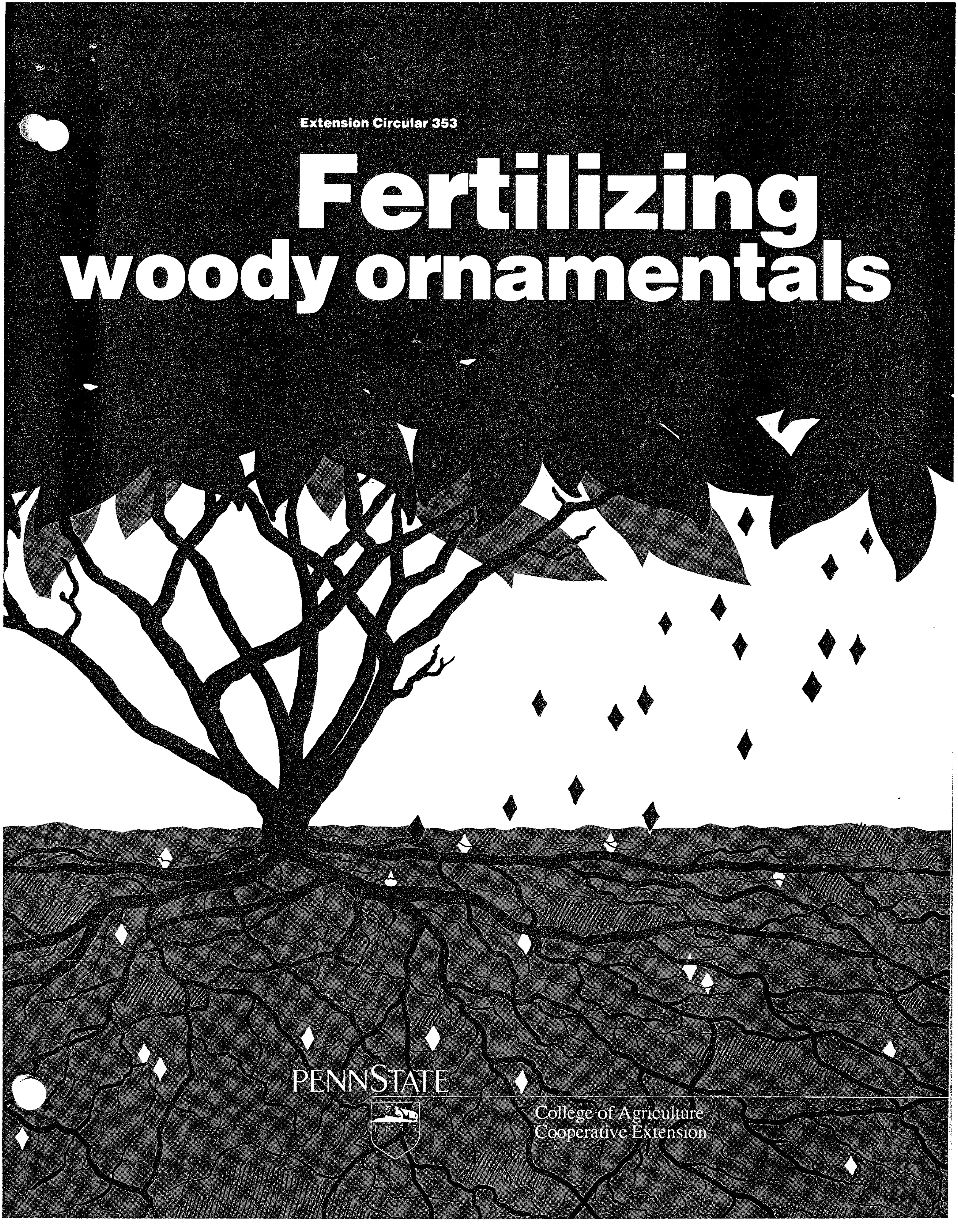
Extension Circular 353

Fertilizing woody ornamentals



PENNSTATE

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The objective of the commercial nursery operator is to produce a crop as high in value as possible in as short a time as possible, a task that requires meeting all of the cultural requirements of the crop at the right time. Insects, diseases, and weeds must be controlled and mineral elements must be provided in optimum amounts and form. Insect, disease, and weed control suggestions are presented in two Cooperative Extension Service publications of The Pennsylvania State University: "Pest Control Suggestions" and "Weed Control Recommendations for Nursery, Landscape, and Christmas Tree Plantings." The objective of this publication is to help growers determine the nutritional needs of their plants and how best to meet them.

ESSENTIAL MINERAL ELEMENTS

Certain mineral elements are essential for plant growth. Nine, called macronutrients, are required in relatively large amounts. Plants obtain carbon, hydrogen, and oxygen from air and water; nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur are normally absorbed by the roots. The macronutrients are usually present in field soils, but their levels require careful management to obtain maximum growth.

Seven other elements, required in small amounts by plants, are called micronutrients. They include iron, manganese, zinc, boron, molybdenum, copper, and chlorine. Micronutrients are at low levels or totally lacking in most soilless media, so it is important to supply them when growing plants in such media. Micronutrients are rarely deficient in field soils, but may occur in chemical forms that some plants cannot use. Extreme pH conditions (either too acidic or too alkaline) are the most frequent cause of nutrients occurring in unavailable forms.

If plants absorb any of these essential elements in insufficient or excessive amounts, they will not achieve their maximum growth. Proper feeding and management of plants require knowledge and understanding of what plants need and how nutrients become available or unavailable because of conditions in the soil. Figure 1 illustrates the relative availability of some of the mineral elements at different pH levels. Specific information on each macronutrient and general information on the micronutrients follow.

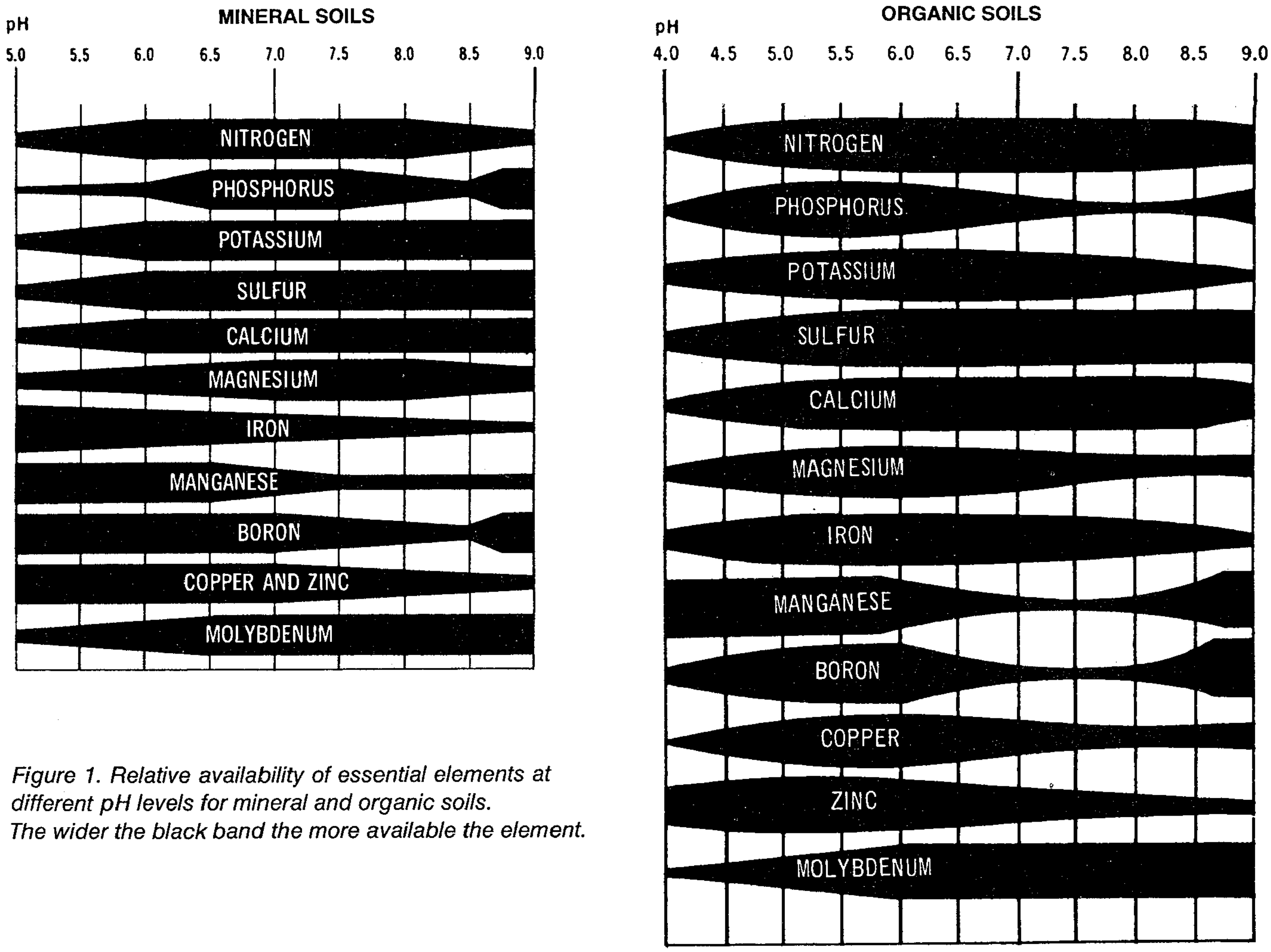

Figure 1. Relative availability of essential elements at different pH levels for mineral and organic soils. The wider the black band the more available the element.

Nitrogen

Nitrogen (N) is the element that most commonly limits growth in plants. Almost all plants respond to the addition of ogen fertilizers.

The amount of nitrogen available to plants in soil depends first on how much is present, then how much is added, and finally how much is used or lost.

Nitrogen becomes available to plants through:

- mineralization (decomposition) of organic matter by soil microorganisms
- addition of fertilizers
- fixation of nitrogen in the air by bacteria

Nitrogen in the soil becomes unavailable to crop plants through:

- absorption by weeds
- absorption by microorganisms decomposing organic matter low in nitrogen
- denitrification by soil organisms
- loss from the root zone by leaching

Except for the direct application of fertilizer, these processes are all influenced by the environment (temperature, moisture, soil aeration, pH, and microorganisms).

Several different chemical forms of nitrogen fertilizers come in a variety of formulations (liquid, granular, sulfur coated, encapsulated, etc.). The nitrogen in most farm grade fertilizer is readily available to plants. In recent years several trogen products have been developed that delay or extend nutrient release over a period of time. These "slow release" fertilizers are described on page 9.

Plants absorb nitrogen in one of two forms: ammonium-nitrogen (NH_4^+) or nitrate-nitrogen (NO_3^-). Nitrate-nitrogen carries a negative charge and is not adsorbed onto soil particles. It moves with the soil water and is available for absorption by plant roots or other organisms. If an excess of water is applied through irrigation or rainfall, some of the nitrate may leach below the root system and be lost to the plants. Nitrate-nitrogen can also be lost to the atmosphere through denitrification when soils become water saturated.

Ammonium-nitrogen carries a positive charge and is adsorbed onto the cation exchange capacity of soil particles. Nitrogen in the ammonium form is not lost through leaching. Although ammonium ions can be absorbed by most plants, they commonly are transformed to the nitrate form by soil microorganisms before moving down into the root zone. This process occurs rapidly (beginning within two to three days following application) when the soil temperature is warmer than 50°F. Conversion from ammonium to nitrate is usually complete within two to four weeks following application. Plants respond more slowly to ammonium-nitrogen than to nitrate-nitrogen, but ammonium ions are less readily leached from the soil.

The long-range effect of ammonium-nitrogen fertilizers is o reduce soil pH. Anhydrous ammonia, urea, mono- or di-ammonium phosphate, and ammonium sulfate greatly, but temporarily, increase soil pH to 9.0 or higher in the zone of application when first applied. Care is required in applying these materials because they release ammonia, which can "burn" germinating seeds or seedling roots in the area of fertilizer placement. However, in the conversion of ammonium ions to nitrate, an acid residue forms, lowering soil pH. This may lead to the formation of an "acid roof" on the soil. In an "acid roof," the pH in the upper inch or two of soil may be as much as an entire pH unit less than the soil beneath. Failure of triazine herbicides to control susceptible weeds may be due to the pH of the upper two inches of soil. A general rule of thumb suggests applying six pounds of limestone for each pound of nitrogen applied as ammonium sulfate, or three pounds of limestone for each pound of nitrogen applied as anhydrous ammonia, urea, or ammonium phosphate.

Urea is a water soluble form of organic nitrogen that moves easily into the soil. In the soil, urea converts first into ammonium nitrogen, then into nitrate. Significant quantities of nitrogen can be lost from urea by volatilization of the ammonia. These losses are accelerated by warm, moist soils, high pH, and surface organic matter. Losses are higher on soils with low cation exchange capacity (CEC) and sandy soils than on clay soils with a high CEC. Urea fertilizers should be applied in cool weather or incorporated into the soil by tillage or water movement. Urea is not recommended as a starter fertilizer because of the potential for ammonia toxicity to germinating seedlings or young roots.

Organic forms of nitrogen other than urea, either natural or synthetic, must be decomposed or transformed into more soluble forms to move into and through the soil to plant roots. The rate of decomposition or transformation is usually dependent on the forms of the material, temperature, soil moisture, and the abundance of soil microorganisms.

Phosphorus

Phosphorus (P) exists in soils in both organic and inorganic forms. Mineral soils, especially those that are acidic, tend to fix or tie-up phosphorus in forms not readily available to plants. Calcium, iron, and aluminum ions and silicate clays may combine with phosphorus in low pH environments. An advantage of this soil fixation of phosphorus is that little if any phosphorus is lost by leaching.

Many soils in Pennsylvania are low in phosphorus. Corrective applications based on soil test results should be made. Since phosphorus is not very mobile in the soil, it may move as little as one inch per year from the site of application. It is important to incorporate phosphorus prior to planting so that it is in the zone of root growth at the time of planting.

Single superphosphate (0-20-0) is preferred over triple superphosphate (0-40-0 or 0-46-0) because it supplies sulfur as well as calcium and phosphorus. Ammonium and potassium phosphates can also be used.

Although superphosphate can be added to soil at relatively high rates without directly injuring plants, soil levels of phosphorus exceeding five hundred pounds per acre should be avoided. In soils with higher phosphorous levels certain micronutrient deficiencies, particularly zinc or copper, may be induced.

In fertilization experiments with a variety of ornamental plants, conifers have shown the greatest growth increases in response to phosphorus applications.

Potassium

Potassium (K), or potash (K_2O) as it is known to many growers, is used in relatively large amounts by plants. It is the third of the macronutrients that is most likely to limit plant performance.

Potassium exists in the soil in three forms: nonexchangeable, exchangeable, and soil solution. Plants can absorb the exchangeable and soil-solution potassium with relative ease. As the exchangeable potassium is used by plants, it is partially replaced by nonexchangeable potassium. Nonexchangeable potassium is important because it can sustain plant growth over several growing seasons and thus alleviate the need for annual applications of potassium. Fields in which the potassium content is at a recommended level, may not need additional potassium for five years.

Potassium can be added as potassium sulfate, potassium chloride (also called muriate of potash), or potassium nitrate. The last formulation supplies both potassium and nitrogen.

Magnesium and calcium

Magnesium and calcium are positively charged ions that are strongly adsorbed by clay particles or organic matter. They must be applied to the root zone to be effective within a reasonable time. Preplant incorporation of fertilizers containing these elements is recommended.

Magnesium can be supplied in two forms — as magnesium sulfate (Epsom salts) or as dolomitic limestone (a mixture of calcium and magnesium carbonates). Selection of the form to be used depends on the soil pH. Magnesium sulfate is used in neutral or alkaline soils; dolomitic limestone under acid conditions. Magnesium sulfate can be broadcast on the soil surface, but dolomitic limestone must be incorporated into the soil to be effective.

As in the case of magnesium, selection of the calcium formulation added depends on the soil pH. Calcium sulfate (gypsum) should be applied to neutral or alkaline soils. Lime and limestone supply calcium and increase the pH of soils to which they are applied. Calcium nitrate can be used to add calcium and nitrogen to the soil.

In the soil, magnesium and calcium move from exchangeable forms into the soil solution as they are taken up by plants. In this way, they are maintained at adequate levels in the soil solution until the exchangeable sources are depleted. Therefore, one application of these elements may meet plant needs for several years.

Sulfur

Sulfur is rarely deficient in Pennsylvania soils. The primary use of this element is to decrease the pH of soil or soilless media. Details are given on page 8.

Micronutrients

Iron and manganese are the micronutrients most often found to be deficient in plants. In almost all locations where plants show symptoms of iron or manganese deficiency, these elements are present in the soil in concentrations adequate to support normal growth. The deficiency occurs because the iron or manganese occurs in a chemical form that prevents its use by the plants. The situation is usually corrected by adjustments in soil pH. Plants in well-drained soils with a high pH are especially susceptible to this condition.

The remaining micronutrients are rarely deficient in woody plants grown in soil. However, plants grown in soilless media often develop micronutrient deficiencies. Micronutrients, or trace elements, must be incorporated when mixing the media or applied postplant at least once a year to prevent deficiencies.

Nutrient-element balance

Plant growth is a function of both the total amount of nutrient elements available and the balance among the elements. Deficiency symptoms can develop in plants grown in soil in which all nutrients are present in adequate amounts, but not in the proper balance.

1. High levels of magnesium or calcium decrease the plants ability to obtain potassium.
2. High levels of potassium, ammonium nitrogen, or calcium can induce a magnesium deficiency.
3. Conversely, high levels of magnesium can induce a calcium deficiency.
4. Very high phosphorus levels may induce certain micronutrient deficiencies, such as copper or zinc.
5. Conifers may show little or no response to increases in nitrogen fertility unless phosphorus levels are in balance with the nitrogen.
6. When nutrient imbalance is caused by too much potassium, plant leaves are large, but relatively inefficient at photosynthesis. The resulting abnormally high concentration of nitrogen compounds compared to carbohydrates in the leaves makes the leaves more susceptible to fungal and bacterial diseases and drought stress.

The important point is that *fertilizer applications that are not based on soil test results may be a waste of money or may actually do more harm than good.*

DETERMINING NUTRITIONAL REQUIREMENTS

Plants often survive and appear to grow normally under a wide variety of soil conditions without the addition of any supplemental fertilizers. In almost all situations, the addition of one or more nutrients would significantly increase the growth of the plants. There are three ways of estimating how well the nutritional requirements of a crop are being met: observing its growth, testing the soil, or testing the foliage.

Deficiency symptoms

The nutrient status of a plant can be determined by observing the length of shoot growth; leaf color, color pattern, and size;

and time of leaf fall. A slight nutrient deficiency may reduce shoot growth without producing any other noticeable symptoms. The observer must have enough experience to know what constitutes "normal" growth. In more extreme cases, the visual symptoms described in Table 1 are evident.

Deficiency symptoms may be difficult to interpret for several reasons. Deficiency symptoms of some elements are hard to distinguish. For example, deficiencies of iron or manganese produce an interveinal chlorosis on new leaves. Multiple deficiencies may be difficult to diagnose individually.

Table 1. Nutrient deficiency symptoms of woody plants.

Element	Foliar symptoms
Nitrogen (N)	General yellowish-green, more severe on older leaves. Stunted growth; small, fewer leaflets; early leaf drop.
Phosphorus (P)	Dark green to blue green, slightly smaller leaves. Veins, petioles, or lower surface may become reddish-purple, especially when young; death of lower needles of pines.
Potassium (K)	Partial chlorosis of most recently matured leaves in interveinal area beginning at tips, followed by necrosis. Older leaves may become brown and curl downward.
Calcium (Ca)	Death of terminal buds, tip dieback, chlorosis of young leaves; leaves may become hard and stiff. Root injury is the first apparent sign.
Magnesium (Mg)	Marginal chlorosis on older leaves followed by interveinal chlorosis. Tips and margins may become brittle and curl upward.
Sulfur (S)	Uniform chlorosis of new leaves; older leaves usually are not affected.
Iron (Fe)	Interveinal chlorosis of young leaves (sharp distinction between green veins and yellow tissue between veins). Older basal leaves greener; exposed leaves bleached.
Manganese (Mn)	Interveinal chlorosis of young leaves beginning at margins and progressing toward midribs; followed by necrotic spots.
Zinc (Zn)	Young leaves may be yellow, small ("little-leaf"), deformed or mottled with necrotic spots. There may be a tuft of leaves at the shoot tips.
Boron (B)	Terminal growth dies, lateral growth that develops has sparse foliage. Young leaves may be red, bronzed, or scorched. Leaves may be small, thick, distorted, or brittle.
Copper (Cu)	Rosetting of terminal growth. In extreme cases, terminal growth may die. Leaf symptoms not usually pronounced, but veins may be lighter than blades.
Molybdenum (Mo)	Cupping of the older leaves; marginal chlorosis followed by interveinal chlorosis.

Problems not nutrient-related sometimes mimic deficiency symptoms. Bacteria or virus infections, overwatering, high soluble salts, or root damage may all cause symptoms resembling a nutrient deficiency. Therefore considerable experience is needed to "read" a plant's nutritional status.

Perhaps the most important point to be remembered is that when a deficiency symptom is noticed, some damage has already been done. It is too late to make up the loss in growth and value. Any corrective actions taken only benefit future growth.

Soil analysis

Testing field soils or container media prior to planting a crop reveals nutrient deficiencies or imbalances and provides an accurate basis for their correction. Preplant amendments can be added to prevent any loss of growth that might occur between the time of planting and the first fertilizer application. Some materials such as lime, sulfur, and phosphorus are most effective if incorporated into the soil, and this is much easier to achieve before the crop is planted. Soil samples should be tested and the required amendments incorporated the year prior to planting in order to allow time for them to produce their desired effect. Soils for nursery crops should be tested every two to three years and corrective actions taken as needed.

A soil analysis laboratory is operated by the Cooperative Extension Service of The Pennsylvania State University. To test soil or soilless media, a mailing kit including a container for the sample, sampling instructions, and mailing information can be purchased from County Cooperative Extension Service offices. The final report includes the chemical analysis and a lime and fertilizer recommendation to meet the needs of a particular crop.

The testing laboratory offers several different tests. The Soil Test measures soil pH; available P; exchangeable K, Ca, and Mg; cation exchange capacity; and percent base saturation. It should be used for all field soils. Table 2 provides information for interpreting the results. The Greenhouse Soilless Media Test includes all of the above as well as soluble salts and nitrates. It should be used for greenhouse or container media that do not contain soil. Table 3 provides information for interpreting the results. Several other tests, available on an individual basis, include tests for organic matter, sulfur, boron, ammonium-nitrogen, and nitrate-nitrogen.

Nitrogen is not regularly tested by most laboratories because of its unstable nature in soils. It is readily leached from the root zone area and is used in large amounts by plants. For these reasons, N applications are usually needed annually by field-grown stock and continuously for plants growing in containers.

Kits are also available to test mushroom compost, peat, and soil particle size.

Table 2. A guide to the evaluation of field soil test results from the Penn State Soil Testing Laboratory.

Soil pH — Recommendations will be given to adjust the pH to 5.5, a range of 6.0 – 6.5, or 7.0, depending on the plants being grown.

Phosphorus (P) — The pounds per acre of available P present in the soil is indicated. Critical phosphorus levels are:

Low — 0-130 lb/acre
Medium — 130-300
High — 300-500

Recommendations will be given to adjust the P level to 200 lb/acre.

Potassium (K), Magnesium (Mg), and **Calcium (Ca)** are presented in milli-equivalents per 100 grams of soil and as a percent of the base saturation.

The milli-equivalents of each in the soil are determined so that its cation exchange capacity (CEC) can be calculated. The CEC is a measure of the soil's ability to store nutrients. The storage capacity of Pennsylvania soils is essentially saturated with hydrogen, K, Mg, and Ca. The CEC of a soil can not easily be changed.

Percent base saturation is the concentration of each element expressed as the percent of the CEC. A balanced soil will fall within these ranges:

K — 1 to 5 percent
Mg — 10 to 15 percent
Ca — 60 to 80 percent

Recommendations for the addition of these elements are based as much on their ratios to each other as they are on total amounts in the soil.

Foliar analysis

The leaves of plants are analyzed to determine the mineral element content within a plant. The information gained from this analysis complements that which was obtained with the soil test. It is possible to have a soil test indicate that adequate levels of all nutrients are present in a soil and still have nutrient deficiency symptoms appear on a plant. The nutrients may occur in a form that is unavailable to the plant. For instance, in high pH soils, iron occurs in a form that is unavailable to plants like pin oak and rhododendron. There may also be physical problems within the soil, such as compaction, poor drainage, or poor aeration that can affect nutrient absorption. The problem may even be localized in a field that has "clay pockets" scattered throughout. It is also possible that the soil samples were taken in a way that did not properly represent the area tested. In any case, foliar analysis is useful in diagnosing deficiency symptoms.

At this time, the use of foliar analysis for woody ornamental plants is confined largely to research studies and to confirming visual diagnoses. More correlation among tissue analysis, plant symptoms, and fertilizer responses is needed before standards can be developed for determining the nutrient status and needs of woody ornamental plants. The guidelines presented in Table 4 are based on work with a limited number of species and should be used with that understanding.

The greatest opportunity to make use of a foliar testing program is in the production of plants in containers. The soilless media that are generally used have very few naturally occurring nutrients. Many of the nutrients that are added are rapidly lost to leaching or absorption by the plant roots that may fill the containers. In such a situation, tests of the

Table 3. A guide to evaluation of greenhouse soil test results

		Low	Medium	High	Excess
Soil pH	Mineral soil	4.5-5.5	5.6-6.8	6.9-7.4	7.5+
	Soilless mix	Less than 4.4	4.5-6.0	6.1-6.6	6.7+
Nitrate nitrogen[1] PPM	Mineral soil	0-75	76-125	126-250	250+
	Soilless mix	Less than 100	100-400	401 and above	
Soluble salts[2]	Dilution 1:2	0-39	40-140	141-180	180+
	Dilution 1:20	0-100	101-300	301-400	

[1] Nitrate nitrogen levels vary greatly with the crop, stage of development, time of year, and method of fertilization. In growing mixtures of less than 25 percent soil a nitrogen level of 126 to 250 ppm might be considered medium under a weekly fertilizer schedule. Using a growing mixture of more than 25 percent soil and fertilizing each time you water, a nitrogen level of 76-125 ppm might also be considered medium. A combination of high nitrate nitrogen and high soluble salts may be damaging and levels should be reduced by leaching.

[2] A soluble salts level of 80-90 or above on a 1:2 dilution is excessive for seedlings, newly planted bedding plants, azalea liners, and newly benched snapdragons or cuttings.
Leaching reduces excessive soluble salt levels.
Leaching can be achieved by applying 2 gallons of water per square foot so that water runs out of the bottom of the bench or bed in three applications one hour apart. For pots, enough water should be applied so that it runs out of the bottom in three applications one hour apart.

Table 4. Ranges of mineral element content in the leaves of woody ornamentals. This listing is based on limited data and should be used as a general guideline only.

	Deficient	Low	Sufficient	High
		Percent		
N (evergreens)	0-1.0	1.5	3.5	5.5
(deciduous)	0-1.5	2.0	4.5	7.0
P	0-0.1	0.2	0.6	1.0
K	0-1.0	1.5	3.5	6.0
Ca	0-0.2	0.5	2.5	4.0
Mg (evergreens)	0-0.1	0.2	1.0	2.5
(deciduous)	0-0.2	0.3	1.0	2.5
		Parts per million (PPM)		
Mn	0-20	30	800	1000
Fe	0-30	50	700	1000
B	0-20	30	50	100
Cu	0- 4	6	40	200
Zn	0-25	30	75	100
Mo	0- 0.4	0.6	6	20

medium are of limited value because the concentrations of the mineral elements present are changing so rapidly. But by regularly analyzing the mineral element content of the leaves optimum levels for a crop can be determined. Deviations from the optimum, either up or down, can then be corrected before any serious deficiency or toxicity ever occurs.

The regular use of foliar analysis can help growers maximize the growth rate of their plants. Using foliar analysis only when nutritional problems are suspected does not yield the greatest grower returns.

In general, leaf samples should be taken between mid-June and mid-September, or later with evergreens, and from plants that represent conditions within the planting, whether normal or abnormal. Samples should include the most recently matured leaves, which are about midway on shoots of the current season's growth. Approximately 30 to 100 leaves, depending on size, should be selected from trees, shrubs, and broadleaved evergreens. For narrow-leaved evergreens, the collection should include about 50 terminal cuttings, 2 inches long, from as many different plants as possible that represent the planting. Comparison of healthy plant tissue with chlorotic plants is essential when diagnosing plant nutrient problems because nutrient levels vary greatly among different genera, species, and varieties of woody ornamentals.

County offices of Pennsylvania's Cooperative Extension Service have mailing kits and information on this program.

On-site test

Some plants growing in soil with a pH of around 7 or above are unable to absorb enough micronutrients for normal growth. The most obvious symptom of micronutrient deficiencies is chlorosis (yellowing) of the leaves. The most commonly deficient nutrients are iron and manganese. Oaks are often iron deficient, while maples and sweetgum are generally manganese deficient in the same types of soils.

Since applying iron to a manganese deficient plant, or vice versa, may make the problem worse rather than better, it is important to determine which nutrient is deficient before trying to correct the problem. Analyzing foliage can provide that information but can be fairly expensive. A simple inexpensive test for the deficient element uses the following procedure:

1. Fill three 1-gallon wide mouth jars with distilled water and add 4 or 5 drops of nonionic surfactant (wetting agent). Label the jars: 1, 2, and 3.
2. Add ½ teaspoon Sequestrene Chelated Manganese to the first jar, and 1½ teaspoons of Sequestrene Chelated Iron to the second jar. Add equivalent amounts of both nutrients to the third jar.
3. In the spring, submerge newly formed leaves in the solutions.
4. Carefully tag the treated limbs to identify which jar the leaves were submerged in.
5. Within one or two weeks, the leaves should respond to one or more of the treatments by becoming greener. If there is no response to the treatments, the chlorosis must be due to some other cause.

SOIL CHARACTERISTICS THAT AFFECT FERTILIZATION

Soils physically support plants and act as reservoirs for the water and nutrients needed by plants. Soils are complex mixtures of mineral particles of various shapes and sizes; living and dead organic materials including microorganisms, roots, and plant and animal residues; air; and water. Closely interrelated physical, chemical, and biological reactions occur constantly. The physical form of the soil greatly influences the nature of biological and chemical reactions. Optimum plant growth depends as much on a favorable physical environment as it does on what is called soil fertility.

The primary physical characteristics of a soil are its particle size (texture) and arrangement of the individual soil particles (structure). Texture and structure determine the pore space between particles. Pore space is necessary for the movement of water, dissolved nutrients, and air, and for providing space for roots to grow. The organic matter content of a soil also affects its physical characteristics.

Soil texture

Soil texture is a term that describes the mixture of different sizes of mineral particles. It relates primarily to particles smaller than 2 millimeters (.08 in.) in diameter — sand, silt, and clay — since these are the particles most active in the soil processes that support plant growth. Coarser particles, gravel and stones, are either chemically inert or interfere with plant cultivation.

Sand, the coarsest of the particles, feels gritty when rubbed. Sandy soils usually have rapid water infiltration and good aeration, but low water holding and nutrient storage capacity. However, there is a considerable range in these properties within the sand fraction.

Silt, the intermediate size, feels smooth when dry, and slippery (but not sticky) when moist. Because the smaller particle size creates smaller pore spaces between particles, silty soils have a slower water intake rate but higher water holding capacity than sandy soils. Silt is an essential component of the medium textured, versatile soil called loam.

Clay, the finest of the soil particles, gives the soil a sticky or plastic feel. One property of clay is an attraction (called adsorption) for positive ions such as calcium, magnesium, potassium, ammonium, and others. This property allows the clay component in soils to store large quantities of the plant nutrients that form positive ions. This storage capability is referred to as cation exchange capacity and is discussed later (page 8). On the other hand, plant nutrients that form negative ions (such as nitrate, phosphate, and sulfate) are repelled by clay particles and are subject to leaching. Clay, partly because of its small particle size and partly because of the positive ions associated with it, also has a strong attraction for water.

These are reasons that soil texture directly influences the amount of nutrients a soil can hold. The finer the texture, the more nutrients (and water) are held. *To supply the same amount of nutrients to plants, a sandy soil requires more frequent applications at lower rates than a clay soil.*

Soil structure

Soil structure refers to the arrangement of soil particles. Sand, silt, and clay particles seldom occur as separate units in the soil; rather, they combine into aggregates held together by small binding forces of clay and organic matter. The size and form of aggregation determine the structure of the soil. Soil structure is one of the more important physical characteristics of soil, yet perhaps the least understood. Plant growth is strongly influenced by soil structure because of its effects on the movement of water, air, and roots.

A granular soil structure provides an ideal environment for plant roots and is particularly suitable for establishing plants from seeds or transplants. Pores between the granular aggregates are large and continuous, and roots penetrate them easily.

Water drains readily through a granular soil, yet sufficient moisture is held in its aggregates to supply root needs. One of the good features of clay is that it promotes the formation of granular structure in medium textured soils by swelling and shrinking as it alternately absorbs water and dries out.

Although some breakdown of soil structure within the upper foot of soil may be inevitable in land that is intensively cultivated, an understanding of soil texture and structure enables growers to use cultural practices that minimize structural breakdown. Structural breakdown is easier to prevent than cure. Practices that help prevent structural breakdown include:

1. Plow and cultivate soil at an intermediate moisture content — not too wet, not too dry. Judging soil-moisture content requires experience, but there is a general test: The soil is dry enough if a soil ball that is firmly compressed falls apart when tapped.
2. Avoid recompaction of freshly plowed or loosened soil. The less activity in a field after tillage, the better.
3. Make tractor and implement tracks on the smallest amount of land possible. Try to use the same tracks for all operations.
4. Use heavy equipment in the field only when the soil is as dry as possible, within the limitations of weather and a timely schedule of operation.

If compaction is severe, it is possible to rejuvenate structure. Some factors that favor the formation of granular structure are:

1. Wetting and drying or freezing and thawing of soils improve aggregation through swelling and shrinking. The effect of swelling and shrinking is particularly noticeable with medium- or fine-textured soils that are plowed in the fall and left rough through the winter.
2. Bacterial decomposition of plant residues produces gums that help bond soil particles together. Incorporating the residues of a cover crop grown before replanting a field should be a standard management practice.
3. Planting fibrous-rooted cover crops, particularly grasses, between rows of nursery stock helps push soil particles together to form aggregates with continuous pore spaces between them.

Organic matter

Organic matter in soil is a limited source of nutrients, including nitrogen, phosphorus, and some micronutrients. The decomposition of organic matter helps improve soil structure. As organic matter breaks down into humus, it becomes colloidal in nature and develops a cation exchange capacity similar to that of clay particles. The incorporation of organic matter increases the cation exchange capacity and water holding capacity of sandy soils and the drainage and aeration of clay soils.

The level of organic matter in the soil cannot be easily changed. Soil microorganisms break down the organic compounds and use them for energy. In the process, they convert the carbon, hydrogen, and oxygen into carbon dioxide and water, and at the same time return the other essential elements to their inorganic form. Growing a cover crop for a season and plowing it under may increase the organic matter content of a soil by less than 0.1 percent. This practice may benefit succeeding crops in other ways, though. Soil structure and the balance between beneficial and harmful soil microorganisms may be improved.

Incorporating organic matter such as fresh bark or sawdust, materials that have a high carbon:nitrogen (C:N) ratio, may cause a temporary deficiency in soil nitrogen available to plants. When microbes decompose plant and animal residues with high C:N ratios, they use most of the inorganic nitrogen in the soil. The nitrogen does not become available to plants again until all of the organic matter is decomposed and the microbes in turn die and decompose. Temporary deficiencies can be overcome by applying supplemental nitrogen with the fresh organic matter.

Soil reaction (pH)

The reaction of a soil, also called pH, represents its degree of acidity or alkalinity. It is measured on a scale of 0 to 14 with ues below 7 considered acidic and values above 7 alkaline. As discussed earlier, the pH of a soil strongly influences the availability of the mineral elements needed for plant growth (Fig. 1).

When the pH of a mineral soil is 4.5 or below, aluminum, iron, and manganese are so soluble that they may become toxic to certain plants. Other mineral elements such as nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium may become limiting for plant growth at low pH. In addition, the activity of bacteria is markedly reduced.

As the pH increases, ions of aluminum, iron, and manganese precipitate, and the availability of these elements decreases. If the pH becomes alkaline, deficiencies of iron and manganese are likely to occur. Under alkaline conditions, phosphorus complexes with calcium to form insoluble calcium phosphates.

A soil reaction between a pH of 5.5 and 7.5 is favorable for the growth of most plants. Within this range, the essential mineral elements are readily available to most plants, the microorganisms of the soil can carry on their beneficial functions, and aluminum toxicity is not a problem. However, some species of plants grow best under acid conditions and others under more alkaline conditions. Nursery operators should be familiar with the optimum pH range for their particular crops and select sites for their production cordingly. Optimum pH ranges for selected species are isted in Table 9 (page 14).

Modifying soil reaction. If soil pH is too low for optimum plant growth, it can be modified by applying limestone. The amount of limestone to be added depends on the amount of change desired, soil texture, organic-matter content, and form of limestone used. Various forms of limestone have different abilities to modify the acidity of soils. This difference in ability is referred to as the "neutralizing value." All forms of limestone are rated against the neutralizing value for pure calcium carbonate, which has been assigned a rating of 100.

If a soil is too alkaline, it can be acidified by the application of sulfur. The amount to be applied depends on the soil type and the degree of change desired. The approximate amounts of sulfur required to decrease the pH of silt-loam soils are listed in Table 5. Aluminum sulfate can be used for acidification, but the quantity necessary to decrease the soil pH to the same degree is four to five times greater than the amount of sulfur required. For this reason, the use of aluminum sulfate should be considered only for small areas or individual trees or shrubs.

The best recommendations for the amount of limestone or sulfur to apply are based on soil tests performed by state or private laboratories. In Pennsylvania, soil test kits can be purchased from County Cooperative Extension Service fices.

Changing the pH of soils is best done prior to planting. The material should be spread evenly over the soil and thoroughly incorporated. The maximum amount of lime that should be applied in any season is 3 tons/acre. Nursery soils should be retested in one to three years to determine if additional lime is needed.

Table 5. Approximate amounts of sulfur necessary to lower the pH of a silt loam soil.

pH		Sulfur required	
From	To	lb/1000 sq ft	lb/acre
8.0	6.5	30	1300
8.0	6.0	40	1750
8.0	5.5	55	2400
8.0	5.0	70	3000
7.5	6.5	20	870
7.5	6.0	35	1525
7.5	5.5	50	2175
7.5	5.0	65	2830
7.0	6.0	20	870
7.0	5.5	35	1525
7.0	5.0	50	2175
6.5	5.5	25	1090
6.5	5.0	40	1750

Cation exchange capacity (CEC)

A cation is a positively (+) charged ion. Negatively (−) charged ions are called anions. Fertilizers are combinations of both cations and anions (Table 6).

Pennsylvania soils have negatively charged sites that tend to attract and hold (adsorb) positively charged ions (cations). The amount of these sites that a soil contains is called the cation exchange capacity (CEC) of the soil. It is called exchange capacity because the cations are loosely held (adsorbed, not absorbed) and can be easily absorbed by roots or exchanged for other cations in the soil.

Fine textured soil (clay) and organic matter have high CECs. Coarse textured soil (sand) has a low CEC. The CEC of silt soil lies in between.

In Pennsylvania soils, the CEC is primarily filled by hydrogen, calcium, magnesium, and potassium.

The hydrogen ions account for the acidity of the soil and offer no nutrient value to plants. The greater the number of hydrogen ions, the more acid the soil and the fewer the

Table 6. The chemical form and ionic makeup of common fertilizers and soil amendments.

Fertilizer	Chemical form	Cation	Anion
Ammonium nitrate	NH_4NO_3	NH_4^+	NO_3^-
Potassium nitrate	KNO_3	K^+	NO_3^-
Calcium nitrate	$Ca(NO_3)_2$	Ca^{++}	NO_3^-
Potassium chloride	KCl	K^+	Cl^-
Lime	$CaCO_3$	Ca^{++}	$CO_3^=$
Gypsum	$CaSO_4$	Ca^{++}	$SO_4^=$
Epsom salt	$MgSO_4$	Mg^{++}	$SO_4^=$

nutrients available for plant growth. When lime is added to a soil, it not only neutralizes the acidity, but replaces the hydrogen on the soil particles with calcium (and magnesium if dolomitic limestone is used).

Calcium, magnesium, and potassium held by the CEC of the soil resist leaching and can remain in the soil until absorbed by plants or replaced by some other cation. For this reason, levels of these nutrients can be built up in the soil and may not have to be reapplied for several years.

The cations (positive ions) in deicing salts, sodium in sodium chloride or calcium in calcium chloride, can replace other cations on the CEC. Since sodium is of no value to the plant, it is better to use calcium chloride (though if overapplied, it too can injure plants).

The nitrate form of nitrogen carries a negative charge and is not adsorbed by the CEC of the soil, so it is readily leached. The ammonium form has a positive charge and is adsorbed by the CEC. It resists leaching until it is converted to the nitrate form by soil microorganisms.

SLOW-RELEASE FERTILIZERS

Root growth and nutrient absorption can take place anytime the soil temperature is above about 40°F. To obtain maximum growth nutrients should be available to the roots at all times. Standard inorganic fertilizers release their nutrients over a relatively short period of time, beginning as soon as there is available soil moisture. Phosphorus has a low solubility, and potassium enters into an exchangeable/nonexchangeable complex, so both remain in the root zone for a long time. But if the nitrogen is not absorbed within two to four weeks, it is lost through leaching or volatilization.

Slow-release fertilizer formulations contain one or more essential elements that are released or made available to the plant over an extended period of time. They can be divided into three categories based on the mechanism by which the fertilizer is released.

1. Materials with a limited solubility that dissolve slowly (often listed on fertilizer bag labels as water insoluble nitrogen — WIN).
2. Materials from which the nitrogen is released through the action of microorganisms.
3. Materials coated by a resin or sulfur membrane that controls the rate of diffusion from the granule.

Types of slow-release fertilizers

Isobutylidene diurea (IBDU). This material is produced by the reaction between urea and isobutyraldehyde. Alone, it contains approximately 31 percent nitrogen. It may be mixed with other fertilizers to provide formulations containing various percentages of phosphorus and potassium. The rate of release of the nitrogen from IBDU depends primarily on a process called hydrolysis, which is a reaction with water. The more water passing through the soil, the faster the release rate. The solubility of the nitrogen is also influenced by particle size of the fertilizer, soil pH, and temperature. Small particles, low pH, and high temperatures all favor faster release. The rate of release of nitrogen from IBDU is not affected by microbiological activity.

Magnesium ammonium phosphate (Mag Amp). Mag Amp is very slowly soluble in water. Its release rate is dependent on the amount of water passing through the soil and the size of its particles. The larger the particles, the slower the release. Mag Amp is available in an 8-40-0 formulation with 14 percent magnesium or a 7-40-6 formulation with 12 percent magnesium. Nitrogen in the ammonium form may be lost from surface applications of Mag Amp, especially under alkaline conditions.

Ureaformaldehyde (UF). This product is approximately 38 percent nitrogen and is formed when urea and formaldehyde are combined. The ratio of urea to formaldehyde determines the solubility of the final product. The urea provides relatively short-chained molecules that are quite soluble, and the formaldehyde provides longer-chained molecules with a low solubility. Both chemical and biological activity are required for complete release of the nitrogen, therefore the release rate is more rapid in warm weather. Soil bacteria release approximately one-third of the nitrogen (in the commonly available ureaformaldehyde fertilizers) in the first four to six weeks following application. About 70 percent of the nitrogen is released within six months after application, and the remaining 30 percent is released by the end of the year. During the dormant season, when soil bacteria are inactive, ureaformaldehyde remains in place, even in sandy soils. Release is extremely slow at temperatures below 50°F.

Choice. This is a relatively new slow-release complete fertilizer that also includes micronutrients. The nitrogen, phosphorus, and potassium are in a very slowly soluble form, and the micronutrients are fritted. Fritted nutrients are coated with a glasslike material to slow the rate of release. Choice is especially formulated for plants growing in artificial media likely to be deficient in micronutrients.

Sulfur-coated fertilizers. Sulfur can be used to coat soluble materials such as urea or potassium chloride to slow the rate of release of these nutrients. Melted sulfur and a soft wax sealant containing a microbicide are used as coating materials. The sealant slows water transfer, and the microbicide slows the rate of sealant decomposition by microorganisms. The nitrogen content of sulfur-coated products is usually between 32 and 37 percent. The release rate is determined by the thickness of the sulfur coating and temperature of the growing medium. The thicker the coating and the lower the temperature, the slower the release rate. These materials provide the advantages of relatively low cost and the addition of sulfur, another essential element. The sulfur reduces the pH of the medium.

Two materials currently available are Sulfur Coated Urea (SCU) and Sulfurkote. The latter is available in several complete fertilizer formulations.

Resin-coated fertilizer (Osmocote). To manufacture this material, soluble fertilizers are coated with several layers of resin. When the fertilizer particles come in contact with water, the coating swells and its pores increase in size to permit some of the dissolved fertilizer to diffuse into the wing medium. The release rate depends on the coating kness, temperature, and water content of the medium. A decrease in coat thickness or an increase in temperature or water content increases the release rate. There is often a large fertilizer release in the first two or three days because of imperfections in the coating. Osmocote is available in several different formulations and release rates.

Reasons to use slow-release fertilizers

Applying fertilizers in the slow release form has several advantages. Fertilizer does not need to be applied as frequently if applied in a slow release form because nutrient release occurs over an extended period of time. Higher amounts of fertilizer can be added at each application without raising salt levels enough to injure plant roots. Nitrogen is used more efficiently; research has shown that a higher percentage is absorbed by plants. The higher efficiency of slow-release fertilizers means less nitrogen contributes to pollution of streams and subsurface water.

The primary disadvantage of slow-release fertilizers is the higher cost. However, when an analysis is done to determine the cost of nitrogen that actually is absorbed by the plant, the unit cost of slow-release fertilizers is actually lower than that of readily available materials.

TIMING FERTILIZER APPLICATIONS

Preplant incorporation

The best time to improve the fertility of a soil is prior to planting because nutrients that are not very mobile in the soil can be thoroughly incorporated and distributed throughout the area in which roots will be growing. Phosphorus is the most important element in this category because it moves most slowly.

Potassium, calcium, and magnesium reserves can be built up in the soil because both are positively charged ions (cations) that bind to soil particles. The higher the cation exchange capacity (CEC) of the soil, the more that can be added. Amounts sufficient to support crop growth for five years can be built up in clay soils or in soils high in organic matter. Sandy soils have lower CECs and cannot hold as many nutrients.

Lime or sulfur applied to correct extremes in soil pH is most effective if incorporated during the season prior to planting. The materials should be incorporated to provide a more even distribution of the materials and a more uniform pH in the root zone. In addition, the chemical reactions that cause the change in pH have time to occur before planting.

Nitrogen levels can also be built up in soil prior to planting. Inorganic nitrogen sources are usually unacceptable at this time because they leach easily and at high levels may "burn" the fine roots of newly planted materials. Slowly ailable organic materials are the best sources of nitrogen for preplant use. In the landscape, these may be fish emulsion or well-composted manure. In the nursery, a green manure cover crop can be grown the year or two before planting. Inorganic nitrogen fertilizers should be applied to these crops to force vegetative growth. They should be mowed several times and left on the field to be incorporated in the fall or the spring before planting. The applied nitrogen is bound in the cover crop and slowly released to the nursery stock through decomposition.

Postplant applications

The nutrient that provides the greatest improvement in plant growth when applied after planting is nitrogen. There are several reports of deciduous plants responding as well to applications of nitrogen alone as they did to applications of complete fertilizers. Other research has shown that conifers respond to nitrogen applications only if the phosphorus level of the soil is high. The general recommendation remains to have soil tested and amended accordingly prior to planting and to apply a fertilizer high in nitrogen after planting.

Roots absorb nutrients most efficiently when they are actively growing in early spring, about the time of bud break, and late summer to early fall. The best time to apply fertilizer is about two weeks prior to these periods so that the nitrogen is leached into the root zone in time to be available to the roots.

There is a lag time between the fertilizer application and the plant's growth response to that application. Nitrogen cannot be used directly as nitrate or ammonium ions by the plant, but must be converted to other chemical forms. Therefore fall applications of nitrogen provide a greater increase in spring growth than spring applications. Nutrients applied in the spring are either used in later season growth or stored for the following year.

Some plants, like forsythia, can continue to grow through the entire season. They go through a repeating cycle of active root growth, followed by active top growth. To maximize growth of these plants, sufficient nitrogen must be present each time the roots are actively growing. In the landscape or field, this can be accomplished by applying slow-release forms of nitrogen in the spring. In container production operations, the slow-release forms of nitrogen are usually supplemented by applying liquid fertilizers throughout the growing season.

APPLICATION RATES

The rate of application for all nutrients except nitrogen must be based on a soil test or analysis of the foliage. No general recommendations can be given. The rate of application for nitrogen depends on several factors including species, stage of development of the plant, location, and formulation. Recommendations may range from 2 to 6 pounds of nitrogen per 1000 square feet (about 90 to 260 pounds per acre) per year. Amounts to apply around individual small trees or shrubs are presented in Table 7.

The rate within this range that should be used depends on the objective of the application, location, plant type being fertilized, soil texture, and type of fertilizer used. A discussion of each of these considerations follows.

Table 7. The approximate amounts of fertilizer required to provide the equivalent rate of 3 pounds of nitrogen per 1000 square feet on circles 12 to 48 inches in diameter. Amounts are presented in ounces and grams.

Diameter of area (inches)	Nitrogen		Percent N in the fertilizer							
			5		10		20		46	
	oz	g	oz	g	oz	g	oz	g	oz	g
12	0.038	1	0.75	20	0.4	10	0.2	5	0.1	3
18	0.085	2.5	2	50	1.0	25	0.5	13	0.25	5
24	0.15	4.5	3	85	1.5	40	0.8	20	0.3	9
30	0.24	7	5	135	2.5	70	1.2	35	0.5	15
36	0.34	10	7	200	3.4	100	1.7	50	0.7	21
48	0.60	17.5	12	350	6.0	175	3.0	90	1.3	38

Newly planted trees or shrubs should receive one-half the amount specified. Established plants with most or all of their roots within 48 inches should receive the amount listed. Larger plants with roots extending well beyond 48 inches may receive two or three times the amount listed.

Objective

At the time of planting, nitrogen availability should be relatively low, but sufficient to support the new root and top growth that will take place. High rates should be avoided because they may force excessive top growth that cannot be supported by the limited root system. Approximately half the amount recommended in Table 7 should be applied.

Maximum growth is usually wanted when nursery or landscape plants are in the early stage of development. To achieve maximum growth, high rates of nitrogen are needed. As the plant matures and a rapid growth rate is no longer needed or desired, lower levels of nitrogen are sufficient to maintain the vigor of the plant.

A moderate application of nitrogen fertilizer sometimes helps plants recover from stress factors such as insect or disease attacks or from physical damage to the roots or trunk.

Location

Plants in locations that do not restrict their root systems can receive high rates of fertilizers. Plants with root zones restricted by walks or pavements should receive lower rates. High rates of nitrogen may encourage excessive top growth that cannot be supported by the restricted roots.

Plant type

Some plants naturally grow fast and produce excessive growth that requires increased maintenance. Siberian elm, silver maple, willow, forsythia, honeysuckle, and privet are examples of plants that require little or no nitrogen fertilization. Other plants such as red oak, sugar maple, arborvitae, and viburnums may be heavily fertilized. The growth forced on these plants is strong and well-structured and requires little, if any, extra care.

Plants with shallow fibrous root systems, such as azalea, rhododendron, hemlock, and dogwood are sensitive to high rates of fertilizer. Fertilizers are salts and can burn their roots.

Soil texture

Fine textured soils (soils high in clay content) or soils with a high organic matter content have high cation exchange capacities. Higher rates of fertilizer can be applied to these soils than to coarse textured soils (silty/sandy soils), which have low cation exchange capacities. Coarse textured soils should receive low rates at more frequent intervals.

Type of fertilizer

Nitrogen in the slowly available forms can be applied at higher rates than readily available nitrogen. Because less of the nitrogen is in the soil solution at any one time, the chance of root injury is reduced.

APPLICATION METHODS

Many methods are currently being used to fertilize trees, but the simplest is the best. Uniform broadcast applications of fertilizer have consistently provided increases in growth as good as, or greater, than any other method. Trees or shrubs that are growing in the middle of turfgrass benefit from fertilizers applied to the turf. Many people believe that the grass roots absorb all the nutrients before they wash down and become available to the tree roots. This is not true. Many roots of woody plants grow near the soil surface and intermingle with the grass roots. Research has shown that about 80 percent of the fibrous roots of broadleaved shade trees are found in the upper 12 inches of the soil. Many are found in the upper 6 inches.

Deep root feeding is achieved by liquid injection or drilling or punching holes in the soil around a tree and filling them with a fertilizer mixture. This system is time-consuming and expensive, may require specialized equipment, and in most cases places some or all of the fertilizer below most of the feeder roots of trees and shrubs. Deep-root feeding may be of some value in compacted soil, as creation of the holes may improve the aeration of the soil. Also, if a tree needs to receive more fertilizer than the turfgrass, fertilizer can be placed in holes 6 to 10 inches deep around the tree. The standard recommendation is to drill holes in concentric circles 2 feet apart in the soil around the plant, beginning 2 to 3 feet from the main stem and extending 3 feet beyond the dripline. The holes should be spaced 2 feet apart and the recommended amount of fertilizer uniformly distributed among the holes.

Premeasured fertilizer packets, pills, or spikes are generally unsatisfactory. The fertilizer they contain is extremely expensive on a per unit basis, and they provide a poor distribution pattern. If applied according to label directions, the fertilizer comes in contact with very little of e root system.

Foliar feeding is not normally necessary for landscape plants. It can be used to temporarily overcome chlorosis due to deficiencies of micronutrients such as iron or manganese. Applications should be made just before or during a period of active growth, usually in spring or early summer. The effectiveness of the application depends on the species, age of the plant, time of year, severity of the deficiency, and soil conditions under which the plant is growing.

Systems have recently been developed to inject nutrients into the trunks of trees. These systems should only be used under two conditions. First, if the plant has a micronutrient deficiency because of an incorrectable soil condition, trunk injections of the micronutrient provide longer term control than foliar sprays. Second, if much of the root system of a tree is under some impermeable barrier such as pavement or sidewalks, trunk injections may be the only way to provide adequate nutrients.

FERTILIZER PLACEMENT

Nutrients that move or react slowly in the soil should be incorporated in the upper 6 to 10 inches of the soil prior to planting. These include lime or sulphur for pH adjustment, and phosphorus, potassium, and magnesium.

Postplant fertilizer applications should be made uniformly ver the root system of the plants. The old standard recommendation, "fertilize to the dripline," is only a very rough guideline. The fibrous root network of most plants extends far beyond their dripline. Eight to 10 years after a 1½ inch caliper tree is planted, the radius of its root system may be twice that of its crown. The ratio of dripline to root radius varies considerably with species — there is no functional relationship between branch spread and root spread.

In tree nurseries, fertilizers can be band applied to prevent the fertilization of weeds growing between the rows.

FERTILIZING CONTAINER-GROWN NURSERY STOCK

Most nursery operators who grow plants in containers now use soilless media because they are well drained and aerated and there are fewer weed or disease problems compared to media containing soil. Though soilless media provide an excellent physical environment for root growth, they present the grower with some challenges regarding fertility.

Except for composted sewage sludge, the constituents of most soilless media contain few or no plant nutrients. All of the nutrients required for plant growth must be added. The good drainage provided by soilless media requires frequent irrigation of the plants, which results in the leaching and relatively rapid loss of applied fertilizers.

Because of the variation in media used, crops grown, and production systems in use, no specific recommendations can be made for use by all growers. General recommendations that can be adapted for an individual grower's special conditions can be offered.

A fertilization program for container-grown nursery stock includes three basic steps: incorporation of nutrients with the medium, addition of a slow release fertilizer, and supplemental applications of liquid fertilizers through the irrigation system.

Incorporation of nutrients

Some nutrients should be mixed with the potting medium so that they are present in the root zone at the time of planting.

Single superphosphate (0-20-0) supplies an inexpensive source of phosphorus and sulfur, both essential elements for plant growth.

Dolomitic lime raises the pH of the medium and provides calcium and magnesium — two elements that are essential for shoot growth and chlorophyll formation.

Gypsum provides a source of calcium without raising the pH.

Micronutrients, also called trace elements, must be added to soilless media because they contain very low levels of micronutrients. The exceptions are media containing composted sewage sludge — they contain adequate micronutrients. Correct application rates of micronutrients are critical since excessively high rates are toxic and can stunt or even kill an entire crop of container plants. The amounts of different formulations that should be added vary widely. For example, 2 ounces per cubic yard of some fritted trace elements are recommended, while 1½ pounds of Micromax or 3 to 6 pounds of Esmigran per cubic yard are required.

Low levels of nitrogen and potassium may be incorporated into the potting mix to give plants a quick start. Ureaformaldehyde is often added at approximately 3 pounds per cubic yard to supply a slow-release source of nitrogen. Potassium nitrate may be included as a quick source of nitrogen and potassium. Other slow-release fertilizers can be incorporated or topdressed.

Suggested amounts of nutrients to be added to a potting mix prior to planting are presented in Table 8. There are also commercially available combinations of these ingredients. *Pro-Start II,* formulated by the Sta-Green Fertilizer Company, contains all but the dolomitic lime. *Micromax Plus,* produced by Sierra Company, contains all the nutrients except the nitrogen and potassium.

Slow-release fertilizers

Because of the high amounts of water applied to container-grown nursery stock, the only dry fertilizers applied should be those with nutrients in the slow-release form. Readily available nutrients remain in the root zone for only a short time before they are leached away.

Any of the slow-release fertilizers described on page 9 are suitable for use in container production systems. Several companies have created formulations especially for use in containers. Some contain N, P, K, and micronutrients and are meant to be incorporated prior to planting. Others can be incorporated or applied to the container surface.

Table 8. Suggested amounts of additives to be incorporated into soilless potting mixes.

Additive	Per cubic yard	Per bushel
Dolomitic limestone	8 lb[1]	8 level Tsp[1]
Gypsum	2 lb	2 level Tsp
Superphosphate(0-20-0)	2 lb[2]	2 level Tsp[2]
Urea formaldehyde	3.5 lb[3]	
Potassium nitrate	8 oz	1.5 level tsp
Micronutrients[4]	follow label recommendations	
Granular wetting agent	1.5 lb	3 level Tsp
Sulfur[5]		

[1] If plants require an acid soil, cut this rate in half and double the amount of gypsum added.

[2] If only triple superphosphate (0-46-0) is available, use it at one-half this amount.

[3] This can be replaced by other slow-release nitrogen sources at their recommended rates.

[4] Depending on the micronutrient formulation selected, additional iron and manganese may be required.

[5] If using composted sewage sludge, add sulfur at the rate of 5 lb/cubic yard.

Slow-release fertilizers should be incorporated into the medium only if the equipment is capable of uniformly mixing the fertilizer with the other components. If there is any doubt that this can be done, the fertilizer should be evenly distributed on the surface of the container medium after planting. The disadvantage of the surface application is the possibility that the fertilizer may wash out of the container during a heavy rain or spill out during handling.

Slow-release fertilizers should not be incorporated in a medium prior to steam sterilization or sooner than three weeks before use. If the medium is not used within three weeks, it should be thoroughly leached before planting.

Liquid feeding

To supplement the incorporated and/or topdressed fertilizers, liquid fertilizers can be applied in the irrigation water. Dilute solutions can be applied with each irrigation, or more concentrated solutions can be applied on a weekly basis. The amount of fertilizer added should be adjusted according to the following recommendations:

1. Use lower rates early in the season before plants are fully developed.
2. Use lower rates for newly planted stock.
3. Use lower rates for ericaceous plants like azaleas and rhododendrons, and slow growing narrow-leaf evergreens.
4. Media with excellent drainage are highly leached and require more frequent light applications of fertilizer than media that have slower drainage.

The amount of fertilizer applied can be based on concentration or amount per acre. Concentrations between 100 and 400 parts per million (ppm) nitrogen are commonly used. If applying on a per acre basis, 30 pounds of nitrogen (78 pounds of ammonium nitrate) can be used as a general recommendation.

Potassium should be applied at half the nitrogen rate. If phosphorus is incorporated in the mix and is applied in the slow release form, it should not be needed in the liquid form. Soilless mixes should be tested during the growing season. If the phosphorus level is low, one or more of the liquid fertilizer applications should include phosphorus.

Anyone growing plants in containers should purchase a solubridge to measure the salt level in the media once a week. When the salt level exceeds 70 mhos x 10^{-5} (0.7 millimhos) with a 1:2 soil-water solution, additional fertilizer applications should be delayed. For azaleas and rhododendrons, feeding should be delayed if the reading exceeds 40 mhos x 10^{-5} (0.4 millimhos).

HIGHLIGHTS AND RECOMMENDATIONS

1. The fibrous root networks of most woody plants extend far beyond the spread of their branches (driplines).
2. About 80 percent of all fibrous roots are found in the upper 12 inches of soil; many grow in the upper 6 inches.
3. Soil pH or deficiencies of phosphorus, potassium, and magnesium should be corrected prior to planting. Base applications on the results of a current soil test.
4. Nitrogen is the nutrient that most frequently limits plant growth. It is often the only nutritional element that accelerates the growth of ornamental plants. Two to 6 pounds of nitrogen per 1000 square feet (about 90-260 pounds per acre) per year should be applied. The rate within this range to be used depends on the objective of the application, location, plant type, soil texture, and type of fertilizer used.
5. Most landscape and nursery soils contain sufficient phosphorus and potassium to support the accelerated growth of ornamental plants caused by the addition of nitrogen. Higher levels of phosphorus and/or potassium may be needed for better bud set on some plants, i.e., conifers.
6. A general recommendation for nursery and landscape plantings is to use a fertilizer with a ratio of approximately 3 to 4 parts nitrogen and 1 to 2 parts of phosphorus and potassium (examples: 4-1-1, 3-1-1, 3-1-2, 4-2-1).
7. Uniformly broadcasting fertilizer over the root system is an efficient and effective method of application.
8. Other methods of application are no better than broadcast applications. These include deep root feeding by injection or placing dry fertilizer in holes, foliar feeding, trunk injections, or the use of pills or spikes.
9. Increases in the growth of shade trees due to nitrogen applications do not weaken the tree's structural strength or suppress an increase in trunk diameter relative to the growth in height and crown.
10. Late summer or early fall fertilizer applications rarely induce a flush of growth that will be damaged by frost or affect the plant's ability to properly harden off before winter.
11. A program for the fertilization of container stock should include the preplant incorporation of nutrients, an application of a slow release fertilizer, and supplemental liquid feeding.
12. All growers of container stock should own and know how to properly use a solubridge.

Table 9. Soil reaction (pH) preferences for selected ornamental plants (Spurway, 1944; Penn State Soil Test).

	Acid, below pH 6	Slightly acid, pH 6-7	Slightly alkaline, above pH 7
Abelia grandiflora — Glossy Abelia		X	X
Abies balsamea — Balsam Fir	X		
Abies fraseri — Fraser Fir	X		
Acer rubrum — Red Maple	X		
Acer saccharum — Sugar Maple		X	
Ajuga reptans — Carpet Bugleweed		X	X
Amelanchier canadensis — Serviceberry	X		
Arctostaphylos uva-ursi — Common Bearberry	X		
Aristolochia durior — Dutchman's Pipe		X	X
Aronia spp. — Chokeberry	X		
Berberis thunbergii — Japanese Barberry		X	X
Betula lenta — Sweet Birch	X	X	
Betula pendula — European White Birch	X	X	
Buddleia davidii — Butterfly-bush		X	X
Buxus sempervirens — Boxwood		X	X
Calluna vulgaris — Scotch Heather	X		
Calycanthus floridus — Sweet Shrub		X	
Caragana arborescens — Siberian Pea Shrub		X	
Carpinus caroliniana — American Hornbeam			X
Carya ovata — Shagbark Hickory		X	
Carya illinoinensis — Pecan		X	X
Castanea spp. — Chestnut		X	
Cephalanthus occidentalis — Buttonbush		X	X
Celastrus scandens — American Bittersweet	X		
Cercis canadensis — American Redbud	X		
Chaenomeles japonica — Japanese Flowering Quince		X	
Chamaecyparis obtusa — Hinoki Falsecypress	X		
Chionanthus virginicus — White Fringetree	X		
Cladrastis lutea — Yellow-wood			X
Clematis spp. — Clematis	X	X	
Cornus florida — Flowering Dogwood		X	
Cornus mas —Corneliancherry Dogwood			X
Cornus sericea flaviramea — Golden-twig Dogwood		X	
Cotoneaster horizontalis — Rock Cotoneaster		X	
Cotoneaster spp. — Cotoneaster		X	X
Crataegus spp. — Hawthorne		X	X
Daphne spp. — Daphne		X	X
Deutzia spp. — Deutzia		X	X
Enkianthus campanulatus — Redvein Enkianthus	X	X	
Euonymus alatus — Winged Euonymus	X	X	
Fagus grandifolia — American Beech	X	X	
Forsythia spp. — Forsythia		X	
Franklinia alatamaha — Franklinia	X		
Fraxinus americana — White Ash		X	
Ginkgo biloba — Ginkgo		X	
Gleditsia triacanthos — Honey Locust		X	X
Gymnocladus dioicus — Kentucky Coffeetree		X	X
Halesia carolina — Carolina Silverbell	X		
Hammamelis virginiana — Witch Hazel		X	
Hedera helix — English Ivy		X	X
Hibiscus syriacus — Rose-of-Sharon		X	X
Hydrangea petiolaris — Climbing Hydrangea		X	
Hydrangea paniculata 'Grandiflora' — Peegee Hydrangea		X	
Hypericum prolificum — Shrubby St. Johnswort		X	

Table 9. Soil reaction (pH) preferences for selected ornamental plants (continued)

	Acid, below pH 6	Slightly acid, pH 6-7	Slightly alkaline, above pH 7
Ilex aquifolium — English Holly	X		
Ilex crenata — Japanese Holly	X	X	
Ilex glabra — Inkberry	X		
Ilex laevigata — Smooth Winterberry	X		
Ilex opaca — American Holly	X		
Juglans nigra — Black Walnut			X
Juniperus horizontalis — Creeping Juniper	X		
Juniperus horizontalis 'Plumosa' — Andorra Juniper	X		
Kalmia latifolia — Mountain Laurel	X	X	
Kolkwitzia amabilis — Beautybush		X	X
Laburnum x watereri — Goldenchain Tree			X
Larix decidua — European larch	X		
Leucothoe fontanesiana — Drooping Leucothoe	X		
Liquidambar styraciflua — Sweetgum		X	
Ligustrum ssp. — Privet		X	
Lindera benzoin — Spicebush	X		
Liriodendron tulipifera — Tuliptree		X	
Lonicera spp. — Honeysuckle		X	X
Magnolia grandiflora — Southern Magnolia	X		
Magnolia soulangiana — Saucer Magnolia	X		
Magnolia stellata — Star Magnolia	X		
Mahonia aquifolium — Oregon Grapeholly			X
Malus floribunda — Japanese Flowering Crabapple	X	X	
Malus prunifolia — Plum-leaved Crabapple		X	
Malus pumila — Common Apple	X	X	
Myrica pensylvanica — Northern Bayberry	X		
Nerium oleander — Oleander		X	X
Nyssa sylvatica — Sour Gum		X	
Oxydendrum arboreum — Sourwood	X	X	
Paxistima Canbyi — Canby Paxistima	X		
Pachysandra terminalis — Japanese Pachysandra	X		
Parthenocissus quinquefolia — Virginia Creeper		X	
Parthenocissus tricuspidata — Boston Ivy		X	X
Philadelphus coronarius — Mock orange		X	X
Picea abies — Norway Spruce	X		
Picea pungens — Colorado Spruce		X	
Picea glauca — White Spruce	X		
Pieris japonicum — Japanese Pieris	X		
Pinus mugo — Swiss Mountain Pine	X	X	
Pinus resinosa — Red Pine	X		
Pinus strobus — Eastern White Pine	X		
Pinus sylvestris — Scotch Pine	X	X	
Platanus occidentalis — American Sycamore		X	X
Prunus americana — American Plum		X	X
Prunus armeniaca —Apricot		X	X
Prunus avium — Sweet Cherry		X	X
Prunus glandulosa — Dwarf Flowering Almond		X	
Prunus persica — Peach		X	X
Prunus triloba — Flowering Almond		X	X
Prunus virginiana — Common Chokecherry	X		
Pseudotsuga menziesii — Douglas Fir		X	
Pyracantha coccinea — Firethorn		X	X
Pyrus communis — Common Pear		X	X

Table 9. Soil reaction (pH) preferences for selected ornamental plants (continued)

	Acid, below pH 6	Slightly acid, pH 6-7	Slightly alkaline, above pH 7
Quercus alba — White Oak	X	X	
Quercus palustris — Pin Oak	X		
Quercus phellos — Willow Oak	X		
Quercus robur — English Oak		X	X
Quercus rubra — Red Oak	X		
Quercus velutina — Black Oak		X	
Quercus virginiana — Live Oak	X		
Rhododendron carolinianum — Carolina Rhododendron	X		
Rhododendron catawbiense — Catawba Rhododendron	X		
Rhododendron hirsutum — Alpine Rhododendron		X	X
Rhododendron mucronulatum — Korean Rhododendron	X		
Rhododendron obtusum — Hiryu Azalea	X		
Rhododendron periclymenoides — Pinxterbloom Azalea	X		
Rhodotypus scandens — Black Jetbead		X	
Rhus glabra — Smooth Sumac	X		
Rhus typhina — Staghorn Sumac	X		
Rosa rugosa — Rugosa Rose		X	
Rosa spp. — Hybrid Tea Rose	X	X	
Rosa wichuriana — Memorial Rose		X	
Rubus idaeus — Red Raspberry		X	X
Rubus occidentalis — Black Raspberry	X	X	
Salix babylonica — Weeping Willow	X		
Sassafras albidum — Common Sassafras		X	
Sorbus americana — American Mountain Ash	X		
rbus aucuparia — European Mountain Ash		X	X
Spirea vanhouttei — Vanhoutte Spirea		X	
Styrax japonica — Japanese Snowbell	X		
Symphorocarpos albus — Common Snowberry		X	
Syringa persica — Persian Lilac		X	X
Syringa vulgaris — Common Lilac			X
Taxus cuspidata — Japanese Yew		X	
Teucrium chamaedrys — Wall Germander			X
Thuja occidentalis — American Aborvitae		X	X
Tilia americana — American Linden		X	
Tsuga canadensis — Canada Hemlock	X		
Tsuga caroliniana — Carolina Hemlock	X		
Ulmus americana — American Elm		X	
Vaccinium corymbosum — Highbush Blueberry	X		
Viburnum acerifolium — Mapleleaf Viburnum	X		
Viburnum lantana — Wayfaring Tree	X	X	
Viburnum plicatum tomentosum — Doublefile Viburnum		X	X
Vinca minor — Common Periwinkle		X	
Vitex agnus-castus — Chaste Tree		X	
Weigela florida — Weigela		X	
Wisteria floribunda — Japanese Wisteria		X	X