnEDTA are recommended for foliar sprays.

Manganese

Most manganese in soils is precipitated as manganese oxide or hydroxide. The form available to plants is the Mn^{2+} ion. Manganese availability is related more to soil pH than soil test manganese levels. Manganese recommendations are based on the crop being grown and soil pH. On low pH mineral soils (pH less than 4.8), manganese can be toxic to plants. A few suspected deficiencies have been reported in fruit and vegetable crops grown on alkaline mineral soils. Manganese deficiency problems are most likely to occur on organic soils with a pH greater than 5.8. Soil and foliar application rates of manganese based on crop and soil pH are presented in **Table 43** (organic soils). If crops grown on mineral soils show signs of manganese deficiency or have low tissue manganese levels, a foliar application at the rate of 0.2 lb Mn/A is recommended. Two or three applications are usually required. Apply with 50 to 100 gallons of water per acre. Chelated sources of manganese are recommended for foliar spays.

Molybdenum

Molybdenum is available to plants as the MoO_4^{2-} ion. Deficiencies may occur on acid sandy soils and acid peats. Certain vegetable crops such as cauliflower are particularly susceptible to molybdenum deficiency. Soil tests for molybdenum are not reliable for making molybdenum fertilizer recommendations. Liming soils to a pH of 6.0-6.5 is the best method to correct molybdenum deficiency; however, some cauliflower cultivars seem to be susceptible to molybdenum deficiency even in limed soils. Soil applications of 0.25-0.5 pounds per acre of actual molybdenum can be used if molybdenum deficiency is a problem. Foliar applications of 1-2 oz/A of actual molybdenum are suggested for cole crops where a deficiency is known or expected. Do not overapply molybdenum as high rates can be toxic to animals.

Nickel

Nickel has only recently been shown to be an essential nutrient for plants. The form of nickel available to plants is the Ni^{2+} ion. Deficiencies of nickel have not been reported in field soils in Minnesota; however, some plants (for example, river birch) grown in peat based potting media are susceptible to nickel deficiency. High levels of zinc seem to accentuate nickel deficiency. Soil tests for nickel have not yet been calibrated. Actual requirements for nickel are low and adequate levels of nickel are believed to be present in most soils, although further research is necessary to actually determine nickel requirements of field grown crops in Minnesota. For potted plants showing nickel deficiency, drenches with solutions containing 3 to 6 ppm nickel as nickel nitrate, chloride, or sulfate can correct the problem. High levels of nickel can be toxic to plants. Elevated nickel levels are sometimes found in sewage sludge.

Zinc

The form of zinc available to plants is the Zn^{2+} ion. Zinc deficiency can occur on alkaline soils and sandy soils low in organic matter. High levels of phosphorus coupled with low levels of soil zinc may induce zinc deficiency. If zinc deficiency is known or suspected, zinc sulfate can be blended with a dry bulk fertilizer. Application rates of zinc based on a soil test are presented in **Table 44**. Zinc applied in the row should not come in contact with the seed. For crops showing zinc deficiency during the growing season, foliar applications of zinc chelate (2 oz/A actual zinc) are suggested.

Table 44. *Zinc recommendations for all fruit and vegetable crops.*

Soil Zinc Test	Relative Level	Zinc to Apply Broadcast	Row
ppm		------------- lb/A	----------------
0 - 0.5	low	10	2
0.6 - 1.0	medium	5	1
1.1+	high	0	0

Procedures Used in the University of Minnesota Soil Testing Laboratory

The following analyses are offered:

1. Estimated texture category+
2. Total organic matter (%)* (loss on ignition), maximum amount measured is 99.9%
3. Soil pH+ (1:1, water:soil suspension)
4. Lime requirement+ (SMP buffer index)
5. Extractable phosphorus+ (Bray-P1 extractant, Olsen-P sodium bicarbonate extractant)
6. Exchangeable potassium+ (ammonium acetate extractant)
7. Soluble salts* (electrical conductivity, 1:1 soil suspension, saturation extract)
8. Extractable sulfur* (calcium phosphate extractant)
9. Extractable zinc* (DTPA extractant)
10. Extractable zinc, copper, iron, and manganese* (DTPA extractant)
11. Nitrate-nitrogen* (0.01 M $CaSO_4$ extractant)
12. Exchangeable magnesium and calcium* (ammonium acetate extractant)
13. Hot water extractable boron* (0.1% $CaCl_2 \cdot 2H_2O$ extractant)

+ Tested routinely
* Tested only on request

Sample Preparation

At the laboratory, each sample is assigned a number, transferred to a paper bag, and then placed in a metal tray. Every 12th sample is a quality control sample, either a check sample of known chemical properties to ensure accuracy, or a duplicate sample to evaluate laboratory precision.

Samples are dried in a cabinet equipped with a heating element and an exhaust fan to remove moisture-laden air. The temperature in the cabinet does not exceed 104°F in order to approximate air-drying conditions.

Samples are crushed with a mechanical grinder equipped with a porcelain mortar and stainless-steel auger. They are subsequently passed through a stainless-steel 10-mesh sieve to remove larger clods and unwanted debris. Crushed and sieved samples are dried overnight before analysis.

Texture and Organic Matter

The relative amounts of sand, silt, and clay are estimated by the feel of the soil in a moist condition. The soils are then classified into three categories: C (coarse textures of sand, loamy sand, and sandy loam), M (medium textures of loam and silt loam), and F (fine textures of clay loam, silty clay loam, silty clay, and clay).

Organic matter is determined by ashing a 5-gram scoop of sample at 360° C for 2 hours in a muffle furnace. The loss by weight during this ignition is calculated as the organic matter. Results are reported as percent by weight in the soil.

Soil pH and Lime Requirement

The pH is determined using a glass and reference electrode with a pH meter on a 1:1 suspension (5-gram scoop of soil to 5 milliliters water). The water soil mixture is stirred vigorously for 5 seconds and then let stand for 10 minutes before reading. Samples of mineral soils with pH values of less than 6.0 are analyzed further using the following lime requirement test.

The SMP buffer index (lime requirement test) is determined by adding 10 milliliters of buffer solution to the above 1:1 sample. The buffer index of the suspension is determined with a pH meter, after the sample has been stirred intermittently for 15 minutes.

Extractable Phosphorus

Bray-P1 Method—The soil phosphorus measured is that which is extracted by a solution consisting of 0.025 normal HCl and 0.03 normal NH_4F, referred to as Bray-P1 extractant. A 1-gram scoop of soil and 10 milliliters of extractant are shaken for 5 minutes. The amount of phosphorus extracted is determined by measuring the intensity of the blue color developed in the filtrate when treated with ammonium molybdate-sulfuric acid solution and then ascorbic acid solution. The color is measured with a fiberoptic probe colorimeter at 880 nm. The result is reported in parts per million (ppm) phosphorus (P) in the soil.

Olsen-P Method—For highly calcareous soils (pH greater than 7.4), the Olsen-P sodium bicarbonate method is used. A 1-gram scoop of soil and 20 milliliters of 0.5 molar sodium bicarbonate ($NaHCO_3$) solution are shaken for 30 minutes. Blue color in the filtered extract is developed with successive additions of an ammonium molybdate-sulfuric acid solution and then an ascorbic acid solution and measured with a fiberoptic probe colorimeter at 880 nm. Results are reported as parts per million (ppm) phosphorus (P) in the soil.

Exchangeable Potassium

Potassium is extracted from the soil by mixing 10 milliliters of one normal, neutral, ammonium acetate with a 1-gram scoop of soil and shaking for 5 minutes. The exchangeable potassium is measured by analyzing the filtered extract on an atomic absorption spectrophotometer set on emission mode at 766.5 nm. The results are reported as parts per million (ppm) potassium (K) in the soil.

Soluble Salts

Soil samples are evaluated for salinity by first determining the electrical conductivity of a 1:1 suspension. Three 10-gram scoops of soil and 30 milliliters of deionized water are measured into large test tubes and shaken for 30 minutes. The electrical conductivity of this slurry is determined with a dip cell and conductivity meter, and reported as millimhos per centimeter (mmhos/cm).

Slightly to strongly saline soils (conductivity more than 0.9 millimhos) are subjected to a more precise test. A saturated soil paste is prepared by slowly adding deionized water to about 150 grams of soil until the mixture is a thick paste. After an equilibration time of 2 hours, the saturation paste is filtered under suction. The electrical conductivity is determined on the filtrate with a conductivity meter and reported as millimhos per centimeter (mmhos/cm).

Extractable Sulfur

Readily soluble and adsorbed sulfates are extracted with a monocalcium phosphate [$Ca(H_2PO_4)_2$] solution containing 500 ppm of phosphorus. A 10-gram scoop of soil is treated with 25 milliliters of extracting solution and shaken for 30 minutes. The sulfate content in the filtrate is determined turbidimetrically by the addition of $BaCl_2$. The results are reported as parts per million (ppm) of extractable sulfur (S) in the soil.

Extractable Zinc, Copper, Iron, and Manganese

Zinc, copper, iron, and manganese (Zn, Cu, Fe, and Mn) are determined by treating a 10-gram scoop of soil with 20 milliliters of DTPA extracting solution (0.005 molar DTPA, 0.1 molar TEA, and 0.01 molar $CaCl_2$, adjusted to pH 7.3). After shaking for 2 hours, the extract is filtered and the filtrate analyzed for metals with an inductively coupled plasma atomic emission spectrometer (ICP-AES). The results are reported as parts per million (ppm) for each metal in soil.

Nitrate-Nitrogen

Nitrate-nitrogen is determined by adding 60 milliliters of 0.01 M $CaCl_2$ extracting solution to a 2-gram scoop of soil and shaking for 15 minutes. The nitrate level in the filtered extract is measured on a continuous flow analyzer by the cadmium reduction method. The results are reported as pounds per acre (lb/A) of nitrate-nitrogen (NO_3-N) in the top 2 feet of soil, or as parts per million (ppm) nitrate-nitrogen (NO_3-N) in the soil for all other depths.

Hot Water Extractable Boron

A 10-gram scoop of soil and 20 milliliters of 0.1% $CaCl_2 \cdot 2H_2O$ (calcium chloride) solution are boiled in a metal container for 5 minutes under reflux using a fiber digestion condenser apparatus. Boron in the filtered extract is determined with an inductively coupled plasma atomic emission spectrometer (ICP-AES). The results are reported as parts per million (ppm) boron (B) in the soil.

Exchangeable Calcium and Magnesium

Calcium and magnesium are extracted from the soil by mixing 10 milliliters of one normal, neutral, ammonium acetate with a 1-gram scoop of soil and shaking for 5 minutes. The filtered extract is analyzed with an inductively coupled plasma atomic emission spectrometer (ICP-AES) for calcium and magnesium. The results are reported in parts per million (ppm) calcium (Ca) and magnesium (Mg) in the soil.

Diagnosing Nutrient Deficiency and Toxicity Symptoms in Fruit and Vegetable Crops

The following list describes general symptoms associated with nutrient disorders in plants. It should be remembered that nutrient deficiencies or toxicities can resemble nonnutritional disorders such as disease or herbicide damage. Use of soil and/or tissue analysis may help confirm whether symptoms are nutritional. More detailed information on determining nutrient disorders based on visual symptoms can be found at: http://www.extension.umn.edu/distribution/horticulture/M1190.html.

Nitrogen (N): Deficiency—Leaves turn pale green to yellow. Oldest leaves are affected first, but in severe cases the whole plant may be yellow. Growth is usually stunted. Occurs most frequently on sandy soils. **Excess**—Nitrogen excess can occur with high rates of nitrogen fertilizer. The result is usually excessive vegetative growth and poor fruit growth.

Phosphorus (P): Deficiency—Leaves appear reddish-purple. Oldest leaves are affected first. Plant growth is stunted. Common in acid and alkaline soils or those soils low in native phosphorus. Frequently occurs on cool wet soils in the spring; however, plants may grow out of phosphorus deficiency as soil warms. **Excess**—High rates of phosphorus fertilizer may induce zinc or iron deficiency.

Potassium (K): Deficiency—Leaves develop gray or tan areas near the margins. Oldest leaves are affected first with characteristic symptoms of scorching around the leaf margins. Occurs on sandy soils and soils low in native potassium. **Excess**—High rates of potassium fertilizer can cause salt burn. Soils with high potassium levels can induce magnesium deficiency on sandy soils.

Calcium (Ca): Deficiency—Growing points of plant may die. Younger leaves are affected. Root tips die and root growth is slow. Tipburn of cabbage, cauliflower, lettuce; black heart of celery; and blossom end rot of tomatoes are due to localized calcium deficiency within the plant. These disorders may occur on high calcium soils. Calcium deficiency may occur on acid and/or dry soils. **Excess**—Not known to occur in Minnesota.

Magnesium (Mg): Deficiency—Oldest leaves turn yellow between the veins. In severe cases, younger leaves may be affected and older leaves may drop off. May occur on acid soils, sandy soils, or soils with high potassium levels. **Excess**—Not known to occur in Minnesota.

Sulfur (S): Deficiency—Symptoms of sulfur deficiency are similar to nitrogen deficiency except that youngest leaves are usually affected first. Can occur on sandy soils low in organic matter. **Excess**—Rare, usually associated with saline conditions.

Boron (B): Deficiency—Usually occurs on younger plant tissue. Growing points die and leaves appear distorted. May cause hollow stem and internal browning in cauliflower and broccoli; cracked stem in celery; internal browning in beets and turnips. Can occur on sandy soils in crops with a high boron requirement. **Excess**—Boron can be highly toxic to some plants at low levels. Avoid excess boron applications. Toxicity symptoms usually occurs on oldest leaves as a scorching of the margins.

Chlorine (Cl): Deficiency—Rare. Not known to occur in the field. **Excess**—Marginal scorch of older leaves. Can occur on salt-affected soils, near streets where deicing salt is used, or when excessive rates of fertilizer containing chlorine are used.

Copper (Cu): Deficiency—Yellowing or dieback of youngest leaves. Sometimes yellowing between the veins. Most copper deficiencies occur on organic soils (peats or mucks). **Excess**—Can occur due to continuous use of copper-containing fungicides. May induce iron chlorosis and cause stunted root systems.

Iron (Fe): Deficiency—Yellowing between the veins on youngest leaves; veins remain green (often referred to as interveinal chlorosis). Occurs frequently on high pH soils (pH greater than 7.2). Some plant species more susceptible than others. With acid-loving plants (e.g., blueberry), chlorosis may occur at a pH as low as 5.5-6.0. **Excess**—Rare. High levels of iron may induce manganese deficiency.

Manganese (Mn): Deficiency—Similar to iron deficiency. Yellowing between the veins of youngest leaves. Usually only the main veins remain green causing a fishbone-like appearance. In some plants older leaves may develop gray streaks or dots. Occurs on high pH soils (pH greater than 7.2). Can also occur on organic soils with pH greater than 6.0. **Excess**—Manganese toxicity can occur on acid soils (pH less than 4.5) or after heat sterilization of greenhouse soils. Excess symptoms include brown spots on leaves and chlorosis (yellowing).

Molybdenum (Mo): Deficiency—Pale distorted narrow leaves. Causes “whiptail” of cauliflower. Can occur on acid soils (pH less than 5.0). **Excess**—Rare.

Nickel (Ni): Deficiency–Small, wrinkled and sometimes cupped leaves; necrotic leaf margins; shortened internodes resulting in stunted plants and witches-broom appearance; referred to as “mouse-ear” disorder in some plants. Occurs in peat-based potting mixes and is accentuated by excess zinc. **Excess**–induces iron and zinc deficiency.

Zinc (Zn): Deficiency—Short internodes may cause rosetting appearance in trees. Younger leaves usually affected first and may show signs of yellowing between the veins. High levels of phosphorus fertilizer may induce zinc deficiency. Can occur on high pH soils or acid sandy soils. **Excess**—May induce iron deficiency.

Plant Analysis for Fruit and Vegetable Production

Plant analysis is a powerful tool growers can use to help diagnose nutrient disorders that may occur during the growing season. Plant analysis can also be used to help fine-tune the efficiency of a fertilizer program before nutrient deficiency symptoms appear and is especially useful for perennial crops. The technique involves determining the elemental composition of plant tissue during the growing season and then comparing these values with those already established for a normal, healthy plant. From this comparison, nutrient deficiencies or excesses can be determined.

It should be recognized that plant analysis is not a substitute for a routine soil test. Soil testing provides information on lime and fertilizer needs prior to planting and is particularly well calibrated for nutrients such as phosphorus, potassium, magnesium, calcium, sulfur, boron, and zinc. Soil tests for nutrients such as nitrogen (eastern Minnesota), iron, manganese, copper (mineral soils), and molybdenum are often not reliable for predicting fertilizer needs. Therefore, when used in conjunction with soil testing, plant analysis can provide additional information related to crop nutrition and the effectiveness of a particular fertilizer program.

What and When to Sample

The basis behind plant analysis is that maximum yields are associated with an optimum range of nutrients in the leaf or tissue sampled. Usually the leaf plus petiole or just the petiole alone is sampled for nutrient determination. If the level of a nutrient falls outside this range, then corrective measures should be taken. These optimum nutrient ranges are based on samples collected at a particular growth stage and tissue maturity. Samples collected too early or late in the growing season may not be interpreted accurately using the established sufficiency values. The proper time and plant part to sample are presented in **Table 45**.

When troubleshooting suspected nutrient deficiency or toxicity symptoms, it may not be possible to collect the samples at the recommended time. For these situations, samples should be collected from plants showing a problem and then compared to those collected from both healthy plants and plants only showing minor symptoms. Comparing nutrient levels in these samples as well as looking at soil test results can help determine whether the problem is nutritional.

Sampling and Handling Procedures

The following instructions may be used as a guide for proper sampling and handling procedures:

1. Refer to **Table 45** for proper times to sample and the plant part to collect.
2. Obtain a representative composite sample from a uniform area. Areas of different soil type should be sampled separately. Each sample should not represent more than 10 acres even in uniform areas. Refer to **Table 45** for the number of plants or leaves required for each sample. Samples should consist of tissue collected over the entire area. Leaves showing insect, disease, or mechanical damage should not be selected for sampling. Do not sample if foliar fertilizers have been recently applied unless you are only interested in nutrients other than those applied.
3. Avoid sampling dirty or dusty leaves. Consult your tissue testing laboratory for specific information on how to handle and send in the samples. Some general guidelines for handling dirty samples are as follows. If leaves are dirty or dusty, they should be rinsed quickly in distilled or demineralized water. A mild non-phosphate detergent may be added if necessary. Do not let the leaves soak in water as the nutrients can leach out. Particulate matter may be removed with a clean cloth dampened with distilled or demineralized water. Dried tissue should not be rinsed. Samples should be dried as rapidly as possible. Forced air drying at 150-170° F is preferred, but air drying is also permissible. Transport the samples to the laboratory in loose fitting, clean paper or cloth bags. Do not use plastic bags unless the samples have been previously dried or are transported to the laboratory within a few hours.
4. The University of Minnesota Research Analytical Laboratory (phone: 612-625-3101) offers tissue testing services for a fee. An information sheet along with current prices can be found at the following web site: http://ral.coafes.umn.edu/Forms/DIAGNOSTIC%20PLANT2003a.pdf

   A number of private laboratories also offer tissue testing services. Contact your Extension Office or fertilizer dealer for information about commercial laboratories in your area or look in the Yellow Pages under "laboratories."

Interpretations

The established sufficiency levels for a healthy crop are presented in **Table 46**. Even though many of these levels have been determined from research conducted outside of Minnesota, they do provide a starting point for interpretation.

Table 45. Procedures for sampling plant tissue.

Crop	Stage of Growth	Plant Part Sampled	Approximate Number of Plants or Leaves to Sample
Apples	July 15-Aug. 15	Leaf from middle of current terminal shoot	60
Asparagus	Mature fern (August)	Fern from 17 to 35 inches up	20
Beans, snap	Initial flowering	Young mature trifoliate	50
Beets, table	Mature	Young mature leaf	20
Blueberries	First week of harvest	Young mature leaf	50
Broccoli	Heading	Young mature leaf	15
Brussels sprouts	Maturity	Young mature leaf	15
Cabbage	Heads, half-grown	Young wrapper leaf	15
Cantaloupe	Early fruiting	Fifth leaf from tip	25
Carrots	Midgrowth	Young mature leaf	25
Cauliflower	Buttoning	Young mature leaf	15
Celery	Half-grown	Young mature leaf	20
Cucumbers	Early fruiting	Fifth leaf from tip	20
Eggplant	Early fruiting	Young mature leaf	15
Garlic	Bulbing	Young mature leaf	25
Grapes	Full bloom	Petiole from leaf opposite basal fruit cluster	75
Lettuce	Heads, half-size	Wrapper leaf	20
Onions	Midgrowth	Top, no white portions	25
Peas	First bloom	Recently mature leaflet	50
Peppers	Early fruiting	Young mature leaf	20
Potatoes	40-50 days after emergence	Fourth leaf from tip	20
Potatoes	40-50 days after emergence	Petiole from fourth leaf from tip	40
Pumpkin/Squash	Early fruiting	Young mature leaf	15
Radishes	Midgrowth to harvest	Young mature leaf	40
Raspberries	First week in August	Leaf 18 inches from tip	50
Spinach	30-50 days old	Young mature leaf	35
Strawberries	Mid-August	Young mature leaf	20
Sweet corn	Tasseling to silk	Ear leaf	10
Tomatoes	First mature fruit	Young mature leaf	20
Watermelons	Midgrowth	Young mature leaf	15

Table 46. *Nutrient concentration sufficiency ranges for fruit and vegetable crops.*[1]

	Nutrient Concentration Ranges											
Crop	N	P	K	Ca	Mg	S	Fe	B	Cu	Zn	Mn	Mo
	%						ppm					
Apples	1.9-2.3	0.09-0.40	1.2-1.8	0.8-1.6	0.25-0.45	0.20-0.40	50-200	30-50	6-12	20-50	25-135	>0.1
Asparagus	2.4-3.8	0.25-0.50	1.5-2.4	0.4-1.0	0.25-0.30	—	40-250	40-100	5-25	20-60	25-160	—
Bean, snap	5.0-6.0	0.25-0.75	2.2-4.0	1.5-3.0	0.25-0.70	—	50-300	20-60	7-30	20-60	50-300	>0.4
Beets, table	3.5-5.0	0.25-0.50	3.0-4.5	2.5-3.5	0.30-1.00	—	50-200	30-80	5-15	15-30	70-200	—
Blueberries	1.7-2.1	0.10-0.40	0.4-0.7	0.35-0.8	0.12-0.25	0.12-0.30	70-200	25-70	5-20	9-30	50-600	—
Broccoli	3.2-5.5	0.30-0.70	2.0-4.0	1.2-2.5	0.23-0.40	0.30-0.75	50-150	30-100	4-10	20-80	25-150	0.3-0.5
Brussels sprouts	3.1-5.5	0.30-0.75	2.0-4.0	1.0-2.5	0.25-0.75	0.30-0.75	60-300	30-100	5-15	25-200	25-200	0.25-1.0
Cabbage	3.6-5.0	0.33-0.75	3.0-5.0	1.1-3.0	0.40-0.75	0.3-0.75	30-200	25-75	5-15	20-200	25-200	0.4-0.7
Cantaloupe	4.5-5.5	0.30-0.80	4.0-5.0	2.3-3.0	0.35-0.80	0.25-1.0	40	50-300	25-60	7-30	20-200	50-250
Carrots	2.5-3.5	0.20-0.30	2.8-4.3	1.4-3.0	0.30-0.50	—	50-300	30-100	5-15	25-250	60-200	0.5-1.5
Cauliflower	3.3-4.5	0.33-0.80	2.6-4.2	2.0-3.5	0.27-0.50	—	30-200	30-100	4-15	20-250	25-250	0.5-0.8
Celery	2.5-3.5	0.30-0.50	4.0-7.0	0.6-3.0	0.20-0.50	—	30-70	30-60	5-8	20-70	100-300	—
Cucumbers	4.5-6.0	0.30-1.25	3.5-5.0	1.0-3.5	0.30-1.00	0.30-0.70	50-300	25-60	5-20	25-100	50-300	—
Eggplant	4.2-5.0	0.45-0.60	5.7-6.5	1.7-2.2	0.25-0.35	—	—	20-30	4-6	30-50	15-100	—
Garlic	3.4-4.5	0.28-0.50	3.0-4.5	1.0-1.8	0.23-0.30	—	—	—	—	—	—	—
Grapes	1.2-2.2	0.15-0.46	1.5-2.5	1.2-2.5	0.30-0.50	—	40-180	30-50	7-15	25-100	25-150	0.2-0.4
Lettuce	2.5-4.0	0.40-0.60	6.0-8.0	1.4-2.0	0.50-0.70	—	50-500	30-100	7-10	26-100	30-90	>0.1
Onions	5.0-6.0	0.35-0.50	4.0-5.5	1.5-3.5	0.30-0.50	0.50-1.0	60-300	30-45	5-10	20-55	50-65	—
Peas	4.0-6.0	0.30-0.80	2.0-3.5	1.2-2.0	0.30-0.70	0.20-0.40	50-300	25-60	5-10	25-100	30-400	>0.6
Peppers	3.5-4.5	0.30-0.70	4.0-5.4	0.4-0.6	0.30-1.50	—	60-300	30-100	10-20	30-100	26-300	—
Potatoes (leaf)	3.5-4.5	0.25-0.50	4.0-6.0	0.5-0.9	0.25-0.50	0.19-0.35	30-150	20-40	5-20	20-40	20-450	—
Potatoes (petiole)	—	0.22-0.40	8.0-10.0	0.6-1.0	0.30-0.55	0.20-0.35	50-200	20-40	4-20	20-40	30-300	—
Pumpkin/ Squash	4.0-6.0	0.35-1.00	4.0-6.0	1.0-2.5	0.30-1.00	—	60-300	25-75	6-25	20-200	50-250	—
Radishes	3.0-6.0	0.30-0.70	4.0-7.5	3.0-4.5	0.50-1.20	0.20-0.40	50-200	30-50	6-12	20-50	25-130	—
Raspberries	2.2-3.5	0.20-0.50	1.1-3.0	0.6-2.5	0.25-0.80	0.20-0.30	50-200	25-300	4-20	15-60	25-300	—
Spinach	4.2-5.2	0.30-0.60	5.0-8.0	0.6-1.2	0.60-1.00	—	60-200	25-60	5-25	25-100	30-250	>0.5
Strawberries	2.1-2.9	0.20-0.35	1.1-2.5	0.6-1.8	0.25-0.70	0.20-0.30	90-150	25-60	6-20	20-50	30-100	—
Sweet corn	2.8-3.5	0.25-0.40	1.8-3.0	0.6-1.1	0.20-0.50	0.20-0.75	50-300	8-25	5-25	20-100	30-300	0.9-1.0
Tomato	4.0-6.0	0.25-0.80	2.9-5.0	1.0-3.0	0.40-0.60	0.40-1.2	40-200	25-60	5-20	20-50	40-250	—
Watermelon	2.0-3.0	0.20-0.30	2.5-3.5	2.5-3.5	0.60-0.80	—	100-300	30-80	4-8	20-60	60-240	—

[1] *Portions of this table were adapted from* Plant Analysis Handbook *by J.B.Jones, Jr., B. Wolf, and H.A. Mills. MicroMacro Publishing, Inc., 1991.*

Tissue Nitrate Analysis for Vegetable Crops

Tissue nitrate analysis has proved to be a valuable tool to guide in season applications of nitrogen. The tissue usually sampled for analysis is the leaf petiole, although for some crops the leaf midrib is collected. The petiole is the stem portion of the leaf. Petiole analysis is especially recommended for scheduling nitrogen applications for overhead and drip irrigation and has been used extensively for potato production. Traditional petiole analysis is based on collecting petioles at defined stages of growth, sending the petioles to a laboratory, and then receiving results of the nitrate analysis within 48 hours to one week. Results are presented on a dry weight basis. For most crops, the plant part to sample is the most recently mature leaf. All leaflets or leaf blade portions should be removed immediately and the petiole saved for analysis (see **Figure 3**). For some crops such as cabbage, broccoli, cauliflower, and lettuce, the leaf midrib should be saved for analysis (see **Figure 4**). Time of day can affect tissue nitrate concentrations. To reduce variability, it is recommended that tissue be sampled before noon. Tissue handling is similar to that described above for plant analysis.

Advances have also been made in quantitative determination of nitrate in petiole sap. Portable nitrate electrodes such as the Cardy meter and color test strips have been shown to be useful for determining nitrogen needs. The advantage of the sap test is that results can be obtained more quickly than with conventional dry weight analysis. The same tissue is collected for sap analysis as for conventional petiole analysis. The difference is that instead of drying the tissue in a laboratory, the petioles are crushed to express the sap and then the sap is immediately analyzed for nitrate.

Ideally, petioles should be processed immediately; however, if this is not possible, whole petioles can be stored in a plastic bag on ice in a cooler or in a refrigerator for up to 8 hours or at room temperature for up to 2 hours. Be sure that all leaf blade portions have been removed before storing.

Sap can be expressed with a garlic press or hydraulic sap press. Petioles can also be placed in a plastic bag and then crushed with a rolling pin to express the sap. Follow sap analysis instructions of the manufacturer. For the Cardy meter, sap generally does not need to be diluted. For other portable electrodes or the color test strips, the sap needs to be diluted to obtain an accurate reading.

Most interpretations are on a nitrate-N basis. In some cases, results are expressed on a nitrate basis instead of a nitrate-N basis. To convert from ppm nitrate to ppm nitrate-N, multiply ppm nitrate by 0.225. Nitrate concentrations usually decline as the crop matures and the season progresses. Therefore, interpretation is based on stage of growth. Nitrate-N concentrations on a dry weight or sap basis for selected crops are presented in **Table 47**. If nitrate-N concentrations fall below the sufficiency range, then fertigation with urea-ammonium nitrate is recommended. An application of up to 40 lb N/A can be made with overhead irrigation systems. Smaller (5 to 10 lb N/A) more frequent applications can be made with drip irrigation.

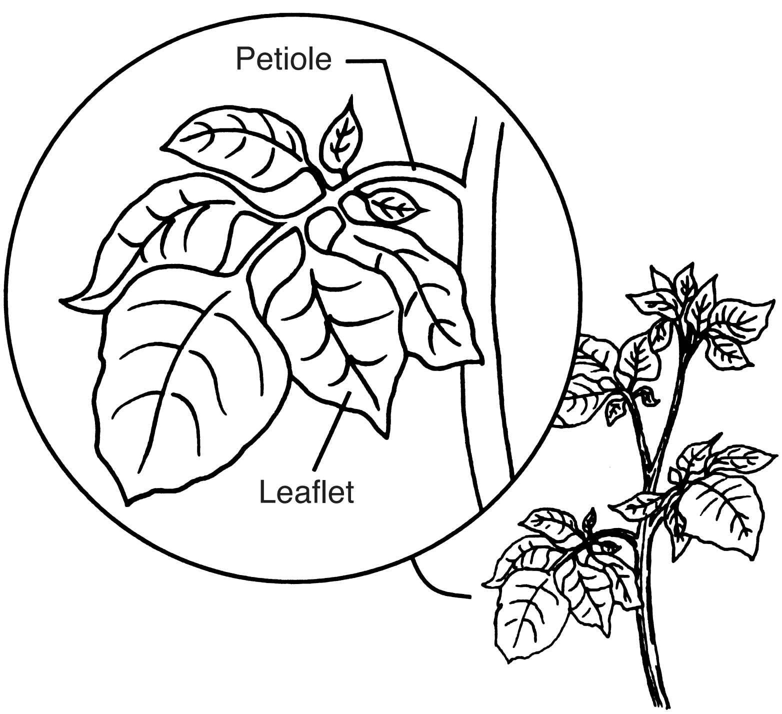


Figure 3. *Potato leaf consisting of leaflets and petiole.*

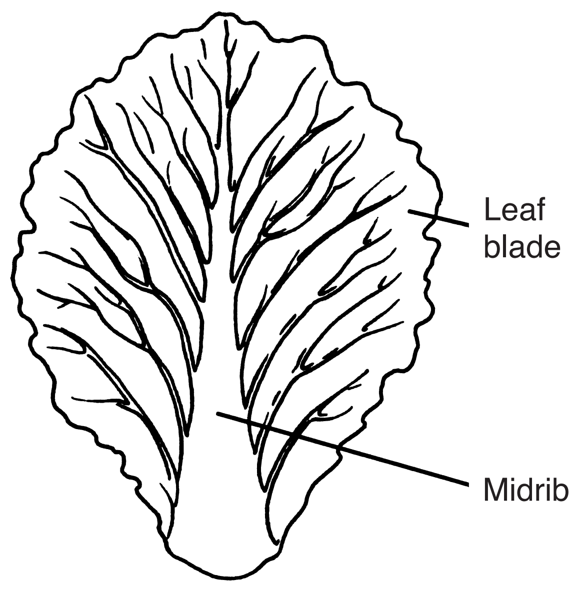


Figure 4. *Cabbage leaf consisting of midrib and blade.*

Table 47. *Sufficiency nitrate-N concentration ranges for petioles/midribs of selected vegetable crops on a dry weight and sap basis. Petioles/midribs should be collected from the most recently matured leaf.*[1]

Crop	Tissue Sampled	Growth Stage	Nitrate-N	
			dry weight	sap
			%	ppm
Broccoli	Midrib	Buttoning	0.9 - 1.2	800 - 1100
Cabbage	Midrib	Heading	0.7 - 0.9	NA
Carrots	Petiole	Midgrowth 1/4 inch diameter shoulder	0.75 - 1.0	550 - 750
Cauliflower	Midrib	Buttoning	0.7 - 0.9	NA
Celery	Petiole	Midgrowth	0.7 - 0.9	500 - 700
Cucumbers	Petiole	First blossom	0.75 - 0.9	800 - 1000
		Early fruit set	0.5 - 0.75	600 - 800
		First harvest	0.4 - 0.5	400 - 600
Eggplant	Petiole	Initial fruit	NA	1200 - 1600
		First harvest	NA	1000 - 1200
Lettuce	Midrib	Heading	0.6 - 0.8	NA
Muskmelon	Petiole	First blossom	1.2 - 1.4	1000 - 1200
		Initial fruit	0.8 - 1.0	800 - 1000
		First mature fruit	0.3 - 0.5	700 - 800
Peppers	Petiole	First flower	1.0 - 1.2	1400 - 1600
		Early fruit set	0.5 - 0.7	1200 - 1400
		Fruit 3/4 size	0.3 - 0.5	800 - 1000
Potatoes	Petiole	Vegetative	1.7 - 2.2	1200 - 1600
		Tuber bulking	1.1 - 1.5	800 - 1100
		Maturation	0.6 - 0.9	400 - 700
Tomatoes	Petiole	Early bloom	1.4 - 1.6	1000 - 1200
		Fruit 1 inch diameter	1.2 - 1.4	400 - 600
		Full ripe fruit	0.6 - 0.8	300 - 400
Watermelon	Petiole	Early fruit set	0.75 - 0.9	1000 - 1200
		Fruit 1/2 size	NA	800 - 1000
		First harvest	NA	600 - 800

NA = Not available.

[1] *Portions of this Table were adapted from "Sufficiency Ranges for Nitrate-Nitrogen and Potassium for Vegetable Petiole Sap Quick Tests." G.J. Hochmuth,* HortTechnology. *Pages 218-222. 1994.*

UNIVERSITY OF MINNESOTA
Soil Testing Laboratory

FARM/FIELD CROPS and COMMERCIAL HORTICULTURAL CROPS

Report No.

Instructions for filling out this form are given on the back side

SOIL SAMPLE INFORMATION SHEET

LOCATION REFERENCE

Name ____________________

Address ____________________

City, State, Zip ____________________

Phone ____________________

Soil location: County ____________________

Township ____________________

Check for $__________ enclosed

Customer Number ____________________
(pre-arranged accounts only)

MAIL REPORT TO:

Name ____________________

____

Address ____________________

City, State, Zip ____________________

Phone ____________________

Sample Identification			1 Crop History				2 Proposed Crops						3 CHECK TESTS REQUESTED (plow layer sample)								
			Crop Grown Before Last		Last Crop Grown		Option 1		Option 2		Option 3		* Regular Series P, K, pH, %OM	Sulfur **	Zinc	Zinc, Copper, Iron, Manganese	Boron	Calcium and Magnesium	Nutrient Management P	Soluble Salts	Nitrate Before selecting this test please read section on nitrate on the BACK SIDE. Sampling to 24" is required for this test.
Laboratory Number (Lab Use Only)	Field or Sample No. or Letter	Check If Irrigated	Crop Code No.	If Alfalfa check plants per sq ft	Crop Code No.	If Alfalfa check plants per sq ft	Crop Code No.	Expected Yield	Crop Code No.	Expected Yield	Crop Code No.	Expected Yield	$9	$4	$4	$10	$6	$6	$5	$5	
				❑ 4+ ❑ 2-3 ❑ 0-1		❑ 4+ ❑ 2-3 ❑ 0-1							Prices subject to change								Nitrate ❑ 0-6"/6-24" sample $5.00 ❑ 0-24" sample $5.00
				❑ 4+ ❑ 2-3 ❑ 0-1		❑ 4+ ❑ 2-3 ❑ 0-1															Nitrate ❑ 0-6"/6-24" sample $5.00 ❑ 0-24" sample $5.00
				❑ 4+ ❑ 2-3 ❑ 0-1		❑ 4+ ❑ 2-3 ❑ 0-1															Nitrate ❑ 0-6"/6-24" sample $5.00 ❑ 0-24" sample $5.00
				❑ 4+ ❑ 2-3 ❑ 0-1		❑ 4+ ❑ 2-3 ❑ 0-1															Nitrate ❑ 0-6"/6-24" sample $5.00 ❑ 0-24" sample $5.00
				❑ 4+ ❑ 2-3 ❑ 0-1		❑ 4+ ❑ 2-3 ❑ 0-1															Nitrate ❑ 0-6"/6-24" sample $5.00 ❑ 0-24" sample $5.00
				❑ 4+ ❑ 2-3 ❑ 0-1		❑ 4+ ❑ 2-3 ❑ 0-1															Nitrate ❑ 0-6"/6-24" sample $5.00 ❑ 0-24" sample $5.00

Recommendations available for these crops ** See comment on back side * THE REGULAR SERIES NOW INCLUDES PERCENT ORGANIC MATTER

Crop Code	Name	Yield Unit
	LEGUMES	
01.	Alfalfa, New Seed	tons/acre
02.	Alfalfa, Established	tons/acre
03.	Birdsfoot Trefoil	tons/acre
04.	Legume/Grass Hay	tons/acre
05.	Legume/Grass Pasture	-
06.	Red Clover	tons/acre
	CORN	
07.	Corn, Grain	bu./acre
08.	Corn, Silage	tons/acre
09.	Sweet Corn	tons/acre
	SMALL GRAINS	
10.	Barley	bu./acre
11.	Oats	bu./acre
12.	Rye/Triticale	bu./acre
13.	Wheat	bu./acre
	MISCELLANEOUS	
14.	Buckwheat	lb./acre
15.	Edible Beans	lb./acre
16.	Fallow	-
17.	Flax	bu./acre
18.	Grass Hay	tons/acre
19.	Grass Seed Prod.	lb./acre
20.	Grass Pasture	-
21.	Millet	lb./acre
22.	Native Grasses	tons/acre
23.	Potatoes	cwt/acre
	MISCELLANEOUS (continued)	
24.	Rape/Mustard/Canola	cwt/acre
25.	Sorghum Sudan	-
26.	Soybeans	bu./acre
27.	Sugarbeets	tons/acre
28.	Sunflowers	lb./acre
29.	Wild Rice	-
	VEGETABLES	
30.	Asparagus, New Planting	
31.	Asparagus, Establ. Planting	
32.	Beans, Snap	
33.	Beets, Table	
34.	Broccoli	
35.	Brussels Sprouts	
36.	Cabbage	
37.	Cauliflower	
38.	Carrots	
	VEGETABLES (continued)	
39.	Celery	
40.	Cucumbers	
41.	Lettuce	
42.	Melons	
43.	Onions, Dry	
44.	Onions, Green	
45.	Parsnips	
46.	Peas	
47.	Peppers	
48.	Pumpkins/Squash	
49.	Radishes	
50.	Turnips	
51.	Rhubarb	
52.	Rutabagas	
53.	Spinach	
54.	Tomatoes	
	FRUITS	
55.	Apples	
56.	Blueberries	
57.	Grapes	
58.	Raspberries/Brambles	
59.	Strawberries	
	TURF	
60.	Cultured Sod	
61.	**NURSERY – FIELD STOCK TREES/SHRUBS** Suggested tests: Regular, Soluble Salts, Nitrate. For sampling instructions, please see Nursery Form MI-3658-GO.	
62.	**Other** __________	

REV 3/03

INSTRUCTIONS FOR COMPLETING SOIL SAMPLE INFORMATION SHEET

Field History (1): This information is essential for us to provide the most accurate nitrogen recommendations. Indicate crops grown the past **two** most recent growing seasons. BE SURE TO USE THE CROP CODE NUMBER FROM THE LISTING ON THE FRONT SIDE. If alfalfa was the crop grown during either or both of the two previous growing seasons, it's important to indicate the number of plants (crowns) per sq. ft.

Proposed Crops and Yield Goals (2): You can select recommendations for up to three crops by entering the corresponding crop code number, **or three yield goals** for one crop. At least one option must be completed to receive a fertilizer recommendation, but there is no requirement to complete all options. If alfalfa is planned for the second crop year, list the crop code 01 under Option 2 or Option 3 with the desired yield in order to get a lime recommendation to pH 6.5. For CRP acres, list the crop most similar to that being seeded (e.g., 04 for legume/grass hay, or 22 for native grasses.)

Tests Requested (3): Indicate the test choices for each sample. Cost for each test is shown. **Before selecting nitrate, read the information below for Nitrate Test** to see if it applies to your area or crop.

- Regular Series: Sample the plow layer for cultivated land, or to 3 inches for pastures or sod fields. Includes phosphorus, potassium, pH and lime requirement, percent organic matter, estimated texture.
- Special Tests: These tests are to be determined only on the plow layer sample. Includes zinc, copper, iron, manganese, boron, calcium, magnesium, soluble salts (electrical conductivity).
  Copper recommendations apply only for peat or muck soils. Research has shown that for Minnesota soils, tests for iron and manganese are not practical; they are included because of requests for the test.
- Sulfur Test: The sulfur test is not a reliable predictor of sulfur needs. Sulfur recommendations are based on crop and soil texture. See your county extension educator for details.
- Nutrient Management P Test: This test is an Olsen extractable P method, but is designed for situations where the soil test level for phosphorus is expected to be in the high range (>50 ppm Olsen) and is required for nutrient management decisions. Range is 20 – 250 ppm extractable Olsen P.
- Nitrate Test: For the N recommendation to be based on the nitrate value, the soil MUST be collected to a depth of 24 inches. There are two options: 1) submit two samples, 0-6" depth (if a regular series or other tests are included) and a 6"-24" depth sample; 2) collect the soil from 0-24" for the nitrate test only. The test applies to non-sandy soils in western Minnesota with an exception noted below. This test is preferred for making N recommendations for the counties west of and including Lake of the Woods, Beltrami, Becker, Otter Tail, Douglas, Pope, Kandiyohi, Renville, Redwood, Cottonwood and Jackson. In these counties, the test is used in making N recommendations for corn, small grains, potatoes and sugar beets.
  For the counties EAST of those cited, the nitrate test is used to recommend N only if the sample is collected in the spring before or near planting (April 1 – June 15).
  N fertilizer recommendations will not be based on the analysis of only plow layer samples for nitrate-nitrogen. If only a plow layer sample is submitted, N recommendations will be based on cropping history, intended crop, yield goal, and soil organic matter level.
  Samples collected for the nitrate test must be air-dried immediately to slow down microbial activity. Drying can be accomplished by spreading the soil in the sun, or placing near a heat source. If only nitrate is to be determined, the samples can be dried in a microwave oven using several 2-minute power cycles, stirring between each cycle. Alternatively, samples can be frozen and sent to the lab in a well-insulated package, which is additional shipping expense by the sender.

SAMPLING INSTRUCTIONS

Divide the field into uniform areas. Each area should have the same soil color and texture, cropping history, fertilizer, lime and manure treatments. One sample should not represent more than 20 acres on level, uniform landcapes, or 5 acres on hilly or rolling land. Within each area collect 15-30 sub-samples (cores, borings or spade slices) in a zig-zag pattern throughout the designated field area. The more variable the soil, the more sub-samples should be combined per area sampled. Mix the sub-samples thoroughly in a clean plastic pail, and fill the sample box or bag to the fill line (1 pint). If samples must be taken wet, they should be dried before being mixed and submitted to the laboratory. Do not exceed a drying temperature of 97°F, and do not use a microwave oven unless only the nitrate test is requested.

Sample each area as follows: Scrape off all surface residue. Sample to a depth of 6-8 inches (plow layer) for cultivated crops or 3 inches for pasture or sod fields. Sample row crop fields between rows, except for ridge-till plantings. Where RIDGE-TILL is used, take the sample to a depth of 6-8 inches on the shoulder of the ridge, avoiding the starter fertilizer band. Also avoid sampling dead or back furrows, terraces, old fence rows, lime or fertilizer spill areas, headlands, eroded knolls, low spots, or small saline areas. Sample at least 300 feet away from gravel or crushed limestone roads because their dust changes soil pH.

SHIPPING INSTRUCTIONS

Fill out the information sheet as completely as possible so that accurate recommendations can be given. Keep a copy for your records. Place samples in a shipping carton, enclose the information sheet with check made payable to The University of Minnesota. Please do not send cash. The lab is not responsible for cash sent through the mail. If the shipping carton is a re-used box, wrap in heavy brown paper.

Ship samples to:

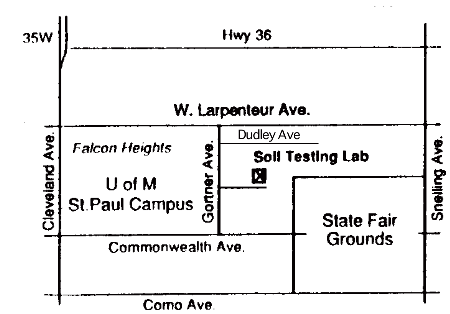
Soil Testing Laboratory
University of Minnesota
135 Crops Research Building
1902 Dudley Avenue
St. Paul, MN 55108

For additional information or requests for additional soil sample information sheets and collection bags, call or visit your local county extension office, or call the laboratory at (612) 625-3101 or fax (612) 624-3420.

Website: http://soiltest.coafes.umn.edu

Location of the Laboratory

↑ N



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