


Soil Test Interpretations and Fertilizer Management for Lawns, Turf, Gardens, and Landscape Plants


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EXTENSION

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Table of Contents

Introduction

Optimum growth of turf, flowers, fruits, and vegetables depends on many management factors, one of which is ensuring a sufficient supply of plant nutrients. There are at least 17 essential elements required for plant growth: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, zinc, copper, boron, molybdenum, chlorine, and nickel. Plants obtain carbon, hydrogen, and oxygen from air and water. The remaining elements are derived from the soil. When the soil cannot supply the amount of these nutrients required for adequate growth, supplemental fertilizer applications become necessary. Many urban soils are disturbed during the construction process. Top soil is often scraped off and removed and, as a result, nutrient and organic matter levels are often lower in these disturbed sites than in native soils. Adding organic matter as well as fertilizer may be necessary to improve the growth of plants on these sites.

Accurate fertilizer recommendations are important, because problems can result from either inadequate or excessive fertilization. Too little fertilizer leads to poor plant growth, but too much fertilizer can also reduce plant growth and quality. In addition, excessive applications of fertilizer can be harmful to the environment.

Fertilizer recommendations are based on the kinds of plants that are grown, the type of soil they are growing in, and the results of soil tests. Soil testing provides information on the availability of nutrients in the soil and is required for accurate fertilizer and lime recommendations.

This bulletin presents current fertilizer and lime recommendations for home lawns, vegetable and flower gardens, small fruits, tree fruits, and ornamental trees and shrubs. Basic recommendations for home lawns are also generally applicable to other turfgrass areas such as golf courses, athletic fields, parks, cemeteries, schools, industrial grounds, and commercial sod farms. Commercial nursery or greenhouse growers interested in fertilizer recommendations for container grown crops should use different soil tests. Contact the University of Minnesota Soil Testing Laboratory at 612-625-3101, or check online at http://soiltest.cfans.umn.edu/ for the appropriate form for container grown crops.

Taking a Soil Sample

Proper interpretation of soil test results depends upon collecting a representative sample of the soil. Soil samples can be taken at any time of the year, although spring and fall sampling are usually the most convenient. Separate samples should be collected from areas that differ in soil texture, soil color, the kinds of plants previously grown, and previous applications of fertilizer, organic amendments, and lime.

Samples are most easily collected using a soil tube, soil auger, or a garden trowel or spade. Scrape off all surface vegetation or litter and take the sample to the desired depth. Standardized sampling depths are as follows:

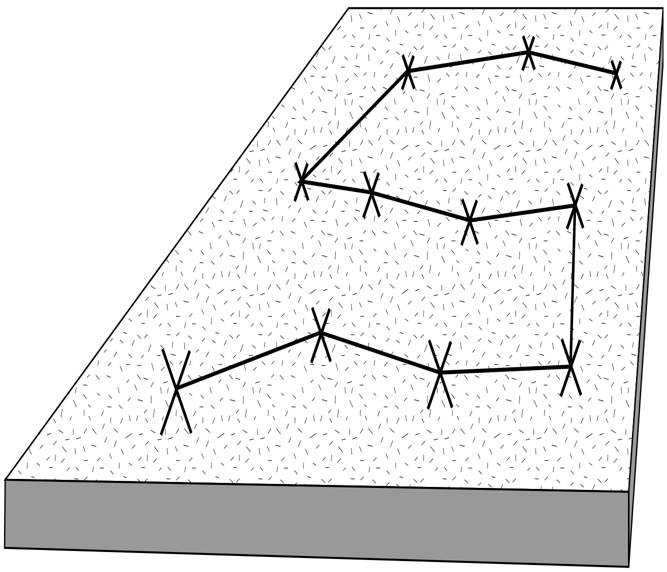

Figure 1. Soil sample collection for a lawn or garden.

- Sample garden soils and soils to be used for establishing a lawn or turf to a depth of 6 inches.
- Sample established turfgrass to a depth of 3 inches.
- For trees and shrubs, sample to a 12 inch depth.
- Soils sampled for lead because of health concerns with young children, should be sampled separately to a depth of 3/4 inch or to the depth to which a child may be exposed.

Each soil sample should be a composite of subsamples collected from randomly selected spots within the chosen area (**Figure 1**). Take 5–10 subsamples for relatively small areas (less than 1000 square feet) in home lawns, flower borders, and gardens. Take 10 to 15 subsamples for larger turfgrass areas like industrial grounds and athletic fields. Collect the subsamples in a clean plastic pail, mix the soil thoroughly, and put about one pint of this mixture in a sample bag or box. Label the sample container and keep a record of the area represented by each sample taken. 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 online at http://soiltest.cfans.umn.edu/.

Addresses of other commercial soil testing laboratories can be obtained from your local Extension office or consult the yellow pages of your phone book.

Soil pH Modification

Soil pH is a measure of soil acidity. A pH of 7 is neutral, a pH below 7 is acid, and a pH above 7 is alkaline. The pH of urban landscapes tends to be higher than corresponding native undisturbed soils. A higher pH in urban soils is most likely due to: 1) large amount of cement used during construction, 2) scraping away of top soil and exposing the more calcareous subsoil, and 3) use of irrigation water high in bicarbonates. Soil pH is an important chemical property because it affects the availability of nutrients to plants and the activity of microorganisms in the soil. A pH measurement is therefore an important part of a soil testing program. The effect of pH on microbial activity and nutrient availability in mineral soils is shown in **Figure 2**.

While many plants can tolerate pH ranges between 5.2 and 7.8, most plants grow best in mineral soils (soils with an organic matter content less than or equal to 19%) when soil pH is between 6.0 and 7.0 (slightly acid to neutral). This general rule applies to most of the commonly grown fruits, vegetables, flowers, trees, and shrubs. Most turfgrasses tend to grow best between 5.5 and 6.5. Many evergreen trees and shrubs prefer a pH range of 5.0 to 6.0. Potatoes tolerate a wide range in soil pH, but potato scab can be a problem if the pH is above 5.3.

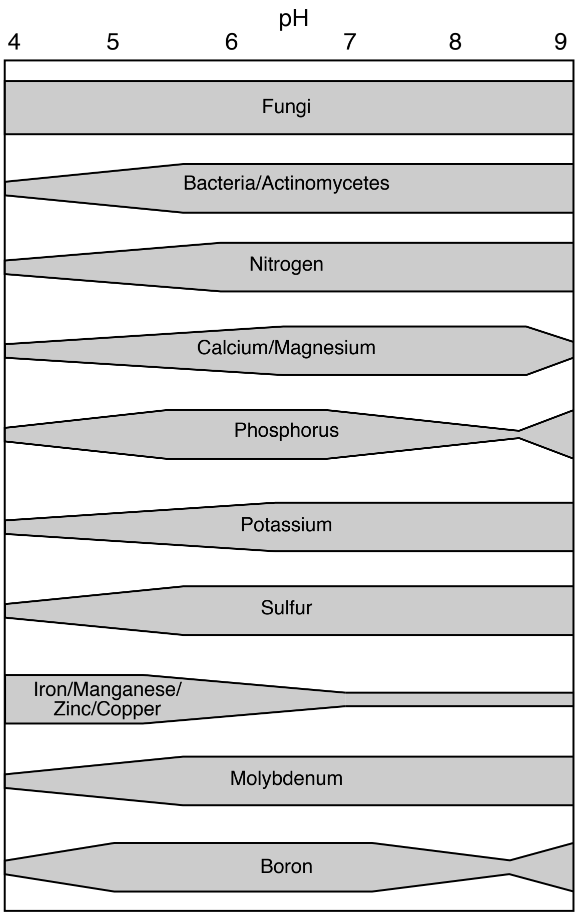

Figure 2. Nutrient availability and microbial activity as affected by soil pH; the wider the band, the greater the availability or activity. (Adapted from Brady, N. *The Nature and Properties of Soils,* 10th ed. Macmillan Publ. Co., New York, 1990)

Some noted exceptions include blueberries, azaleas, and rhododendrons (acid-loving plants) that require acid conditions between pH 4.5 and 5.2. Blue hydrangeas also require a pH lower than 5.0 to induce the blue flower color.

Specific soil pH preferences for selected landscape plants grown in Minnesota are listed in the appendix at the end of this bulletin.

The optimum pH range for plant growth in organic soils (peats and mucks - soils with an organic matter content greater than 19%) is lower than the optimum range in mineral soils. For many plants, the most favorable range in organic soils is pH 5.4 to 6.2.

If a soil test indicates that soil pH is not in the optimum range for the plants you wish to grow, use the following recommendations to either raise or lower the soil pH.

Raising Soil pH

Pulverized limestone is the most common material used to raise soil pH. Limestone consists either of calcium carbonate (calcitic limestone) or calcium/magnesium carbonate (dolomitic limestone). On soils low in magnesium, dolomitic limestone is the preferred form. Lime recommendations for raising soil pH are given in terms of pulverized limestone (**Table 1**), but other liming sources can be used. For further information on liming materials, see the University of Minnesota Extension fact sheet "Liming: Taking a Look at Liming Materials" (AG-FS-2677).

Apply lime only if a need is indicated by the results of soil testing and the requirements of the plants being grown. Overliming can reduce nutrient availability, especially of micronutrients like iron, manganese, and zinc. Iron deficiency (chlorosis) of pin oak, for example, is common when soil pH is greater than 7.0.

Mineral Soils

Lime recommendations for mineral soils are based on a soil pH measurement and determination of the SMP buffer index. The soil 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 depends upon reserve soil acidity, which is measured by the SMP buffer test and reported as the SMP buffer index. The lower the buffer index, the larger is the quantity of lime required to raise soil pH to the desired level.

The SMP buffer index is routinely determined for soil samples with a soil pH less than 6.0. The amount of lime required to raise soil pH to 6.5, at different values of the SMP buffer index, are given in **Table 1**. Recommendations are given in both lb./1000 sq. ft., which is the area used in fertilizer recommendations for lawns and turf and in lb./100 sq. ft., which is consistent with the area used in fertilizer recommendations for vegetables, flowers, fruits, trees, and shrubs.

Table 1. Lime recommendations for mineral soils to increase soil pH to 6.5

SMP Buffer Index	Incorporated before planting		Topdressed on establishing plantings	
	Amount of pulverized limestone to apply*			
	lb./1000 sq. ft.	lb./100 sq. ft.	lb./1000 sq. ft.	lb./100 sq. ft.
Above 6.6	140	14	35	3.5
6.6	180	18	40	4.0
6.5	200	20	45	4.5
Below 6.5	220	22	50	5.0

*Multiply by 44 to convert the rates in lb./1000 sq. ft. to lb./acre.

Most liming materials take several months to react with the soil, so for best results they should be applied and incorporated to a depth of 6 inches well before planting time. For established lawns or turfgrass areas, perennial vegetables and flowers, small fruits, fruit trees, and ornamental trees and shrubs, topdress applications of lime can be used, but are much less effective than mixing lime with the soil prior to establishment. Lime recommendations are reduced for established plantings to reflect the fact that only the upper 1 to 2 inches of soil will be affected. The best time to apply lime to established turf is following core aeration for thatch control. Spread lime uniformly around other types of established plants. If possible, work it lightly into the soil, while avoiding the disturbance of plant roots.

Organic Soils

The pH range of maximum nutrient availability is lower for organic soils than mineral soils. Lime is recommended for organic soils only if the soil pH is 5.4 or less. The SMP buffer index is not determined on organic soils. If soil pH is 5.4 or less, the recommended lime rate is 140 lb./1000 sq. ft. (14 lb./100 sq. ft.) if lime is incorporated to a depth of 6 inches prior to planting. Apply 35 lb./1000 sq. ft. (3.5 lb./100 sq. ft.) if lime is topdressed on established plantings.

Soil Acidification

Neutral to Slightly Acid Soils

For most plants soil acidification is unnecessary, but lowering soil pH is frequently required to grow blueberries, azaleas, and rhododendrons successfully. These plants require an acid soil with a pH between 4.5 and 5.2. If soil pH is above this range, it is usually desirable to lower soil pH to 4.5 prior to planting. Over time pH will tend to increase, especially if the water supply used for irrigation is alkaline as it is in many parts of Minnesota and in most municipal water supplies.

Elemental sulfur is one amendment that can be used to lower soil pH. The soil type, present pH, and the desired pH are used to determine the amount of elemental sulfur needed. **Table 2** provides guidelines to lower the pH of a soil with elemental sulfur by one unit on an area basis and volume basis. **Table 3** provides guidelines for elemental sulfur use to lower soil pH to 4.5. Because it reacts slowly with the soil, elemental sulfur should be applied and incorporated to a depth of 6 inches the year before planting for best results. Test soil pH again 3 to 4 months after the initial application. If soil pH is not in the desired range, reapply according to the recommendations in Tables 2 or 3.

Iron sulfate can also be used to acidify soils. This material reacts much faster than elemental sulfur, usually within 3 to 4 weeks following application. Multiply the rate of elemental sulfur recommended in **Table 2** by 6 to determine the rate of iron sulfate required for an equivalent pH reduction. Do not apply more than 9 lb./100 sq. ft. of iron sulfate in a single application. If higher rates are required, split applications are recommended to avoid excessive levels of soluble salts.

Table 2. Elemental sulfur application rates to lower soil pH by one unit

Soil texture	Amount of elemental sulfur (S) to apply* Area basis		Volume basis
	lb./100 sq. ft.	lb./1000 sq. ft.	lb./cubic yard
sand, loamy sand, sandy loam	0.8	8.0	1.0
loam, silt loam	2.4	24.0	3.0

*Multiply by 44 to convert the rates in lb./1000 sq. ft. to lb./acre.

Aluminum sulfate will also lower pH, but except for blue hydrangea it is not recommended as a soil acidifying amendment because of the potential for aluminum toxicity to plant roots.

Acid sphagnum peat incorporated into the soil prior to planting will provide a favorable root environment for the establishment of acid-loving plants in high pH soils. Incorporate peat at the rate of 1 to 2 cubic feet per plant. The positive effects of acid peat will last 6 to 10 years, but unless other measures are used the pH of the soil will eventually increase.

Ammonium sulfate or **urea** used as nitrogen fertilizer sources will also help maintain low soil pH. However, do not use them at rates greater than those required to meet the nitrogen needs of the plants (see **Table 25**). Fertilizers that contain nitrogen only in the nitrate form will increase soil pH and should not be used for acid loving plants.

Table 3. Elemental sulfur application rates to lower soil pH to 4.5

Initial pH	Soil texture: sand, loamy sand, sandy loam	Soil texture: loam, silt loam
	Amount of elemental sulfur (S) to apply lb./100 sq.ft.	
7.0	1.9	5.8
6.5	1.5	4.6
6.0	1.2	3.5
5.5	0.8	2.4
5.0	0.4	1.2

Alkaline Soils

Fine-textured clay and clay loam soils, and high lime soils such as those in western Minnesota with a pH greater than about 7.3, require higher rates of acidifying amendments than given in **Table 2**. *These soils are not recommended for growing acid-loving plants, because the amendment rates required to lower soil pH initially result in excessive levels of soluble salts and the soil pH will eventually increase.* The best strategy on these soils is to select plants that are adapted to high pH conditions (Refer to appendix at the end of this bulletin).

Cation Exchange Capacity

The cation exchange capacity (CEC) of a soil refers to the amount of positively charged ions a soil can hold. When dissolved in water, the nutrients are either positively charged or negatively charged. Examples of positively charged ions (cations) include: calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^{+}), sodium (Na^{+}), and ammonium (NH_4^{+}). Soils have a slight negative charge due to the presence of clay particles and organic matter. Thus, the higher the clay content and organic matter content, the higher the CEC of the soil. Soils with a high CEC will tend to hold on to nutrients better than soils with a low CEC. The CEC of a soil can be increased somewhat by increasing the soil's organic matter content. Because the CEC of a soil is relatively constant unless large amounts of organic matter are added, it is not measured or reported with a routine soil test.

Some soil testing labs will report ideal calcium to magnesium ratios for plant growth. However, most plants tolerate a very wide range of soil calcium to magnesium ratios. Adjusting the ratios of calcium and magnesium on the exchange complex by adding gypsum (calcium sulfate) or Epsom salts (magnesium sulfate) has not been shown to significantly benefit plant growth. Addition of gypsum or Epsom salts may be beneficial if calcium, magnesium or sulfur are deficient in the soil.

Soluble Salts

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, measurement of the electrical conductivity of a soil extract gives an indication of the total concentration of soluble salts in the soil. The electrical conductivity measurement is reported in units of millimhos per centimeter (mmhos/cm), although some labs report decisiemens per meter (dS/m). One decisiemen per meter is equal to one mmhos/cm. Soluble salt levels in the soil are important, because high soluble salts can reduce water uptake by plants, restrict root growth, cause burning of the foliage, inhibit flowering, and limit fruit and vegetable yields. Sensitivity to soluble salts differs among plant species/cultivars and their stage of growth. Seed germination and seedling growth are more sensitive to salt stress than the growth of mature plants. A soluble salt test can be useful when investigating the cause of poor plant growth, determining the suitability of a new planting site, or monitoring the quality of "black dirt" for use on landscaped areas. Relative salinity levels for different soluble salt test values and their effect on plant growth are given in **Table 4**. The relative salt tolerance of various cultivated plants is given in **Table 5**.

Table 4. Soluble salt test values and relative sensitivity levels of plants

Electrical conductivity*	Salinity level	Effect on plant growth
mmhos/cm		
0 to 2	non-saline	none
2.1 to 4	very slightly saline	sensitive plants are inhibited
4.1 to 8	moderately saline	many plants are inhibited
8.1 to 16	strongly saline	most cultivated plants inhibited
over 16	very strongly saline	few plants are tolerant

*saturated paste extract

Some soils in western Minnesota are naturally high in soluble salts (particularly sodium), but most soils in Minnesota are non-saline and soluble salt problems are the result of human activities. Excessive rates of fertilizer application and placing fertilizer too close to seeds or plant roots creates soluble salt problems. Pet urine and feces can increase soluble salts in localized areas resulting in plant damage or death. The use of deicing salts (primarily in the form of sodium chloride) on streets and sidewalks frequently results in high soluble salt levels in adjacent areas that restrict the growth of turfgrass, flowers, and shrubs.

Table 5. Relative salt tolerance of various cultivated plants

Nontolerant (0-2 mmhos)	Slightly tolerant (2-4 mmhos)	Moderately tolerant (4-8 mmhos)	Tolerant (8-16 mmhos)
azalea	apple	beet	arborvitae
begonia	cabbage	black locust	asparagus
blueberry	celery	boxwood	juniper
carrot	creeping bentgrass	broccoli	Russian olive
cotoneaster	cucumber	chrysanthemum	Swiss chard
green bean	grape	geranium	alkaline grass
onion	forsythia	marigold	
pea	Kentucky bluegrass	muskmelon	
radish	lettuce	Nugget Kentucky bluegrass	
raspberry	linden	red oak	
red pine	Norway maple	seaside creeping bentgrass	
rose	pepper	spinach	
strawberry	perennial ryegrass	squash	
sugar maple	potato	tomato	
viburnum	red fescue	white ash	
white pine	red maple	white oak	
	snapdragon	zinnia	
	sweet corn		

Correcting Soluble Salt Problems

In soils where internal drainage is poor, prevention may be the only feasible approach for reducing salt problems. In well-drained soils, leaching with good quality water will help to correct soluble salt problems. Incorporation of gypsum (calcium sulfate) at the rate of 10 to 15 lbs./100 sq. ft. followed by leaching with good quality water can also be used. Gypsum is most effective in situations where sodium is the cause of high soluble salts. High levels of sodium in the soil will tend to disperse soil particles, resulting in poor soil structure and making water infiltration difficult. The calcium in gypsum will displace sodium and the sodium will then move (leach) out of the soil profile with irrigation water and/or rainfall. Soils high in calcium have better structure than those high in sodium. Use of gypsum on soils where sodium is not high has generally not been shown to be effective in improving soil structure. Thus, on low sodium soils, topdressing lawns with gypsum is not an effective way to improve soil structure and therefore not a recommended practice.

Lead

Lead is not a plant nutrient, but a soil test is available for lead due to concerns about possible health problems from elevated lead levels in soil. High concentrations of lead are most likely in soil near heavily traveled roads and around structures where lead-based paint has peeled away. Even though lead-based paints and leaded gasoline are not presently used to a great extent, lead is very immobile in the soil and will persist for a long time. Most plants do not absorb and accumulate lead to the extent it will be a health hazard. Health concerns from lead are primarily due to direct ingestion of contaminated soil and dust from contaminated soil. This soil and dust may be ingested along with fruits and vegetables grown on contaminated soil due to adherence of soil particles on root crops or from rain splashed on above-ground parts. For this reason, soils that have a lead test result above 300 ppm are not recommended for growing fruit or vegetable crops for consumption. For more information on lead in soils see the University of Minnesota Extension publication FO-02543 *Lead in the Home Garden and Urban Soil Environment*.

Overview of Essential Nutrients

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 compared to other essential nutrients.

Nitrogen

Of all the essential nutrients, nitrogen (N) is the one most often limiting for plant growth. Many soils contain large amounts of nitrogen, but most of it is tied up in the organic fraction of the soil and only slowly released.

Nitrogen is available to plants in two forms, ammonium and nitrate. In most soils, ammonium is quickly converted to nitrate. Nitrate is not held on soil particles and is easily dissolved in water. Thus it is susceptible to leaching. Therefore the timing and rates of nitrogen fertilization are important from both a plant growth 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 irrigation. Nitrogen deficiency may result, as well as an increased potential for nitrate contamination of groundwater. Nitrogen fertilizer should be applied in a series of smaller applications on sandy soils.

Because of the mobility of nitrate in soils and the complex transformations of nitrogen from soil organic matter, soil tests for nitrogen are not reliable for predicting nitrogen fertilizer needs in many situations. Nitrogen fertilizer recommendations in this bulletin are based on the kinds of plants being grown and the organic matter content of the soil. Nitrogen recommendations are reduced as the organic matter level increases. The classifications used for organic matter are:

- **low** - organic matter less than 3.1%
- **medium** - organic matter 3.1–4.5%
- **high** - organic matter 4.6%–19%.

Organic soils are classified as those soils with an organic matter content greater than 19%.

Phosphorus

Phosphorus (P) forms very insoluble (hard to dissolve) complexes with aluminum and iron at low pH and with 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 apply it as a topdressing.

Phosphorus is the main nutrient associated with algal blooms in lakes. Phosphorus can enter lakes by runoff and wind erosion of soil particles as well as runoff of organic phosphorus from decaying leaves, seeds or grass clippings that are left on streets, driveways, and other hard surfaces.

Research has shown that excessive applications of phosphorus fertilizer on high testing soils can result in significant water degradation if it leaves the site via runoff. Because many lawns in Minnesota test very high in P, the Minnesota legislature passed a state-wide law that restricts the application of P fertilizer to established turf. A brief summary of the law is as follows. Lawn fertilizer use is restricted to 0% phosphate (P_2O_5) content. Exceptions include 1) if a new lawn is being seeded or sodded and only during the first year of establishment, 2) if a soil or tissue test shows a need for P, or 3) if the fertilizer is used on a golf course by a person certified by an approved training program. In those cases, lawn fertilizers with P can be used. More detail pertaining to the law can be found in Chapter 18C.60 of Minnesota Statues (http://www.revisor.leg.state.mn.us/stats/18C/). Because of this law, soil testing becomes even more important for managing applications of phosphorus to turf. Refer to the lawn and turf section of this bulletin where P recommendations for established turf are presented in **Table 15.**

Phosphorus fertilizer recommendations are based on the kinds of plants being grown and the phosphorus soil test level. 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 amount of extractable phosphorus using the Bray-P1 test is not equivalent to the amount of extractable phosphorus using the Olsen-P test. Relative levels of phosphorus based on each soil test are presented in **Table 6**.

Table 6. Relative levels of Bray and Olsen soil test phosphorus

Relative level	Bray-P1	Olsen-P
	Soil test P	
	ppm	ppm
low	0 - 5	0 - 3
medium	6 - 10	4 - 7
high	11 - 25	8 - 18
very high	over 25	over 18

Potassium

Movement of potassium (K) in soils depends on soil texture. As clay content increases, potassium movement decreases. For most soils, it is important that applied potassium be incorporated into the soil rather than topdressed because it is relatively immobile. In sandy soils, potassium is quite mobile and can actually leach out of the root zone. Consequently, sandy soils tend to be low in available potassium. Potassium fertilizer

Table 7. Relative levels of soil test potassium

Relative level	Soil test K
	ppm
low	0 - 50
medium	51 - 100
high	101 - 150
very high	over 150

recommendations are based on the kinds of plants being grown and the potassium soil test level. Relative levels of potassium based on the potassium soil test are presented in **Table 7**.

Secondary Macronutrients

Calcium, magnesium, and sulfur are taken up in relatively large amounts by plants and are termed the secondary macronutrients. Because most soils in Minnesota contain adequate amounts of these nutrients, they are not generally limiting to plant growth. Deficiencies of the these nutrients may occur on acid sandy soils that are low in organic matter. Soil tests are available for these elements, but they are recommended only under certain conditions where a deficiency might be expected to occur. This publication gives recommendations for secondary macronutrients only for intensively grown turfgrass areas such as golf courses and sod farms.

Micronutrients

Micronutrients, which include boron, chlorine, copper, iron, manganese, molybdenum, nickel, and zinc, are required in lower amounts than other essential nutrients. Soils in Minnesota generally contain sufficient quantities of micronutrients to meet plant needs, although deficiencies can occur under some conditions. This bulletin gives soil testing and fertilizer recommendations for micronutrients only for intensively grown turfgrass areas such as golf courses and sod farms. Copper can be limiting on some organic soils. High pH (greater than 7.2) can limit availability of iron, manganese, and zinc. Using composted yard waste and manure in gardens will help to supply micronutrients.

Fertilizers

Inorganic and Organic Fertilizers

Any substance that contains one or more essential plant nutrient elements has the potential to be used as a fertilizer. Fertilizers are broadly classified as either organic or inorganic, although the distinction between the two types is not always clear-cut. Urea, for example, is a naturally occurring organic compound, but chemically synthesized urea is generally grouped with inorganic fertilizers. 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, hydrogen, and oxygen) that are essential for plant growth. Organic food production, however, allows for a broader definition that includes naturally occurring inorganic substances such as rock phosphate, elemental sulfur, and gypsum that are not chemically modified.

Plant roots absorb the majority of their nutrients from the soil solution as simple, inorganic ions (charged atoms or molecules). Larger molecules can also be absorbed, but their rate of absorption is slow. Most inorganic fertilizers dissolve readily in water and are immediately available to plants for uptake. When used according to recommendations, these types of fertilizers efficiently supply the required nutrients for plant growth and are safe for the environment. However, excessive rates can injure plant roots and potentially lead to environmental degradation.

Organic fertilizers are more complex chemical substances that take time to be broken down into forms usable by plants. They are slow-release type fertilizers, compared to the quick-release characteristics of most inorganic fertilizers. It is important to apply these organic fertilizers well before periods of rapid plant growth. Organic fertilizers usually have a low salt index, so larger amounts can be applied at one time without causing injury to plant roots. With organic nitrogen sources (except urea), one application can be made without having to be concerned about losing most of the nitrogen to leaching. However, even organic fertilizers applied at excessive rates can cause environmental degradation due to nitrate leaching or runoff of soluble organic compounds. The cost of organic fertilizers at garden centers on a per pound of nutrient basis is usually higher than quick-release inorganic fertilizers.

Manure, compost, and many other materials used as organic fertilizers add considerable quantities of organic matter to the soil. Organic matter can increase soil drainage, aeration, water holding capacity, and the ability of the soil to hold nutrients. The beneficial effects of organic matter on soil structure can have a greater effect on plant growth than the fertilizer value of some of these organic materials.

Slow-Release Fertilizers

Slow-release fertilizers are inorganic fertilizers made up of either larger molecules that require microbial action for degradation or regular fertilizer such as urea that is coated in some way to reduce solubility. Like organic fertilizers they have a low burn potential. They also release fertilizer over a longer period of time. Many formulations are now available that have release rates of 50 days to over one year. They are particularly useful on sandy soils where leaching of nitrogen is a concern. Higher rates of fertilizer can be applied without the fear of losing nitrate with excessive rainfall. The main disadvantages of slow release fertilizer are the high cost relative to quick-release fertilizer and the release rate is too slow for fast growing crops.

Fertilizer Grades

The grade or analysis of a fertilizer represents its percent composition of the three primary plant nutrients. By convention, nitrogen is expressed on an elemental basis as percent N, whereas phosphorus and potassium are expressed on an oxide basis as percent P_2O_5 (phosphate) and percent K_2O (potash), respectively. Minnesota state law requires that any material sold as fertilizer be clearly labeled with its fertilizer grade (e.g., 10-10-10) and this analysis is guaranteed by the manufacturer. The first number in the series is the percent N, the second number is the percent P_2O_5, and the third number is the percent K_2O. It should be noted that N, P_2O_5, and K_2O do not exist in fertilizer in these forms. Rather, these forms are calculated based on the elemental analysis and then simply used to allow a convenient way of comparing the nutrient value of one fertilizer with another. For example, a 10-20-10 fertilizer has the same amount of nitrogen and potash, but twice as much phosphate as a 10-10-10 fertilizer. Also note that the percentages do not add up to 100. This is because the fertilizer is made up of other elements not included in the analysis and in some cases may also contain a filler or carrier.

The nutrient composition of common inorganic/chemical fertilizer sources is provided in **Table 8**. The approximate, primary macronutrient composition of selected organic fertilizers is provided in **Table 9**. Organic fertilizers also provide other plant nutrients including variable amounts of micronutrients.

Table 8. Approximate nutrient composition of various inorganic/chemical fertilizers; fertilizers marked with an asterisk (*) are acceptable for organic fruit and vegetable production

Nutrient	Fertilizer material	Composition		
		N	P_2O_5	K_2O
		-----------------	%	--------------------
Nitrogen Sources	(quick release)			
	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-ammonium nitrate (UAN)	28-32	0	0
	(slow release)			
	Isobutylidene diurea (IBDU)	31	0	0
	Polymer coated urea	40-44	0	0
	Sulfur coated urea (SCU)	36	0	0
	Urea formaldehyde (UF)	38	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
Calcium Sources		% Ca		
	*Calcium sulfate (gypsum)	22		
	Calcium nitrate	20		
	Calcium chloride	36		
	*Calcitic lime	30-40		
	*Dolomite	22		
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	28		
	Sodium pentaborate	14		
	Sodium tetraborate	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		% Ma		
	Manganese sulfate	27		
	Manganese chelate	12		
Molybdenum Sources		% Mo		
	Ammonium molybdate	54		
	Sodium molybdate	39		
Zinc Sources		% Zn		
	Zinc oxide	80		
	Zinc sulfate	23		
	Zinc chelate	14		

Table 9. Approximate nutrient composition of various organic fertilizers[1]

Organic materials	N	P_2O_5	K_2O
	% dry weight basis		
Manures			
Beef	1.2	2.0	2.1
Dairy	2.1	3.2	3.0
Horse	2.1	3.2	2.0
Poultry	3.0	5.0	2.0
Rabbit[2]	2.4	1.4	0.6
Sheep	1.6	1.2	1.0
Swine	2.5	2.1	2.0
Alfalfa hay	2.5	0.5	2.5
Blood meal	13.0	2.0	1.0
Bone meal, raw	3.0	22.0	0.0
Bone meal, steamed	1.0	15.0	0.0
Composted yard waste	1.3	0.4	0.4
Cottonseed meal	6.0	3.0	1.5
Fish meal	10.0	6.0	0.0
Grain straw	0.6	0.2	2.1
Kelp/seaweed	1.5	1.0	4.9
Lawn clippings	2.5	0.3	2.0
Leaves, broadleaves	0.9	0.2	0.8
Milorganite[3]	5.0	3.0	2.0
Sawdust	0.2	0.1	0.2
Soybean meal	7.0	1.2	2.0
Wood ashes	0.0	2.0	6.0

[1]These are total concentrations and only slowly available over weeks, months, or years. Many materials will vary in composition due to methods of handling and moisture content.
[2]The composition of rabbit manure is on a fresh weight basis.
[3]Not recommended for fertilizing fruit or vegetables.

Calculating Fertilizer Rates from Soil Test Recommendations

All fertilizer recommendations are based on the amount (lbs.) of nutrient (N, P_2O_5, K_2O) to apply per given area. Lawn and turf recommendations are given in pounds per 1000 sq. ft. and garden, tree, and shrub recommendations in pounds per 100 sq. ft. From this recommendation it is necessary to select an appropriate fertilizer grade and then determine how much of this fertilizer to apply to the garden area.

Fertilizers are sold in many grades. Complete fertilizers such as 10-10-10 or 5-10-10, contain all three primary nutrients. Single nutrient fertilizers contain only one, but they generally are a high analysis, economical source of that nutrient (e.g., 46-0-0, 0-46-0, 0-0-60). Single nutrient fertilizers are available through fertilizer dealers, but are either not available or very expensive at most garden centers.

Numbers on the fertilizer bag indicate the exact percentages of nutrients by weight. For example, a 100 lb. bag of 5-10-10 fertilizer contains 5 lbs. of nitrogen (N), 10 lbs. of phosphate (P_2O_5) and 10 lbs. of potash (K_2O). Most garden fertilizers are complete fertilizers. With the new phosphorus law, most turf fertilizers contain just nitrogen and potash. Complete fertilizers are convenient to use, but it may be difficult to find one that exactly matches the ratio required in the fertilizer recommendation. *Since meeting the exact amount required for each nutrient will not be possible in all cases, it is most important to match the nitrogen required.* Calculating the amount of fertilizer to apply from its analysis requires basic arithmetic and an example is provided below. To reduce the number of calculations required, the amount of fertilizer to apply that will give the recommended amount of nitrogen can also be obtained from **Table 10**.

NOTE: 2 cups (1 pint) of dry fertilizer weighs approximately 1 pound.

To calculate fertilizer rates, the following example is provided:
A soil test recommendation for a garden calls for 0.1 lb. N/100 sq. ft., 0 lb. P_2O_5/100 sq. ft. and 0.1 lb. K_2O/100 sq. ft. The garden is 40 feet by 10 feet.

Four steps are required to determine how much of a given fertilizer is required for a given area:

Step 1 Measure the garden area to be fertilized in square feet.

Formula for calculating size of area to be fertilized:
feet long X feet wide = square feet

Example:
40 feet long X 10 feet wide = 400 square feet

Step 2 Select the fertilizer(s) to use based on the soil test by matching the ratio of nutrients recommended to the fertilizer grades available.

Example:
The N-P-K nutrient ratio based on the soil test should be 1-0-1. Ideally, a fertilizer such as a 10-0-10, 20-0-20 or 25-0-25 should be selected. At the local garden store, fertilizer bags marked 20-10-10, 27-3-3 and 25-0-12 were available. The one marked 25-0-12 best matched the ratio of 1-0-1 recommended by the soil test.

Step 3 Determine the amount of fertilizer to apply by:

a. dividing the recommended amount of the nutrient by the percentage of the nutrient (on a decimal basis) in the fertilizer

$$\frac{\textbf{lb. nutrient recommended/sq. ft.}}{\textbf{\% nutrient in fertilizer}} = \textbf{lb. fertilizer/sq. ft.}$$

Example: *(use nitrogen percentage to determine the rate to apply)*

$$\frac{\textbf{0.1 lb. nutrient recommended/100 sq. ft.}}{\textbf{25\% nutrient in fertilizer (0.25)}} = \textbf{0.4 lb. fertilizer/100 sq. ft.}$$

b. **Table 10** simplifies the calculation by providing the total amount of fertilizer to apply based solely on its nitrogen content.

Example from Table 10:
The nitrogen recommendation calls for 0.1 lb. N/100 sq. ft. and the fertilizer grade selected has a ratio of **25**-0-12 (column one), apply 0.4 lb. (column two) of this fertilizer per 100 sq. ft.

Step 4 Adjust the amount of fertilizer to apply for the garden or lawn area.

$$\frac{\text{lb. fertilizer}}{\text{sq. ft.}} \quad X \quad \frac{\text{sq. ft.}}{\text{garden or lawn}} \quad = \quad \frac{\text{lb. fertilizer}}{\text{garden or lawn}}$$

Example:

$$\frac{\text{0.4 lb. fertilizer}}{\text{100 sq. ft.}} \quad X \quad \frac{\text{400 sq. ft.}}{\text{garden or lawn}} \quad = \quad \frac{\text{1.6 lb. 25-0-12 fertilizer}}{\text{garden or lawn}}$$

or about 3 cups of a 25-0-12 fertilizer per 400 sq. ft. garden/lawn

Because most fertilizers sold at garden centers have more nitrogen than potash, there is a potential for soils to become low in potassium. If soil test potassium is less than 100 ppm, it may be beneficial to apply a single nutrient fertilizer such as 0-0-60. To supply 0.3 lb. K_2O per 100 sq. ft., 0.5 lb. (0.3 divided by 0.6) of 0-0-60 fertilizer should be applied. To supply 3.0 lbs. K_2O per 1000 sq. ft., apply 5.0 lbs. of 0-0-60 fertilizer.

Calculating Organic Fertilizer Rates

Calculating fertilizer rates using organic fertilizer sources is often difficult. Their exact nutrient content is frequently unknown, so fertilizer rates can only be approximated using general values such as those in **Table 9**. Even though a total nitrogen content of the material is often reported, only a portion of that nitrogen may be available to plants the year of application. Nitrogen availability in organic materials depends on many factors including soil temperature, moisture, and carbon-to-nitrogen ratio of the material. The weight of the applied organic material must also be corrected for its moisture content. Bulky organic materials are usually low in nitrogen and must be supplemented with inorganic nitrogen fertilizers or an organic source that is high in nitrogen.
See page 21 for suggested application rates of yard waste compost.

Some types of organic fertilizer can be purchased in bags that are labeled with their fertilizer grade. *Fertilizer rates for these products can be calculated in the same manner as for inorganic fertilizers.*

Table 10. Total amount of fertilizer to apply based on recommended amounts of actual nitrogen.

Fertilizer Nitrogen Percent (First number of fertilizer grade on bag)	**Nitrogen Recommended**			
	0.1 lb.	**0.15 lb.**	**0.2 lb.**	**1.0 lb.**
	per 100 sq. ft.			**per 1000 sq. ft.**
	Total amount of fertilizer to apply*			
	lbs. per 100 sq. ft.			**lbs. per 1000 sq. ft.**
46 (urea)	0.22	0.33	0.44	2.2
40	0.27	0.41	0.54	2.7
36	0.28	0.42	0.56	2.8
34	0.29	0.44	0.58	2.9
33 (ammonium nitrate)	0.30	0.45	0.60	3.0
32	0.31	0.47	0.62	3.1
30	0.33	0.50	0.66	3.3
29	0.34	0.51	0.68	3.4
28	0.36	0.54	0.72	3.6
27	0.37	0.56	0.74	3.7
26	0.39	0.59	0.78	3.9
25**	**0.40**	0.60	0.80	4.0
24	0.42	0.63	0.84	4.2
23	0.43	0.65	0.86	4.3
22	0.45	0.68	0.90	4.5
21 (ammonium sulfate)	0.48	0.72	0.96	4.8
20	0.50	0.75	1.00	5.0
19	0.53	0.80	1.06	5.3
18	0.56	0.84	1.12	5.6
17	0.59	0.89	1.18	5.9
16	0.63	0.95	1.26	6.3
15	0.67	1.00	1.34	6.7
14	0.71	1.07	1.42	7.1
13	0.77	1.16	1.54	7.7
12	0.83	1.25	1.66	8.3
11	0.91	1.37	1.82	9.1
10	1.00	1.50	2.00	10.0
9	1.11	1.67	2.22	11.1
8	1.25	1.88	2.50	12.5
7	1.43	2.15	2.86	14.3
6	1.67	2.51	3.34	16.7
5	2.00	3.00	4.00	20.0
4	2.50	3.75	5.00	25.0
3	3.33	5.00	6.66	33.3
2	5.00	7.50	10.00	50.0
1	10.00	15.00	20.00	100.0

* 1 cup of fertilizer weighs about 0.5 lbs.

** See example on page 18.

Methods of Applying Fertilizers

Fertilizers can be applied in several ways. The most important point to remember is to apply them at the proper rate, as over-application can result in plant damage or death. Follow soil test recommendations or manufacturer's directions. Some of the common fertilizer application methods are as follows:

Broadcast Application

Broadcasting refers to uniformly applying the fertilizer over the entire area before planting. This is the safest and easiest method for the home gardener and best accomplished with a mechanical spreader. The fertilizer should be worked into the soil to a depth of 4 to 6 inches.

Band Placement

Banding fertilizer refers to placement of fertilizer 2 to 3 inches to each side and below the seed at planting. This technique is risky for gardeners to use as placement too close to the seed or at too high rate can cause fertilizer burn and inhibit germination.

Sidedress Application

Sidedressing refers to placing the fertilizer beside the row during the growing season. This technique is usually used to apply additional nitrogen during the growing season and is particularly useful for applying nitrogen on sandy soils.

Topdress Application

Topdressing is similar to sidedressing except that the fertilizer is applied around the plant. *Caution: fertilizer applied too close to the plant can cause fertilizer burn.*

Starter Solution Application

Starter solution fertilizers are soluble in water, usually high in phosphorus, and applied as a liquid around the plant roots at the time of planting. They are primarily used for vegetable transplants to hasten root development and establishment. Follow manufacturer's directions for application rates. A general recommendation for 8-16-16 or 15-30-15 is to dissolve 2 tablespoons in 1 gallon of water. Then apply 1 cup of the solution around the roots of each transplant.

Foliar Applications

Foliar fertilizers are dilute solutions applied directly to the leaves. They should not be relied upon to supply the total nitrogen, phosphorus, and potassium needs of plants. They can used to supplement soil applications of these nutrients. Foliar applications of micronutrients, especially iron, may be beneficial when high soil pH conditions make the soil iron unavailable to plant roots (refer to section on iron chlorosis on page 38).

Yard Waste Compost Application

Well-composted yard waste usually has a nitrogen availability between 10 to 15% the first year. Application of composted yard waste for general gardening is usually made to improve soil physical properties as well as to provide nutrients. An application of 100 lbs. of moist compost per 100 square feet (about 4 to 6, 5-gallon buckets) is sufficient for most gardens. Incorporate the compost to a depth of 6 to 8 inches. With this application of compost, the amount of fertilizer recommended can be cut in half.

Compost that is immature or not well decomposed should be used primarily as a mulch. Incorporation of immature compost into the soil may result in nitrogen deficiency and poor plant growth. Do not reduce fertilizer application if the compost is used as a mulch.

New Lawns and Turf

Nitrogen Recommendations

An initial nitrogen (N) application of 0.5 lb. N/1000 sq. ft. (22 lb./acre) is recommended at the time of establishment for a new home lawn or commercial turfgrass area. If the grass is established from seed, incorporate N fertilizer into the surface 1/2 to 1 inch of soil. Either mix it into the soil along with the seed or till it in just before planting. If the grass is established from sod, N fertilizer should be applied over the sod the day after it is laid and watered in lightly. Sod is watered heavily immediately after it is laid, so it is important to delay fertilization or the N will be leached below the root zone.

An additional 0.5 lb. N/1000 sq. ft. (22 lb./acre) should be applied 2 weeks after seedling emergence or sodding and watered in. After this, the rates and timing of N fertilization are based on the cultural practices that are used, and recommendations for established lawns and turf in **Tables 13 and 14** should be followed.

Phosphorus and Potassium Recommendations

Phosphorus (P) and potassium (K) fertilizer recommendations for a new lawn or turf are given in **Tables 11 and 12**. After preparing the site and testing the soil, broadcast the recommended amounts of P and K and incorporate the fertilizer into the top 4 to 6 inches of soil.

Phosphorus and K applications before planting are very important, because both elements are relatively immobile in most soils. Topdress applications following establishment will move very slowly through the soil, so it will be difficult to make substantial changes in P and K fertility levels after the grass is planted. Soil preparation before seeding or sodding offers an opportunity to make basic P and K applications by placing these nutrients in the plant root zone. Establishment of turf is usually quicker with adequate P in the root zone. Current law allows application of P fertilizer to turf during the establishment year. Soil tests for P and K are especially important before planting, because they permit an accurate assessment of fertilizer needs.

Potassium will leach through coarse-textured soils, so sands, loamy sands, and artificially prepared sandy mixtures such as those used in constructing golf course greens should receive no more than 2 lb. K_2O/1000 sq. ft. (85 lb./acre) prior to seeding or sodding. If the K soil test is low and the recommendation calls for a higher rate, apply the remainder as part of the regular fertilization program after establishment. On sandy mixes and sandy soils, K fertilizer should be surface applied at no more than 1 lb. K_2O per 1000 square feet per application.

Table 11. Phosphorus recommendations for a new lawn or turfgrass area before seeding or sodding

Phosphorus (P) Soil test level		Amount of phosphate (P_2O_5) to apply*
----------- ppm -----------		lb. P_2O_5/1000 sq.ft.
Bray-P1	Olsen-P	
0-10	0-7	5
11-25	8-18	2
over 25	over 18	1

*Multiply by 44 to convert the rates in lb./1000 sq. ft. to lb./acre.

Table 12. Potassium recommendations for a new lawn or turfgrass area before seeding or sodding.

Potassium (K) Soil test level	Amount of potash (K_2O) to apply*
----------- ppm -----------	lb. K_2O/1000 sq.ft.
0-50	6**
51-100	4**
101-150	2
over 150	0

*Multiply by 44 to convert the rates in lb./1000 sq. ft. to lb./acre.
**On sandy soils incorporate only 2 lb. K_2O/1000 sq. ft. prior to seeding or sodding and fertilize regularly with fertilizer containing potassium after establishment.

Established Lawns and Turf

Nitrogen Recommendations

Nitrogen (N) fertilizer recommendations for established lawn and turfgrass areas are based on the organic matter content of the soil and the management practices that are followed in maintaining the turf (**Table 13**). Nitrogen is gradually released from decomposing organic matter during the growing season, so less fertilizer N is required as soil organic matter levels increase. A well-watered lawn grows more vigorously and requires more N than one that is not watered and goes dormant in mid-summer. Removal of grass clippings also increases N needs. Clippings left on the lawn gradually decompose over a 3- to 4-week period and the nutrients in them are recycled, reducing the need for fertilizer by about 1 lb. N/1000 sq. ft. per year.

When using fertilizers containing quickly available forms of N, no more than 1 lb. N/1000 sq. ft. should be applied at any one time. Higher rates can burn the grass. They are also inefficient and pose a potential pollution problem, because not all of the N can be immediately utilized and it may leach through the soil and out of the plant root zone. Fertilizers containing slow-release forms of N can be applied at a rate of up to 2 lb. N/1000 sq. ft. and the number of applications reduced. When using slow-release fertilizers, be sure to follow manufacturers' recommendations as in some cases only a small portion of the N is in the slow-release form.

Late summer and fall are the best times of the year to fertilize lawns. This is contrary to the traditional springtime application of lawn fertilizer, but applying the majority of the fertilizer in the late summer or fall produces healthier lawns by improving the balance between root and shoot growth. Early spring applications of N can stimulate shoot growth that depletes stored energy reserves in plant roots. When summer stress periods occur, the plants are weaker and less able to survive. Late summer and fall fertilization lengthens the period that the turf remains green in the fall, results in earlier green-up in the spring without stimulating excessive shoot growth, results in higher stored energy reserves during the spring and summer, and reduces the incidence of some of the summer diseases.

The optimum timing of N fertilizer applications is shown in **Table 14**. The potential for fertilizer burn is greater at high temperatures and if the grass is wet at the time of application. Fertilization with quick-release nutrients should be avoided at temperatures greater than 85° F. Use a mechanical spreader for uniform application. For the drop type spreaders, apply the fertilizer in two directions. In most situations, turf should be watered immediately following fertilizer application to wash the fertilizer off the leaves and into the soil. For fertilizer containing an herbicide, follow label instructions for watering. Fall applications should be made when soil temperatures are still warm enough (above 40° F at the 2-inch depth) for N absorption by roots and when shoot growth has stopped, usually from early September to mid-October.

Never apply fertilizer to frozen ground because surface runoff can contribute to water pollution problems. Immediately clean up any fertilizer that spills over onto sidewalks or streets during application or it will be washed into storm sewers and contribute to environmental problems.

Phosphorus Recommendations

Application of Phosphorus (P) fertilizer to established turf in Minnesota is regulated by state law. Unless a soil test indicates a need, P fertilizer cannot be applied to established turf. Phosphorus recommendations for established lawn and turf are based on P soil test levels and are presented in **Table 15**.

For low-testing soils requiring P, the best time to apply P fertilizer is following core aeration of the turf for thatch control in late summer or early autumn. In this way, immobile P is applied or washed into the bottom of the holes made by the coring machine and placed in the vicinity of plant roots. Phosphorus moves very little in soil and becomes bound to soil particles.

If soils test above 25 ppm Bray P or 18 ppm Olsen P, a fertilizer grade without P should be used (middle number on the bag should be 0).

Potassium Recommendations

Potassium (K) recommendations for established lawn and turf are based on K soil test levels and the management practices that are followed in maintaining the turf (**Table 16**). Recommendations are also modified for sandy soils, where K moves readily, compared to finer-textured soils where K is relatively immobile.

As with N, regular irrigation increases K requirements by increasing growth and the removal of grass clippings increases K requirements by removing K that could be reused in future growth. No more than 1 lb. K_2O/1000 sq. ft. should be applied at any one time. Higher rates can burn the grass, especially when applied as a complete fertilizer that also contains N.

If the soil is a sand or loamy sand, the recommended annual rate of K_2O should be divided into split applications to prevent K deficiency due to leaching beyond the root zone. Regular K_2O applications can be made in combination with N according to the schedule for N fertilization in **Table 14**. On finer-textured soils such as loams, silt loams, and clay loams, K does not move readily through the soil and the most effective method of application is to fertilize following soil coring as described above for P.

Table 13. Annual nitrogen recommendations for an established lawn or turfgrass area

Maintenance Practices	Soil organic matter level[1] Low	Medium to high	Organic soil
	Amount of nitrogen (N) to apply[2,3]		
	------------ lb. N/1000 sq. ft. ------------		
Regular irrigation			
Clippings removed	4.0	3.0	2.00
Clippings not removed	3.0	2.0	1.00
No irrigation			
Clippings removed	2.0	1.0	0.50
Clippings not removed	1.0	0.5	0.25

[1]Low organic matter = less than 3.1%, medium to high = 3.1 to 19%, organic soil = greater than 19% organic matter.
[2]Multiply by 44 to convert the rates in lb./1000 sq. ft. to lb./acre.
[3]Apply no more than 1 lb. of quick-release N/1000 sq. ft. in a single application.

Table 14. Timing of annual nitrogen fertilizer applications to established lawn or turfgrass; apply no more than 1 lb. of quick-release nitrogen/1000 sq. ft. in a single application

Number of Applications Required	Optimum timing of applications
1	early Sept.
2	mid- to late Aug.// mid-Oct.
3	May or June // mid- to late Aug. // mid-Oct.
4	May or June // Aug. // Sept. // mid-Oct.

Table 15. Annual phosphorus recommendations for an established lawn or turfgrass area

Phosphorus (P) Soil test level		Amount of phosphate (P_2O_5) to apply*
----------- ppm -----------		lb. P_2O_5/1000 sq.ft.
Bray-P1	Olsen-P	
0-10	0-7	1.0
11-25	8-18	0.5
over 25	over 18	0.0

*Multiply by 44 to convert the rates in lb./1000 sq. ft. to lb./acre.

Table 16. Annual potassium recommendations for established lawn and turfgrass

Potassium (K) Soil test level	Maintenance practices: Regular irrigation		No irrigation	
	Clippings Removed	Clippings Not removed	Clippings Removed	Clippings Not removed
	Amount of potash (K_2O) to apply[1,2,3]			
----- ppm ------	------------------ lb. K_2O/1000 sq. ft. -------------------			
0-50	4	3	3	2.0
51-100	3	2	2	1.0
101-150	2	1	1	0.5
over 150	0	0	0	0.0

[1]Multiply by 44 to convert the rate from lb./1000 sq ft to lb./acre.
[2]Apply no more than 1 lb. K_2O/1000 sq. ft. in a single application.
[3]On sandy soils the recommended rate should be divided into split applications made on a regular basis.

Cultured Sod Production

Basic P and K fertilizer recommendations and management practices for cultured sod production are similar to those given for other turf-grass areas in the preceding two sections and **Tables 11**, **12**, **15**, and **16**. *Note: cultured sod production is exempt from the phosphorus law because it is considered to be an agricultural crop.* The only other difference is that maximum sod production, under high levels of management, will require higher levels of N fertilization following establishment. Suggested N fertilizer management for cultured sod seeded in late summer or early fall is presented in **Table 17**.

Table 17. Nitrogen fertilizer recommendations for cultured sod seeded in late summer or early fall

Timing of application	Soil organic matter level[1]: Low	Medium to high	Organic soil[2]
	Amount of nitrogen (N) to apply[3]		
	------------------ lb. N/A ------------------		
seeding	20	20	20
first mowing	30	25	20
early-mid October	30	25	20
late May	30	25	20
June	30	25	20
August	20	20	20

[1]Low organic matter = less than 3.1%, medium to high = 3.1 to 19%, organic soil = greater than 19% organic matter.
[2]Lower rates of N may be used on organic soils not previously used for sod or crop production
[3]Irrigated fields may require 1 to 2 additional applications between May and August to sustain growth.

Secondary Macronutrients for Commercial Turfgrass and Cultured Sod Production

Calcium Recommendations

Calcium (Ca) deficiency due to low soil Ca is rare, but may occur on acid, sandy soils. Calcium is generally not deficient in Minnesota soils when soil pH is 5.5 or above. If soil pH is less than 5.5, use lime to add Ca at the rates recommended in **Table 1**.

Magnesium Recommendations

Magnesium (Mg) deficiency may occur on acid, sandy soils or be induced by high rates of potassium fertilizer on sandy soils that are already low in Mg. Recommended rates of Mg based on a soil test are given in **Table 18**. If soil pH is low and liming is recommended, the use of dolomitic limestone will supply Mg.

Sulfur Recommendations

Sulfur (S) deficiency is most common on sandy soils that are low in organic matter. Sulfur recommendations based on a soil test are given in **Table 19**. The S soil test is only accurate for low or medium organic matter soils (less than 4.6% organic matter).

Table 18. Magnesium recommendations for new and established turfgrass

Magnesium (Mg) Soil test level	Amount of magnesium (Mg) to apply*
----------- ppm -----------	lb. Mg/1000 sq.ft.
0-50	1
over 50	0

*Multiply by 44 to convert the rates in lb./1000 sq. ft. to lb./acre.

Table 19. Sulfur recommendations for new and established turfgrass

Sulfur (S) Soil test level[1]	Amount of Sulfur (S) to apply[2]
----------- ppm -----------	lb. S/1000 sq.ft.
0-6	0.5
over 6	0.0

[1]The sulfur soil test is reliable only for low or medium organic matter soils (less than 4.6% organic matter)
[2]Multiply by 44 to convert the rates in lb./1000 sq. ft. to lb./acre.

Micronutrients for Commercial Turfgrass and Cultured Sod Production

Boron Recommendations

Response by turfgrass to boron (B) has not been reported in Minnesota; therefore, none is recommended. Excessive applications of boron can be toxic to turfgrass, causing dieback of the shoots.

Copper Recommendations

Response by turfgrass to copper (Cu) on mineral soils has not been reported in Minnesota; therefore, none is recommended.

Copper deficiency, characterized by shoot dieback, is most likely on organic soils and Cu recommendations based on a soil test are given in **Table 20**. The Cu soil test is reliable only for organic soils. Copper can be applied to the soil or directly to plants as a foliar spray. Applications of Cu are suggested on a trial basis only.

Iron Recommendations

Soil test results for iron (Fe) are not reliable for predicting Fe fertilizer needs. Iron availability is related more to soil pH than it is to soil test Fe levels. If soil pH is greater than 7.2 and chlorosis is observed, a short term "greening" response in turfgrass may be obtained with foliar Fe applications. Apply 0.2 oz. Fe/1000 sq. ft. (0.55 lb. Fe/acre) as a foliar spray.

Manganese Recommendations

Soil test results for manganese (Mn) are not reliable for predicting Mn fertilizer needs. As with iron, Mn availability is related more to soil pH than it is to soil test Mn levels. Deficiencies, characterized by shoot yellowing, are possible on mineral soils with a pH greater than 7.2 and organic soils with a pH greater than 5.8. If Mn deficiency is suspected, apply 0.1 to 0.2 oz. Mn/1000 sq. ft. (0.25 to 0.55 lb. Mn/acre) as a foliar spray.

Zinc Recommendations

Zinc (Zn) deficiency can occur on alkaline soils and sandy soils low in organic matter. High levels of phosphorus coupled with low levels of soil Zn may induce Zn deficiency. Zinc recommendations based on a soil test are given in **Table 21**. Zinc can be applied to the soil or as a foliar spray.

Table 20. Copper recommendations for both new and established turfgrass areas (for organic soils only)[1]

Copper (Cu) Soil test level	Application method: Soil Broadcast	Application method: Foliar Spray[2]
	Amount of Cu to apply/1000 sq. ft.[3]	
-- ppm --	-- lb. Cu --	-- oz. Cu --
0-2.5	0.1-0.3	0.4
over 2.5	0.0	0.0

[1]Applications are suggested on a trial basis only.
[2]Apply foliar sprays at the recommended rate 2 to 3 times per year.
[3]Multiply by 44 to convert the rate from lb./1000 sq. ft. to lb./acre; multiply by 2.7 to convert from oz./1000 sq. ft. to lb./acre.

Table 21. Zinc recommendations for both new and established turfgrass areas

Zinc (Zn) Soil test level	Application method: Soil Broadcast	Application method: Foliar Spray
	Amount of Zn to apply/1000 sq. ft.*	
-- ppm --	-- lb. Zn --	-- oz. Zn --
0-1.0	0.2-0.3	0.4-0.8
over 1.0	0.0	0.0

*Multiply by 44 to convert the rate from lb./1000 sq. ft. to lb./acre; multiply by 2.7 to convert from oz./1000 sq. ft. to lb./acre.

Vegetable and Flower Gardens

Nitrogen Recommendations

Nitrogen (N) fertilizer recommendations for vegetable and flower gardens are based on the organic matter content of the soil and the crops that are grown. Basic N recommendations are given in **Table 22**. Nitrogen fertilizer should be applied in the spring, prior to planting annual vegetables and flowers, or at the time growth begins for most established perennials. Fall applied N can be lost through leaching. Nitrogen fertilizer can be either surface applied or incorporated into the soil. An additional 0.15 lb. N/100 sq. ft. may be needed as a sidedress application 3 to 4 weeks after planting for sweet corn, vine crops, tomatoes, potatoes, and cole crops.

Split applications of N are recommended on sandy soils to reduce leaching losses. Divide the basic and sidedress recommendations in half and apply twice as often. Do not exceed the total recommended rates. Another option is to use slow-release N fertilizers or natural organic N sources.

Phosphorus and Potassium Recommendations

Phosphorus (P) and potassium (K) fertilizer recommendations for vegetable and flower gardens are given in **Tables 23 and 24**. Phosphorus and potassium can be applied in either fall or spring. For annual plantings and new perennial plantings, broadcast the recommended amounts of P_2O_5 and K_2O and incorporate the fertilizer into the top 4 to 6 inches of soil. For established perennials, topdress fertilizer around the plants and work it lightly into the soil to avoid disturbing plant roots.

Applications of P and K before planting are very important in new perennial plantings, because both elements are relatively immobile in most soils. Topdress applications following establishment will move very slowly through the soil, so it will be difficult to make substantial changes in P and K fertility levels in the plant root zone after planting. Soil tests for P and K are especially important before planting perennials, because they permit an accurate assessment of fertilizer needs.

Table 22. Nitrogen recommendations for vegetable and flower gardens

Soil organic matter level[1]	Amount of nitrogen (N) to apply[2]
	lb. N/100 sq. ft.
Low	0.20
Medium to high	0.15
Organic soils	0.10

[1]Low organic matter = less than 3.1%, medium to high = 3.1 to 19%, organic soil = greater than 19% organic matter.
[2]An additional 0.15 lb. N/100 sq. ft. may be needed as a sidedress application 3-4 weeks after planting for sweet corn, vine crops, tomatoes, potatoes, and cole crops.

Table 23. Phosphorus recommendations for vegetable and flower gardens

Phosphorus (P) Soil test level		Amount of phosphate (P_2O_5) to apply
----------- ppm -----------		lb. P_2O_5/100 sq.ft.
Bray-P1	Olsen-P	
0-5	0-3	0.4
6-10	4-7	0.3
11-15	8-11	0.2
16-25	12-18	0.1
over 25	over 18	0.0

Table 24. Potassium recommendations for vegetable and flower gardens

Potassium (K) Soil test level	Amount of potash (K_2O) to apply
----------- ppm -----------	lb. K_2O/100 sq.ft.
0-50	0.4
51-100	0.3
101-150	0.2
151-200	0.1
over 200	0.0

Trees, Shrubs, and Fruits

Nitrogen Recommendations

Nitrogen (N) fertilizer recommendations for landscape trees and shrubs, fruit trees, and small fruits are based on the organic matter content of the soil, the age of the planting (new vs. established), and the level of maintenance or degree of desired growth.

Landscape Trees and Shrubs: Landscape plants typically go through three stages of nitrogen need: 1) newly planted stage, 2) young, rapid growth stage, and 3) mature, maintenance stage. Nitrogen needs should be adjusted to account for the stage of growth.

Growth Stage 1 - Newly planted: Most transplanted trees or shrubs lose roots during the transplanting process. High rates of quick release N applied at this time will not be used efficiently and may push canopy growth at the expense of root growth. This low N stage typically lasts for a full year after planting.

During the newly planted phase, quick-release N levels should not exceed 0.1 lb. N/100 sq. ft. per year. The N rate can be adjusted downward by soil organic matter level according to the low maintenance recommendations in **Table 25**. As an alternative, a higher rate of a slow-release fertilizer, up to 0.2 lb. N/100 sq. ft. per year, can be used.

Slow-release and natural organic fertilizers can be incorporated into the backfill soil. Quick-release fertilizers should be broadcast after planting and then watered in. Do not mix quick-release forms with the soil used to backfill the planting hole, because direct contact with fertilizer will burn the roots.

Growth Stage 2 - Rapid growth of young trees and shrubs: On young landscape trees and shrubs where rapid growth is desirable, use the high maintenance rate given in **Table 25**. During the rapid growth phase, the N rate should be 0.1 to 0.2 lb. N/100 sq. ft. per year and should be applied in the spring or early summer. A low maintenance level should be used in situations that restrict growth (e.g., slow growing and dwarf species, dry or compacted soils, and when the plant has a restricted root zone).

For trees in lawn areas, do not exceed 0.1 lb. N/100 sq. ft. per application unless a slow-release or natural fertilizer is used. Higher rates will burn the grass.

Growth Stage 3 - Maintaining maturing trees and shrubs: As trees and shrubs mature and growth rate naturally slows down, the need for N drops. The low maintenance level in **Table 25** should be used for established trees and shrubs. The purpose of this low maintenance level is to maintain landscape plants in a healthy condition without excessive vegetative growth.

Trees and shrubs planted in lawn areas will likely receive adequate N from lawn fertilizations. In non-lawn areas a rate of 0.4 lb. N/100 sq. ft., once every 4 to 5 years may be used in place of annual applications, except on sandy soils.

Established landscape trees and shrubs may be fertilized in early spring or late fall. Do not make late fall applications after the ground is frozen as it will be lost in runoff.

On sandy soils, late fall applications should not be made because the N will leach beyond the root zone before growth resumes in the spring. Split applications of N are recommended in the spring to reduce leaching losses. Divide the recommendations in half and apply twice as often. Do not exceed the total N rate recommended. Another option is to use slow-release or natural organic N sources.

Since feeder roots of trees extend beyond the dripline of the branches, broadcast nitrogen fertilizer uniformly in a broad band around the dripline (i.e., under the tree canopy and about 4 feet beyond the tree's dripline). A thorough watering is necessary to move broadcast N fertilizer into the tree or shrub root zone. Alternative application methods, as discussed below for P and K fertilization, may be required to place adequate N in the tree or shrub root zone.

Using ammonium sulfate or urea as the N source will help maintain low soil pH for plants like blueberry, azalea, and rhododendron that prefer acid conditions. Do not apply them at rates that exceed the recommendations for supplying N. See the section on Soil pH Modification - Soil Acidification for more information on lowering soil pH.

Tree Fruits: For newly planted fruit trees, follow recommendations for landscape plants in Growth Stage 1. For young nonfruiting trees, follow recommendations for Growth Stage 2.

On established fruit trees use only the low maintenance rate given in **Table 25.** Higher rates of N will stimulate excessive vegetative growth at the expense of fruit production, may also reduce winter-hardiness, and will predispose apples and pears to fireblight. When growing fruit trees in a lawn area, avoid fertilizing the lawn more than once a year to prevent excessive growth of the fruit tree.

Table 25. Nitrogen recommendations for tree fruits, landscape trees, and shrubs

Soil organic matter level[3]	Maintenance level: Low[1]	Maintenance level: High[2]
	Amount of nitrogen (N) to apply -- lb. N/100 sq. ft. --	
Low	0.10	0.20
Medium to high	0.07	0.15
Organic soils	0.05	0.10

[1]Use the low maintenance level:
- a) for newly planted fruit trees and landscape plants
- b) to maintain health of mature trees and shrubs where rapid growth is not desirable
- c) for established fruit trees
- d) for young trees and shrubs under restricted growing conditions

[2]Use the high maintenance level on young nonfruiting trees and young landscape plants when rapid growth is desired.

[3]Low organic matter = less than 3.1%, medium to high = 3.1 to 19%, organic soil = greater than 19% organic matter.

Apply fertilizer in the early spring after the ground thaws. Broadcast the N fertilizer in a wide band around the dripline and four inches beyond and water it in.

Small Fruits: Nitrogen recommendations for small fruits are given in **Table 26**. For June-bearing strawberries, N should be topdressed when the bed is renovated after harvest. On everbearing/day-neutral varieties, the fertilizer application should be split in monthly applications from May to August. Typical annual application rate is 0.5–0.8 lb. N/100 linear feet of row.

Other small fruits like raspberries, grapes, and blueberries should be sidedressed when growth begins in the spring. Typical application rates on established grapes and raspberries are 0.5 to 1 lb. N/100 linear feet of row. Use higher rates to stimulate shoot growth. Use the lower rate if shoot growth is excessive. On blueberries, a standard N rate is $^{1}/_{4}$ cup of ammonium sulfate per young plant and 2 cups ammonium sulfate per mature plant.

Table 26. Nitrogen recommendations for small fruits

Soil organic matter level*	Amount of nitrogen (N) to apply
	lb. N/100 sq. ft.
Low	0.20
Medium to high	0.15
Organic soils	0.10

*Low organic matter = less than 3.1%, medium to high = 3.1 to 19%, organic soil = greater than 19% organic matter.

On sandy soils, split applications of N are recommended to reduce leaching losses. Divide the recommendations in half and apply twice as often. Do not exceed the total recommended rates. Another option is to use slow-release N fertilizers or natural organic N sources.

Phosphorus and Potassium Recommendations

Phosphorus (P) and potassium (K) fertilizer recommendations for small fruits, tree fruits, and landscape trees and shrubs are given in **Tables 27 and 28**. Preplant P and K applications are very important in new plantings, because both elements are relatively immobile in most soils. Topdress applications following establishment will move very slowly through the soil, so it will be difficult to make substantial changes in P and K fertility levels in the plant root zone after planting. Soil tests for P and K are especially important before planting, because they permit an accurate assessment of fertilizer needs.

Table 27. Phosphorus recommendations for fruits, trees, and shrubs

Phosphorus (P) Soil test level		Amount of phosphate (P_2O_5) to apply
----------- ppm -----------		lb. P_2O_5/100 sq.ft.
Bray-P1	Olsen-P	
0-5	0-3	0.20
6-10	4-7	0.10
11-25	8-18	0.05
over 25	over 18	0.00

Table 28. Potassium recommendations for fruits, trees, and shrubs

Potassium (K) Soil test level	Amount of potash (K_2O) to apply
----------- ppm -----------	lb. K_2O/100 sq.ft.
0-50	0.20
51-100	0.10
101-150	0.05
over 150	0.00

For new plantings where the entire area can be cultivated, such as strawberry and raspberry beds, hedges, and groups of trees or shrubs, broadcast the recommended amounts of P_2O_5 and K_2O and incorporate the fertilizer into the top 4 to 6 inches of soil. Where cultivation of the entire area is not feasible, as when planting individual fruit trees and ornamental trees or shrubs in lawns, quick release P and K fertilizer can be incorporated into the bottom of the planting hole if the hole is dug deep enough to allow fertilizer placement well below plant roots. Dig the hole $1^1/_2$ ft. deeper than the roots will be set, mix the fertilizer thoroughly with enough soil to fill the bottom 1 ft. of the hole, add a 6 inch layer of unfertilized soil as a buffer zone, and plant the tree above this using only unfertilized soil as backfill. Fertilizer may also be incorporated adjacent to the planting hole (see **Figure 3**). If slow-release fertilizers are used, $^1/_2$ to $^3/_4$ of the recommended fertilizer can be mixed in the planting hole. Do not exceed recommended rates for the area fertilized.

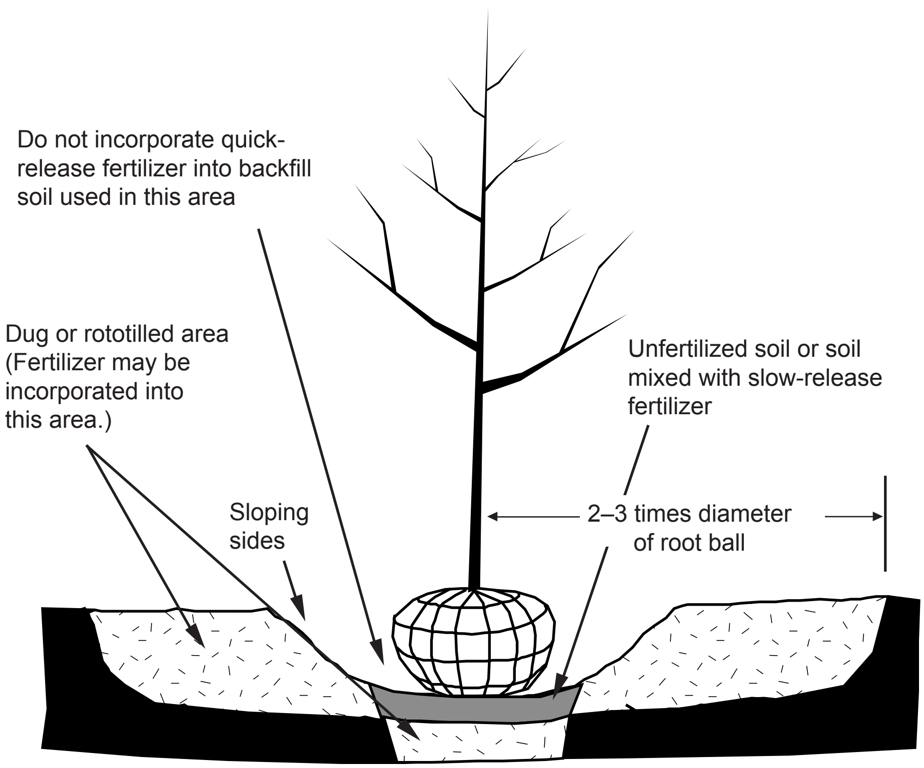

Figure 3. Fertilizing new plantings.

On established plantings, P and K can be applied in either the fall or spring. Spread fertilizer uniformly around the plants and if possible work it lightly into the soil to avoid disturbing plant roots. Deep placement of fertilizer is required to efficiently fertilize established trees with P and K. It may also be necessary for supplying adequate N to the roots of trees growing in lawn or turf. One effective method of deep placement is to drill a series of evenly spaced holes under the trees with a soil auger. The holes should be $^1/_2$ to 2 inches in diameter, 12 to 18 inches deep, and spaced 2 feet apart. The area covered should extend 2 feet beyond the tree canopy, but no hole should be within 3 feet of the trunk to prevent damaging the root collar. The recommended amount of fertilizer for the entire area is divided equally among the holes and mixed with the soil used to refill them.

Correcting Iron Chlorosis

In cases where the soil pH is above the optimum range for the growth of a particular plant species, interveinal chlorosis or yellowing between veins may occur on their foliage. Azaleas, pin oaks, as well as other species that prefer acid soils may exhibit this symptom. The chlorosis is an indication of poor iron availability in the soil. The soil contains enough iron, but the plant is not able to take up and use the iron effectively.

The long-term solution to solving this problem is to lower soil pH according to the section on soil acidification on page 5 (preferably before planting).

A short-term solution is to apply a foliar iron chelate to the leaves or soil. Chelates are a chemical compound that keeps the iron available over a wide pH range. Various chelate products are available at garden stores. Follow label directions for appropriate rates to apply. Foliar applications have to be repeated several times during the growing season. Soil applications need to be made on a yearly basis. However, higher rates are needed compared to foliar applications leading to increased cost.

The chlorotic tree can also be injected with iron chelates. This technique can correct the problem for a few years, but repeated injections may be necessary leading to some damage of the tree trunk. The best means to avoid or minimize iron chlorosis problems is to plant species tolerant of high soil pH conditions (see appendix).

Resources from the University of Minnesota Extension Service

The following publications can be ordered through the Extension Store at http://shop.extension.umn.edu/; or place credit card orders at (800) 876-8636; or e-mail requests to: ShopExtension@umn.edu.

Publication Title	Order Numbers
Boron for Minnesota Soils	FO-0723
Evaluating Soil Texture for a House Site	FO-0817
Liming: Taking a Look at Liming Materials	FS-2677
Lead in the Home Garden and Urban Soil Environment	FO-2543
Preventing Pollution Problems from Lawn and Garden Fertilizers	FS-2923
Soils and Landscapes of Minnesota	FO-2331
Soil Compaction—Cause, Effects and Control	FO-3115
Lime Needs for Minnesota	FO-5956
Magnesium in Minnesota Soils	FO-0725
Understanding Nitrogen in Soils	FO-3770
Phosphorus for Minnesota Soils	FO-0792
Sulfur for Minnesota Soils	FO-0794
Fertilizer Urea	FO-0636
Zinc for Crop Production	FO-0720
Fertilizing Lawns	FO-3338
Understanding Phosphate Fertilizers	FO-6288
Nutrient Management for Commercial Fruit and Vegetable Crops in Minnesota	BU-5886
Clean Water – Pesticide Selection Can Make a Difference	MI-3986
Groundwater Contamination	FO-5866
What Is Groundwater?	FO-5867
Composting and Mulching: A Guide to Managing Organic Yard Wastes	FO-3296
Backyard Composting	FS-3899
Structures for Backyard Composting	FS-5553
Turfgrass Management for Protecting Surface Water Quality	BU-5726
Responsible Fertilizer Practices for Lawns	FO-6551

Other Resources:
University of Minnesota Soil Testing Laboratory - (612) 625-3101
The University of Minnesota Extension Service website - www.extension.umn.edu

Appendix Soil pH Preferences for Selected Landscape Plants

	Acid, below pH 6	Slightly acid, pH 6-7	Slightly alkaline, above pH 7
Abeliophyllum distichum - Korean Abelialeaf	X	X	X
Abies balsamea - Balsam Fir	X		
Abies concolor - White Fir		X	X
Abies fraseri - Fraser Fir	X		
Acer ginnala - Amur Maple	X	X	X
Acer negundo - Boxelder	X	X	X
Acer platanoides - Norway Maple	X	X	X
Acer rubrum - Red Maple	X		
Acer saccharinum - Silver Maple		X	X
Acer saccharum - Sugar Maple		X	
Acer x freemanii - Freeman Maple		X	X
Ajuga reptans - Carpet Bugleweed		X	X
Alnus glutinosa - Common Alder	X	X	X
Amelanchier canadensis - Serviceberry	X		
Aesculus glabra - Ohio Buckeye		X	
Arctostaphylos uva-ursi - Common Bearberry	X		
Aristolochia durior - Dutchman's Pipe		X	X
Aronia spp. - Chokeberry	X		
Berberis koreana - Korean Barberry	X	X	X
Berberis thunbergii - Japanese Barberry		X	X
Betula lenta - Sweet Birch	X	X	
Betula nigra - River Birch		X	
Betula papyrifera - Paper Birch	X	X	X
Betula pendula - European White Birch	X	X	
Buxus microphylla koreana - Korean Littleleaf Boxwood		X	X
Buxus sempervirens - Common Boxwood		X	X
Calycanthus floridus - Sweet Shrub		X	
Campsis radicans - Common Trumpet creeper	X	X	X
Caragana arborescens - Siberian Pea Shrub		X	
Carpinus caroliniana - American Hornbeam			X
Carya cordiformis - Bitternut Hickory		X	X
Carya ovata - Shagbark Hickory		X	
Castanea spp. - Chestnut		X	
Catalpa speciosa - Northern Catalpa		X	X
Celtis occidentalis - Hackberry	X	X	X
Celastrus scandens - American Bittersweet	X		

	Acid, below pH 6	Slightly acid, pH 6-7	Slightly alkaline, above pH 7
Cephalanthus occidentalis - Buttonbush		X	X
Cercis canadensis - American Redbud	X		
Chamaecyparis pisifera - Sawara False Cypress	X	X	
Cornus sericea - Red Osier Dogwood	X	X	X
Chionanthus virginicus - White Fringetree	X		
Cladrastis lutea - Yellowwood			X
Clematis spp. - Clematis	X	X	
Cornus alba - Tatarian Dogwood	X	X	X
Cornus alternifolia - Pagoda Dogwood	X	X	
Cornus canadensis - Bunchberry	X	X	
Cornus racemosa - Gray Dogwood	X	X	X
Corylus americana - American Hazelnut	X	X	X
Cotinus coggygria - Smokebush	X	X	X
Cotoneaster spp. - Cotoneaster		X	X
Crataegus spp. - Hawthorne		X	X
Daphne spp. - Daphne		X	X
Deutzia spp. - Deutzia		X	X
Diervilla lonicera - Dwarf Bush-Honeysuckle	X	X	X
Dirca palustris - Leatherwood		X	X
Elaeagnus angustifolia - Russian Olive	X	X	X
Euonymus alatus - Winged Euonymus	X	X	
Euonymus fortunei - Wintercreeper Euonymus	X	X	X
Forsythia spp. - Forsythia		X	
Fraxinus americana - White Ash		X	
Fraxinus nigra - Black Ash	X	X	X
Fraxinus pennsylvanica - Green Ash		X	X
Ginkgo biloba - Ginkgo		X	
Gleditsia triacanthos - Honey Locust		X	X
Gymnocladus dioicus - Kentucky Coffeetree		X	X
Hammamelis virginiana - Common Witchhazel		X	
Hydrangea arborescens - Smooth Hydrangea	X	X	X
Hydrangea paniculata 'Grandiflora' - Peegee Hydrangea		X	
Hypericum prolificum - Shrubby St. Johnswort		X	
Ilex verticillata - Winterberry		X	X
Juglans cinerea - Butternut		X	X
Juglans nigra - Black Walnut			X

	Acid, below pH 6	Slightly acid, pH 6-7	Slightly alkaline, above pH 7
Juniperus chinensis - Chinese Juniper	X	X	X
Juniperus communis - Common Juniper	X	X	X
Juniperus horizontalis - Creeping Juniper	X		
Juniperus sabina - Savin Juniper		X	X
Juniperus scopulorum - Rocky Mountain Juniper		X	X
Juniperus virginiana - Eastern Red Cedar		X	X
Larix decidua - European Larch	X		
Larix laricina - Eastern Larch	X	X	X
Ligustrum ssp. - Privet		X	
Liriodendron tulipifera - Tuliptree		X	
Lonicera spp. - Honeysuckle		X	X
Maackia amurensis - Amur Maackia		X	X
Magnolia acuminata - Cucumber Tree Magnolia		X	X
Magnolia x loebneeri - Loebner Magnolia		X	X
Magnolia salicifolia - Anise Magnolia		X	X
Magnolia soulangiana - Saucer Magnolia	X		
Magnolia stellata - Star Magnolia	X		
Malus spp. - Flowering Crabapple	X	X	
Malus pumila - Common Apple	X	X	
Menispermum canadense - Common Moonseed		X	X
Microbiota decussata - Russian Cypress		X	X
Morus alba tatarica - Russian Mulberry	X	X	X
Myrica pennsylvanica - Northern Bayberry	X		
Ostrya virginiana - Ironwood		X	X
Pachysandra terminalis - Japanese Pachysandra	X		
Parthenocissus quinquefolia - Virginia Creeper		X	
Parthenocissus tricuspidata - Boston Ivy		X	X
Paxistima canbyi - Canby Paxistima	X		
Phellodendron amurensis - Amur Corktree	X	X	X
Philadelphus coronarius - Mockorange		X	X
Physocarpus opulifolius - Common Ninebark	X	X	X
Picea abies - Norway Spruce	X		
Picea glauca - White Spruce	X		
Picea pungens - Colorado Spruce		X	
Pinus banksiana - Jack Pine	X	X	X
Pinus cembra - Swiss Stone Pine		X	

	Acid, below pH 6	Slightly acid, pH 6-7	Slightly alkaline, above pH 7
Pinus koraiensis - Korean Pine		X	
Pinus mugo - Swiss Mountain Pine	X	X	
Pinus nigra - Austrian Pine		X	X
Pinus ponderosa - Ponderosa Pine		X	X
Pinus resinosa - Red Pine		X	
Pinus strobus - Eastern White Pine	X		
Pinus sylvestris - Scotch Pine		X	X
Populus spp. - Poplar		X	X
Potentilla fruticosa - Bush cinquefoil		X	X
Prunus americana - American Plum		X	X
Prunus armeniaca - Apricot		X	X
Prunus maackii - Amur Chokecherry		X	X
Prunus nigra - Canada Plum		X	X
Prunus pennsylvanica - Pin Cherry	X	X	
Prunus serotina - Black Cherry		X	X
Prunus tomentosa - Nanking Cherry		X	X
Prunus triloba - Flowering Almond		X	X
Prunus virginiana - Common Chokecherry	X		
Pseudotsuga menziesii - Douglas Fir		X	
Ptelea trifoliata - Wafer Ash	X	X	X
Pyrus communis - Common Pear		X	X
Pyrus ussuriensis - Ussurian Pear		X	X
Quercus alba - White Oak	X	X	
Quercus bicolor - Swamp White Oak		X	X
Quercus ellipsoidalis - Northern Pin Oak	X	X	X
Quercus macrocarpa - Bur Oak	X	X	X
Quercus palustris - Pin Oak	X		
Quercus ruba - Red Oak	X		
Quercus velutina - Black Oak		X	
Rhododendron mucronulatum - Korean Rhododendron	X		
Rhododendron spp. - Northern Light Azalea	X	X	
Rhododendron spp. - PJM Rhododendron	X	X	
Rhus glabra - Smooth Sumac			
Rhus typhina - Staghorn Sumac	X		
Rhus aromatica - Fragrant Sumac		X	
Ribes alpinum - Alpine Currant		X	X

	Acid, below pH 6	Slightly acid, pH 6-7	Slightly alkaline, above pH 7
Robinia pseudoacacia - Black Locust		X	X
Rosa rugosa - Rugosa Rose			X
Rosa spp. - Hybrid Tea Rose	X	X	
Rubus idaeus - Red Raspberry		X	
Rubus occidentalis - Black Raspberry	X	X	
Salix alba - White Willow		X	X
Salix pentandra - Laurel Willow		X	X
Sambucus spp. - Elderberry		X	X
Shepherdia argentea - Silver Buffaloberry			X
Sorbaria sorbifolia - Ural False Spirea		X	X
Sorbus americana - American Mountain Ash	X		
Sorbus aucuparia - European Mountain Ash		X	X
Spiraea x bumalda - Bumald Spirea	X	X	X
Spiraea x vanhouttei - Vanhoutte Spirea		X	
Staphylea trifolia - American Bladdernut		X	X
Symphoricarpos albus - Common Snowberry		X	
Syringa x chinensis - Chinese Lilac		X	X
Syringa meyeri - Meyer Lilac		X	X
Syringa reticulata - Japanese Tree Lilac		X	X
Syringa villosa - Late Lilac		X	X
Syringa vulgaris - Common Lilac			X
Taxus cuspidata - Japanese Yew		X	
Thuja occidentalis - American Aborvitae		X	
Tilia americana - American Linden		X	
Tilia cordata - Littleleaf Lindon	X	X	X
Tsuga canadensis - Canada Hemlock	X		
Ulmus americana - American Elm		X	
Ulmus siberica - Siberian Elm		X	X
Vaccinium spp. - Blueberry, Lingonberry, Cranberry	X		
Viburnum dentatum - Arrowwood Viburnum		X	X
Viburnum lantana - Wayfaring Tree Viburnum	X	X	
Viburnum lentago - Nannyberry		X	X
Viburnum opulus - European Cranberry Bush Viburnum		X	X
Viburnum trilobum - American Highbush Cranberry		X	X
Vinca minor - Common Periwinkle		X	
Vitis spp. - Grape		X	
Weigela florida - Weigela		X	
Wisteria spp. - Wisteria		X	X

Source: Spurway, 1944. Mich. State Agric. Sta. Bull. 306, modified by M. Zins for Minnesota conditions.

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