CHAPTER 12. NUTRIENTS AND FERTILIZATION

By: Jack T. May,
Forest Nursery Consultant
Dadeville, AL
(Professor Emeritus
University of Georgia)

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FERTILITY

A nursery soil is a highly artificial medium in which the soil reaction, exchange capacity and the content of nutrients are adjusted to meet the requirements of the species to be produced. All of the essential elements used by seedlings must be either derived from the mineral and organic fractions of the soil or provided in the form of inorganic fertilizers. Exceptions are carbon, hydrogen, oxygen, and sometimes nitrogen, sulfur and chlorine.

Fertility in a nursery soil can be defined as that quality which enables the soil to provide the proper elements or components in the proper amounts for the growth of the species. Productivity of soil can be defined as its capacity to produce a crop of seedlings of a given species under a specified system of management. A productive soil must be fertile, but a fertile soil may not necessarily be productive. For example, a nursery soil may be productive for longleaf or loblolly pine seedlings, but at the same level of fertility it may not be productive for hardwoods.

NUTRIENTS AND PLANTS

The regulation of a balanced supply of nutrients is one of the most important procedures in the nursery. This requires a delicate balance of both macro- and micronutrients.

Macronutrients

Mineral nutrients have many functions in plants including:

1. Constituents of plant tissue
2. Catalysts in physiological reactions
3. Osmotic regulators
4. Constituents of buffer systems
5. Regulators of membrane permeability

The elements required in rather large quantities are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). These six elements are the major or macronutrients. Although N is not a mineral element, it is usually included with them.

A severe deficiency of any element is usually accompanied by symptoms that can be easily seen, such as color changes in seedlings. See table 12-1. However, remember that symptoms do not always indicate causes. For example, a loblolly pine seedling may show symptoms that suggest a nutrient deficiency, but the true cause may be the destruction of absorbing roots by a disease or nematodes, rather than a low level of the nutrient.

N, S, Mg, and iron (Fe) deficiencies all cause the foliage to turn a yellow-green to yellow. This symptom is called chlorosis. Ca and boron (B) deficiencies cause terminal tips to exude resin and growing tips to die. P and K deficiencies cause purple and bronze discoloration of needles (figure 12-1). Unfortunately these same symptoms can be caused by an excess of some other elements, by a seedling disease, chemical or mechanical injuries, or an environmental disturbance such as shallow wrenching.

The first step in determining the cause of any abnormality in growth or foliage is to remove the seedling from the soil and carefully examine all parts of it. Pay particular attention to the roots.

Seedlings markedly deficient in one or more nutrients may exhibit deficiency symptoms in many different ways. Examples include unusual colors of needles, reduced growth of vegetative parts and unusual morphology of plant parts. Shoots may not lengthen and may even die back. Roots may be short and stubby. Needles may be smaller and the number of needles in the bundles may be fewer than normal. These seedlings may become extremely susceptible to damage by frost, drought, insect or fungal attack.

Any single, deficient element is likely to produce one or more symptoms in a seedling that can be confused with another deficiency, toxic levels of other elements, antagonistic effects of one element on another, pathogen or insect injury, extreme climatic conditions, excess soil wetness or other environmental disturbances. Symptoms reflecting a deficiency of a single element are usually distinct for that species. Consequently, you should note all the symptoms exhibited by a seedling and not rely on one symptom alone for the deficiency diagnosis. Some of the symptoms that can be used in a diagnosis include:

1. Abnormal needle color and patterns of discoloration.
2. Abnormal size, shape and fascicles of the needles.
3. Bud abnormalities.
4. Resin exudation from buds, needles or stems.
5. Dieback of needles and shoots.
6. Unusual branch patterns.
7. Root abnormalities.

These symptoms are based on work reported by Wilde and Voigt 1952; Wilson 1953; Gilmore 1956; Fowells and Krauss 1959; Hamilton 1960; Sucoff 1961, 1962; Steinbeck et al 1966; Hacskaylo et al 1969; Lyle 1969; Aldhous 1972; Armson and Sadreika 1979 and Stone et al. 1982. Also see Appendices 12-1, 12-2 and 12-3.

A thorough knowledge of all growth manifestations of seedlings is essential to recognize deficiency effects. Each visual symptom of abnormal growth should be related to some specific function of the element in question. Thus, knowledge of the life history, growth habits and disease and insect pests of each species is necessary for adequate interpretation of visual symptoms associated with a seedling's element deficiency.

Generally, changes in needle color are the first sign of nutritional problems. The Munsell Color Charts provide a standard system for identifying and recording colors. Three aspects of color are used in the system: hue, value and chroma. Hue is the color's relation to red, yellow,

Table 12-1. — Visual symptoms of element deficiencies and excesses.

MINERAL	NEEDLE COLOR	NEEDLE AND STEM APPEARANCE	ROOTS AND OTHER
	Loblolly, slash and shortleaf pines		
Nitrogen deficiency	° Light or pale green or yellowish green ° Tips pink or deep red in advanced stages	° Short and stiff ° Slender, may be succulent	° Small roots
	Longleaf pine		
	° Pale green on lower half and light brown from middle to tip.		° Long, covered with numerous lenticels.
Excess	Loblolly, slash and shortleaf pines		
		° Weak stems with large thin-walled cells ° Chlorosis or necrosis of the terminal shoot or entire seedling.	
	Loblolly, slash and shortleaf pines		
Phosphorous Deficiency	° Yellow, yellowish-red color, varies with growing season; in cold weather, will be dark green to purple	° dead needle tips ° cotyledons and older needles at base of seedlings red or purple ° Short, slender stems	° Small roots
	Longleaf Pine		
		° Short needles ° Very few fascicles develop 3 needles	° Small roots, poor growth
	Loblolly, slash and shortleaf pines		
Excess	° Chlorosis	° Necrosis of terminal shoot	° Abnormal roots
	Loblolly, slash and shortleaf pines		
Potassium Deficiency	° Cotyledons red or chocolate brown ° Bluish green to copper or yellow-red to red from base to tip.	° Shoot dieback ° Reduced or lack of growth	° Small roots, poor growth
	Longleaf Pine		
		° Stunted, low vigor ° Develop only a few short, fascicled needles	
Excess		° Reduced growth	

(Continued)

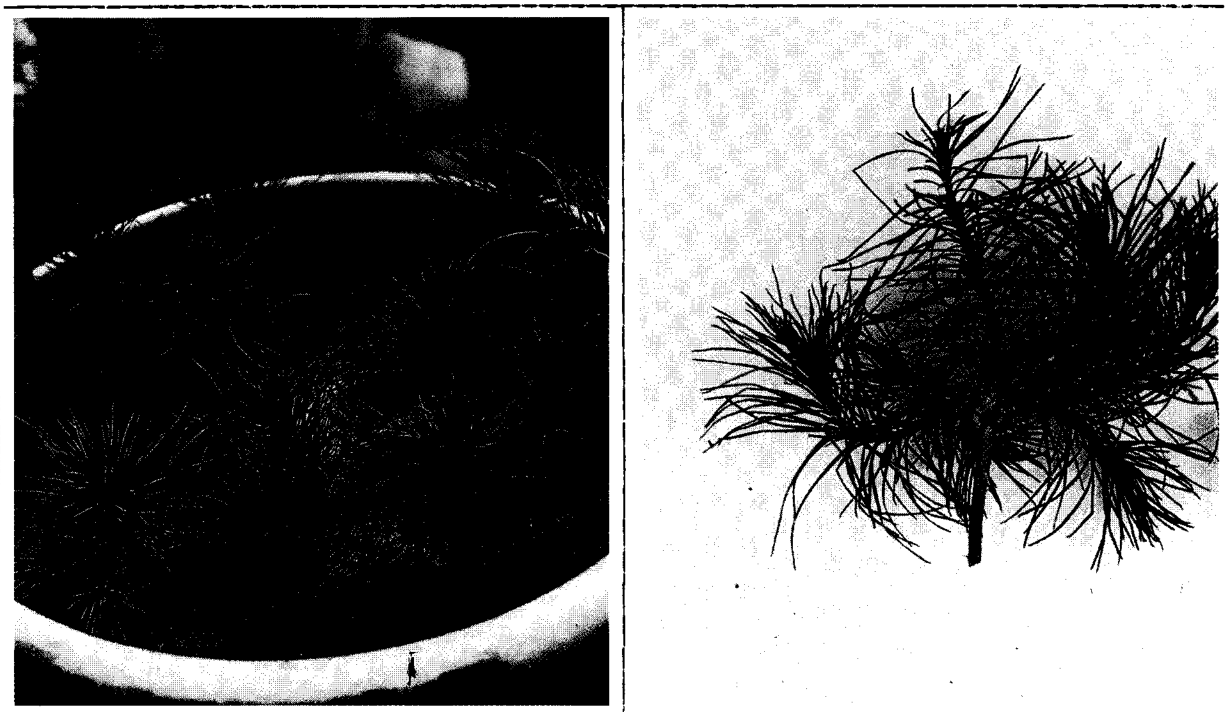
Table 12-1. — Visual symptoms of element deficiencies and excesses. (Continued)

Mineral	Needle color	Needle and stem appearance	Roots and other
	Loblolly, slash and shortleaf pines		
Calcium deficiency	° Yellow-green to brown or brown blotches	° Stunted stem ° Terminal bud brown and appears to be dead ° Lateral buds may develop but produce little active growth ° Terminal buds exude resin	° Root system small and stunted ° Short, stubby with numerous short, stiff laterals near the tip ° Some root tips may be large and blunt with a knot on end or rounded with blunt ends ° Root tips brittle and dead
	Longleaf pine		
		° Lose turgor and become delicate, weak and spindly ° Terminal buds may exude resin under moderate deficiencies ° Needles exude resin under extreme deficiencies	
	Longleaf pine		
Excess	° Chlorotic	° Necrosis of stem tip ° Short, brittle stems	° Depresses the intake of Mg, P, K, and Fe
	Loblolly, slash and shortleaf pine		
Magnesium deficiency	° Yellowish-green similar to N-deficient needles, but may be lighter or more yellow ° Tips turn yellow to reddish-brown or red ° Mottling or bronze streaking may develop along the needle length ° Severe deficiency causes secondary needles to have a brown tip, a yellow middle and a dark green base	° Appears on older needles first ° Tips of needles turn upward	° Symptoms appear on roots later in the season than does nitrogen deficiency
	Longleaf pine		
	° Tips become pale green or yellowish	° Needles very weak	° Few lateral roots develop
	Loblolly, slash, shortleaf, and longleaf pines		
Sulfur deficiency	° Yellowish-green color changes begin from the terminal needles and then spread to the entire seedling ° Characteristics similar to N deficiency	° Slow stem growth	° Slow growth

(Continued)

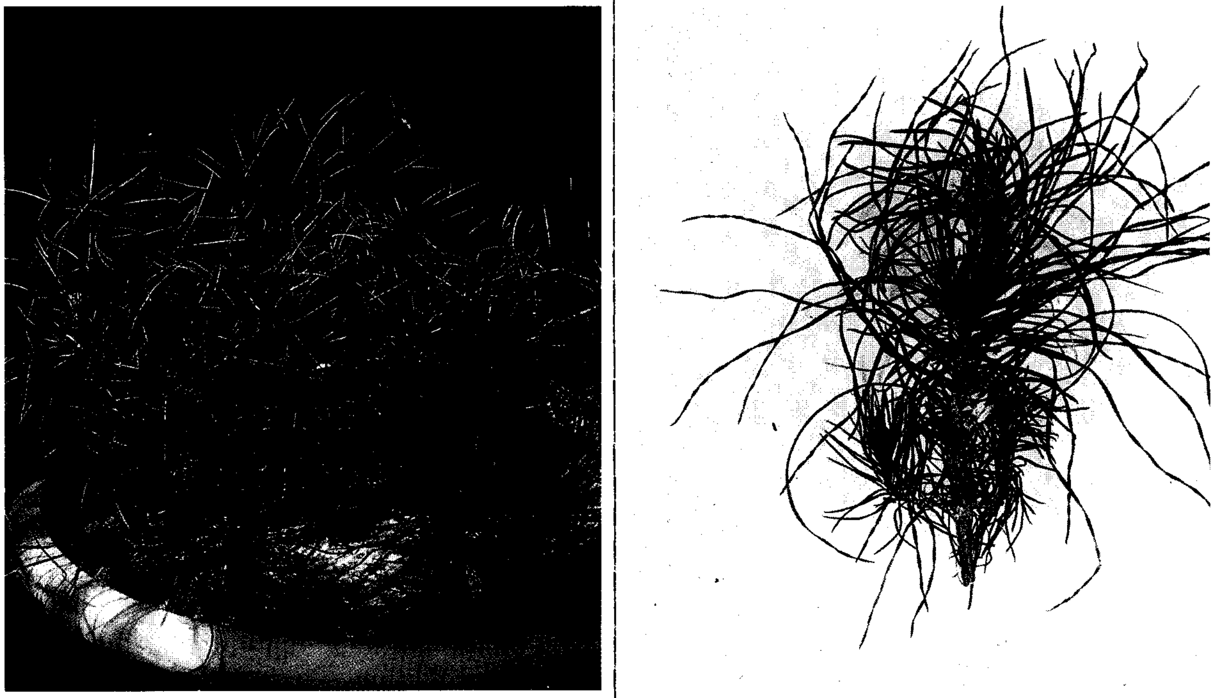
Table 12-1. — Visual symptoms of element deficiencies and excesses. (Continued)

Mineral		Needle color	Needle and stem appearance	Roots and other
Loblolly, slash, shortleaf and longleaf pines				
Iron	deficiency	° Yellowish-green to pale yellow to almost white, beginning with new needles ° Serious deficiencies resemble those of N and S		
Manganese	deficiency	° Greenish-yellow in early stages ° Pronounced green to yellow to red color changes in later stages		° Symptoms rarely develop
Zinc	deficiency	° Dark green ° Dull or dark reddish brown in later stages	° Needles short, thick and twisted	
Copper	deficiency	° Color changes in definite increments beginning at needle tip. Each section appears as a distinct band. ° Color change progresses from greenish yellow to reddish yellow to dull reddish brown		
	Excess		° Stunted	° Stubby roots that resemble Treflan damage
Boron	deficiency	° Dark green	° Terminal buds fail to develop ° Stem tip is a cluster of underdeveloped terminal buds ° stem elongation in spring is delayed because of lack of buds	
Molybdenum	deficiency	° Light green or slightly pale	° Developing terminal buds may exude resin ° Meristem death ° Stunted growth	



Virginia pine - low Mg

Virginia pine - low K



Loblolly pine - low Mg

Loblolly pine - low K

Figure 12-1. — Nutrient deficiencies of loblolly and Virginia pine seedlings grown in sand culture. Photos: Edward Sucoff, University of Minnesota.

green, blue and purple. Value is its range between white and black insofar as lightness is concerned. Chroma is the strength of the color in relation to a neutral gray of the value under consideration. (Wilde and Voigt 1952; Munsell Color Co., Inc. 1973; Hamilton 1960; Lyle 1969).

Nitrogen

Nitrogen (N) is a constituent of all proteins and occurs in many other compounds. N-containing compounds make up 5 to 30 percent of the dry weight of plants. N stimulates rapid vegetative growth, provided other elements, particularly phosphorus, are not in short supply. N deficiency is accompanied by failure to synthesize normal amounts of chlorophyll. Symptoms for N deficiency are shown in table 12-1 and figure 12-1.

N deficiency symptoms may develop:

1. Temporarily during periods of rapid shoot growth when the plant grows faster than the uptake of N.
2. When an excess of sawdust or other high C/N material is in the soil.
3. During periods of frequent precipitation, especially with seedlings growing in sandy soils that have little organic matter.
4. When complex sources of N are used, resulting in low levels of NH_4 and NO_3.
5. Where there is a definite deficiency of total or available N.

Phosphorus

Phosphorus (P) is a constituent of the cell nuclei and is essential for cell division and for development of meristematic tissue. The high-energy bonds associated with the phosphate groups seem to constitute the chief medium for energy transfer in plants.

In a P-deficient soil seedling stands show irregular and stunted growth of both stems and roots. Even if the foliage and roots appear healthy, the seedlings fail to grow.

Potassium

Potassium (K) remains in inorganic form and does not become a part of the plant structure. K has numerous roles, including the regulation of carbohydrate synthesis and sugar transport. Plants with sufficient K make more efficient use of water during stress. They are more able to withstand drought and cold, and may be able to better overcome the shock of transplanting and unfavorable environmental conditions.

A K deficiency rarely develops in micaceous soils of the mountains, piedmont or upper coastal plain.

Calcium

Calcium (Ca), in the form of calcium pectate, is a basic constituent of cell walls. Ca is involved in nitrogen metabolism and is required for the proper growth of meristematic tissue and for proper development and functioning of roots.

Magnesium

Magnesium (Mg) is a constituent of the chlorophyll molecule. Mg serves as a catalyst in the transfer of phosphate and is involved in several other enzyme systems.

Sulfur

Sulfur (S) is important as a constituent of amino acids, biotin and thiamin. S is also essential in fat synthesis and cell energetics. S deficiency causes chlorosis and a failure to synthesize proteins. Soils low in organic matter often exhibit S deficiency. Soil organic matter is an important storehouse for S as well as nitrogen. Although plants can get much of their S from the atmosphere, pollution with SO_2 can be toxic to seedlings.

Micronutrients

Elements required in very small amounts are called minor elements or micronutrients. Minerals such as copper (Cu), iron (Fe) or zinc (Zn) are essential because they are coenzymes of certain enzyme systems. Manganese (Mn) and magnesium (Mg) function as activators or inhibitors of enzyme systems. Elements such as boron (B), Cu and Zn, are also required in minute quantities in enzyme systems. These elements may become toxic if present in large enough quantities. See figure 12-2 and table 12-2.

Iron

Iron (Fe) is essential for the synthesis of the protein in chlorophyll. Fe occurs in a number of respiratory enzymes and acts as a catalyst or oxygen carrier in the oxidation-reduction processes occurring in living cells.

Manganese

Manganese (Mn) is essential for the synthesis of chlorophyll. The principal function of Mn is the activation of enzyme systems and to improve the availability of iron. Deficiency symptoms rarely develop.

Zinc

Zinc (Zn) is essential to many enzymes, including those which lead to the synthesis of indoleacetic acid (auxin).

Copper

Copper (Cu) is a constituent of certain enzymes important in the energy reactions of photosynthesis and respiration. Only very small quantities of Cu are needed by seedlings.

Boron

Boron (B) deficiencies inhibit sugar transport and affect many other plant characteristics in ways yet unknown. Death of the meristems of the plant may occur as a result of B deficiency.

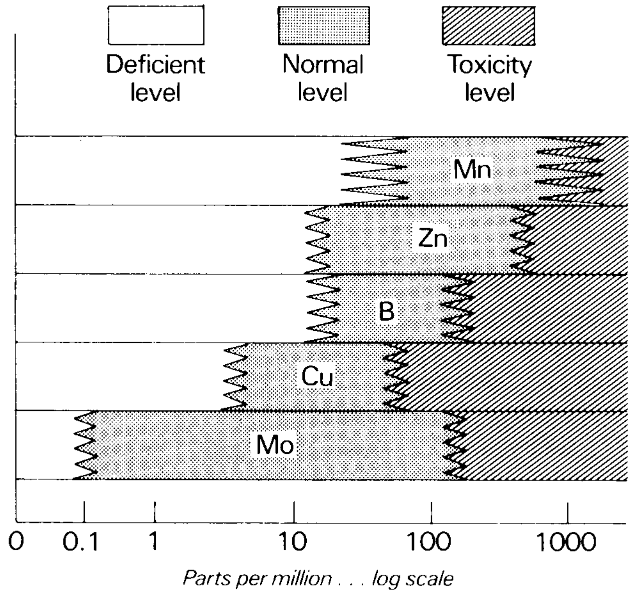
Molybdenum

Molybdenum (Mo) is involved in nitrogen fixation and the nitrate-reducing enzyme system. Mo deficiency may cause a metabolic disturbance.

Chlorine

Chlorine (Cl) is essential to photosynthesis. Accretions of Cl from the atmosphere are usually sufficient to meet plant needs.

MICRONUTRIENT LEVELS IN PLANTS



Source: Handbook on Soils. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 1961. [Unpublished administrative document; FSH 2509.15.]

Figure 12-2.—Micronutrient levels in plants.

Table 12-2. — Micronutrient concentrations in soils and plants.

Nutrient	Relative content in soil	Concentration in plants Normal	 Deficiency	 Excess
	--------------------	--------------------	ppm	--------------------
Fe (Fe^{2+}, Fe^{3+}) (1-5%)	25,000	30-150	10-80	Generally non-toxic
Mn (Mn^{2+})	2500 100-4000	15-100	5-20	>1000; depends on Fe:Mn ratio
Cu (Cu^{2+})	50 2-100	5-15	3-5	>20; depends on Fe:Cu ratio
Zn (Zn^{2+})	100 10-30	10-50	15	200-500
B (BO_3^{3-})	50 2-100	5-50	2-15	75-300
Mo (MoO_4^{2-})	2 0.2-5	1-100	0.1-0.3	Generally non-toxic
		--------------------	percent	--------------------
Cl (Cl^-)	50 50-500	0.2-1.0	<00.2	0.5-2.5

NUTRIENT INTERACTIONS AND AVAILABILITY

The need of a seedling for one nutrient depends on the availability of other nutrients in the soil. Frequently, ionic interactions affect the uptake and use of one or more nutrients. For example, seedlings appear to have a fixed capacity for absorbing nutrient bases, but it makes little difference which of the bases are absorbed to satisfy this capacity. Thus, if Ca is overabundant, the absorption of K and Mg may be depressed, possibly even to the point of a deficiency.

Sometimes a nutrient may react with another ion or nutrient in a way that reduces the efficiency with which it is used after the plant absorbs it. Too much of a nonfunctional ion may displace a nutrient ion from its normal position in a physiological system. Another effect may be the conversion of the nutrient to an unusable form. This interference is called antagonism. Micronutrients are usually more involved in harmful antagonistic effects than macronutrients.

Seedlings may absorb excessive amounts of nutrients if the supply is greater than the need. This excess consumption may occur at a low level of fertility if plants are stunted by a nonnutritional factor, or at a high level of fertility when more of the nutrient is made available than can be effectively used. In addition to wasting nutrients, excessive uptake of some nutrients, particularly micronutrients such as Boron, copper or manganese, may be toxic to plants.

The availability of essential nutrients often depends upon factors other than the simple addition of the nutrient in the form of fertilizers. The availability of most soil nutrients depends on the soil pH (chapter 1, figure 1-9). N, P, K, Ca, S, and Mg are more available as the pH value approaches 7.0.

The availability of micronutrients decreases as the pH is increased. This effect is especially strong for Fe and Mg, both of which are converted to less soluble forms, principally the oxides Fe_2O_3 and MnO_3. Soil moisture supply, aeration, light, temperature, seedbed density and any growth-controlling factors will modify to some degree the nutrient requirements of a seedling.

Simple fertilizer responses for one nutrient are usually linear over a narrow range and then become curvilinear. For instance, the additions of N and P beyond a certain amount do not result in any significant increase in seedling size. Manipulating soil fertility is seldom limited exclusively to one element. N, P and K are commonly added elements. The growth response to added N P K and their interactions may be positive, negative, or zero.

Two seedlings of equal size may be obtained by different combinations of soil fertility adjustments. A comparison of vigor and quality of pine seedlings grown under different nutrient regimes indicates that seedlings which are supplied with all of the essential elements are the most vigorous and show the best growth and development. Researchers and nursery managers have found that seedlings of good quality can be produced at various soil fertility levels and that these fertility levels can encompass a wide range of conditions (Andrews 1941, Rosendahl and Korstian 1945, Maki 1950, Allen and Maki 1955, May and Posey 1956, Switzer and Nelson 1956, May 1957, Switzer and Nelson 1963, Gilmore and Kahler 1965, Armson and Sadreika 1979).

SEEDLING NUTRIENT REQUIREMENTS

The nutrient requirements of a seedling may be defined as the minimum quantity of nutrients the plant will absorb to attain the desired morphological size and physiological condition. Nutrient requirements vary for different stages of development throughout the growing season. The rate of nutrient supply is often as important as the total amount of nutrients a soil can supply during the entire growing season.

Responses of seedlings growing in different soils will be quite different even when similar rates of fertilizers are applied. In medium-textured soils, excesses of N, Ca, and P may result in more pronounced abnormalities than would deficiencies of these nutrients. In sands, nutrient deficiencies may produce growth or color abnormalities more quickly than excesses of these nutrients.

Absolute verification of the cause of a growth or foliage color abnormality in seedlings is frequently not needed if the adjustments of nutrient levels or changes in cultural practices result in normal plant development. In addition to visual observations, other diagnostic techniques include the use of soil and foliar fertilization, soil analysis and foliar analysis. Of these, foliar analysis may be the most difficult to interpret correctly, as nutrient concentrations in needles, stems and roots are influenced by a number of variables. These include inheritance, stage of development, season of the year, years or cyclic effects, fertilization, types of cover crops, sawdust or other material incorporated into the soil, fumigation of the soil with methyl bromide, injury to seedlings by pathogens or chemicals, rainfall patterns, and irrigation (van den Driessche 1974). A useful technique for the diagnosis of mineral deficiencies was developed by Lyle (1972). Foliar applications of nutrient solutions are used to verify the deficient mineral. See Appendix 12-5.

The range of nutrients in seedling foliage, stems and roots is so wide that it is difficult to determine the levels that will signify deficiencies or excesses of either macro or micronutrients or a discrepancy in their ratios. Some nutrient concentrations from healthy seedlings are given in table 12-3. Additional information on foliar nutrients may be found in chapter 1, table 1-8.

Table 12-3. — Nutrient concentrations of healthy seedlings.[1]

Nutrient	Component		
	Needles	Stems	Roots
N,%	1.50[2]	.60	--
P,%	.18	.17	.15
K,%	.60	.60	.50
Ca,%	.20	.13	.04
Mg,%	.12	.12	.10
Na,%	.02	--	--
Fe, ppm	175	--	--
Mn, ppm	300	--	--
Zn, ppm	50	--	--
Cu, ppm	3.5	--	--
B, ppm	7.0	--	--

[1] Source: May et al 1962, Steinbeck et al 1966, and others.

[2] Example of range: N - 0.8 to 2.2 percent.

SOIL TESTING

Soil analysis is the major tool for determining the range of critical and acceptable values of soil fertility, and for maintaining optimum levels of nutrients. Many attributes of the soil can be measured by chemical and physical analyses. Physical properties, such as texture and cation exchange capacity, need to be determined only once. Chemical analyses for phosphorus, potassium, calcium, and magnesium, as well as pH, lime requirements and organic matter, should be done every year. The fall or early winter is preferred to minimize variations in readings of tests made in other seasons of the year. Soil nitrogen is not readily measured and is generally not evaluated in soil tests (Armson and Sadreika 1979). However, the need for nitrogen can be assessed by determining the amount of nitrogen in a sample of lifted seedlings (Davey 1972).

Method of Sampling

First decide what areas should be sampled. Each nursery block or operating unit should be sampled separately. Any sub-section or part of a block that visibly differs from the rest of the block, or on which seedlings regularly grow markedly better or worse than elsewhere in the block, should be sampled separately. The aim in soil sampling is to get representative samples from each block or section. This can be done by collecting about 24 small samples taken with a soil sampling tube to a consistent depth of 6 inches (15 cm). A ***W***-shaped, criss-cross or similar sampling pattern evenly distributed over the sampling area may be used. With the ***W***-pattern, six samples will come from each leg of the ***W***. See figure 12-3.

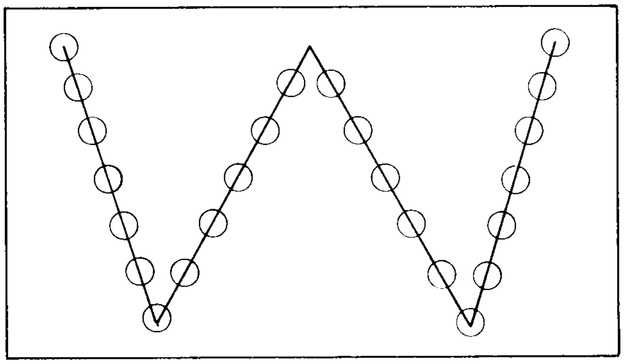


Figure 12-3: Diagram of soil sampling pattern.

Use a clean bucket or container for the composite sample. All samples from a given block should be mixed thoroughly and then reduced by halving until about one pint of soil is left to use for analysis. Put the sample in a special box provided by the soil testing laboratory, or in double, number-2 kraft bags, or in a strong polyethylene bag. Do not collect samples when the soil is saturated or completely dry. Soil moisture tension should be between 0.3 and 5 bars, i.e., when the soil is loose and friable. The soil sample should be labled as follows:

Name and address of sender.
Date of collection.
Sample number.
Block or section of the nursery.
Analysis required.
Crop to be grown following the analysis.

Nursery managers should have a map showing the location of samples, crops, and fertilizers since the last analysis and any other relevant information such as deficiencies observed, quality of last crop and unusual summer rainfall.

Testing Services

Each major land grant university operates a soil testing laboratory that tests agricultural soils. Laboratories in the 13 southern states were established to provide routine lime and fertilizer requirements for a particular soil-crop situation. The College of Environmental Science and Forestry, State University of New York, Syracuse University, operates a laboratory that tests nursery and forest soils. Private laboratories also provide soil and foliar analyses. All laboratories do not use the same techniques or extracting solutions, although there is considerable uniformity in methodology within a given region. Standard analytical methods for forest nursery soil testing are listed by Bickelhaupt et al. (1983).

Very definite risks are involved in the extrapolation of results from one crop to another crop, from one laboratory to another, and from one soil series to another. The soil test extractants usually do not remove all of the available nutrients from the soil, nor do different extractants remove identical amounts of nutrients. A most important point is for nursery personnel to be *consistent*, i.e., use the same collection procedures at the same time each year and use the same laboratory year after year. A southern nursery soil testing service has been established with the cooperation of Dr. C. B. Davey, A & L Laboratories, Inc. and Auburn University. See Appendix 12-4 and South and Davey (1983).

Testing services at the State university laboratories may be free or at a minimal cost for routinely determined pH, and extractable P and K. Most states routinely provide additional tests for extractable Ca and Mg and for lime requirements. Tests for organic matter, soluble salts, and extractable B, Mn, Zn, Fe, Cu, Na and NO_3 are available in a number of laboratories upon request.

Other tests that are sometimes useful, and are available at some laboratories, are reserve P and total P, potassium supplying power and the total quantity of several elements. The following tests should be obtained for each nursery before the first year of operation: pH, organic matter, available or extractable P, K, Ca, Mg, B, Mn, Zn, Fe, Cu, Na, and S; also reserve P and potassium supplying power, if available. Most laboratories have peak loads during winter and early spring. Planning for soil testing should include about 60 days for analyses.

Reporting of Results

One of the most confusing aspects of soil testing is in the reporting of results. A rating scale employed by some southern soil testing laboratories classifies soil as being very low (VL), low (L), medium (M), high (H), and very high (VH) in a particular plant nutrient such as Ca, Mg, P, K or NO_3. Such a rating implies a specific definition generally on the basis of nutrient sufficiency for crops in general or in terms of relative crop yields without fertilization. Rates of fertilization required at each rating are influenced by the crop and its yield, the nutrient sources, the time and method of application and whether accelerated soil fertility buildup is desired.

Soil test results have been reported in the following forms: (1) parts per million of each element; (2) pounds per acre of each element; (3) pounds per acre of P_2O_5: K_2O: CaO, and MgO; (4) milliequivalent per 100 grams for Ca and Mg and (5) percent for N. For convenience in interpretation and comparisons all results, except N, should be reported in either parts per million or pounds per acre.

Expression of soil test results as parts per million, pounds per acre, or kilograms per hectare is of little value to most farmers, except when interpreted in terms of crop response and fertilizer needs. Pine seedlings at densities of 800,000 to 1 million per acre have a more complex soil-plant relationship than do most farm crops.

ADJUSTMENTS OF SOIL FERTILITY

In practical terms, nursery managers are concerned with the following questions: (1) which fertilizer should be used, (2) how much fertilizer should be used, (3) when should fertilizer be applied, and (4) how should fertilizer be applied? The answers to these questions are based mainly on the degree to which managers can define the needs of their crop and relate these to their own nursery conditions.

Fertility Levels

No single set of fertilizer recommendations is likely to fit all circumstances. Nevertheless, a range of nutrient levels can be prescribed for broad soil types. See table 12-4.

A pH range from 5.3 to 5.8 is optimum for pine seedling production (chapter 1). Nitrification and nitrogen fixation take place vigorously in mineral soils at pH levels well above pH 5.5. The availability of Ca, Mg, K, P, and S is close to optimum at pH 6.0+. However, a lower pH is usually better insurance against pathogenic fungi.

Table 12-4. – Range of pH and nutrient levels recommend for pine nursery soils.

Soil texture	Organic matter	N	pH	P	K	Ca	Mg
	---percent---			---lbs/ac---			
Sands and light loamy sands	1.5	0.07	5.3-5.8	50-100	75-125	400-600	50-60
Loamy sands and sandy loams	2.0	0.10	5.3-5.8	75-100	125-175	600-900	60-90
Loams, silt loam and clay loam	>3.0	0.15	5.3-5.8	75-125	150-250	>900	>90

The Amount of Fertilizer to be Applied

Consideration must be given to (1) the nutrient requirements of the plants, (2) the available and nonavailable nutrients in the soil, (3) the fixation of nutrients by clay or organic fractions, or both, i.e., the cation exchange capacity of the soil, and (4) mineral losses that result from leaching, erosion, or both.

The amount of N and K which can be recovered by seedlings varies according to the type of soil, fertilizer material and method of application. The amount recovered averages about 50 to 70 percent of the amount applied. The recovery rate for phosphorus is much lower, ranging from 15 to 30 percent in many of the acid sandy soils.

The amount of nutrients removed by a crop of seedlings can for practical purposes be considered as 125, 25, 60, 40, and 15 pounds per acre for elemental N, P, K, Ca, and Mg respectively.

The adjustment of soil fertility to an optimum level depends basically on two conditions: (1) the system of rotation and (2) the soil type. Using a 1:1, 1:2, 2:2, or 2:3 rotation, it is possible to provide nearly all of the nutrients to the cover crop and then during the following year the nutrients become slowly available to the seedlings during that growing season. One or two light applications of N, at 25 pounds per acre, may be sufficient for the seedling crop. When seedlings follow seedlings, fertilization before seeding and during the growing season must provide the nutrient requirements for the seedling crop.

Sandy soils have a very low inherent fertility level whereas finer-textured soils usually have higher fertility levels. Both types of soil may contain small fractions of micas, feldspar and ferromagnesium minerals. These weathered minerals are insoluble in the weak extracting solutions used in laboratory determinations. However, their nutrients are extractable by roots of seedlings endowed with mycorrhizal fungi.

A sandy soil will require at least the equivalent of 1,000 pounds of 10-10-10 per acre plus 300 pounds of ammonium nitrate to produce a crop of seedlings. An alluvial loamy soil with a high K supplying power and unweathered ferromagnesium clay minerals may require only N. Ca and Mg are usually present in sufficient quantities when the pH is above 5.5. These levels can be maintained with applications of dolomitic limestone at the rate of 1 ton per acre at 3- to 5-year intervals. Minor nutrients, if deficient, can be supplied to the cover crop or seedling crop in such formulas as Frit 503G, which contains the following percentages of four minerals: B and C—2.4, Mo—6, and Zn—5.6. Excess use of mineral fertilizers may result in serious problems, many of which resemble diseases, herbicide injury or nutrient deficiencies.

Fertility Diagrams

The status of the fertility in a nursery can be diagrammed by a cluster of axes calibrated to delineate the critical deficiencies or undesirable excesses, or both, of various soil constituents (Wojahn and Iyer 1974). Each radius of the diagram represents an essential soil element, the pH, or organic matter. The outer circle marks the maximum desirable levels for this soil, while the inner circle marks the minimum (critical) levels. The polygon is formed by connecting points representing the current soil analysis values.

Fertility diagrams for three nurseries represented in figures 12-4, 12-5, 12-6 reflect the nutrient levels recommended in table 12-4. Figure 12-4 represents a mountain nursery located on an alluvial loam soil on an island in the forks of a river. The site was in row crops for many years and had been heavily limed. This history is reflected in the high Ca and Mg levels.

This nursery produced high-quality seedlings for many years, using a 1:1 rotation and a minimum of additional fertilization with N and P. The inner circle represents the minimum levels needed to raise loblolly pine seedlings on a loam soil in the South. The polygon indicates the current need for only P and K.

Figure 12-5 represents a loamy nursery soil in an alluvial bottom of the upper coastal plain. The area was in soybeans for many years. The high pH and high Ca levels reflect the past liming practices.

The inner circle indicates minimum nutrient levels needed to raise southern pines on a sand to loamy sand. Note the unbalanced fertility, with deficient N and organic matter, high pH, and unbalanced Ca:Mg ratio.

Figure 12-6 represents a loamy sand in a lower coastal plain nursery. The area was in seedlings for about two decades, but with intermittent cover crops. Organic matter, N and P were maintained at acceptable levels by heavy applications of sawdust and chemical fertilizers (N and P). Lime was not applied resulting in low levels of Ca (112 pounds per acre) and Mg (9 pounds per acre) and a low pH. Potassium was also below the minimum level.

Figures 12-4, 5, and 6 clearly indicate that the adjustment of soil fertility to an optimum level should not be accomplished by single applications of fertilizers, but by the systematic annual analysis of soil and a gradual adjustment of soil factors. Soil analysis must be supplemented by observations of nursery stock quality, including its size and color; height-diameter ratio; top-root ratio; development of root systems (especially the fibrous rootlets and mycorrhizal short roots), and in some instances by foliar analysis. Unusually low or high levels of any of these soil factors may result in seedlings which are undersized, over-developed or have a low potential for survival and growth.

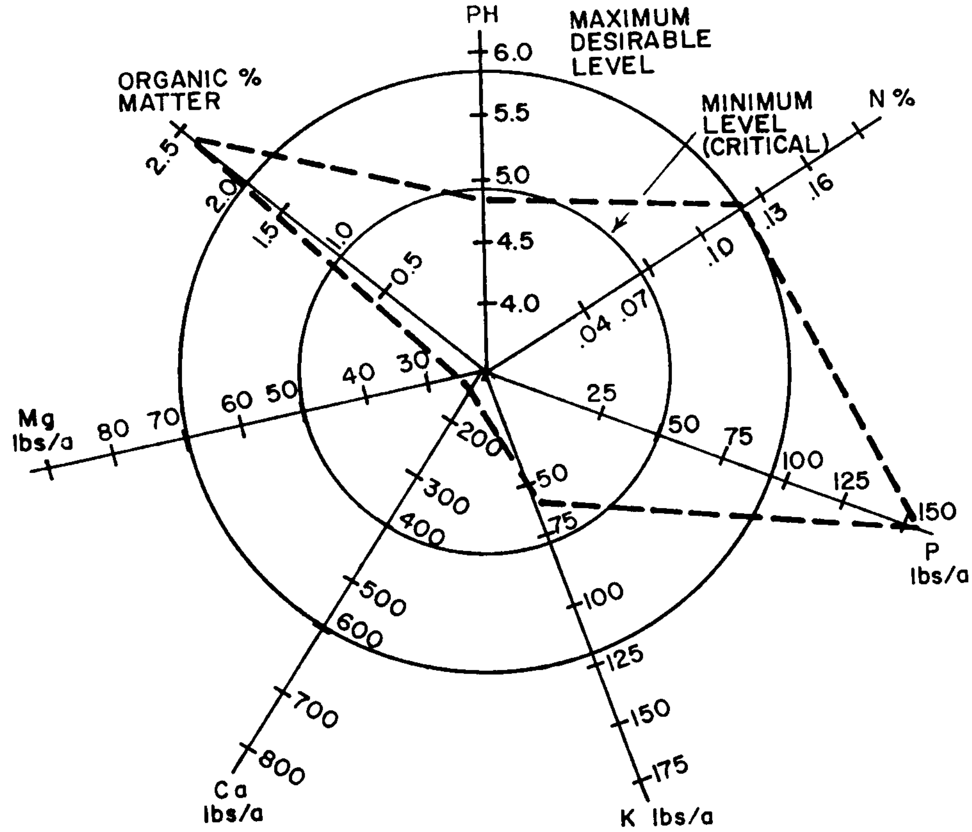


Figure 12-6.—Lower coastal plain nursery soil fertility diagram: loamy sand.

fertilizers contain up to 10 percent sulphur and minute quantities of micronutrients. Some States require that complete fertilizers be nonacid forming.

Table 12-5. — Soil characteristics of two southern pine nurseries.

Soil Attributes	Nursery A	Nursery B
Particle size		
Sand, %	93	43
Silt, %	5	41
Clay, %	2	16
Organic Matter, %	.3	4.0
Exchange capacity, me/10g	.4	13.1
pH	5.6	5.4
Total N ppm	trace	1,638
Exchangeable Ca, lbs/a	100	2,450
Available K, lbs/a	12	113
K supplying power, lbs/a	-	1,886
Available P lbs/a	80	43
Reserve P lbs/a	-	134

Table 12-6. — Conversion from ppm to lbs/ac or kg/ha.

	Conversion Of:		
ppm of:	To lbs/ac of:	Multiply ppm by	For kg/ha
P	P	P(2)	P(2.242)
P	P_2O_5	P(4.6)	P(5.157)
K	K_2O	K(2.4)	K(2.690)
Ca	CaO	Ca(2.8)	Ca(3.139)
Mg	MgO	Mg(3.3)	Mg(3.699)

Example: 50 ppm of P = 230lbs/ac (50 x 4.6) of P_2O_5
= 257.85kg/ha(50 x 5.157)

Fertilizer formulas tend to further complicate the process. The fertilizer formula expresses the concentration of essential elements in the material. Nitrogen is expressed as a percentage of N; thus a 100 pound bag of ammonium nitrate (NH_4NO_3) contains 33 pounds of N (33-0-0). The content of the other elements are stated in the oxide form, e.g., phosphorus as P_2O_5; potassium as K_2O; calcium as CaO; and magnesium as MgO. Values can be converted easily from ppm to pounds per acre (lbs/a) or kg/ha with the use of table 12-6. Also see table 12-7.

Table 12-7. — Conversion factors for elemental and fertilizer units.

To convert fertilizer amounts to element amounts multiply by	Element	Fertilizer	To convert elemental amounts to fertilizer amounts multiply by
0.200	N	Ammonium sulphate $(NH_4)_2SO_4$ (20-0-0)	5.00
0.242	S	" "	4.13
0.333	N	Amonium nitrate NH_4NO_3 (33-0-0)	3.00
0.461	N	Urea $CO(NH_2)_2$ (46-0-0)	2.17
0.130	N	Mono ammonium phosphate $NH_4H_2PO_4$ (13-52-0)	7.69
0.227	P	" "	4.41
0.160	N	Di ammonium phosphate $(NH_4)_2HPO_4$ (16-48-0)	6.25
0.210	P	" "	4.77
0.080	P	Ordinary superphosphate OSP $Ca(H_2PO_4)_2$ (0-18-0)	12.50
0.204	Ca	" "	4.90
0.201	P	Concentrated superphosphate CSP (0-46-0)	5.05
0.240	P	Phosphoric acid (0-55-0)	4.16
0.407	K	Potassium sulphate K_2SO_4 (0-0-49)	2.46
0.184	S	" "	5.43
0.498	K	Potassium chloride KCl (0-0-60)	2.00
0.710	Ca	Calcium oxide CaO	1.41
0.401	Ca	Calcium carbonate $CaCO_3$ (pure)	2.49
0.286	Mg	Magnesium carbonate $MgCO_3$ (pure)	3.50
0.097	Mg	Magnesium sulphate $MgSO_4 - 7H_2O$	10.31
0.130	S	" "	7.69

Source: Armson and Sadreika 1979.

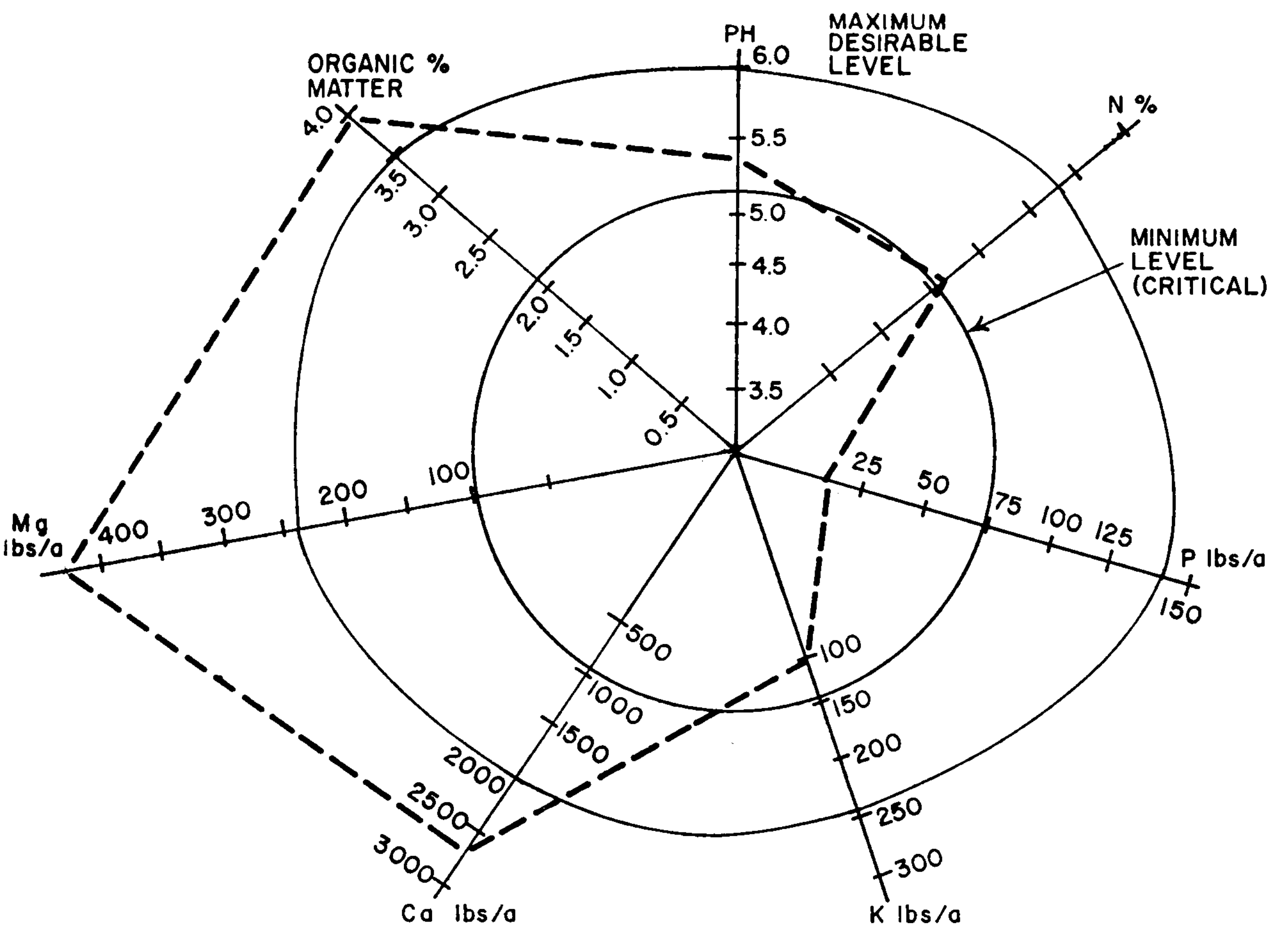


Figure 12-4.—Mountain nursery soil fertility diagram: alluvial loam.

TIMING OF FERTILIZERS

A comparison of two nursery soils will illustrate the range of fertility adjustments needed to produce comparable grades of loblolly pine seedlings. See table 12-5.

In nursery A, an initial application of fertilizer before seedbed preparation must be followed by frequent applications of N and K and possibly other elements. In nursery B, one light application of N and P before preparation of seedbeds is all that would be needed during the growing season. Nursery B soil is inherently fertile and needs little additional fertilizer. In contrast, nursery A soil is infertile and does not have the soil characteristics needed to retain nutrient elements.

When seedling crops are rotated with cover crops on a 1:1, 1:2, 2:2, or 2:1 rotation, additions of both macronutrients and micronutrients should be made before the soil is prepared for sowing the cover crop. Some supplemental fertilizer is often added when the cover crops are turned under or partly disked-in during the fall. Also, supplemental fertilizer may be applied in the spring either before or during the time of land preparation for the seedling crop.

Ca and Mg are usually applied only in relation to pH adjustments, and the rates are determined on this basis. Exceptions are when a high pH is caused by other base elements (e.g., Na) and the levels of Ca and Mg are low.

The amounts of P and K applied are usually many times beyond the amount taken up by the seedling crop.

Fall Fertilization

Occasionally seedlings do not attain plantable size by September, or the foliage color indicates a nutrient deficiency, especially after an early frost. Should seedlings be fertilized between September 15 and November 15? The few studies on later fertilization, i.e., before lifting, show that proper fertilization can increase height and diameter growth. Field survival also may be significantly increased (U.S. Department of Agriculture 1943, Gilmore et al. 1959, Anderson and Gessel 1966). However, there is a significant risk of delaying dormancy, resulting in poor storage and low survival.

Fall applications of muriate of potash (KCl) have resulted in poor survival of seedlings stored for 2 weeks as well as those planted within 1 day of lifting (Dierauf

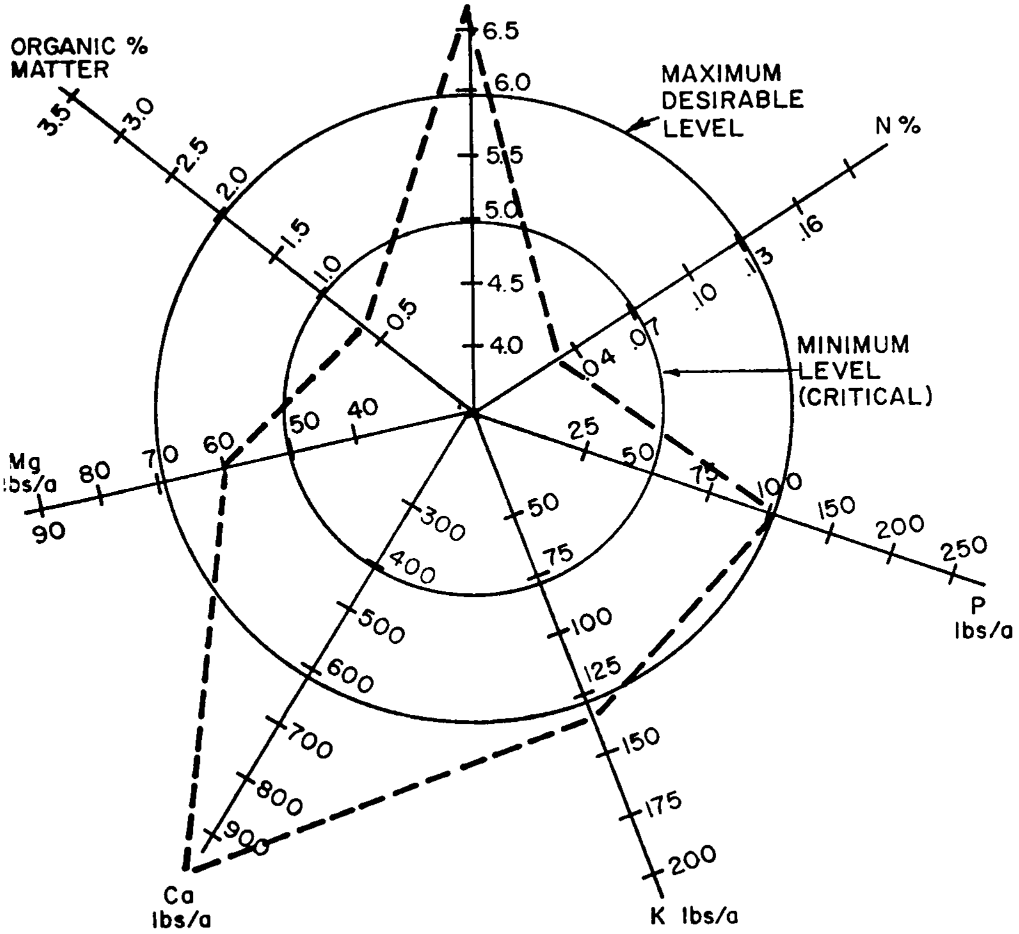


Figure 12-5.—Upper coastal plain nursery soil fertility diagram: loam.

1979). Fertilizers applied in January or later in the winter may reduce the survival of field planted seedlings (Ursic 1956). In general it is best to avoid fertilization within 3 months of lifting.

THE USE OF INORGANIC FERTILIZERS

A single fertilizer contains one essential element; a mixed fertilizer combines two or more essential elements. The fertilizer formula expresses the concentration of essential elements in the material. A complete fertilizer contains N, P, and K. N is expressed as a percentage and the other elements are expressed in the oxide form. Your State's department of agriculture or another designated agency in the State prepares specifications and recommendations for complete fertilizers to be manufactured within the State. These criteria are based on needs for agricultural crops.

Many nursery managers use complete fertilizers rather than special mixtures, or they prepare their own mixtures. Many complete fertilizers have a neutral reaction, i.e., no effect on soil acidity; others increase the acidity or may bring about an alkaline reaction. For general information on fertilizers, contact your State's department of agriculture, the extension service, or the department of agronomy at the land grant university.

Conversion factors for five major elements and common fertilizer units are given in table 12-6. The following descriptions of fertilizers cover the more popular materials in the South. A complete list of fertilizers appears in the Plant Food Section of the Farm Chemicals Handbook (Berg 1984).

Complete Fertilizers

Low-analysis fertilizers such as 8-8-8 were once widely used. Since the 1950's, there has been a trend toward the use of high-analysis fertilizers for reasons of economy. A very popular mixture in many southern states is 13-13-13, which contains 13 pounds of N, 5.6 pounds of P and 10.8 pounds of K in 100 pounds of fertilizer. A typical analysis shows 15 percent organic nitrogen from cyanamid and urea and 85 percent inorganic N from ammonium sulfate, ammonium nitrate and ammoniated superphosphate; 13 percent P_2O_5 from superphosphate and 13 percent K_2O from muriate of potash. Some complete

Calculation of Fertilizer Amounts

To calculate fertilizer quantities needed:

1. Desired level of P = 40 ppm.
   = 40 × 4.6 = 184 lbs. P_2O_5 per acre.
2. Lab report level of P = 15 ppm
   = 15 × 4.6 = 69 lbs. P_2O_5 per acre.
3. Needed: Desired level minus actual level = 184 − 69 = 115 lbs P_2O_5 per acre.
   (or 40 − 15 = 25; 25 × 4.6 = 115 lbs P_2O_5 per acre).
4. Using superphosphate (0-20-0) to supply P:
   Superphosphate
   Amount of P needed = 20% P
   Concentration of P $= \frac{115}{.20} = 575$ lbs

NITROGEN ADJUSTMENT

The nitrogen in a nursery soil is derived from cover crop residues (green manures), commercial fertilizers, ammonium and nitrate salts brought down by precipitation and free-living nitrogen fixers. The nitrogen in the soil is subject to continual loss:

1. Used by microogranisms.
2. Used by seedlings or other plants.
3. Lost in drainage by erosion or leaching.
4. Lost through volatilization.

A crop of 800,000 1-0 pine seedlings per acre will require 150 to 200 pounds of nitrogen per acre. The exact quantity depends on the texture, amount of organic matter, and climatic conditions during the growing season. The average nitrogen content of seedlings will vary by species and often differs within species. The nitrogen content depends on the age and growth rate of the seedling, the availability of nitrogen in the soil, climatic conditions and the season of the year. The usual forms of nitrogen absorbed by seedlings are ammonia (NH_4^+) and nitrate~~s~~ (NO_3^-) ions. The NH_4 ions are more readily used by seedlings during the early stages of the seedlings' growth and possibly through the entire season.

Soil nitrogen may be present in living or dead plants, insects, and microorganisms; fixed in the cation exchange position of some clay minerals; in the soil solution; or as free nitrogen in a gaseous state. Nitrogen transformations in the soil are continuous through the processes of aminization, ammonification and nitrification. The greater part of the NH_4^+ ion not fixed in organic form occurs in an exchangeable form on the clay colloids. The NO_3^- is negatively charged and not subject to cation exchange absorption. When the NO_3^- ion dissolves in the soil solution, it remains in a highly mobile state and moves readily to the root zone, or out of the soil in the leaching waters.

Organic Sources of Nitrogen

The productivity of a nursery soil depends on both the presence of large quantities of nutrients in organic matter and the rapidity with which these nutrients are liberated in an available form. Green plant tissue contains about 75 percent water and 25 percent dry matter. Over 90 percent of the dry matter is composed of carbon, hydrogen, and oxygen. The remaining 10 percent consists of nitrogen, sulfur, calcium, phosphorus, potassium and other minerals. The carbon-nitrogen (C/N) ratio of organic residues that are frequently added to the soil ranges from 12 for some legumes (chapter 1, table 1-11) to 400 for sawdust. When large quantities of carbonaceous residues are added to the soil, decay organisms place a heavy demand on the supply of soil nitrogen.

Organic residues with a narrow C/N ratio, (i.e. less than 15), have enough N in them to satisfy the requirements of the decomposing microorganisms. As the residue decomposes, there will likely be more N than needed by the microflora. This N will be released as ammonia, which can be used by seedlings as decomposition proceeds.

When the C/N ratio is large, (i.e., 60 to 400), and the supply of available nitrogen is low, competition between plants and microorganisms can be especially keen. Where high C/N residues such as sawdust are incorporated into the soil immediately before preparing land for a cover crop or a seedling crop, proper growth will be maintained only if fertilizer N is applied in an amount adequate to promote the rapid decay of the residue while providing sufficient available N to meet the needs of the plants.

The N factor expresses the extent to which a material is deficient in nitrogen for decomposition. The N factor is the number of units of inorganic N that must be supplied to prevent immobilization of most available soil N. For comparison, assume an N-factor of 1.0 for both straw and sawdust: 5 tons of dry straw will require 100 pounds of inorganic nitrogen. Twenty tons (1 inch per acre or 135 cubic yards per acre) of dry sawdust will require 400 pounds of inorganic nitrogen.

The decomposition of organic matter in the soil is a biochemical process and any factor that affects the activities of the soil organisms will nessarily affect the rate of organic matter decay. Among the factors affecting the rate of organic matter decomposition are:

1. The nature of the plant material, including the kind and age of the plants and its chemical composition.
2. Soil factors, including aeration, temperature, moisture, acidity and fertility level.
3. Climatic factors, especially moisture and temperature.
4. Use of biocides, especially sterilants, fumigants, fungicides, nematicides and insecticides.

The organic residues are not decomposed as a whole, i.e., the chemical constituents may be attacked independently of one another. Soil organisms differ greatly in their food requirements; what may be a source of readily available food for one group may not be available to other groups. Sooner or later, the original material loses its identity and is transformed to a variety of end products or soil humus. Laboratory analyses usually report organic matter content as the amount of humus or material which has undergone extensive decomposition.

In the absence of fertilizer nitrogen, plant or seedling growth depends on the quantity of available nitrogen stored in an inorganic form (NH_4^+ or NO_3^-) at the beginning of the season, and on the amount slowly released by mineralization during the growth period that follows. When cover crop residues or additions such as sawdust or bark are incorporated in the soil before seedbed preparation, there is seldom an excess of nitrogen; rather there is usually a nitrogen deficiency unless nitrogen fertilizer is applied during land preparation.

A rule of thumb to determine the approximate amount of nitrogen in the soil is to divide the organic matter content by 20. (Using the figure of 2 million pounds for the surface 6-7 inches of soil on 1 acre: each 1 percent of organic matter (by weight) = 20,000 pounds. Thus 20,000 lbs. ÷ 20 = 1,000 pounds N per acre: (1,000 lbs. = .0005 × 2,000,000). The annual release of nitrate and ammonia nitrogen in nursery soils is about 1 percent of the total nitrogen or about 10 pounds of nitrogen per acre per year for this nursery.

Where a 1-2 rotation is used (one seedling crop followed by a summer cover crop, a winter cover crop and a second summer cover crop) mineralization or decomposition of the first two crops provides nitrogen and other minerals for the third crop and the following crop of seedlings. If adequate nitrogen is supplied to the cover crops the C/N ratio may be narrow enough to provide released nitrogen to the seedlings during the entire growing season beyond that needed by the microflora.

Inorganic Sources of Nitrogen

The questions frequently asked about N fertilization are: How much N is recovered by the crop? How much is lost? How much is used in mineralization? What forms of N should be used? When and how should N be applied? And how much should be applied? Practically all studies on fertilization of southern pine seedlings show that ammonium nitrate is the most effective source of N unless there were confounding factors that favored other sources. The common salts of most nitrogen fertilizers, ammonia (NH_4^+) and nitrate (NO_3^-), dissolve and ionize readily in water. Principal sources of nitrogen are listed in table 12-8.

Table 12-8. – Sources of nitrogen for southern pine nurseries.

Compound	Formula	Nitrogen Content (percent)
Ammonium nitrate	NH4NO3	33.5%
Ammonium sulfate	(NH4)2SO4	21.
Diammonium phosphate	(NH4)2 HPO4	21
Anhydrous ammonium	Liquid NH3	82
Urea	CO(NH2)2	45
Calcium N	Ca(NO3)2	15
Mixed fertilizers - as	10-10-10	10

Nitrification results in the formation of free hydrogen ions and therefore has an acid-producing effect on soils. Where large quantities of NH_4 fertilizers are added to the soils of low buffering capacity, the formation of acids can have a drastic effect on soil pH. Also, in nitrification two reactions or steps are involved in the transformation of NH_4 to NO_3. The first step terminates with the formation of nitrite (NO_2) ions which in any concentration are toxic to seedlings and other plants. The second step results in the final conversion of NO_2 to NO_3. Under most conditions favoring the two reactions, the second transformation usually follows so closely after the first as to preclude any great accumulation of nitrites. However, nitrites have been responsible for some chlorosis and stunting of pine seedlings (Gilmore 1956, Landis 1976).

The problem of N control in a nursery soil is twofold:

1. The maintenance of an adequate supply of N in the soil.
2. The regulation of the turnover to assure a ready availability of N when needed to meet demands of seedlings or cover crops.

Where the humus content is low, apply inorganic N during the land preparation before preparing seedbeds. Rates are variable, but frequently 100 to 150 pounds of ammonium nitrate per acre is sufficient. Supplemental N should be supplied as needed to maintain the desired rate of growth. Usually a light or pale yellowing of the foliage is visible evidence of N deficiency.

Guidelines for N sources based on pH conditions are in table 12-9.

Table 12-9. – Recommended nitrogen sources based upon soil pH.

Best Nitrogen Source	pH value
Calcium Nitrate $Ca(NO_3)_2$	< 5.0
Ammonium Nitrate NH_4NO_3	5.0 - 6.0
Ammonium Sulfate $(NH_4)_2SO_4$	> 6.07

The frequency of N fertilization depends on the soil texture, soil mineral content, level of organic matter and weather conditions. N may be applied through the irrigation system to seedlings or cover crops. Conventional fertilizer distributors can supply N to large or small areas depending on the N needs. Wash the N off the seedlings immediately after application to prevent chemical burning of the foliage and new shoots.

Slowly-available urea has been effective on some soils and during some years (May and Posey 1956). This form of N is not recommended for sandy soils low in organic matter because of the possible build up of NO_2 and the possibility of causing chlorosis.

Diammonium phosphate is sometimes used when both N and P are low even though no specific symptoms for P deficiency appear other than slow growth and poor root development.

Ammonium nitrate

Ammonium nitrate, NH_4NO_3 is 33 percent N. This fertilizer is the most widely used source of N other than complete fertilizers. NH_4NO_3 is usually available in granular or prilled form, which makes it easy to distribute as a top dressing over the seedbeds.

NH_4NO_3 is readily soluble in water and can be distributed through the irrigation system. This form of N has been more effective in stimulating growth of southern pine seedlings than any other source of N. One-half of the N is in an ammonium form and the other is nitrate which can easily be lost by leaching. Ammonium nitrate must be stored with care as it will absorb moisture, and also will form an explosive when in contact with oils.

Ammonium sulphate

Ammonium sulphate, $(NH_4)_2SO_4$, is 20 percent N. This fertilizer is a crystalline substance readily soluble in water. The NH_4 ion is readily absorbed by the cation exchange complex of the soil. Use of ammonium sulphate has a residual acid effect and will reduce the pH. This fertilizer has not been used extensively in southern nurseries because most nursery soils in the South are acid. Ammonium sulphate is a good source of N where the pH is high or where the irrigation water is alkaline. If ammonium nitrate or ammonium sulphate are broadcast directly on growing seedlings, brush the plants to dislodge any crystals or granules which may lodge in the foliage. The seedlings should then be irrigated lightly to ensure that the N is dissolved and carried into the soil.

Urea

Urea, $CO(NH_2)_2$, is 45 percent N. This fertilizer is a white crystalline solid that is very soluble in water. Urea is used as a foliage spray to correct chlorosis caused by a N deficiency. When urea is applied to the soil, it is hydrolyzed by an enzyme in the soil. This process converts urea N to the (NH_4) ion.

Urea-formaldehyde

Urea-formaldehyde, or Uramite is 38 percent N. The N in this urea-formaldehyde fertilizer becomes slowly available over a controlled period of time. The N will not leach out of the soil until it has been nitrified. This fertilizer is used occasionally, but the time and rate of release may not coincide with the plant's need for N.

Ammonium Phosphate

Ammonium phosphate is available in two forms: mono $NH_4H_2PO_2$ (13-52-0) and di- $(NH_4)_2HPO_4$ (16-48-0). These products are usually sold in granular or crystalline form and are ostensibly water-soluble. They can be applied in granular form or through irrigation or spray systems. Nozzles may plug if all the solids do not dissolve. This fertilizer is most frequently used during the growing season when top dressing of both N and P are required.

Liquid Fertilizers

These products are usually available as an ammonium or ammonium phosphate solution with analyses of 32-0-0, 8-20-0, 10-34-0, or 11-37-0. They are sometimes used between seedling crops or before a cover crop is planted. An ester form of 2,4-D can be mixed with the liquid fertilizer for control of weeds at the same time. Anhydrous nitrogen, NH_3 is 82 percent N. This fertilizer is injected in the soil before cover crops and seedlings are grown.

PHOSPHORUS ADJUSTMENTS

Much of the P fertilizer applied is fixed in the soil in slowly available or relatively insoluble compounds of Fe, Al, Mn, Ca and Mg. P is generally considered more available when fixed as Ca and Mg compounds than as compounds of Fe or Al. The capacity of the soil to fix P is affected by the soil pH, organic matter content, soluble Ca and Mg content, the quantity of Fe and Al in a reactive form, and the amount and chemical nature of the soil colloids. Fixed P does not leach from the soil but also is not available to seedlings. Fixation prevents the penetration of P into the soil. Phosphates applied as top-dressings frequently become fixed in the soil surface and the downward movement into the root zones is very slow.

Plants absorb P from the soil mostly in the form of $H_2PO_4^-$ or HPO_4^- ions. A large part of the soluble P in the soil may be concentrated near grains of phosphate minerals or decaying organic fractions. As much as 30 to 60 percent of the total P in the soil may be in organic combinations, depending on the source of the organic matter (chapter 1, table 1-10). Decomposing organic materials either supply a large percent of available P or provide numerous acids which favor the availability of P. However, a rapid decomposition of organic matter and a consequent high microbial population temporarily ties up inorganic P in microbial tissue. Some of the organic forms of P behave in the soil much as the inorganic phosphates, combining with Fe, Al and Ca. Even in the presence of considerable quantities of organic forms of P, seedlings may suffer from a P deficiency. Consequently, growth of roots into previously untapped zones of high P concentration may be essential to maintaining a continuous and adequate supply of P to the seedling.

Two of the more effective forms of P fertilizers to use as a top dressing on seedlings during the growing season are the water soluble diammonium and monoammonium phosphates. These compounds can be applied through the irrigation system or with conventional fertilizer spreaders. They provide P in a form that will be carried down through the soil to the root zone by rain or irrigation waters.

Phosphorus Fertilizers

Ordinary superphosphate (0-20-0) is a calcium orthophosphate that contains some calcium sulphate. This fertilizer is available in a granular form, and has a low solubility in water. Superphosphate is usually worked into the soil before planting seedlings or a cover crop. Much of the P in this and other phosphate fertilizers becomes bound in the soil as insoluble Fe, Al or Ca phosphates, especially in acid soils.

Triple superphosphate (0-46-0) is a concentrated fertilizer made by treating superphosphate with phosphoric acid. This product contains less Ca and S than ordinary superphosphate and tends to increase the acidity of the soil.

Ammonium phosphate is discussed in the section on nitrogen fertilizers.

POTASSIUM ADJUSTMENTS

Most mineral soils except sandy soils are comparatively high in total K. The total quantity of this element is generally greater than any other major nutrient. Yet the quantity of K held in an easily exchangeable condition at any one time is often very small. The amount of K rendered unavailable to plants because of fixation varies considerably depending on soil texture, type of clay, amount of organic and inorganic colloidal material, level of exchangeable Ca, presence of excess lime, amount of freezing and thawing, and the amount of wetting and drying.

Upon drying, all soils fix K in forms unavailable to plants. By and large, the K fixation contains appreciable quantities of illite or vermiculite. Kaolinite and soils in which this clay mineral is dominant fix very little K. This is the case for most sandy soils in nurseries of the South.

The various forms of K in soils are classified on the basis of the availability of this element in three general groups. Each group is in an equilibrium with another group as represented by the equation.

$$\begin{array}{c}\text{Nonexchangeable}\\ \text{or slowly}\\ \text{available K}\end{array} \rightleftarrows \begin{array}{c}\text{Exchangeable or}\\ \text{readily available K}\end{array} \rightleftarrows \text{Soluble K}$$

The process of fixation is very rapid: In 10 minutes, 80 to 90 percent of the K is fixed that will eventually be fixed. Competition by microorganisms for K contributes, at least temporarily, to its unavailability to plants.

Because most fixed K can eventually be used by plants, the relationship between soil test values and the availability of K differs greatly for a soil with a low K fixation and a soil with a high K fixation. Where other factors of growth are the same, the soil of a higher fixing capacity needs to have a soil test value of only about one-fourth that of the other soil to provide the same amount of K to seedlings. Much of the K is only temporarily fixed and will become available to plants in time. These differences would be even greater if the soil of a high fixing capacity were compared to one incapable of fixing K. Compare nurseries A and B in table 12-5.

Much of the K absorbed by seedlings is in either exchangeable or nonexchangeable form, neither of which are very mobile in the soil. Most K appears to reach roots by diffusion. Exchangeable K has greater access to the soil solution and therefore its rate of release and diffusion to the roots exceeds that of the nonexchangeable K. These differences in the two forms of K explain why some researchers report that K fertilization is not needed in forest tree nurseries.

Unlike the P, much K is lost by leaching in the soil solution. The magnitude of this loss from sandy soils may approach or exceed that of K removal by seedlings. Under most field conditions and with an adequate nutrient supply, K removal by pine seedlings is high, often three to four times that of P and Ca (May et al 1962). A 30-to-40 ton silage corn or silage sorghum cover crop can remove 150 to 200 pounds of K per acre, compared to roughly 60 pounds per acre removed by pine seedlings.

Potassium Fertilizers

Potassium fertilization of seedlings grown on sandy soils is critical, especially when the organic matter is low. A single application of K before the land is prepared for sowing of a cover crop or a seedling crop is insufficient because of losses by K-fixation, leaching and crop use. Frequent, light applications of K are usually superior to heavier and less frequent ones.

On medium- to fine-textured soil with more than 2 percent organic matter, one light application of K before seedbed preparation and once again in September is usually all that is needed.

All K fertilizer salts are soluble in water and considered readily available. None appear to be a superior source of K. See table 12-10.

Table 12-10. – Common potassium fertilizer salts.

Compound	Formula	K Content(%)
Potassium chloride (Muriate of potash)	KCl	39-51
Potassium sulfate	K_2SO_4	39-42
Potassium sulfate - (magnesium sulfate)	K_2SO_4 $MgSO_4$	21-25
Potassium nitrate	KNO_3	36

Potassium Chloride

Potassium chloride is also called muriate of potash: KCl (0-0-60). This fertilizer is widely used in southern nurseries as a top dressing. The use of KCl is discouraged when large applications of K must be made because of danger from the toxicity of the chlorine (Cl^-) ion. Where pH values are high, potassium sulfate or Sul-Po-Mag may be more suitable than potassium chloride.

Potassium Sulphate

This fertilizer, K_2SO_4 (0-0-50), is a whitish, readily water-soluble salt which contains 18 percent sulphur. K_2SO_4 can be applied as a solid or as a liquid fertilizer. When any K is applied as a solid during the growing season, the plants should be brushed to remove lodged particles and then watered lightly.

Sulfate of Potash Magnesia

This fertilizer, K_2SO_4 $2MgSO_4$ (Sul-Po-Mag), is a brownish-white salt that dissolves very slowly. This compound contains more than 25 percent K_2O and more than 25 percent $MgSO_4$ and less than 2.5 percent Cl. Top dressing of this fertilizer burns succulent growing tissue.

CALCIUM AND MAGNESIUM ADJUSTMENTS

Calcium and magnesium adjustments are discussed in this section, under Adjustment of Soil Reaction, and in Chapter 1.

Magnesium Sulphate

This fertilizer, $MgSO_4$ 7 H_2O, contains 16 percent MgO. This compound is crystalline and readily soluble in water. Magnesium sulphate is used to correct deficiencies in soil Mg. It can be broadcast and worked into the soil or applied through the irrigation system.

TREATMENT OF CHLOROSIS

Summer Chlorosis

Summer chlorosis describes the pale foliage resulting from chlorophyll breakdown during hot weather. This condition is a frequent malady in southern pine nurseries. The causes may be: N, S, Mg, or Fe deficiency; high levels of P, Ca, Mn, NO_3, or NO_2; water-logging and poor aeration. Diagnostic procedures include a careful review of past fertilizer treatments, analysis of soil samples, nutritional analysis of foliage samples, and foliar fertilization. The proper foliar treatment may correct the chlorotic conditions within 5 to 10 days.

Incorporation of high rates of sawdust in the soil before seedbed preparation and uneven distribution of sawdust or wood fiber mulch frequently result in low N availability—resulting in chlorosis (Carter 1964, Shoulders and Czabator 1965, Steinbeck et al 1966; Lyle and Pearce 1968, Lyle 1972, and Landis 1976). In these cases it is necessary to add sufficient nitrogen to overcome the deficiency. See the earlier section, Nitrogen Adjustment.

Iron Chlorosis

Chlorosis due to Fe deficiency is sometimes called lime-induced chlorosis. This condition is common in many southern pine nurseries. The symptoms are easily recognized by the white or yellow color of new needles. Fe deficiency can usually be corrected by foliar treatments using chelated Fe at rates as high as 6 to 10 pounds of Fe per acre. Two commonly used forms are Sequestrene 330 iron-chelate containing 10 percent Fe as metallic Fe or iron of ferrous sulfate containing 21 percent Fe.

Sulfur Deficiency

Chlorosis due to S deficiency may appear as the usual common chlorosis with seedlings yellow or almost white toward the top, but not stunted. This condition may develop on soils where concentrated fertilizers low in S are used for several years. Most regular fertilizer mixtures containing superphosphate supply enough sulfur for plant needs. Treatments with either ammonium sulfate or sodium sulfate at rates of 50 to 75 pounds per acre will correct sulfur deficiencies (Lyle and Pearce 1968).

MICRONUTRIENTS

Several standard micronutrient combinations provide elemental Fe, Zn, Cu, B, and Mo. Frit 503, 503G, and 504 are used in many of the coastal nurseries.

ADJUSTMENT OF SOIL REACTION

The basic concepts of soil reaction (pH) are discussed in chapter 1.

Decreasing Soil Acidity

To change an acid soil to one having a less acid reaction, it is possible to add a basic material, such as calcium carbonate (limestone). This treatment will reduce the concentration of H ions, convert them to neutral water, and hence increase the number of Ca ions relative to the Hydrogen ions on the colloid. This change increases the pH (decreases the acidity). The amount of lime to be added varies with the colloidal content (clay and organic matter) of the soil and the amount the pH is to be raised.

Rates will vary from 1 to 2 tons per acre for sands, to 2 to 4 tons per acre for fine-textured soils. Such additions usually will cause a .5 to 1 unit change in pH. The exact amounts to be added in any given situation should be decided after a soil test has been made. Amounts higher than 2 tons per acre are seldom applied at one time, although there are no basic reasons why considerably larger amounts could not be used. Where there is evidence that the magnesium content of the soil is sufficiently low to affect plant growth, and evidence that the soil is also acid, dolomitic limestone (calcium-magnesium carbonate) should be prescribed.

Soil Amendments

Materials most commonly used to reduce the acidity of the soil are the oxides, hydroxides, and carbonates of Ca and Mg. In most lime rocks, a mixture of Ca and Mg will be present because deposits of pure Ca or Mg alone are not common. Use of burned lime, quicklime or slaked lime should be avoided if it is to be placed in contact with young plants, because these materals can injure the seedlings. Ground limestone or dolomite are preferred.

The relative neutralizing value of the amendment is expressed in terms of the calcium-oxide equivalent. Pure calcium carbonate, $CaCO_3$, has a calcium oxide equivalent of 56. In other words, calcium carbonate contains 56 percent calcium oxide. A calcium-oxide equivalent of greater than 100 is possible with certain mixtures of calcium and magnesium oxides. At least 70 to 80 percent of the liming material should be ground to pass a 100-mesh sieve. Four factors should be considered when purchasing these soil amendments:

1. The calcium-oxide equivalent of the material.
2. The kind of material offered for sale, such as calcium and magnesium carbonates, calcium oxide, and ground marl (shell limestone);
3. The relative fineness of the material, i.e., what percentage of the material will pass through a 100-mesh sieve;
4. What is the relative cost of the material compared to equivalent materials for sale in the same area?

The following factors may be used for making conversions to a calcium-oxide equivalent:

Percent $MgO \times 1.389 =$ percent CaO
Percent $CaCO_3 \times .560 =$ percent CaO
Percent $MgCO_3 \times .664 =$ percent CaO
Percent $MgCO_3 \times 1.186 =$ percent $CaCO_3$

INCREASING SOIL ACIDITY

Some nursery soils may be improved by raising the acidity (lower pH). This may be accomplished by adding Fe or Al sulfates, sulfuric acid, or S. Iron and Al sulfates are acidic compounds; S is oxidized by soil microorganisms to form sulfuric acid. In this type of treatment, the H ion content of the soil system is increased relative to the basic ions, with a resulting decrease in pH. Iron and aluminum sulfates and sulfuric acid will react rapidly in the soil and the desired effect will be achieved in a short time. The addition of sulfur will not bring about a rapid change, because a biological oxidation of the material is required, and the resulting acidification occurs slowly over a considerable period of time. Maximum effects should not be expected for at least a year. None of these materials will be very effective in soils that have a high lime content.

In high lime soils, the lime must first be neutralized and then removed by drainage before any great change in soil acidity may be expected. All of the acidifying materials are expensive and the amounts needed to accomplish a desired change may be large. In nurseries where it is practical, the amounts of material to be used should be decided only after soil tests have been made and soils experts consulted. Aluminum sulfate can be toxic to seedlings.

Sources of Sulfur

See the sections discussed earlier on ammonium sulfate and potassium sulphate under N and K fertilizers. The addition of 400 to 500 pounds of sulphur per acre will reduce the pH by about .5 unit, depending on the soil texture and other factors.

OTHER ADJUSTMENT OF SOIL FERTILITY

Adjustments of soil fertility or productivity during the growing season for problems not associated with N, P, K, Ca, Mg, Fe, and S deficiencies are rare. Abnormalities caused by excesses of N tend to disappear if additional N is not supplied. However, seedlings may not completely recover and develop into planting stock of good quality.

Problems associated with excesses of other nutrients are often perennial. For example, old house sites, outhouses, feedlots, fertilizer dumps, residues from well drilling, etc., lose their identity after disappearance of physical features, but may contain excesses of toxic salts. Plants tolerant of high concentrations of some elements may thrive on these sites—however, pine seedlings may not. With soils that have a pH value above 7.00 and calcium levels of 3,000 to 4,000 pounds per acre the options are to withhold fertilizers containing Ca and to treat the sites with S or acid-forming fertilizers, and then wait for time to correct the problem.

Frequent subsoiling, plowing, disking and leveling may ameliorate some problems. Occasional attempts have been made to replace soils that contain excessive concentrations of toxic elements.

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APPENDIX 12-1.—VISUAL SYMPTOMS OF SEEDLING ABNORMALITIES

Observed symptoms	Possible causes
1. Yellow-green, green-yellow, yellow, purple or bronze discoloration. Foliage remains fresh.	Nutrient deficiency: N, S, Mg, P, K. Lime-induced chlorosis, herbicide injury, root damage by pathogens, nutrient excess.
2. Pale green-yellow or white needles.	Iron deficiency, lime-induced chlorosis.
3. Straw-colored or light brown foliage.	Fertilizer excess, deficiency of minor nutrients such as Cu, herbicide damage, heat injury, fungal attack.
4. Withering, drying or dying of green foliage.	Fungal attack, damping-off, herbicides, sun scorch or heat damage, water deficiency, insect damage to roots or stems.
5. Necrosis of stem tips, yellow discoloration of needles.	Fertilizer excess, especially Ca, P, or N.
6. Resin exudes from terminal buds and sometimes the needles; needle color is abnormal.	Ca and B deficiency.
7. Dead root collar or dead stem at surface, roots still healthy.	Fungal attack, sun scorch, herbicides, insects.
8. Dead roots, black surface, loss of laterals.	Fungal attack, water logging, insect damage.
9. Visible loss of bark on roots or stems, loss of foliage.	Insect attack, mechanical damage, hail, wind and sand.
10. Stubby roots, stunted growth.	Herbicide damage, nutrient excess, insect or pathogen damage.

APPENDIX 12-2.—VISUAL DEFICIENCY SYMPTOMS IN CONIFERS[1]

N deficiency.—General chlorosis and stunting of needles increasing with severity of deficiency; in most severe cases needles are short, stiff, yellow-green to yellow; in some cases purple tipping is followed by necrosis of needles at the end of the growing season.

P deficiency.—Youngest needles are green or yellow-green; older needles are distinctly purple-tinged; purple deepens with severity of deficiency; in very severe cases in seedlings, all needles are purple.

K deficiency.—Symptoms vary: usually needles are short, chlorotic, with some green near the base and, in some severe cases, purpling and necrosis with top dieback or little or no chlorosis, but purpling, browning or necrosis of needles evident whenever they are found.

Ca deficiency.—General chlorosis is followed by necrosis of needles especially at branch tips; in severe cases death of terminal bud and top dieback; resin exudation.

Mg deficiency.—Yellow tipping of current needles is followed in severe cases by tip necrosis.

S deficiency.—General chlorosis of foliage is followed in severe cases by necrosis.

Fe deficiency.—More or less diffuse chlorosis is confined in milder cases to new needles; in more severe cases bright yellow discoloration with no bud development.

Mn deficiency.—Needles are slightly chlorotic; severe cases show some necrosis of needles.

B deficiency.—Tip dieback late in growing season with associated chlorotic-to-necrotic foliage, intergrading to dieback of leading shoot with characteristic crooking.

Zn deficiency.—Extreme stunting of trees with shortening of branches; needles are yellow, short, crowded together on twig, sometimes bronze tipped; older needles shed early, with resultant tufting of foliage; in severe cases trees rosetted with top dieback.

Cu deficiency.—Needles are twisted spirally, yellowed or bronzed; ''tipburn'' or nercrosis of needle tips is evident; in severe cases young shoots are twisted or bent.

Mo deficiency.—Chlorosis of leaves is followed by necrosis of tissue, beginning at the tip and eventually covering the whole leaf.

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[1] Summarized from the literature by Morrison 1974.

APPENDIX 12-3.

Mineral Deficiency Symptoms in Loblolly Pine Seedlings[1]

E. S. Lyle, Jr.[2]

ABSTRACT

Loblolly pine (*Pinus taeda* L.) seedlings were grown in nutrient solutions each deficient in one of the essential elements. A description of observed deficiency symptoms is given for each essential element. Coloration symptoms are described by means of Munsell color charts and were tested for significance. Munsell color charts proved to be practical and consistent for color descriptions. Symptoms that proved to be unique were used in the development of a dichotomous key for the identification of essential element deficiencies.

Additional Key Words: **Dichotomous key, Munsell color charts.**

DEFICIENCY symptoms in plants are exhibited in many different ways, such as reduced vegetative growth, unusual morphology of plant parts, reduced fruit production, and unusual coloration of plant parts. The most obvious and spectacular of these symptoms is unusual coloration. This usually occurs because leaf cells fail to synthesize necessary amounts of chlorophyll. Disruption of normal metabolic processes resulting in synthesis of anthocyanins and related pigments is also often associated with mineral element deficiencies. In the case of extreme deficiencies, part or all of the foliage dies. However, this necrotic foliage may also have a color or other feature that is characteristic of the deficiency.

These visual symptoms have a tendency to be similar in the varying species for any single deficiency, but this tendency is not strong enough to utilize any one set of symptoms for detecting a particular deficiency in all higher plants. In broad-leaved plants, the coloration of veins and inter-veinal areas is of significance, but this tendency in coniferous plants has no meaning. In general, the overall color exhibited by deficient foliage and age of the foliage first affected remains the same for all plants. For example, nitrogen and iron deficiencies are exhibited practically always in foliage as a uniform yellowing of the leaves. However, chlorosis from nitrogen deficiency usually appears first in the upper or newest leaves (Wallace 1953).

Any single deficient element is likely to produce one or more symptoms in a plant that can be confused with another deficiency, environmental disturbance, or even a disease. However, the complete set of symptoms caused by a deficiency is usually distinctive for that plant. Because of this it is necessary to note all of the symptoms exhibited by the plant and not rely on one symptom for the deficiency diagnosis (Wallace 1951). Some of the symptoms that can be used are: *1.* foliage color, *2.* leaf size, *3.* leaf shape, *4.* location of affected foliage, *5.* bud abnormalities, *6.* resin exudation from leaves, *7.* unusual branch growth, and *8.* patterns of discoloration.

The universal symptom for nitrogen deficiency in loblolly pine as well as other plants appears to be yellow or yellowish-green foliage (Addoms, 1937; Fowells and Krauss, 1959). Addoms (1937) described the symptom for loblolly pine as a yellowing of needles, whereas, Fowells and Krauss (1959) described it as short, stiff yellowish-green needles. Foliage discoloration produced by phosphorus deficiency has been variously described as purple, violet, reddish, or reddish-purple for some pines. However, Fowells and Krauss (1959) report no foliage discoloration but did report early needle abscission in loblolly. For severe potassium deficiency in loblolly, Sucoff (1961) describes the symptom as purple or brown coloration of older primaries with the rest of the needles grayish-green. As the deficiency progressed the uppermost needles became purple and tufted, spiralling around the terminal. For less severe deficiencies the needles looked as though they had been painted with water colors in shades of purples, brown, yellows, and greens.

A consistent symptom of calcium deficiency in plants is necrosis or lack of development of the terminal bud. Davis (1949) and Sucoff (1961) found discolorations of loblolly pine foliage, such as pale green or yellow-green, as well as bud abnormalities. For magnesium deficiency in loblolly, Sucoff (1961) lists the symptoms for severe deficiency in secondary needles as brown tip, yellow middle, and dark green base. After a period of time all of the needle turns brown except for the basal 1 or 2 cm, which remains dark green.

There has not been much work on symptoms in loblolly caused by micronutrient deficiencies. However, Ludbrook (1940) does describe symptoms for boron deficiency as a breakdown of meristematic tissues and foliage color of bluish-green. Zinc deficiency symptoms are described by Wilson (1953) as short needles and some chlorosis.

Usually, a mineral element-deficient soil or other growth medium will be relatively lower in one mineral than in others, and the deficiency of this one element will result in characteristic symptoms. However, it must be kept in mind that once this deficiency is corrected another element may become limiting and other characteristic symptoms may appear. In most cases only one element will be deficient and the correction of the first set of symptoms will restore the plant to its usual growth and appearance. Therefore, it seems logical to approach the problem of mineral deficiency diagnosis from the standpoint of individual mineral deficiency symptoms. Again, it must be kept in mind that an unusual appearance of some plant part may be because of disease, insect injury, or extreme climatic conditions rather than mineral deficiency. This circumstance usually can be detected by examination of the plant or comparison of recent with past weather conditions. Another possibility is the antagonistic effect of one element on another, causing the ordinarily sufficient second element to be actually deficient. Finally, it is possible that an excess of an element or elements may cause a plant condition that can be mistaken for a deficiency symptom.

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[1] Received for publication, Sept. 21, 1968.

[2] Department of Forestry, Auburn University Agricultural Experiment Station, Auburn, Ala. 36830.

The purpose of this research was to identify and record mineral deficiency symptoms for loblolly pine seedlings in such a way that other workers would have standard descriptions of each set of mineral element deficiency symptoms. These symptoms are intended for use in preliminary identification of deficiencies. To verify a particular deficiency, it would be necessary to use foliar fertilization, foliar analysis, soil fertilization, soil analysis, or some combination of these methods. The advantages of the technique described in this paper are its speed and the fact that no special training or complicated equipment are required for its application.

MATERIALS AND METHODS

It seemed possible that loblolly pine seedlings from different parts of their geographical range would react differently to a single mineral deficiency. Therefore, two different lots of seed were used in the first experiment, which was designed to reveal symptoms of potassium deficiency. One lot of seed was collected in central Georgia and the other in east-central Alabama.

Seeds from each lot were germinated in acid-washed sand and transplanted to 2-liter containers. Each container held three seedlings with their roots submerged in an aerated nutrient solution. There were four replications of each of four levels of potassium for each seed source, totaling 32 containers and 96 seedlings. No differences were found between Alabama and Georgia seedlings. Therefore, the rest of the element deficiencies were determined with a mixture of the two seed lots. It was assumed that the other elements would also show no differences because of differences in seed lot.

Salts and nutrient concentrations used at the varying treatment levels, are presented in Table 1. The calculated osmotic pressures of the solutions used were within the range 0.70 ± 0.05 atm and their initial pH values were within the range 4.5 ± 0.3. Both of these values changed as the seedlings absorbed ions and water.

No changes in coloration were noted because of decreases in volume of nutrient solution and subsequent changes in salt concentrations. Therefore, no attempt was made to change nutrient solutions according to any schedule except that volumes were not allowed to fall below 1 liter. When solutions reached this level, they were replaced with 2 liters of the appropriate nutrient solution.

Plants were examined periodically until differences because of treatments appeared. At this point foliage color and other distinctive differences were recorded. Foliage color was determined by comparing the needle colors with Munsell color charts (Munsell Color Co. Inc., 1952). These color charts provided a standard system for identifying and recording colors. Three aspects of color are used in the system; namely, hue, value, and chroma. Hue is a color's relation to red, yellow, green, blue, and purple. Value is its location between white and black insofar as lightness is concerned, and chroma is the strength of the color in relation to a neutral gray of the value under consideration.

Munsell color notations are written with a symbol for hue followed by a fraction. The numerator of the fraction denotes value and the denominator denotes chroma. A color recorded as 7.5 GY 5/6 would be greenish green-yellow with a value of 5 and chroma of 6. The merit of this system lies in the fact that a color can be precisely identified and recorded in a way that future workers can confidently utilize written color information. Hamilton (1960) suggested the use of Munsell color charts for foliage color standardization in 1960.

Color comparisons were tested by having both men and women make some of the same determinations to minimize the chances of inaccuracies because of an individual's partial color blindness. It was found within a group of two women and three men that color disagreements occurred about once in 21 determinations. Unusual seedling colorations and other characteristics were observed and recorded periodically until they become relatively stable. The final recordings were considered the true deficiency symptoms for the particular nutrient and were analyzed for statistical significance.

The experimental design was a randomized block. Variations in color and/or other characteristics appearing in a treatment were tested against the control or treatment receiving sufficient quantities of all nutrients (Spiegel, 1961).

Table 1. Nutrient concentrations and salts used in varying treatment levels.

		Treatment level, meq/liter			
Nutrient	Salt	0	1	2	3
N	NH_4NO_3	0	8.0×10^{-2}	8.0×10^{-1}	8.0×10^{0}
H_2PO_4*	KH_2PO_4	0	2.0×10^{-2}	2.0×10^{-1}	2.0×10^{0}
K*	$KH_2PO_4 + KCl$	0	4.0×10^{-2}	4.0×10^{-1}	4.0×10^{0}
Ca	$CaCl_2$	0	6.0×10^{-2}	6.0×10^{-1}	6.0×10^{0}
Mg†‡	$MgSO_4$	0	4.0×10^{-2}	4.0×10^{-1}	4.0×10^{0}
SO_4†‡§	$MgSO_4$	0	4.0×10^{-2}	4.0×10^{-1}	$4.0 + 10^{0}$
Fe	Fe EDTA	0	2.1×10^{-6}	2.1×10^{-5}	2.1×10^{-4}
BO_3	H_3BO_3	0	1.2×10^{-5}	1.2×10^{-4}	
Mn	$MnCl_2 \cdot 4H_2O$	0	1.8×10^{-7}	1.8×10^{-6}	1.8×10^{-5}
Zn¶	$ZnCl_2$	0	1.5×10^{-8}	1.5×10^{-6}	
Cu¶	$CuCl_2 \cdot 2H_2O$	0	5.9×10^{-9}	5.9×10^{-7}	
MoO_3¶	Molybdic acid	0	2.8×10^{-8}	$2.8 + 10^{-6}$	

* NaH_2PO_4 was used as a phosphorous source for potassium deficiencies. † Na_2SO_4 was used as a sulfate source for magnesium and sulfur deficiencies. ‡ $MgCl_2 \cdot 6H_2O$ was used as a magnesium source for magnesium and sulfur deficiencies. § Iron tartrate was used as an iron source for sulfur deficiencies. ¶ Solutions were made from glass-distilled H_2O stored in a polyethylene bottle.

Table 2. Deficiency response differences between treatments.

			Proportion giving response		
Element	Treatment	Deficiency response	Treatment	Control	Calculated Z*
N	0	Needles 2.5 GY 7/6	7/10	0/12	3.50
	1		9/12	0/12	3.79
	2		0/10	0/12	
P	0	Needle tips 7.5 YR 7/4	6/10	0/11	3.04
	1	Dead needles 5.0 RP 3/4	1/10	0/11	1.075
	2		0/11	0/11	
K	0	Dead needles 10.0 R 4/2	17/20	0/18	6.99
	1		0/17	0/18	
	2		0/23	0/18	
Ca	0	Resin exudation & needles	7/9	0/10	3.50
	1	10.0 Y 5/4	1/11	0/10	1.075
	2		0/12	0/10	
Mg	0	Needles 2.5 GY 8/6	5/7	0/11	3.29
	1		1/9	0/11	1.128
	2		0/11	0/11	1.128
S	0	Needles 2.5 GY 6/6, 5/6	9/9	0/12	4.5
	1		0/11	0/12	
	2		0/12	0/12	
Fe	0	Needles 2.5 GY 8/6, 8/8,	11/11	0/12	4.76
	1	8/10	12/12	0/12	4.90
	2		0/12	0/12	
Zn	0	Needles short, thick ,	7/7	1/8	3.39
	1	twisted 7.5 GY 4/4, 4/6	1/9	1/8	1.513
Mn	0	Poor secondary development	8/11	0/11	3.55
	1	Dead needles 5.0 R 6/6	0/10	0/11	
	2		0/12	0/11	
B	0	Resin exudation & needles	5/8	0/9	4.33
	1	7.5 GY 4/4, 3/4	0/8	0/9	
Cu	0	Dead needle tips 5.0 YR 5/6,	11/11	0/12	4.91
	1	6/4, 5/4 in banded increments	0/9	0/12	
Mo	0	None	0/12	0/12	
	1		0/12	0/12	

* Critical value of Z at 0.05 level for one-tailed test is 1.645.

RESULTS AND DISCUSSION

The results discussed describe the colors and other characteristics that occurred during a period of time as the seedling were developing deficiency symptoms. Unique deficiency symptoms were subjected to statistical analysis and used in the development of the dichotomous key at the end of this section. Table 2 gives the proportion of seedlings in each treatment yielding a unique deficiency response and the results of statistical analysis. Basic Munsell color designations found necessary for this study along with word descriptions of the colors are: 7.5 GY (green), 2.5 GY (yellowish green), 7.5 YR (brownish yellow), 5.0 YR (reddish brown), 10.0 Y (greenish yellow), 5.0 Y (yellow), 10.0 R (brownish red), 5.0 R (red), and 5.0 RP (reddish purple).

It was observed that nitrogen deficiency resulted in two distinctive symptoms. The first was a change in color from a normal of 7.5 GY 4/6, 5/6 to an abnormal of 2.5 GY 7/6. The second was death of needle tips and a color of 5.0 YR 5/6 for the newly dead tips and 10.0 R 3/4 for the older dead tips. If all of the observed color changes occurred on one needle, it appears that they would progress from the needle base to the tip in the following steps: 7.5 GY 4/6, 7.5 GY 5/6, 7.5 GY 6/6, 7.5 GY 8/8, 2.5 GY 7/6, 5.0 YR 6/6, 5.0 YR 5/6, 10.0 R 5/8, 10.0 R 3/4. No pure yellow color was noted. Wilde and Voigt (1952) state that nitrogen deficiency is indicated by the color of leaf tissue ranging from 2.5 GY 8/4 to 2.5 GY 9/10.

Phosphorus deficiency appeared as dead needle tips that took on the color 7.5 YR 7/4. The cotyledons and old needles at the base of the seedling usually became 5.0 RP 3/4. This is close to the 5.0 RP 4/2 - 4/8 or 5.0 RP 3/6 - 3/10 found by other workers (Wilde and Voigt 1952). The color progression from base to tip of a needle carrying all of the color changes would be: 7.5 GY 4/6, 7.5 GY 5/6, 2.5 GY 6/4, 7.5 YR 7/4, 7.5 YR 6/6, 5.0 YR 5/2, 5.0 RP 3/4.

The live tissue color of potassium-deficient foliage at 7.5 GY 5/4 was within the normal foliage color range. However, in cases of extreme deficiency, the terminal needles spiralled about the bud, died, and developed a color of 10.0 R 4/2 beginning at the needle tip and moving completely to the base. In cases of less severe deficiency, the symptoms appeared on older needles as well as terminals and the needle tips progressed through a 5.0 YR 5/4 phase before becoming 10.0 R 4/2. The basal portions of the needles remained green. A hypothetical needle passing through all the color changes from base to tip would be: 7.5 GY 3/4, 7.5 GY 4/6, 7.5 GY 5/4, 7.5 GY 6/4, 5.0 YR 5/4, 10.0 R 3/4, 10.0 R 4/2. Wilde and Voigt (1952) found a color of 5.0 Y 8/6 - 8/8 to 7/6 to 7/10, which differs markedly from present findings. However, present findings are consistent with those of Sucoff (1961).

Both calcium and boron deficiencies caused terminal buds to exude resin. However, they did not cause the same foliage colors. Calcium deficiency produced needles with a background color of 10.0 Y 5/4 with splotches of 5.0 YR 5/6 located along the needle. Calcium deficiency also caused resin exudation from the needles in extreme deficiencies.

Boron deficiency did not cause needles to exude resin, and the foliage color was 7.5 GY 4/4 or 3/4, which is darker green than the normal color of 7.5 GY 5/4. Stone and Will (1965) obtained a Munsell color of 6-7.5 GY 4-5/6 for boron deficiency in *Pinus radiata* and *P. pinaster*. This color is also a darker green than normal foliage. Goslin[4] describes this symptom for Scotch pine as a very dark-green needle color.

Magnesium deficiency yielded a needle color similar to nitrogen deficiency but usually a lighter or more yellow color. The characteristic color was 2.5 GY 8/6 with needle tip becoming 5.0 Y 8/8 before any YR or R colors developed. Dead tissue at needle tips went from 7.5 YR 6/6, 5/4 to 10.0 R 5/6, 4/4. As needle tissue becomes more deficient, color apparently progresses in the following order: 7.5 GY 4/6, 7.5 GY 5/4, 7.5 GY 6/4, 2.5 GY 8/6, 5.0 Y 8/8, 7.5 YR 6/6, 7.5 YR 5/4, 10.0 R 5/6, 10.0 R 4/4. Wilde and Voigt (1952) report a foliage color of 5.0 Y 8/10 for magnesium deficiency, and again this is quite close to the 5.0 Y 8/8 found in this work.

The deficiency symptom for sulfur was a color of 2.5 GY 6/6, 5/6 beginning with the terminal needles and spreading over an entire seedling. No part of the needle became pure yellow and needle tips did not appear to die because of the deficiency. Some color changes appeared to begin at or near the needle base rather than at the needle tip. Deficiency symptoms for other nutrients almost always begin at the needle tip. Because of the above situation it is difficult to say in which direction color changes take place. However, some of the colors observed were: 7.5 GY 5/6, 7.5 GY 6/8, 7.5 GY 6/6, 7.5 GY 6/4, 2.5 GY 6/6, 5/6.

Iron deficiency produced a needle color of 2.5 GY 8/6, 8/8, 8/10, beginning with new needles and spreading to older needles. Needle color of 2.5 GY was usually accompanied by needle tip color of 7.5 YR 5/6 or 10.0 R 4/4 and sometimes a needle base color of 10.0 Y 8/6. The progressive needle colors from base to tip were: 7.5 GY 5/6, 2.5 GY 6/6, 2.5 GY 7/6, 2.5 GY 8/6, 8/8, 8/10, 7.5 YR 5/6, 10.0 R 4/4.

In extreme cases of manganese deficiency, seedlings produced no secondary needles. The color of the deficient foliage was 7.5 GY 7/8 or 7/5 GY 6/6 for the live portion of the needles and 5.0 Y 6/2, 5.0 YR 6/6, or 5.0 R 6/6 for the dead portion. Changes in needle color as deficiency symptoms get progressively more pronounced are apparently: 7.5 GY 4/6, 7.5 GY 5/4, 7.5 GY 5/6, 7.5 GY 6/6, 7.5 GY 6/10, 7.5 GY 7/8, 5.0 Y 6/2, 5.0 Y 6/6, 5.0 R 6/6.

Zinc deficiency produced needles of a 7.5 GY 4/4, 4/6 color that is darker than the darkest color considered normal. Deficient seedlings also had short, thick, and twisted needles. These were the most distinctive symptoms produced by any deficiency. The color changes that apparently take place as needle tissue progresses from zinc sufficiency to deficiency and finally to death are: 7.5 GY 4/6, 7.5 GY 4/4, 5.0 YR 4/4, 10.0 R 2/4.

Live parts of copper-deficient needles had a normal color or 7.5 GY 5/6, but the dead ends of needles had a color of 5.0 YR. Needle tissue did not change color in infinitely small segments, but rather in finite increments beginning at the needle tip. Each of these sections appeared as a distinct band differentiated from other necrotic tissue on either side. Goslin (1959) described a possible symptom for copper-deficient Scotch pine as occasional necrotic banding, which may be the same symptom found in the present work. The color changes that occur successively as a needle becomes progressively more deficient in copper are: 7.5 GY 5/6, 7.5 GY 5/4, 7.5 YR 6/6, 5.0 YR 6/4, 5.0 YR 5/6, 5.0 YR 5/4.

No symptoms were observed for molybdenum deficiency. All of the foliage colors at the varying levels of molybdenum were within the range of normal colors. Two less extensive experiments were also performed to induce deficiency symptoms. Since molybdenum is believed to be necessary for the reduction of nitrates, one of the smaller experiments utilized nitrate only for the nitrogen source. However, there were still no deficiency symptoms. It is possible that the seedling received enough molybdenum through contaminations to meet their requirements.

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[4] Goslin, W. E. 1959. Effects of deficiencies of essential elements on the development and mineral composition of seedlings of Scotch pine (*Pinus sylvestris* L.). Ph.D. Thesis, Dept. of Botany, Ohio State University.

CONCLUSIONS

All of the nutrient elements studied except molybdenum produced a set of characteristic symptoms at some level of deficiency. In general, these symptoms agreed with previous work on loblolly pine and other plants. Since all nutrients were kept at adequate levels except the one under study, it is possible that a combination of deficiencies would confuse the observer. However, it is believed that the most deficient element will produce its characteristic symptoms. The problem of describing and recording colors produced by deficient seedling foliage is greatly simplified by the use of Munsell color charts. These charts were found easy to use and the results easily recorded and reproducible.

Many of the symptoms have been used in the key that follows in an attempt to provide a method of quickly identifying a particular deficiency. However, it must be kept in mind that only those symptoms that helped to differentiate one deficiency from another were used. Therefore, use of the more complete descriptions in results may be necessary at times.

It is possible that the finer distinctions between similar deficiency symptoms, such as magnesium and sulfur, will not hold true under varying environmental conditions. However, many of the characteristics are most distinctive and should hold true under a variety of conditions. Resin exudation is almost certain to be calcium or boron deficiency, if only nutrient deficiencies are concerned. A darker than normal leaf color is probably boron or zinc deficiency, and the red-purple leaf color of phosphorus deficiency has been demonstrated many times with many plants.

Key to identification of mineral nutrient deficiencies in loblolly pine seedlings.

I. Resin exudation from needles and/or buds:
  A. Needles 10.0 Y 5/4 with splotches of 5.0 YR 5/6. Exudation from buds and needles. (Ca)
  B. Needles 7.5 GY 4/4 or 3/4. Exudation from buds. (B)
II. No resin exudation
  A. Needle color 7.5 GY
    1. Needles 7.5 GY 4/4 or 4/6 and short, thick and twisted. (Zn)
    2. Needles *not* short, thick and twisted.
      a. Some dead needles 5.0 RP 3/4. Dead needle tips 7.5 YR
        (1) Some dead needles 5.0 RP 3/4. Dead needle tips 7.5 YR 7/4. (P)
        (2) Some dead needles 10.0 R or 5.0 R.
          (a) Some dead needles 10.0 R 4/2. Needles spiral about terminals and present tufted appearance. (K)
          (b) Live needles 7.5 GY 7/8 or 6/6 with some dead needles 5.0 R 6/6. Poor secondary needle development. (Mn)
      b. No dead needles RP or R in color but dead needle ends 5.0 YR 5/4, 6/4 or 5/6 with bands at intervals around the dead portions. (Cu)
  B. Needle color 2.5 GY
    1. Large portions of needle vary in color.
      a. Needles 2.5 GY 7/6. Ends of needles YR or R but never Y. (N)
      b. Needles 2.5 GY 8/6. Ends of needles 5.0 Y 8/8 before YR and R stages. (Mg)
    2. Needles tend to have uniform color from tip to base.
      a. Needles 2.5 GY 8/6, 8/8, 8/10. Base of some needles become 10.0 Y 8/6 as deficiency progresses. (Fe)
      b. Needles 2.5 GY 6/6 or 5/6. No part of needle becomes Y. (S)

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APPENDIX 12-4.

United States Department of Agriculture
Forest Service
Suite 3260 - Jackson Mall Office Center
300 Woodrow Wilson Ave., Jackson, Ms. 39213

Reply to: 3230 - Forestation and Tree Improvement

Date: November 1, 1982

Subject: Nursery Soil Tests

To: All Southern Forest Tree Nursery Managers

Last fall, a new program was started to help nursery managers get expert interpretation of soil analyses data. Dr. Charles B. Davey of North Carolina State University agreed to interpret soil analyses from various soils labs and make soil management recommendations for nurseries throughout the South. Over 20 industry and state nurseries participated in the program last year. Dr. Davey spent much personal time on this project, but remains enthused, and we are very fortunate that he has agreed to provide the service again this year.

The State Soil Testing Lab in North Carolina cannot do soil tests for nurseries outside the state. Therefore, nursery managers elsewhere must have analyses run, then send Dr. Davey the results for his interpretation and recommendations. State or commercial labs can be used for the analyses. Although there are many labs, the nurseries that participated last year almost exclusively used:

A & L Agricultural Laboratories, Inc.
411 North 3rd Street
Memphis, Tn. 38105
(901) 527-2780

If you intend to use this service this year and contemplate using a lab other than A & L, please contact Dr. Davey first. His address and phone number are:

Dr. Charles B. Davey
School of Forest Resources
North Carolina State University
P.O. Box 5488
Raleigh, N.C. 27650
(919) 737-2883

For Dr. Davey to make recommendations, he needs to be familiar with past soil management and whether the next crop will be pine or hardwood seedlings or a cover crop. To provide this information, fill out a copy of the "Southern Nursery Soil Management Form". Several copies are attached to this letter. Those who used this service last year will recognize this as a new form. Please use this form and not those supplied last year. Dr. Davey has two additional requests:

1. That soil samples be taken in time for him to receive the soil test data no later than February first (earlier is fine). This will probably require taking the samples before the end of December. They can be taken any time after the middle of October. Thus, there is a 2½-month optimum period to collect soil samples.

2. If they were not done last year, have the tests for sulfur, zinc, manganese, iron, copper, and boron run this year. In those

nurseries where no problems are evident with those elements, micronutrient tests will probably be needed only once each three or four years. However, where problems do exist, they should be run at least every other year until the troubles are corrected.

The method of sampling is also important. Please follow steps on the enclosed "Southern Forest Tree Nursery Soil Sampling Guide". On the back, Dr. Davey's address is repeated along with brief instructions on how to obtain his recommendations. Note that a copy of each analysis and corresponding history form should also go to David South at Auburn University. This information will build a data base of nursery soil management practices and their long-term effects on the soil.

A similar interpretation and recommendation service is offered to members of the Cooperative Research in Forest Fertilization (CRIFF) program by the Soil Science Department at the University of Florida. Soil testing as well as interpretation and recommendations are available for pine seed orchards and nurseries, and for pine, hardwood, and eucalyptus plantations.

I welcome any comments or suggestions about these services or other aspects of sampling or testing nursery soils.

JOHN C. BRISSETTE
Nursery/Tree Improvement Specialist

SOUTHERN FOREST TREE NURSERY SOIL SAMPLING GUIDE

Soil analysis is a prerequisite for good soil management in forest tree nurseries. The results of such analyses provide the information needed to maintain soil conditions at optimum levels for seedling growth. To ensure accurate analysis, proper sampling is essential. Remember, the results of the test will be no better than the sample you send to the laboratory. Time spent in obtaining samples improperly is time wasted. The following steps are a guide to good soil sampling in southern forest tree nurseries.

1. Plan the sampling scheme. Sample the nursery by compartments or other identifiable administrative units. Code the compartments using letters or numbers to identify samples taken from that area.

2. Request shipping containers or specific shipping instructions from the lab that will do the analysis.

3. Take samples during the "cold" season (i.e. November to January) prior to the crop being sown. To ensure sample consistency, the same person should take and handle all soil samples.

4. Each sample should be a composite of 25-30 cores taken at random. If there are visible differences in soils or nursery stock growth in a compartment, a separate sample should be taken from each uniform soil area or area of uniform seedling growth. Two to three composite soil samples per hectare (1/acre) are sufficient.

5. Do not take soil samples from eroded spots, small depressions and unusual areas. Large, small or problem areas that have been treated differently from the rest of the compartment in previous years should not be included in the composite, but sampled and labeled separately.

6. The cores should be taken with soil probe, or tube, and to a consistent depth of 15 centimeters (6 in). Collect the cores forming a single sample in a clean plastic pail (a galvanized pail or one that has contained chemicals will alter the analysis results). Mix the cores thoroughly to form the sample.

7. Air dry the sample (oven drying may alter the chemical composition). Package approximately ½ liter (1 pint) of the sample. Using an indelible pen, label the sample package with the appropriate codes plus the name of the nursery and sender, date, and any other information considered important. Keep a list of samples sent to check against analyses returned.

SOIL TEST DATA INTERPRETATION, RECOMMENDATION, AND STORAGE SERVICES FOR SOUTHERN FOREST TREE NURSERIES

1. For soil analyses to be beneficial to the nursery manager accurate interpretation based on the needs of tree seedlings is required. Such interpretation is available on a trial basis from Dr. Charles Davey, a soil scientist with over 25 years experience in nursery soil management. To obtain his interpretation and recommendations send the following:

   a. One copy of the lab analysis.

   b. A completed copy of the form supplied with these guidelines for each sample sent.

   c. A sketch map of the nursery showing sampling locations with a key to the sampling code.

   His address is:

   Dr. Charles B. Davey
   School of Forest Resources
   North Carolina State University
   P. O. Box 5488
   Raleigh, NC 27650

2. A data base of soil analyses from the most frequently used lab is going to be maintained by the Auburn University Forest Nursery Cooperative as part of this overall effort to improve soil management at southern nurseries. For this purpose send one copy of the lab analysis and copies of the soil sample data sheets to:

   Mr. David B. South
   Auburn University Forest
   Nursery Cooperative
   Department of Forestry
   Auburn University, AL 36849

SOUTHERN NURSERY SOIL MANAGEMENT HISTORY FORM

NURSERY: ________ ADDRESS: ________
COMPARTMENT (BLOCK): ________ UNIT (S): ________
SOIL TEXTURE: ________ % SAND: ______ % SILT: ______ % CLAY: ______
NEXT CROP TO BE GROWN: ________
CONDITION OF LAST CROP OF PINE SEEDLINGS
Chlorotic ☐ Stunted ☐ Below average ☐ Average ☐ Above average ☐
Other ________

	DATE APPLIED	RATE APPLIED	DATE APPLIED	RATE APPLIED
Crop Grown[1]				
FERTILIZERS APPLIED				
Ammonium nitrate				
Ammonium sulfate				
Calcium nitrate				
Calcium sulfate (Gypsum)				
Magnesium sulfate (Epsom salt)				
Diammonium phosphate				
Nitrate of Soda-potash				
Potassium chloride (Muriate)				
Potassium nitrate				
Potassium sulfate				
Sulfate of Potash Magnesia				
Sulfur				
Superphosphate, normal				
Superphosphate, double				
Superphosphate, triple				
Urea				
Other				
MICRONUTRIENTS (list form)				
Boron				
Copper				
Manganese				
Zinc				
Iron				
LIME				
Calcite				
Dolomite				
ORGANIC MATTER				
Pine bark				
Hardwood bark				
Pine sawdust				
Hardwood sawdust				
Pine chips				
Hardwood chips				
Other				

[1] If cover crop, include both winter and summer covercrop.

Is irrigation water high in calcium? No ☐ Yes ☐ High in sodium? No ☐ Yes ☐

Diagnosing Mineral Deficiency By

Foliar Fertilization

E. S. Lyle, Jr. *Department of Forestry*
Auburn University Agricultural Experiment Station

Nurserymen are often dismayed over unusual colorations and other abnormal characteristics of seedlings throughout the growing season. Most of these abnormalities disappear with time and don't seem to cause permanent damage. However, the nurseryman usually wants to know such things in order to prevent possible future problems.

An abnormal plant part may be caused by disease, insect injury, extreme climatic conditions, chemical toxicity, mechanical injury, or mineral deficiency. In some cases, the direct cause of the plants' appearance may be secondary rather than primary. For instance, insect damage to the root system may restrict nitrogen uptake of the seedling and result in a chlorotic condition of the foliage. Fertilization of the seedling foliage with nitrogen would probably correct the chlorosis (thereby indicating a nitrogen deficiency) but would not reveal the primary problem of insect damage.

This article's purpose is to acquaint the nurseryman with foliar fertilization as a method of diagnosing mineral deficiency in tree seedlings. The author has used nitrogen, phosphorous, potassium, magnesium, sulfur, and iron compounds successfully in correcting deficiencies in loblolly pine seedlings for a short time. There is reason to believe that practically any element can be introduced into the plant by foliar fertilization. However, fertilization techniques may vary from plant to plant. Many factors affect the absorption of nutrients by foliage. Some that favor absorption and may be used to the nurseryman's advantage are vigorous new growth, high humidity, and normal growing temperature.

The fertilization procedure used by the author with loblolly pine seedlings is to bend the seedling top over into a glass containing the desired solution; place a plastic bag over the wet foliage, and close the mouth of the bag around the seedling stem. The bag is left on the foliage 24 to 48 hours to keep the solution salts in condition to penetrate the pine needles. It is probably best to apply the solution in the late afternoon or evening to avoid some of the heat buildup within the plastic bag. When the bag is left on the foliage in strong sunlight, it would be wise to shade the seedling. If the seedling does not respond to treatment within 1 week, the solution should be applied again. With hardwood seedlings, probably not as much effort is required to introduce nutrient salts into the foliage and the plastic bag can probably be eliminated.

Many publications describe the mineral deficiency symptoms of field crops and forest trees (*1, 2, 3, 4, 5, 6, 7, 8, 9*). These are helpful for narrowing the field when searching for a deficient element. However, all plants do not show exactly the same symptoms for a given deficiency, and the same plant may exhibit several different symptoms as it progresses from slight to extreme deficiency. Some fairly universal symptoms can be used as a starting point for diagnosis. Nitrogen, sulfur, magnesium and iron deficiencies all cause a yellow-green to yellow foliage coloration. Calcium and boron deficiencies cause growing tips to die, and phosphorous and potassium deficiencies cause purple and bronze discolorations of foliage. Using symptoms as a guide, the nurseryman can often limit the number of fertilizer solutions to be tried.

Table 1 shows some of the more common chemicals that may be used as foliage fertilizers. There are others that can be used as well. Many can be obtained at any pharmacy. The quantity column shows the amount of the chemical to add to one quart of

TABLE 1.—*Some chemicals and quantities used to prepare foliar fertilization solutions.*[1]

	Chemical Source[2]		Quantity[3]		
Elements	*Name*	*Formula*	*Ounces*	*Grams*	*Teaspoons*
Nitrogen	Urea	NH_2CONH_2	0.2	5.0	1-1/2
Nitrogen	Ammonium nitrate	NH_4NO_3	0.3	8.0	2
Nitrogen and phosphorus	Monoammonium phosphate	$(NH_4)\ H_2PO_4$	0.3	8.0	1-1/2
Phosphorus	Orthophosphoric acid	H_3PO_4	0.1	3.0	1/2
Phosphorus and potassium	Monopotassium phosphate	KH_2PO_4	0.4	10.0	1-1/2
Potassium and sulfur	Potassium sulfate	K_2SO_4	0.4	10.0	1-1/4
Potassium	Potassium chloride (muriate potash)	KCL	0.4	10.0	2
Calcium	Calcium chloride	$CaCl_2$	0.4	10.0	2-1/4
Calcium	Calcium hydroxide (slaked lime)	$Ca(OH)_2$	0.2	5.0	2-3/4
Magnesium and sulfur	Magnesium sulfate (Epsom salts)	$MgSO_4.7H_2O$	0.8	20.0	4-3/4
Magnesium	Magnesium chloride	$MgCl_2.6H_2O$	0.4	10.0	2-1/4
Iron and sulfur	Ferrous sulfate (copperas)	$FeSO_4.7H_2O$	1.0	28.0	4
Copper and sulfur	Copper sulfate	$CuSO_4.7H_2O$	0.3	8.0	1-1/4
Zinc and sulfur	Zinc sulfate (white vitriol)	$Zn\ SO_4.7H_2O$	0.2	5.0	1
Manganese and sulfur	Manganous sulfate	$MnSO_4.4H_2O$	0.1	3.0	3/4
Boron	Sodium borate (borax)	$Na_2B_4O_7.10H_2O$	0.1	3.0	1-1/8
Molybdenum	Sodium molybdate	Na_2MoO_4	0.0025[4]	0.07[4]	1/16[4]

[1] Add a few drops of surfactant, spreader, or detergent to each solution.

[2] Chelated elements may also be used. Solution concentrations for foliar application can be obtained from the manufacturer.

[3] Quantity added to 1 quart of water.

[4] Approximately the amount to barely cover one surface of a dime.

water. It will also be necessary, in most cases, to add a spreader, surfactant, or detergent to the solution in order to spread it uniformly over the leaf surface.

Some of the chemicals will provide more than one nutrient element, and care must be taken to interpret results correctly. For instance, let us say that some seedlings exhibit an abnormal yellow foliage coloration and iron or sulfur deficiency is suspected. If a solution of iron sulfate is applied to the seedlings and the chlorosis is corrected, then it is impossible to say whether iron or sulfur was deficient. However, if you apply iron sulfate to one group of chlorotic seedlings and potassium sulfate to a comparable group, you should be able to differentiate between iron and sulfur response. If both the iron sulfate and potassium sulfate solutions correct the chlorosis, the deficiency was probably sulfur. If the iron sulfate alone corrects the chlorosis, the deficiency was probably iron.

Foliar fertilization will not reveal the cause of all your seedling abnormalities, but it should be useful in some cases and help guide you toward the solution of many nutrition problems.

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APPENDIX 12-6.—CHEMICAL ELEMENTS

Element	Symbol	Atomic weight	Ions	Interest to soils
Aluminum	Al	26.98	Al^{+++}	Component of minerals, rocks, clay
Boron	B	10.82	BO_3^{---}, $B_4O_7^{--}$	Plant nutrient
Calcium	Ca	40.08	Ca^{++}	Plant nutrient, soil acidity
Carbon	C	12.01	C^{----}, CO_3^{--}, HCO_3^-	Carbon dioxide, organic matter
Copper	Cu	63.54	Cu^{++}	Plant nutrient
Hydrogen	H	1.01	H^+	Plant nutrient, soil acidity, water
Iron	Fe	55.85	Fe^{++},Fe^{+++}	Plant nutrient, rocks and minerals
Magnesium	Mg	24.32	Mg^{++}	Plant nutrient, soil acidity
Manganese	Mn	54.94	Mn^{++}, Mn^{++++}	Plant nutrient
Molybdenum	Mo	95.95	MoO_4^{--}	Plant nutrient
Nitrogen	N	14.01	NH_4^+, NO_2^-, NO_3^-	Plant nutrient, organic matter
Oxygen	O	16	O^{--}	Plant nutrient, rocks, minerals, water
Phosphorus	P	30.98	$H_2PO_4^-$, HPO_4^{--}, PO_4^{----}	Plant nutrient, organic matter
Potassium	K	39.10	K^+	Plant nutrient, rocks, minerals
Silicon	Si	38.09	Si^{++++}	Rocks, minerals, clay
Sodium	Na	22.99	Na^+	Physical condition of soil
Sulfur	S	32.06	S^{--}, SO_4^{--}	Organic matter, plant nutrient, soil acidity
Zinc	Zn	65.38	Zn^{++}	Plant nutrient