Nutrient Management Module

Certified Crop Advisor

State Performance Objectives

General New Mexico Plant Nutrient Management Competency Areas:

1. Basic concepts of plant nutrition
2. N, P, and K plant requirements and deficiency symptoms
3. Secondary nutrient and micronutrient plant requirements and deficiency symptoms
4. Toxicity symptoms from the field
5. Cropping system effects on field nutrient dynamics

Learning Objectives

The objectives for the New Mexico Nutrient Management Module are:
- Explain the function of soil as a medium for plant growth and yield
- Define how soils impact plant growth and nutrient uptake
- Describe nutrient requirements for plants
- Learn how to identify deficiency and toxicity symptoms in plants and corrective steps in improving plant growth
- Be able to describe how cropping systems and rotations can affect nutrient availability

Competency Area One. Basic concepts of plant nutrition

This competency area will review basic plant nutrient needs.

Pre-Study Questions for Review

1. The availability of phosphorus to a crop is only _____ percent of the total amount of phosphorus in the soil.
   a. 25
   b. 15
   c. 5
   d. 1
2. The parameters that affect the Cation Exchange Capacity (CEC) of soils include the following:
   a. the heavy metals within the soil profile, the parent material and the depth of the A horizon of soil
   b. the total bulk of organic matter on the field, the type of clay in the soil and the number of times the soil is saturated
   c. the types of clay, the amount of organic matter and the soil temperature
   d. the soil moisture, the soil temperature and the number of soil types

3. Boron is one nutrient that works in plants to help in protein synthesis and a deficiency of this nutrient may develop when soil conditions are:
   a. moisture saturated and organic matter is high
   b. with hot temperatures and irrigation is used on the field
   c. when compaction of the field creates a cozy, cool root zone
   d. under hot, dry conditions and the plant uptake slows down

4. The first symptom on a crop with a nitrogen deficiency is:

a. short, stubby whorls of leaves at the top of the plant
b. the bottom leaves simply fall off
c. sporatic flowering of the plant
d. a pale green or yellow-green color to the leaves

5. Three ways that nitrate can move in soil are:
   a. by microbes physically moving the nitrogen, by a plant root displacing the nitrogen with another nutrient, by absorption to the soil colloids
   b. by volatilization, by leaching and by denitrification
   c. by leaching, by wind erosion and by root solution exchange
   d. by denitrification, by volatilization and by wind erosion

Check your answers before proceeding into the unit to find out how much you already know about basic concepts of plant nutrition. Each correct answer is worth 20 points, based on a total of 100 points for the five questions. Answers: 1. d.; 2. c.; 3. d.; 4. d.; 5. b.

Basic concepts of plant nutrition

Across crops grown in New Mexico, thirteen (fourteen counting cobalt) of the sixteen essential nutrients (seventeen counting cobalt needed by legumes in the nitrogen-fixing nodule tissue) for good plant growth are obtained from the soil. These essential nutrients can be organized into three main categories: primary nutrients, secondary nutrients and trace or micronutrients. The nutrients included in each group are:

Primary nutrients: nitrogen (N); phosphorus (P); and potassium (K).

Secondary nutrients: calcium (Ca); magnesium (Mg); and sulfur (S).

Trace or micronutrients: zinc (Zn); iron (Fe); copper (Cu); manganese (Mn); boron (B); molybdenum (Mo); and chlorine (Cl).

The remaining three essential nutrients of the sixteen are derived from the air and water and are carbon dioxide (CO_2) from which plant carbon (C) is made and also from water comes hydrogen (H) and oxygen (O_2). Indeed, plants utilize these sixteen essential nutrients in order to grow and develop. These nutrients account for about ten percent of each plant's dry matter with the rest of the plant composition coming from air and water. Of these sixteen essential nutrients, seven account for the bulk of the mineral portion of the plant and include: potassium, calcium, magnesium, nitrogen, phosphorus, sulfur and silicon. The nutrients may also have to be in a form that is usable by the plant, both for plant uptake from the soil and for plant processes and use within the plant. Listed below is a list of the sixteen essential nutrients and the forms in which they are most commonly used by the plant.

Nutrient Forms Used by Plants for Growth and Development

Nutrient	Chemical	Usable Forms
Nitrogen	N	NO_3^-, NH_4^+
Phosphorus	P	$H_2PO_4^-$, HPO_4^{--}
Potassium	K	K^+
Sulfur	S	SO_4^{--}
Magnesium	Mg	Mg^{++}
Calcium	Ca	Ca^{++}
Oxygen	O	CO_2, H_2O
Carbon	C	CO_2
Hydrogen	H	H_2O
Molybdenum	Mo	MoO_4^{--}

Copper	Cu	Cu^{+}, Cu^{++}
Zinc	Zn	Zn^{++}
Manganese	Mn	Mn^{++}
Boron	B	H_3BO_3, $H_2BO_3^{-}$, HBO_3^{--}, BO_3^{---}
Iron	Fe	Fe^{+++}, Fe^{++}
Chlorine	Cl	Cl^{-}

As you can see, some of the nutrients are available as positive ions and carry a positive (+) electrical charge while others are available as negative ions and carry a negative (-) electrical charge. Clay soils (particles are less than 2 microns in diameter) as well as organic matter have negative charges, or anions (-), that attract positive charges, or cations (+). The negative interface on a clay particle creates an exchange boundary (or site) with nutrients that have a positive charge. On the other hand, sand and silt have fewer negative sites and thus do not attract or retain nutrients with a positive charge as readily. Both cations and anions are found in water films that surround soil particles and this film of water has ions dissolved within it, making the soil solution from which plant roots can absorb needed nutrients. Soil can be measured by the number of anions and cations present by a unit of measure called the milliequivalent and is usually expressed as milliequivalents per 100 grams of soil (meq./100 gm). Indeed, the cations counted on a soil's exchange site can be reported as meq./100 gm of soil by replacing the cations present with another cation in a high concentration such as NH_4^{+}. This can then allow the amount of cations present to be counted as a measure called the Cation Exchange Capacity (CEC) of a soil. Certain nutrients should be present in the CEC in higher concentrations so that they are more readily available to plants. Certain base nutrients should make up a certain percentage of the total CEC. This percent base saturation, defined as milliequivalents of bases, should ideally have:

70-80%	Calcium
10-15%	Magnesium
1-5%	Potassium
1%	Sodium

However, depending on the soil and the irrigation water used and weathering factors the base saturation as well as the CEC may vary greatly among soils depending on a.) the type of clay minerals present; b.) the amount of clay minerals present; and, c.) the amount of organic matter present. As you might guess, organic soils, peats and mucks have a very high CEC and thus can hold on to and exchange cations (positive charged nutrients) readily.

CEC Ranges for Several Soil Types

Soil Type	Exchange Capacity (meq.)	CEC (meq./100 gm soil)
Sand	1-4	1-4
Sandy loam	3-8	3-8
Silt loam	6-20	6-20
Loam	10-15	10-15
Clay loam	18-40	18-40
Clay	30-80	30+
Muck	80-200	
Peat	140-300	

There are three ways in which nutrients can be absorbed by plant roots: mass flow, diffusion, or root interception. The first two means of absorption prevail. With mass flow, soluble nutrients within the soil water simply flow with water into plant roots. One highly soluble nutrient that often is absorbed by roots by mass flow is nitrogen, particularly in the nitrate (NO_3^{-}) form. Nutrients may also enter plant roots through diffusion. The concentration of nutrient charges within the soil water is constantly changing and sometimes, the concentration of certain nutrients outside of the plant root may be higher than that inside the plant root. As the soil water around the root is depleted of these nutrients, it may be replenished as the water solution attempts to reach a new equilibrium of solutes within the soil water. Nutrients thus diffuse toward the root and may be accepted through the cell plasma membrane of the root—allowing diffusion to occur. Root interception of nutrients is less important. In this means of absorption, the root cap and root hairs physically come into contact with nutrients as growth occurs.

As you might guess, some nutrients are more mobile than others, depending on the ionic form of the nutrient. Generally, cations move more slowly than anions, but this depends on the nutrient chemistry, the soil's clay content, as well as the soil's organic matter content. However, this explains why anions such as chloride (Cl^-), nitrate (NO_3^-), sulfate (SO_4^{--}) and even molybdate (MoO_4^{--}) can move rapidly and will diffuse quickly into roots from greater distances than some other nutrients.

Crop plants utilize nitrogen, phosphorus and potassium for plant growth, development, seed production and even into maturation. Plants are unique in that they are autotrophic, they do not need organic molecules to survive but rather they can synthesize the necessary growth constituents from inorganic substances. A nutrient is considered essential for a plant if the plant, when grown in a medium devoid of that nutrient, fails to grow and to complete its life cycle, whereas in the presence of a suitable concentration of that element, the plant can grow and reproduce normally.

Three of the key nutrients based on plant need and quantity used are nitrogen, phosphorus and potassium. You should be able to know the different forms of these nutrients utilized by the plant and how to recognize deficiency symptoms in plants when these nutrients are not plentiful to the plant.

N, P, and K plant requirements and deficiency symptoms

Nitrogen

Nitrogen is most readily available to plants when it is in the nitrate (NO_3^-) form. As this form is readily mobile, additions of nitrogen by use of ammonium (NH_4^+) can be used as a supplemental fertilizer and soil nitrification, a two-part process, will transform NH_4^+ to NO_3^-. In this process, ammonium nitrogen is converted to nitrate nitrogen by nitrifying bacteria in the soil. The process is simply:

1. $2\ NH_4 + 3\ O_2$ ----------nitrosomonas----------→ $2\ NO_2^- + 2\ H_2O + 4\ H^+$ + energy
2. $2\ NO_2^- + O_2$ -----------nitrobacter-----------→ $2\ NO_3^-$ + energy

This nitrification process is promoted or retarded by several conditions in the soil including soil pH, moisture, temperature and aeration. Maximum soil organism activity occurs at a soil pH or 6.0 to 7.4. The nitrifying bacteria necessary for the ammonium conversion process to occur can continue in dry soil conditions but are inactive in saturated soil conditions as there is not enough oxygen to sustain the activity of the nitrifying bacteria. Temperature also affects the conversion process. Nitrification begins slowly at 32F and continues to increase in activity up through about 85F. At higher temperatures, the nitrification process slows. The process also requires aeration, or more importantly, oxygen. Soils with good drainage can influence the rate of nitrification, encouraging the process as long as temperature, moisture and soil pH is not slowing the conversion process.

Unfortunately, nitrogen may also be lost from the soil through not only plant uptake but also through volatilization of ammonia or by erosion of soil and organic matter or even through leaching of nitrate below the plant root zone. Saturated soils under warm conditions are prime conditions for volatilization or leaching of nitrogen to occur in soils. Physical erosion of the nitrogen from the site will also cause essential nitrogen to be lost from a field site. However, because nitrogen is constantly changing in the soil and being used by plants as well as microbes, nitrogen movement and its retention or loss may also be due to the form the nitrogen is in and thus more readily available to certain uses or loss processes. Nitrogen applied as ammonium (NH_4^+) at first is held tightly to the negative-charged clay particles in soil. Movement is limited in this form but as the NH_4^+ is converted to nitrate (NO_3^-) by nitrification, the anion is free to move in the soil water. Indeed, it may move downward as it leaches with rainfall or irrigation water. Or, it may move upwards with evaporative forces where the nitrogen can be lost by volatilization. This process, called denitrification, is where nitrates are reduced to nitrous oxide or elemental nitrogen through the action of soil bacteria on the upper surface of the soil.

NO (nitric oxide) N_2 (nitrogen)

NO_3^- (nitrate) ---→ NO_2^- (nitrate) ---→ ---→(intermediates) ---→ N_2O (nitrous oxide)
Achromobacter
O_2 O_2

This process easily occurs in soils that are waterlogged or saturated and oxygen is excluded allowing the anaerobic decomposition to take place (such as from the achromobacter). Physical erosion of soil with attached ammonium or movement of mobile nitrogen with water erosion will both also cause nitrogen losses from a field.

Nitrogen deficiency symptoms

Plants that need more nitrogen for growth can show deficiency symptoms if the nitrogen limitation is very detrimental. Light nitrogen deficiency, however, may not show visual symptoms but can reduce yields. The first symptom on crops with a more severe nitrogen deficiency is a general pale green or a yellow-green coloration of the leaves. This differentiation will normally occur on the lowest leaves first and then progress to the upper leaves as the deficiency concentrates. Next, general plant stunting and very slow growth of the plant will be noticed. Further limitations in nitrogen availability will cause “firing” on the leaves. An indication of very severe nitrogen deficiency, the dying back of the leaves from the tip in a V-shaped pattern along the leaf mid-rib will occur first on lower leaves and then progress up the plant. Some crops are affected by nitrogen deficiency more quickly than others. The more efficient the crop plant is toward optimizing nutrient use and energy needed by the plant, the more difficult a slight nutrient deficiency may be to see.

Nitrogen toxicity symptoms

Some fertilizer injury can occur to crops with the use of commercial nitrogen formulations. Some crops following within a rotation where high amounts of nitrogen remain may also show toxicity symptoms or simply utilize the nitrogen in luxury consumption. The most common injury to plants when using nitrogen fertilizers is with the use of anhydrous ammonia. Anhydrous ammonia (NH3) can cause vapor damage when crops are sidedressed, particularly if the applicator knives are raised to or above the soil surface. Some crops, such as corn, can usually outgrow the damage if only a portion of the leaves is damaged. Anhydrous ammonia injury can also cause uneven seedling emergence, slow growth of some plants, and wilting of seedlings in dry weather. This injury is detected more frequently in dry weather as under these conditions roots are slow to develop and if a portion of the root is destroyed, water uptake is limited further. This root injury browns the roots and may even, under severe injury, kill the roots.

Non-pressure nitrogen solutions applied over the top of a growing crop may burn leaf tissue. Sprayed solutions will move toward the leaf tips and margins on grass crops and thus may cause greater burning in those areas. Many plants can outgrow this injury if only a portion of the leaves is injured.

Granular urea applied over the top of crops may cause some of the granules to fall into the leaf whorl or lodge in leaf axils. Where granuales lodge, tan burn spots may appear. Crop plants do absorb urea through their leaves so if the amount is excessive, the margins of the leaves may turn white. This symptom of toxicity can usually be outgrown, unless the plants are severely injured.

Alternative plant systems for nitrogen and other soil nutrients

Nitrogen fixation, or the symbiotic association of Rhizobium bacteria on legume plants, can allow mutual benefits for both the plant and the bacteria. These bacteria can invade the plant's root hairs and multiply, forming nodules. In this system, the bacteria are able to obtain carbohydrates manufactured by the host plant during photosynthesis that are translocated into the plant's roots. The bacteria use this energy to convert atmospheric nitrogen to ammonium nitrogen to further the bacteria's growth and reproduction. However, surplus nitrogen is often manufactured and released to the host plant. The plant can utilize this nitrogen to produce amino acids and proteins. Various crops may differ in the amount of nitrogen that can be fixed and how efficient this process is to the plant.

Nitrogen Amount Fixed by Crops

Crop	Nitrogen (lb/A)
Alfalfa	100
Soybeans	30
Peanuts	20

Some of the factors that influence the efficiency and the symbiotic nitrogen fixation process include: soil pH (optimum pH for Rhizobium is 5.5-7.0); soil temperature (optimum for nodule growth is 65F to 82F); soil aeration (rhizobia require free oxygen, thus poor drainage, compaction or surface crusting can limit rhizobia development); soil fertility (essential nutrients for the plant in plentiful supply will increase plant growth and thus will increase nitrogen fixation); nitrogen level in the soil (a balance will allow the nitrogen fixation process to optimize, rather than allowing excess soil nitrogen to limit the symbiotic relationship); molybdenum availability (essential for the conversion process of elemental nitrogen, N_2, to ammonia nitrogen, NH_3, within the bacteria); and photosynthetic rate (nitrogen fixation is high when photosynthesis is proceeding at a moderately high rate but stops when photosynthesis is halted by darkness).

Unavailable nitrogen in the soil may also become available to plants through a process called mineralization. As plant residue is decomposed by microbes in the soil, nitrogen may become available for growing plants.

Organic N ----- mineralization ---→ Inorganic N
or
Organic N ----- immobilization ---→ Inorganic N

Likewise, available nitrogen in the soil may be converted to organic forms, a process called immobilization. This last process occurs readily when fresh crop residues are incorporated into the soil and "tie-up" nitrogen supplies in the soil. This "tie-up" actually occurs when soil microbes that work to decompose residue need supplies of the inorganic nitrogen in order to decompose the fresh residue and to increase their microbial populations during times when residue supplies along with ample energy supplies, the inorganic nitrogen, used to break down the carbon sources (crop residue) are available.

Supplies of nitrogen in the organic or inorganic form are dynamic in soils as mineralization and immobilization are occurring simultaneously, depending on the carbon/nitrogen ratios from the decomposing crop residue. Organic matter in soils contains about 5% nitrogen and 50% carbon with the remaining portion being other elements. This carbon to nitrogen ratio, or 50% carbon to 5% nitrogen, is 10 (50/5 = 10 for the C:N ratio). C to N ratios of plant residue vary from 10 to 1 for legume residue such as alfalfa and up to 200 to 1 for wheat straw. Wheat straw or corn stalks with wide C:N ratios (above 30 to 1) have much more of a carbon supply for the microbes to break down than available nitrogen for the microbes to use as an energy source, thus the soil supply of nitrogen favors nitrogen in the immobile form. On the other hand, green manure crops, such as forage sorghums used between cropping rotations in the Lower Rio Grande Valley, that are turned under when the plants are still fairly small have a narrower C:N ratio (less than 20:1) and favor mineralization of nitrogen. Ratios of about 17:1, favor nitrogen being released for crop plant use. Microbial decomposition of residues toward this mineralization often is within the range of 17:1 down to 12:1. Decomposition of crop residue can be aided in fields where available nitrogen is low by adding commercial fertilizers with nitrogen.

General C:N Ratios for Crop Residues

Crop Residue	Carbon %	Nitrogen %	C:N Ratio
Plant tissue			
Alfalfa hay	40	3.0	13:1
Corn stalks	40	0.7	60:1
Oat straw	37	0.5	80:1
Organic matter			
Under forest	50	2.5	20:1
Under grassland	52	5.0	10:1

Nitrogen “tie-up” or this nitrogen depression period is influenced by three main factors: the C:N ratio of the decomposing residue; the amount of crop residue; and, the environmental conditions of the soil that can hasten or slow the decomposition process. Several environmental conditions determine the decomposition process and may include the soil texture, soil compaction or aeration, the soil’s water holding capacity, soil drainage, soil pH, forms of available nitrogen including mineralized nitrogen and added nitrogen, residue cover, and soil temperature. Any factor that can affect the microbial process of breaking down residue can affect the rate and ratio of nitrogen in the mineralized or immobilized forms.

As mentioned, soil types and the soil environment can influence soil nutrient availability. Soil texture, organic matter content, soil pH as well as the CEC of the soil all play a part in determining how much and which nutrients are available to growing plants.

Sand has the largest particle size and weight over silt or clay particles in soil. However, sand has very little fertility in comparison to the other particle types. Sands contribute to soil drainage, aeration and even tilth but clays have the ability to retain nutrients in plant available forms.

Likewise, organic matter contributes to fertility levels as it too can retain nutrients for plant growth, can tie together soil particles in aggregates to contribute to aeration, soil drainage and soil tilth.

Soil pH can also affect nutrients in the soil and in the soil solution. It may contribute to “tie up” of certain nutrients in acid soils or alkaline soils where the nutrients are not as available or are replaced by other nutrients at high supplies such as calcium or sodium or it makes some nutrients less available such as phosphorus and zinc or it can cause some micronutrients such as molybdenum to become available at high enough amounts to cause toxicity. Soil pH is the acidity or the alkalinity of the soil and is defined as the negative logarithm of the hydrogen ion activity. The pH scale is from 0 to 14 and 7.0 is the midpoint on the scale. From 7.0 down to 0 is acid. From 7.0 up to 14 is alkaline. Each point past 7.0 is an increase by 10 fold in either the acidity or alkalinity. Thus, a soil with a pH of 8.0 is ten times as alkaline as one at 7.0. Most soils range from 2.0 to 11.0, with the more productive, cropped ground usually within the range of 4.5 to 8.5.

Soil Ranges

Soil pH	pH Range
Extremely acid	below 4.5
Very strongly acid	4.6-5.0
Strongly acid	5.1-5.5
Medium acid	5.6-6.0
Slightly acid	6.1-6.5
Neutral	6.6-7.3
Mildly alkaline	7.4-7.8
Moderately alkaline	7.9-8.4
Strongly alkaline	8.5-9.0
Very strongly alkaline	9.1 +

Soils are dynamic and many processes affect soil pH. Irrigation water, application of fertilizers or lime and soil environmental conditions can all make slight changes in the soil pH. The ideal pH range for most crop plants is from 6.0 to 6.5 as most essential plant nutrients are more available at this range. Lower soil pH can limit availability of phosphorus, potassium, calcium, magnesium, iron, copper, zinc, molybdenum and boron. Higher soil pH may affect availability of calcium, magnesium, phosphorus, manganese, iron, zinc, copper, molybdenum and boron.

Other soil environmental conditions can also affect availability of nutrients. Soil temperature can influence plant uptake of nutrients, rate at which nutrients become available from the mineralization process, and organic matter content production and loss from the soil system. Generally, increased soil temperatures speed up organic matter breakdown in soils, thus organic matter content often decreases from north to south in the United States. Rainfall and irrigation can encourage plant growth and help in residue breakdown as well as aid organic matter production. Moisture can influence the movement of mobile nutrients down, up and within the soil profile. Thus, soils in the eastern Midwest where rainfall is more plentiful generally have higher organic matter contents than soils in the drier Southwest.

Cropping systems can affect nitrogen availability

Tillage as well as crop rotation can affect the amount and form that nitrogen is available in soils. Rotation of crops that includes additions of crop residues to insure maintenance or build-up of organic matter will allow more residual nitrogen to be left in the soil. Depending on the microbial population and soil temperatures and timing of residue conversion from crop material into organic matter, the nitrogen may be in several forms with some available and some tightly bound to the soil and organic matter, still unavailable to the plant. Gaining soil tilth so that nitrogen is continually available but not lost through volatilization, erosion or leaching will optimize your nitrogen management system. Tillage can destroy organic matter if ground is over tilled. Reduced tillage systems can add a high level of crop residue that might in the short-run require additional nitrogen fertilizer in order to break down the material into organic matter. However, over time, the soil tilth may be improved so that soil microbes are more abundant and efficient at making nitrogen available to the plant from crop residues. Also, with cropping rotations, additional nitrogen may need to be supplied through the use of commercial fertilizers. Soil testing to determine nitrogen needs is essential in order to develop a crop management plan that includes a maintenance or build-up program for nitrogen needs of specific crops within the rotations. Here are some of the most commonly used supplemental nitrogen fertilizer sources in New Mexico:

Supplemental Nitrogen Fertilizer Sources

Fertilizer	Nitrogen Analysis	Physical Form	Handling Precautions
Anhydrous Ammonia	82.5%	High-pressure liquid	Extreme caution
Aqua Ammonia	20-24%	Water based liquid, some free ammonia	Caution
Ammonium Nitrate	32.5%	Solid	Potentially explosive when in contact With fuel oil
Ammonium Sulfate	20.5%	Solid	No special handling, does have 23% sulfur
Ammonium Sulfate-Nitrate	26%	Solid	No special handling, does have 15% sulfur
UAN	28-32%	Liquid	No special handling
Urea	46%	Solid	No special handling but easily vaporizes off the soil surface

Phosphorus

Available phosphorus in the soil varies with the pH of the soil solution. When the soil is alkaline, as in much of New Mexico, the HPO4 ion is the most common form. As the pH is lowered and the soil becomes moderately acid, both the HPO_4 ion and the H_2PO_4 ion are present. A soil with a mix of the two ions present is preferred in a cropping situation. Soils high in clay content will fix more phosphorus. Very high clay contents, such as in kaolinitic clays, can fix (or bind) phosphorus rapidly. Regardless of the exact clay type in a soil, added phosphorus from fertilizers is rapidly converted to less plant available forms; however, sulfur added to alkaline soils and calcium added on acid soils does seem to increase the availability of added phosphorus. Nitrogen combined within a phosphorus fertilizer also tends to increase the availability of phosphorus. On soils very deficient in phosphorus, zinc added with the fertilizer application can actually restrict phosphorus uptake by plants. A soil pH range of 5.5 to 7.0 will allow soil phosphorus to be the most soluble (available) to plant use. Soil phosphorus exists as both organic and inorganic. The inorganic fraction may include minerals such as apatite or may be combined with iron, aluminum or even calcium. The organic fraction is only about one-third of the soil's supply. The phosphorus concentration across soils averages only one pound per acre; however, soils that are in warmer climates and have lower organic matter content will hold phosphorus better such as here in New Mexico. The soil pH will regulate the availability of phosphorus with less available above pH 7.0 and below pH 5.5.

Phosphorus deficiency symptoms

Phosphorus deficiency can be very difficult to identify when the deficiency is very limited. With severe symptoms, however, the plant will exhibit abnormal coloration, reduced root development, late maturity and even reduced tillering (small grains) or heading (small grains and broadleaf crops). Deficient plants may be shorter and more slender than plants with a more adequate nutrient supply. There may not only be less seed head development, but the seed itself, if it develops, may be shriveled, lighter in test weight and ultimately have lower viability and even a lower germination percentage. As demand for the limited phosphorus is felt by the plant, phosphorus compounds from older leaves are relocated to the younger leaves and up into developing buds, thus symptoms on the plant may progress from the older leaves to the younger leaves on the plant. A deficiency in phosphorus is usually not a delayed symptom. It usually shows up early in the seedling stage of most plants. Demand for phosphorus is very high in seedlings and in crops in which the yield potential is established early, such as in corn where the number of rows on an ear are already determined by the third to fifth leaf stage, a phosphorus shortage can be very detrimental to yields. Also, it is difficult to make effective applications after crop plants are up and growing as commercial phosphorus fertilizers are solids that are slowly available even after incorporation. Phosphorus allows complex carbohydrates and proteins to be formed in plants. Without phosphorus, the plants will not form these complexes but instead will accumulate sugars. In order to utilize these excess sugars, the plant will transform them into pigments. Thus, phosphorus deficient plants may exhibit red or purple (anthocyanin) colors instead of the normal green coloration. This affect can also be caused by very cool temperatures in plants with certain genetics such as sometimes seen in corn planted into very cold soils so soils should be tested to confirm phosphorus deficiencies.

Phosphorus toxicity symptoms

Phosphorus is not usually a problem as most of the phosphorus present in soils is unavailable to plants. Even when soluble sources of the nutrient are supplied in fertilizers, this phosphorus is often fixed or rendered insoluble or unavailable to higher plants, even under ideal field conditions.

Cropping systems can affect phosphorus availability

Several parameters in the field can affect phosphorus availability. Crop rotation, the tillage system used and even the soil itself can make phosphorus less available under certain circumstances. Soil compaction by simply reducing soil aeration and pore space can in turn reduce plant growth and nutrient uptake and thus can lead to phosphorus deficiency. With less root growth, physically a plant roots can not penetrate as much soil area or have as much surface area in which to pull in phosphorus. Likewise, excess soil moisture limits root growth making phosphorus less available. Like with nitrogen, sulfur used on alkaline soils and calcium used on acid soils seems to increase phosphorus availability. Nitrogen within the fertilizer formulation having phosphorus also seem to increase phosphorus availability. Use of zinc can limit the uptake of phosphorus in a plant under extreme conditions. A soil pH of 5.5 to 7.0 has the most soluble, thus available, soil phosphorus. Phosphorus does not tend to move much in soil. This is why reduced tillage systems sometimes show elevated levels of phosphorus in the top few inches of the soil but it is difficult, especially in no-till or ridge-till ground, to actually keep an adequate concentration of phosphorus within the primary root zone of plants. Heavy water erosion that moves soil can also move phosphorus from a field; however, as phosphorus does not move much in soil itself, it takes a major erosion event to move much phosphorus from a field. Soil sampling at least every three years if not every year is one way to insure your phosphorus level is maintained at levels needed for rotational crops over time. Here are a few of the commercial fertilizers used in New Mexico in order to maintain or increase phosphorus levels across a field:

Supplemental Phosphorus Fertilizer Sources

Fertilizer	Phosphorus Analysis	Physical Form	Handling Precautions
Ammonium Polyphosphate	34%	Liquid	No special handling
Monoammonium Phosphate (MAP)	48%	Solid granular	No special handling, contains some nitrogen
Diammonium Phosphate (DAP)	46-53%	Liquid or granular	No special handling, contains some nitrogen

Normal Superphosphate	18-21%	Solid granular	No special handling, 12% sulfur, 20% calcium
Triple Superphosphate	45-46%	Solid granular	No special handling, no sulfur, less than 10% calcium
Superphosphoric Acid	76-83%	Liquid	Precaution from acid
Ground Rock Phosphate (mineral phosphate)	20-40%	Solid particle (various sizes)	No special handling

Potassium

Although not part of the plant structure, potassium serves in a wide range of plant functions. Along with magnesium and calcium, potassium helps to maintain cellular organization and it also provides electrical charge balance, hydration and permeability of cells. It, along with the micronutrients, acts as an enzyme activator or a catalytic entity. Several forms of potassium may exist in soils at any one time. Potassium may be unavailable, exchangeable or in solution. When bound to mineral compounds, it is unavailable until broken down through a chemical reaction. When exchangeable, potassium is in the K^+ ion form and merely attached to clay or organic matter within the soil and is available for uptake by plants. In solution are only a few pounds of potassium per acre. It is simply in equilibrium with the exchangeable potassium that is being removed by crop plants. The average soil has about forty thousand pounds of K_2O in the plow layer, most of which is in the unavailable form.

Potassium deficiency symptoms

The most common symptom caused by potassium deficiency is firing of leaf margins on affected plants. This die-back of the leaves from the tip in toward the plant stem will appear on older leaves in grasses first, but will be more noticeable on the new, upper leaves in broadleaf plants such as cotton. Besides these leaf symptoms, the plant will also exhibit very slow growth and the root system will be very poor. With inadequate roots to sustain good plant growth, yield will be affected both by poor plant growth and development and possibly later due to plant lodging. Without adequate potassium, plants also tend to have a low resistance to disease. Even before visual symptoms appear, low potassium can be causing many limitations to such plant metabolic processes as photosynthesis, carbohydrate metabolism, protein metabolism and even plant-water relations.

Potassium toxicity symptoms

Most soils, except those that are very sandy, are usually high in total potassium. Usually soils have more of this mineral than any other major nutrient. Yet, the amount held in an easily exchangeable condition at any one time is very small. Most potassium is held rigidly as part of the primary minerals or is fixed in forms that are only moderately available to plants. If quantities are added to soils making the nutrient more available, crop plants tend to use more potassium than normally required, a condition called luxury consumption. Toxicity effects are usually not seen.

Cropping systems can affect potassium availability

Cropping systems, rotations and even tillage practices can influence potassium in a field. Under reduced tillage, potassium can accumulate on the soil surface rather than remaining within the root zone for more availability. Potassium has limited movement in soil, so specific fertilizer placement helps to locate the nutrient in the root zone. A sandy soil will need less potassium than a clay soil as the clay will allow the potassium a site to bind to and thus limit the level of exchangeable potassium. Too dry a soil will also limit potassium to roots and calcareous soils has the added disadvantage of having calcium compete with potassium for entrance into the plant roots. Nitrogen added at the time potassium is placed on the soil may make slightly more plant demand for potassium to convert the nitrogen in the plant to a usable protein nitrogen form. Soil testing will insure that potassium levels for specific crops are adequate for the crop growth and development throughout the season. In case supplemental potassium is needed on heavily worked, long-term cropped fields, here are some of the commercial fertilizers commonly used in New Mexico:

Sources of Potassium Fertilizers

Fertilizer	Potassium Analysis	Physical Form	Handling Precautions
Potassium Chloride (muriate of potash)	60-62%	Granular	No special handling, chlorine is present in the formulation
Potassium Sulfate (sulfate of potash)	50%	Solid	No special handling, 18% sulfur is present
Potassium Nitrate	44%	Solid	No special handling, nitrogen is present
Sulfate of Potash-Magnesia	26-30%	Solid	No special handling, 16-22% sulfur and 5-7% magnesium

Secondary nutrient and micronutrient plant requirements and deficiency symptoms

Secondary and Micronutrients

In fields where intensive cropping occurs, the secondary and micronutrients may have to be checked to ascertain if adequate levels are present for crop growth and development. Several conditions may lead to deficiencies in these nutrients that include: crop removal of these nutrients has lead to levels below crop needs; improved crop varieties and fertilizer practices have greatly increased the level of crop production and increased secondary and micronutrient removal; the trend toward high analysis fertilizers has reduced the use of impure salts which contained some of the micronutrients; and, increased knowledge of plant nutrition has helped in the diagnosis of trace deficiencies that previously might have gone unnoticed.

Uses of Secondary and Micronutrients in the Plant
And Most Likely Deficiency Conditions and Treatments

Nutrient	Use	Deficiency Condition	Corrective Treatment
Calcium	Root growth And cell walls	Very low pH	Limestone as specified from soil test
Magnesium	Central constituent Of chlorophyll	Low pH, high K, sandy soils	Broadcast limestone, Mg containing fertilizers

Sulfur	Formation of protein And chlorophyll	Low organic matter, cold/wet soils	Broadcast S containing fertilizers and gypsum
Boron	Protein, N & C Metabolism, root Development, seed Formation, water Relations	High soil pH, low organic matter, sandy soils	Broadcast, strip, starter, foliar or fertigation of Borax, boric formulations, colemanite, solubor
Copper	Respiration, enzymes, Chlorophyll, protein And carbohydrate Metabolism	High organic matter, low organic matter, leaching of other metals	Broadcast, strip, starter, foliar, fertigation of copper containing fertilizers or chelates
Iron	chlorophyll, Respiration, proteins, And enzymes	High pH, compact/ poorly aerated/cool soils	Broadcast, strip, starter, foliar, fertigation of iron fertilizers or chelates
Manganese	N metabolism, Assimilation, Catalyses	High soil pH, high soil organic matter	Broadcast, strip, starter, foliar, fertiligation of Mn fertilizers or chelates
Molybdenum	Symbiotic N fixation, And protein synthesis	Low soil pH, eroded soils	Starter, fertigation, foliar Mo applications
Zinc	Growth hormones, Protein synthesis, Seed maturation	High soil pH, high P levels, cold/wet soils, eroded soils	Broadcast, strip, starter, fertigation, foliar Zn fertilizer or chelates
Chloride	Plant growth and Development	Sandy soils	Broadcast Potassium chloride
Cobalt	Symbiotic N fixation	Sandy soils	Rarely limited

Fertilizers Associated with the Secondary and Micronutrients

Calcium: Calcitric limestone (32%, 85-100 RNV), Dolomitic limestone (22%, 95-108 RNV), Hydrated lime (46%, 120-135 RNV), Burned lime (60%, 150-175 RNV)

Magnesium: Dolomitic limestone (3-12%), Magnesia (56-60% Mg oxide), Magnesium sulfate (9-20%), Potassium-magnesium sulfate (11%)

Sulfur: Thiosulfate (26%), Ammonium sulfate (24%), Gypsum (19%), Sulfate of potash (17%), Elemental sulfur (30-94%), Potassium sulfate (18%)

Boron: Borax (11.3%), Borate 46 (14%), Borate 65 (20%), Boric Acid (17%), Colemanite (10%), Solubor (20%)

Copper: Copper sulfate (22.5%), Copper ammonium phosphate (30%), Copper chelates (5-45%)

Iron: Iron sulfate (19-23%), Iron oxides (69-73%), Iron ammonium sulfate (14%), Iron ammonium polyphosphate (22%), Iron chelates (5-14%)

Manganese: Manganese sulfate (26-28%), Manganese oxide (41-68%), Manganese chelates (12%), Manganese carbonate (31%), Manganese chloride (17%)

Molybdenum: Sodium molybdate (39-41%), Molybdic acid (47.5%)

Zinc: Zinc sulfate (23-55%), Zinc oxide (78%), Zinc ammonia complexes (10%), Zinc chelates (9-14%)

Chloride: Potassium chloride (47%)

Parent material of each soil tends to influence the content of the secondary and micronutrients in cropping fields. Deficiencies of these nutrients can usually be traced back to low content in the parent rocks or transported parent material. Similarly, toxic quantities are usually related to abnormal amounts in the soil-forming rocks and minerals. Because smaller quantities of these materials are needed by plants, less is known about these minerals and all the plant processes in which they play a role. Also, many of the micronutrients are often very dependent on the weathering or erosion of soils for content. Harvested crops do slowly remove nutrients, thus intensive cropping can hasten the onset of micronutrient shortage, particularly when soils are sandy.

Secondary and Micronutrient Deficiency Symptoms

Nutrient	Deficiency Symptoms
Calcium	Death of apical meristems, root tips, and buds. Stunting of the plant roots. Poor yield on fruit or seed even before visual symptoms are noticed. Deficiency is sometimes related to saline or sodic soils and visual symptoms are most common during rapid leaf growth. Common on tomato and sometimes on cauliflower more than in agronomic crops.
Magnesium	Very rare even on very acid soils or very coarse sands, but can exhibit several different symptoms. At first, chlorosis (yellowing) may not be prominent, but instead plants may exhibit purple or red color on leaves or stems. Wheat leaves will be more slender and early growth and tillering is reduced. Later, some general yellowing of leaves can be seen. Eventually necrotic spots may appear on leaves.
Sulfur	This deficiency will occur in wet years, on sandy, intensively cropped land, particularly in plants in the mustard family. Chlorosis of leaves, such a bright yellow it can appear nearly white, will be accompanied with interveinal chlorosis. Eventually the plant exhibits stunting. Legumes may exhibit poor nodule development. Crops may have low yields that are further aggravated in soils with salts or compaction problems.
Boron	Usually a very scattered deficiency. The terminal meristem may look strange as plant cells are disrupted, leading to death of the meristem. Plant growth is inhibited and the phloem, xylem and even cambium in the plant stems may begin to break down. Yellowing or mottling may eventually occur with ragging on leaf margins and black necrotic spots on such crops as sugarbeets. Mustards and celery may exhibit hollow stems and cauliflower may gain a greenish yellow cast.
Copper	Deficiency of copper may first be noticed as withering or wilting of a plant. Later stunting and some chlorosis may appear. Poor fruit and seed production usually results.

Iron	High soil pH or saline/sodic soils can exhibit iron deficiency. Interveinal chlorosis showing pale green to yellow between leaf veins appears. The young leaves are the first to show symptoms. Plants can be stunted and on small grain leaves, gray spots may eventually appear. Iron deficiency is usually difficult to detect, except on crops where the symptoms are more pronounced such as in dry beans or soybeans.
Manganese	A rare deficiency that is usually associated with high pH and when iron additions may block manganese absorption. Chlorosis will show yellow to white bleached bands between the midrib and the leaf margins in grain crops such as wheat or corn. Leaf tips and margins may remain greener. Beans may show spotting and leaf stunting and malformation. Often seen early in the season, this deficiency can create rosetting of some crops. The symptoms can be worse in areas with high phosphorus levels.
Molybdenum	The deficiency symptoms here can mimic those of nitrogen with leaves showing a yellow-green, pale cast. In fact, sometimes the symptoms can be relieved by additions of NH_3 or Mo. Later stunting and low yields may also be seen.
Zinc	This deficiency is common in dry beans, corn and potato. The chlorosis first seen will be interveinal chlorosis on younger leaves. Internodes on plants may be shorter, leaves smaller, and the plant may even show signs of resetting and wrinkled leaves. Ultimately, poor seed production results. Pecans are a high user of zinc foliar treatments in order to optimize nut yields.
Chloride	Very rarely seen as a deficiency. Root crops such as sugarbeet have shown symptoms that are not chlorosis but rather yellowing or mottling of leaf tissue and terminal bud deformation or death. Sunflowers may have malformed or leathery leaf tissue with corky, brittle leaf stems and head deformation. The symptoms will be worse under drought stress.
Cobalt	No symptoms are established in plants as it is rarely seen. However, it has been established as a needed nutrient in plants such as legumes used for animal feeds.

Secondary and Micronutrient toxicity symptoms

Nutrient	Deficiency Symptoms
Calcium	This nutrient easily ties up in soils but at very high rates can add to the flocculation of soil particles. This is usually beneficial as it helps form stable aggregates or granules; however, in arid regions, sodium ions also are prominent in the exchange process and this results in a dispersed condition, making soils impervious to water penetration.
Magnesium	Magnesium is rarely too abundant as this nutrient is very mobile and in plants readily can be translocated from older to younger leaves.
Sulfur	Rarely a toxicity problem, sulfur, like nitrogen, is quickly reduced within plants.
Boron	Requirements for boron and calcium may both be needed for cell wall

	formation and in the metabolism of pectic compounds. In dry soils, levels necessary may be higher than in soils with adequate moisture. If boron fertilization is adequate for a vegetable crop or even for alfalfa, a small grain crop grown in rotation may show toxicity damage. Symptoms may be confused with high salinity and iron deficiency—chlorosis and yellowing near the leaf veins. Plants grown in alkaline soils are more sensitive to boron. Besides chlorosis, speckling of the plant leaves may occur and in more extreme cases, necrosis can occur.
Copper	Copper toxicity is rare as is toxicity to heavy metals unless contamination of a site has occurred, such as on a superfund site being remediated. Toxicity symptoms include an induced iron deficiency, inhibition of root growth and a decrease in the metal in plant shoots.
Iron	Normally not toxic in soils with a pH over 7.0 as iron is usually fixed in alkaline soils and thus less readily available.
Manganese	Varieties differ widely in tolerance to manganese availability. Toxicity is usually induced by high soil water content and low iron availability. In arid regions, problems of toxicity are less as the ion is relatively immobile.
Molybdenum	Toxicity is rare.
Zinc	Toxicity is rare as this nutrient ties up easily in more alkaline soils. When toxicity is noted, like the other metals the symptoms can include an inhibition of root growth.
Chloride	Over application through fertilizers or poor quality water can cause toxicity in sensitive crops such as dry beans and potatoes as well as many vegetables. High supplies of chloride in the soil can lead to salinity problems and unless corrected by leaching salts from the soil can cause lack of growth in crop plants, dehydration of the plants or even plant death.
Cobalt	Toxicity is not known but little is confirmed on the role of cobalt in soils.

Some of the New Mexico Crops Having a High Requirement for Micronutrients

Micronutrient	Crops with High Requirements
Iron	peaches, grapes, nut trees
Manganese	beans, soybeans, onions
Zinc	citrus and fruit trees, beans, corn, soybeans
Copper	citrus and fruit trees, onions, small grains
Boron	alfalfa, clovers, sugarbeets, cauliflower, celery, apples, other fruits
Molybdenum	alfalfa, sweet clover, cauliflower, broccoli, celery

Cropping systems can affect secondary and micronutrient availability

A nutrient balance among the trace elements is essential and more difficult to maintain than that even for the macronutrients. Utilization of some of the trace minerals is dependent upon a proper balance, such as with boron and calcium as well as potassium and copper and potassium and iron (as in potatoes). Copper use is favored by adequate manganese, which can only occur if zinc is present in sufficient amounts. Antagonistic effects can also occur with excesses of some of the nutrients. Excess copper or sulfate may affect the use of molybdenum and iron deficiency may be seen where excess zinc, manganese or copper are found. Excess phosphate may cause deficiencies of zinc, iron or copper. Heavy nitrogen may intensify copper deficiency. Excess sodium or potassium may adversely affect manganese uptake. Iron, copper or zinc may reduce manganese absorption.

Sandy soils, mucks and soils having very high or very low pH values are more likely field candidates for problems with secondary and micronutrients. Intensively cropped land or fields that have had heavy macronutrient fertilization may be deficient in trace minerals. Soils with extreme pH ranges or pH changes even if rather gradual should be more closely monitored.

Drainage and moisture control influences micronutrient solubility so well-drained soils can better oxidize iron and manganese, thus even under unusual acid soil conditions, will prevent toxicity from these reduced nutrients.

Rotations of crops can benefit overall utilization and maintenance of trace minerals, however, making fertilizer recommendations with rotations can be difficult. Thus, more intensive soil sampling during rotations to high dollar crops is essential in determining nutrient requirements. Remember too that some of the commonly used macronutrient fertilizers may contain some micronutrients. For instance, superphosphate may contain up to 20 parts per million of boron. So crop rotation, cropping intensity, soil types and additions of commercial fertilizers all need to be taken into account when managing for secondary and micronutrients.

General fertilizer suggestions for crops in New Mexico

Suggested Application of Fertilizer Nutrients for Irrigated Crops

(Modify the rates of fertilizer applications suggested here by your own experience, local conditions, and management practices. These are general fertilizer questions if soil testing is not available.)

	Pounds per Acre			
Crop	N	P_2O_5	K_2O	Remarks
Alfalfa				
New seedings	20	120	50	A starter of up to 20 pounds of N is recommended for new seedings. Incorporate P_2O_5 for new seedings and top dress established stands in the spring.
Established stands	0	120	50	
Barley				
Spring	120	60	40	Apply P_2O_5 and K_2O at planting time. Apply 1/2 N at planting time and 1/2 prior to jointing.
Winter				
Cabbage, 220	90	40		Apply all P_2O_5 and K2O at planting time.
Broccoli,				Apply 1/3 N at planting time, 1/3 at

Cauliflower				thinning and 1/3 after first fruit has set.
Carrots	120	60	30	Apply P_2O_5 and K_2O at planting time. Apply 1/2 N at planting time and side-dress 1/2 after 6 weeks.
Chile				
Green	60	45	30	Apply P_2O_5 and K_2O at planting time.
Red	80	45	30	Apply 1/2 N at planting time and 1/2 after 8 weeks.
Corn Field and Sweet	200	80	60	Apply P_2O_5 and K_2O at planting time. Apply 1/2 N at planting time and side-dress 1/2 N at lay-by.
Cotton				
Upland	120	60	40	Apply P_2O_5 and K_2O at planting time.
Pima	100	60	40	Apply 1/2 N at planting time and 1/2 at first square.
Cucumbers	100	80	30	Apply P_2O_5 and K_2O at planting time. Apply 1/2 N at planting and 1/2 when vining begins.
Grapes	60	30	20	Apply P_2O_5 and K_2O in the spring. Apply 1/2 N in spring and 1/2 6 weeks later.
Green beans	0-20	60	30	Apply at planting time.
Irrigated Pasture				
Grass	200	60	60	Apply P_2O_5 and K_2O in the spring. Split
Grass Legume	160	75	60	N into 2-4 applications with the first in early spring.
Lettuce	200	100	60	Apply P_2O_5 and K_2O at planting time. Apply 1/5 N at planting, 1/5 at thinning, 1/5 when first heads appear and the rest in 1 or 2 side-dressings during head development.
Oats	100	40	25	Apply P_2O_5 and K_2O at planting time. Apply 1/2 N at planting and 1/2 prior to jointing.
Onions				
Grano				
(Fall planted) Sweet Spanish	200	100	60	Apply P_2O_5 and K_2O at planting time. On granos, apply 48 pounds of N at planting, 60 pounds in the spring when growth begins and the remainder in 3 equal parts with the last 30 days prior to harvest. For sweet Spanish apply 50 pounds N at planting time and 30 pounds at 21-day intervals beginning April 15.

Peanuts	20	60	30	Apply at or before planting.
Peas	20	60	30	Apply at planting time.
Pinto Beans	20	45	25	Apply at planting time
Potatoes				
Irish	200	180	150	Band all P_2O_5 and K_2O at planting time. Band 1/2 N at planting and 1/2 when plants are 6 inches tall.
Rye	120	60	40	Apply all P_2O_5 and K_2O at planting time. Apply 1/2 N at planting and 1/2 just prior to jointing.
Sorghum				
Grain	150	90	60	same as corn.
Forage	200	85	60	same as corn.
Sorghum				
sudangrass	200	80	60	Apply all P_2O_5 and K_2O at planting time. Apply 2 N at planting and the remainder after cutting or grazing as needed.
Sweet potatoes	50	60	30	Apply all P_2O_5 and K_2O when bedding. Apply 1/2 N at bedding and the rest when runners are 6 inches long.
Tomatoes				
Hand (multiple)	160	150	120	Band all P_2O_5 and K_2O below the row at planting. Apply 1/3 N at planting, 1/3 at first cluster set and 1/3 a month later.
Machine harvest	120	150	120	Band all P_2O_5 and K_2O at planting. Apply 1/2 N at planting and 1/2 at thinning.
Watermelon	80	80	60	Band all P_2O_5 and K_2O before bedding. Band 1/2 N before bedding and 1/2 when vines begin to run.
Wheat				
Winter	100	45	25	Apply all P_2O_5 and K_2O at planting time.
Spring				Apply 1/2 N at planting time and 1/2 prior to jointing.

Suggested Application of Fertilizer Nutrients for Orchards and Ornamentals

Established	Pounds per Tree per Year N	Remarks

Apples	1/4	Per inch of trunk diameter to a maximum of 5 lbs. N per tree.
Pears	1/4	Split rate into two applications:
Peaches	1/4	one half before or at bud break, the
Pecans (bearing)	1/4	other half in late May or early June.
Shade or Ornamental Tree	1/4	Do not fertilize after July 10.
Conifers	1/8	Nitrogen fertilization is not recommmended in the first year of establishment.

Post-Study Questions for Review

1. Soil pH for most productive, cropping locations is _____.
   a. a range of 4.5 to 8.5
   b. a range of 2 to ll
   c. a range of 7 to 10
   d. a range of 1 to 14
2. The pH scale is from _____ to _____.
   a. 3 to 9
   b. 2 to 12
   c. 6.8 to 8.6
   d. 1 to 14
3. Ions may become attached to soil colloids or may be available in the film of water around the soil colloids called the _____.
   a. soil hydroplane
   b. soil salt bath
   c. soil solution
   d. soil saturation level
4. Root interception, diffusion and mass flow are three main ways nutrients are:
   a. applied to the field
   b. moved through the soil water
   c. absorbed into plant roots
   d. randomly arranged in the soil
5. Trace minerals may be more deficient in _____ soils.
   a. clay
   b. muck
   c. sandy
   d. silty
6. The C:N ratio is as low as _____ when plant residue will stop being decomposed by soil microbes as nitrogen is limited.
   a. 24:1
   b. 5:1
   c. 2:1
   d. 12:1
7. A soil is considered neutral in pH at _____.
   a. 8
   b. 3
   c. 7
   d. 5
8. How much more alkaline is a soil with a pH of 8.0 than one with a pH of 7.0?
   a. 100 times
   b. 10 times
   c. it is not more alkaline
   d. 1000 times

9. This deficiency in grain crops may appear as interveinal, light striping or a whitish band beginning at the base of the plant and extending towards the tip.
   a. Boron
   b. Calcium
   c. Sulfur
   d. Zinc
10. This deficiency may give plants reddish-purplish leaf tips and margins in early stages of growth.
   a. Potassium
   b. Phosphorus
   c. Nitrogen
   d. Calcium

Check your answers before proceeding to the next unit to find out how much you learned about basic concepts of plant nutrition. Each correct answer is worth 10 points, based on a total of 100 points for the ten questions. Answers: 1. a.; 2. d.; 3. c.; 4. c.; 5. c.; 6. d.; 7. c.; 8. b.; 9. d.; 10. b.