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EC1275

Plant Nutrients and Soil Fertility

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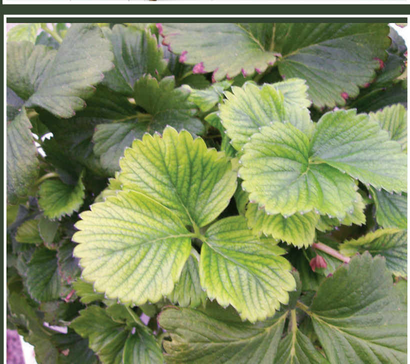

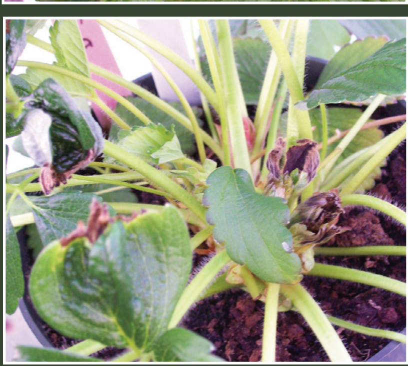

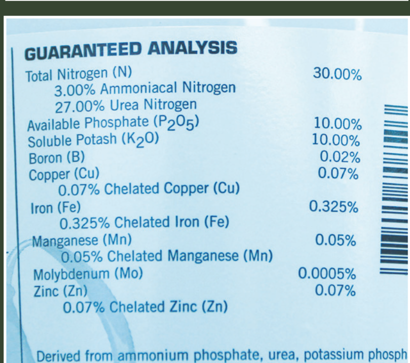

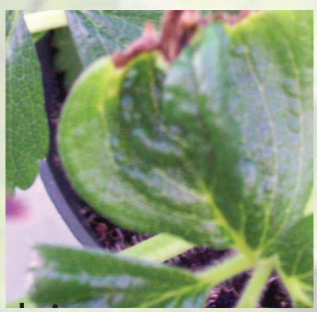

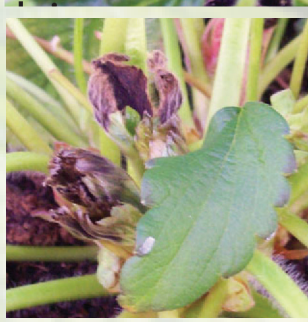

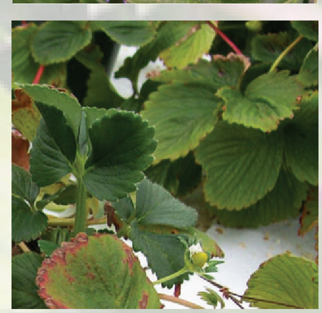

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Knowledge of plant nutrients and soil fertility is essential for gardeners and landscape managers to ensure plants have the nutrients needed at the appropriate times so they can grow, meet aesthetic and functional requirements, and produce high yields while minimizing movement of nutrients into ground and surface waters. This EC is the second in a three-part series and contains information on essential plant nutrients, movement of nutrients in the soil and in the plant, and fertilizers. The first soil publication, *Properties of Landscape Soils* (EC1267), contains information on soil formation, composition, and physical and chemical properties. The third publication, *Managing Landscape Soils* (EC1277), describes specific soil management challenges, including pH, compaction, drainage, and slope.

Essential Plant Nutrients

Plants need 17 essential elements for growth. Essential elements are required for completion of a plant's life cycle, cannot be replaced by another element, and must be directly involved in plant metabolism. If any of these essential elements are missing or deficient, plant growth will be negatively affected. Carbon (C), hydrogen (H), and oxygen (O) are needed in the largest quantities by plants and are obtained by the plant from the air (C) and water (H and O). Elements that come from the soil are called **mineral nutrients**. They are categorized as either macronutrients or micronutrients (*Table 1*).

Table 1. The relative number of each essential element needed for plant growth in relation to molybdenum – the essential element needed in the lowest amount. Macronutrients are shaded dark green and micronutrients are shaded light green.

Element	Relative Number of Each Element	Element	Relative Number of Each Element
Nitrogen	1,000,000	Iron	2,000
Potassium	250,000	Boron	2,000
Calcium	125,000	Manganese	1,000
Magnesium	80,000	Zinc	300
Phosphorus	60,000	Copper	100
Sulfur	30,000	Nickel	2
Chlorine	3,000	Molybdenum	1

- **Macronutrients** are used in relatively large amounts by plants for building large molecules, such as proteins that are the plant cell's tool box, ATP that powers cellular reactions, and DNA and RNA for storing and transmitting genetic information. Molecules containing macronutrients play central roles in processes like photosynthesis, respiration, transport, and storage involved in synthesis and utilization of sugars by the plant. Macronutrients also are critical for controlling cellular processes, such as regulating stomatal opening and closing and cell wall development. Nitrogen (N), phosphorus (P), and potassium (K) are the primary macronutrients and are the nutrients most commonly found in commercial fertilizers. Nitrogen, which is part of all amino acids used in building proteins, is required in the largest amounts. Secondary macronutrients, required in smaller amounts, include magnesium (Mg), calcium (Ca), and sulfur (S).
- **Micronutrients** are used in much smaller amounts by the plant than macronutrients. They are often part of the active site of key enzymes and cofactors used to drive reactions in plants or used to transfer energy. Micronutrients include iron (Fe), zinc (Zn), molybdenum (Mo), manganese (Mn), boron (B), copper (Cu), chlorine (Cl), and nickel (Ni).

The 14 mineral nutrients are taken up in elemental or simple molecule forms, such as Ca++ (calcium) and

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NO_3- (nitrate), as charged ions in a water solution (*Table 2*). Negatively charged ions, such as nitrate, have a higher probability of leaching or moving down through the soil and out of the root zone because of the overall negative charge exhibited by most soils. Some negatively charged ions, such as phosphate (PO_4---), do not leach readily. Positively charged ions, such as Ca++, are attracted to the negative charge of clay particles and organic matter and do not readily leach. Some nutrients found in the soil are not readily available to the plant because the nutrient is found in complex forms that the plant cannot take up, such as dead and decaying plant material or in complex mineral forms. Complex nutrient forms must be transformed to usable forms.

Mineral Nutrient Movement in Soil

Mineral nutrients are found in the soil solution. The soil solution is water found in the soil empty spaces or pores. Nutrients must come in contact with plant roots in order to be taken into the plant. There are three ways that nutrients can come into contact with plant roots, including mass flow, ion diffusion and root interception (*Figure 1*).

- **Mass flow.** Nutrients are transported to root surfaces by water movement through soil pores or open spaces. The rate of nutrient movement to roots depends on the amount of water flow. As long as there is adequate soil water, the movement of water and nutrients in the soil to the root surface is increased by water loss through evaporation (from the soil surface) and transpiration (from plant leaves). Elements and molecules that are not strongly attached to soil particles can easily move with the water and are generally mobile in soil.
- **Ion diffusion.** Diffusion of nutrients in soil solution occurs near

Table 2. Mineral nutrients can only be taken up in elemental or simple molecule forms. Complex nutrient forms, such chlorophyll, must be broken down into simpler forms through microbial degradation before nutrients are available to plants.

Essential Mineral Nutrients	Form Taken Up By the Plant
Nitrogen	NO_3- NH_4+
Phosphorus	H_2PO_4- HPO_4--
Potassium	K+
Calcium	Ca++
Magnesium	Mg++
Sulfur	SO_4--
Chlorine	Cl-
Iron	Fe++ Fe+++
Boron	H_2BO_3-
Manganese	Mn++
Zinc	Zn++
Copper	Cu+ Cu++
Nickel	Ni+
Molybdenum	MoO_4--

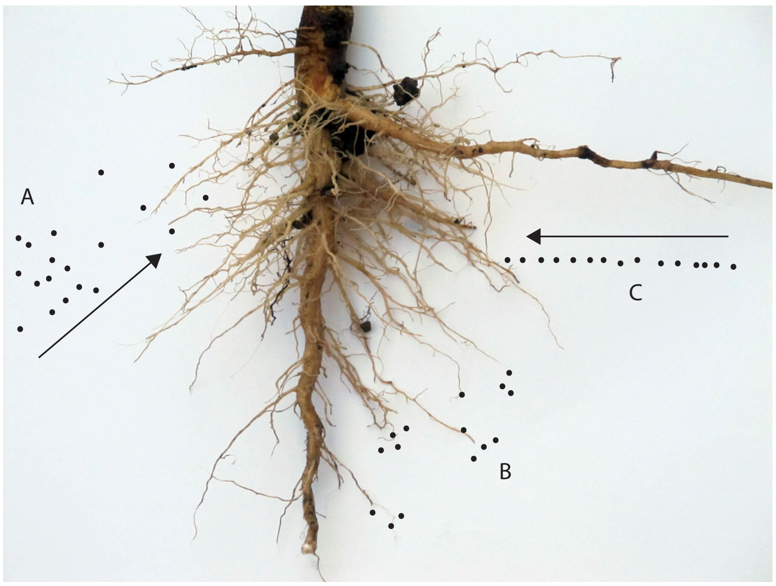

Figure 1. The black dots represent mineral nutrients in the soil. Roots absorb water and nutrients by ion diffusion (A), root interception (B) and mass flow (C).

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roots. Nutrients flow from areas of high concentrations or amount to areas of lower concentration or amount. This concentration difference is created as nutrients are extracted from soil solution near the root. A fertilizer granule is a source of high concentration. As water comes into contact with the granule, diffusion begins. Nutrients will slowly move away from high concentration near the granule to areas of lower concentration, typically near the root.

- **Root interception.** Nutrient availability increases when roots grow into new soil areas as the amount of root surface area increases allowing new roots to come into contact with more ions in the soil solution. Management practices that increase root growth will ultimately increase the amount of nutrients available for plant uptake. Compaction and restricted rootzones result in inadequate root systems to explore the soil and find available nutrients.

Nutrient Movement into the Plant

Root hairs are responsible for much of the water and nutrient uptake. They are small outgrowths from the epidermal cells on roots. These small roots increase the surface area of roots in the soil. Nutrients and water can enter and move through diffusion into the plant by moving through and between cells until they reach a waxy membrane called the Casparian Strip. At this point, water and nutrients must pass through membranes before they enter the xylem. Once in the xylem, water and nutrients are translocated to other areas of the plant.

Nutrient Mobility in Plants

Nutrients are considered to be mobile or immobile in a plant, which refers primarily to movement from one plant part to another. When deficient, mobile nutrients are transported from older plant tissues to the young, growing tissue. Deficiency symptoms of mobile nutrients will first be evident in the older leaves. Symptoms usually include chlorosis or yellowing of the leaves and later necrosis (death of tissue). Immobile nutrients are not transported out of plant tissues so deficiency symptoms of chlorosis and necrosis are usually found on new growth. Calcium, sulfur, boron, copper, iron, and manganese are considered to be immobile nutrients. Symptoms displayed by plants may help determine what element is deficient. (*Figure 2*).

Fertilizers

Fertilizers are sources of nutrients that are applied to soil to improve plant growth and development. Fertilizers can be synthetic or organic.

- **Synthetic fertilizers.** These fertilizers are commercially manufactured. They do not injure the soil or soil biological activity (earthworms or microbes in the soil) when applied appropriately. On the contrary, proper use of synthetic fertilizer provides nutrients to plants and organisms in the soil to produce more organic matter, which can be returned to the soil to stimulate additional microbial activity.
- **Organic fertilizers.** These fertilizers are derived from naturally occurring materials. Examples include cottonseed meal, blood meal, fish emulsion, municipal biosolids, manure, and compost. Organic materials must decompose before plants can use the nutrients. These are effective nutrient sources, but nutrient contents of organic materials are generally low relative to synthetic fertilizers. If the nutrient content of organic materials is not in balance with plant needs, it is difficult to supply needed plant nutrients without applying other nutrients in excess. Release of some nutrients, such as nitrogen from organic materials, is slowed as the ratio if carbon to nitrogen content is relatively high. One approach is to apply organic materials to supply part of the nutrient requirements and add the rest of the needed nutrients with synthetic fertilizers. There are many types of commercially available organic fertilizers. The price may be higher per unit of nutrient due to availability and shipping costs for the large volume of material needed to supply the correct amount of nutrient.

Fertilizers also can be categorized by the rate of nutrient release, especially for nitrogen release.

- **Slow-release or controlled-release.** These fertilizers are designed to release nutrients in synchrony with plant nutrient uptake, reducing the potential for nutrient loss. Slow-release fertilizers also may be labeled WIN for water insoluble nitrogen. Slow-release fertilizers can be applied less frequently than other fertilizers, and more can be applied at once with less danger of plant damage. Release of nutrients in slow-release fertilizers is regulated by soil moisture level, soil temperatures, and microorganism activity, making nutrients available for plant use over a prolonged period of time.
- **Fast-release.** These fertilizers have nutrients that are rapidly available to plants. As such, they pose more potential for salt injury. Fast-release fertilizers may also be labeled WSN for water soluble nitrogen. WSN fertilizers are quick to dissolve in water and usually contain simple forms such as urea, ammonium or nitrate molecules as well as nutrients supplied in molecules containing sulfate or chloride. Fast-release fertilizers tend to be relatively lower cost per unit of nutrient compared with slow-release fertilizers.

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Figure 2. The most common nutrient deficiencies in landscape plants are nitrogen (N), iron (Fe), and calcium (Ca). Nitrogen deficiencies are often found in gardens where plants are routinely harvested and in turf areas with infrequent fertilization. Iron deficiency is common on high pH soils, soils high in calcium or phosphorus, poorly drained soils, and compacted soils. Under these conditions, iron becomes unavailable for plant uptake even though there are adequate amounts in the soil. Calcium deficiencies are often caused by the low mobility of calcium in the soil, drought stress, rapid growth, very low pH, or soil moisture fluctuations. Optimum watering conditions will reduce calcium deficiency symptoms. Images courtesy of Ellen Paparozzi, UNL Agronomy and Horticulture.

Fertilizer Labels

Nitrogen (N), phosphorus (P), and potassium (K) are usually the most limiting in soils and are consequently often applied as a blended NPK fertilizer which has variable percentages of these elements to suit individual soil conditions (*Table 3*). The label of all fertilizers must show a guarantee of nitrogen (N), phosphate (P_2O_5), and potash (K_2O). A fertilizer grade of 10-20-10 means it is guaranteed to contain 10 percent N, 20 percent P as P_2O_5, and 10 percent K as K_2O by weight. The content of other nutrients, such as sulfur, iron or zinc, also must be listed if the fertilizer manufacturer wants to guarantee the amount (*Figure 3*). Fertilizers may be single nutrient fertilizers or

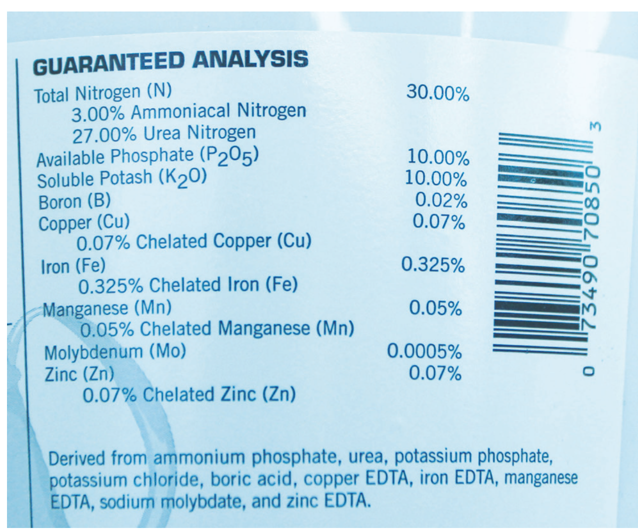

Figure 3. Most fertilizers found in garden centers have multiple nutrient sources blended or compounded into one product. Some fertilizers target specific plants that require unique soil conditions, such as low pH. The effectiveness of these products is based on soil chemical and physical properties.

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Table 3. There are many sources of mineral nutrients available in dry fertilizers for use in landscapes.

Fertilizer	Fertilizer Analysis	Comments
Urea	46-0-0	Concentrated dry, fast-release fertilizer; completely water soluble; needs to be watered in or incorporated into the soil to avoid nitrogen losses due to volatilization; can coat granules with sulfur or polymer for slow-release.
Ammonium sulfate	21-0-0 24% S	Fast-release fertilizer; most soil acidifying nitrogen fertilizer
Ammonium nitrate	33-0-0	Fast-release fertilizer; availability is monitored because of use in explosives
Concentrated, double, or triple superphosphate	0-46-0	Almost all of the P is available for plant growth; release begins soon after application.
Diammonium phosphate	18-46-0	Phosphorus release begins soon after application; also a source of nitrogen.
Monommonium phosphate	11-52-0 or 11-48-0	Phosphorus release begins soon after application; also a source of nitrogen.
Phosphate rock	0-(5-17)-0	Naturally occurring; found in many fertilizers; only a portion of the P is available to plants
Muriate of potash or potassium chloride (KCl)	0-0-60	Least expensive of potassium sources; greatest potential for fertilizer injury due to a high salt index; Cl can damage vines, trees, and vegetable crops but can be beneficial where Cl is deficient.
Potassium sulfate	0-0-50 17% S	Good source of sulfur.
Elemental sulfur	0-0-0 90% S	Causes soil acidification; must be chemically changed to sulfate before plants can use it so early application is important; only effective in warm soils and during the same application season.
Positively charged micronutrients, such as iron, zinc and copper	Varies	Commonly marketed as sulfate, chloride or oxide molecules. Enhanced availability if in a chelated form.

mixed grade (contains two or three of the macro-nutrients — nitrogen, phosphorus, potassium). Single nutrient fertilizers can be blended to make mixed grade fertilizer, also referred to as a fertilizer blend or composite.

Fertilizer Calculations and Spreader Calibration

The amount of product to be applied depends on the grade of the fertilizer and the amount of nutrient needed (*Figure 4*). Fertilizer rates for landscape beds are often in pounds/100 ft^2 while rates for turf are in pounds/1,000 ft^2.

1 lb N/0.10 = 10 lbs of product * 1 (1,000 ft^2 areas)

10 lbs of product * 20% P_2O_5 = 2 lbs of P_2O_5

10 lbs of product * 10% K_2O = 1 lbs of K_2O

Figure 4. If one pound of nitrogen per 1,000 square feet is needed and a material with a grade of 10-20-10 is used, it is necessary to apply 10 pounds of 10-20-10 per 1,000 square feet. This 10 pound rate of 10-20-10 fertilizer results in the application of one pound of nitrogen, two pounds of phosphate (as P_2O_5), and one pound of potash (as K_2O).

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1. To begin calibration, set the spreader to the recommended level.
2. Weigh a cup of product, place it in the fertilizer hopper, and then spread it over a known area. To avoid wasting product, spread the fertilizer over a large piece of plastic.
3. If a 23-12-18 product is being used at spreader setting 6 and 0.5 lbs of fertilizer is collected over a 100 ft^2 area, then the rate of nitrogen per 100 ft^2 is 0.115 lbs (fertilizer applied x N percentage or 0.5 lbs/100 ft^2 x 0.23) and the rate of nitrogen per 1,000 ft^2 is 1.15 lbs (0.115 lbs of N/100 ft^2 x 10 = 1.15 lbs of N/1,000 ft^2).
4. If this is not the desired amount to be applied, adjust the setting to release more (higher number setting) or less fertilizer (low number setting) and calibrate the spreader again.

Figure 5. Steps for calibrating a granular spreader.

Proper calibration of spreaders is important to avoid over fertilizing plants, which may cause plant damage or make plants more susceptible to pests (*Figure 5*). Many fertilizers have spreader settings on their bags, but it is important to confirm the settings each time a new product is used. Fertilizers have different physical characteristics which influence the amount of product needed to cover a specific area.

The 4 R's of Fertilizer Use

The four "rights" of fertilizer use are intended to achieve desired plant performance in an environmentally protective manner.

- **Right product.** Supply only the needed nutrients in the right form (quick or slow release) to avoid negative interactions between nutrients.
- **Right rate.** Apply fertilizers considering the plant needs, the soil's capacity to supply nutrients, and nutrients from other sources.
- **Right time.** Generally apply for early growth and for periods of high nutrient uptake.
- **Right place.** Apply in the correct location, which may be by broadcast, band, point, or deep application. In many cases, incorporation by tillage (before planting) or with water is desired.

Soil Sampling and Testing

Soil tests take the guesswork out of fertilization, are cost effective, and environmentally responsible. A soil test will provide an index of the amount of essential mineral nutrients available and recommend quantities of nutrients to apply. A soil test may reduce fertilizer costs, but will also eliminate over-usage of fertilizers, hence helping to protect the environment. One soil sample taken at the 0-8 inch depth and consisting of 10-15 cores collected randomly in the landscape usually is adequate, unless there are obvious soil differences in the landscape soil. Depth depends on root depth, sample where the majority of the roots are located. Soil testing to estimate mineral nutrients in soil does not need to be done every year. A soil test every fifth year should be adequate unless a major soil amendment, such as lime or compost, was added since the last test or there are problems in the landscape which are suspected to be due to nutrient deficiencies.

Summary

Understanding plant nutrition and soil fertility is important in properly managing landscapes. There are 17 essential elements required for plant growth, and these elements are obtained by the plant from the air, water, and soil. When adequate nutrients are not be found in soils or are not readily available to plants, fertilizers can be added to improve plant growth.

Nutrient application in landscape management is too often excessive as nutrient costs are minor compared with other costs and the perception that more is better. Nutrient over-application has great potential for negative environmental consequences, such as leaching of nitrogen into groundwater; movement of nitrogen, phosphorus and other nutrients and pesticides in runoff to surface water; volatilization of ammonia into the atmosphere; emission of the greenhouse gas nitrous oxide, and deposition of ammonium in nitrogen sensitive ecosystems. Practicing the 4 Rs of fertilizer use is important to grow healthy plants and protect the environment.

Portions of this EC were adapted from the Nebraska Master Gardener Manual.

This publication has been peer reviewed.

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