IV. PLANT NUTRIENT ELEMENTS

1. Introduction

There are sixteen (16) elements that have been established as essential for the optimal growth of chlorophyll-containing plants. These elements have been divided into two groups, nine (9) as major elements [carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S)], since they are found in relatively high (>1.00%) concentrations in the plant, and seven (7) elements as micronutrients [boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn)], since they are found in relatively small (<0.1%) concentrations in the plant. Three of the major elements, carbon, hydrogen, and oxygen, are combined in the process called "photosynthesis" ($H_2O + CO_2$ in the presence of light and chlorophyll = $C_6H_{12}O_6 + O_2$) forming the carbohydrate structure of the plant, hydrogen (H) coming from water (H_2O) and carbon (C) and oxygen (O) coming from carbon dioxide (CO_2) in the air. These three elements constitute 90 to 95% of the dry matter content of most plants.

2. Major Mineral Elements

There are 6 essential major mineral plant nutrient elements, [nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S)], that constitute in total between 5 to 10% of the dry weight of most plants. The following discussion focuses on the soil characteristics for these 6 elements.

a. Nitrogen (N)

The quantity of organic or inorganic nitrogen forms present in the soil that can be easily correlated with plant growth cannot be determined by means of a simple routine analysis of the surface soil. During the growing season, small amounts of nitrogen, perhaps 10 to 20 pounds nitrogen per acre per year, will be released from decomposing soil organic matter and crop residues. This amount of released nitrogen is small compared to that required for optimal crop production.

The nitrogen contained in biosolids, plant residues, and manures cannot be utilized by plants until naturally occurring decomposition begins and their contained nitrogen is released in an inorganic form, usually as ammonium into the soil solution. This decomposition process, termed "mineralization," is carried out by soil microorganisms present in most soils. The rate of decomposition depends on soil temperature, pH, and moisture content, and degree of aeration, rapidly occurring at warm soil temperatures, under moist soil conditions, and when the soil is well aerated (when tilled). Once the inorganic ammonium form is released into the soil solution, it is readily converted to nitrate by soil nitrifying bacteria within one to three weeks. The rate of conversion is dependent on soil conditions and temperature.

Nitrogen exists in the soil solution as either the ammonium (NH_4^+) cation or nitrate (NO_3^-) anion. Under normal conditions of soil temperature, aeration and moisture content, the NH_4^+ cation will be readily nitrified to the nitrate form. Being a cation, NH_4^+ will be retained in the soil on the cation exchange complex, while the NO_3^- anion readily moves within the soil profile by either the downward movement of water as a result of heavy rainfall or applied irrigation water, or by the upward movement of water being evaporated from the soil surface.

Another source of plant-available nitrogen is that remaining in the soil from a previous fertilizer application (residual nitrogen), that may exist in an inorganic nitrogen form, or in crop residues and soil microbial biomass. Poor growing conditions in the previous year and low rainfall through the cool season can result in significant nitrogen retention in the soil profile. That amount can be estimated by extracting nitrate-nitrogen from a soil core taken to a depth of 36 inches.

Unless significant residual nitrate-nitrogen remains in the soil from the previous crop, nitrogen recommendations for non-legume crops are based on:

- crop nitrogen requirement
- yield goal

The nitrogen recommendation rate can be either increased or decreased if local conditions dictate that such an adjustment will be profitable, based on either previous experience or on guidance from the local County Extension Agent. Either too little or too much nitrogen can significantly impact both crop yield and quality. For grain crops, nitrogen applied close to harvest will result in excessive vegetative growth and delayed harvest.

Nitrogen fertilizers should be applied either at planting or as close as practical to the time when the crop needs nitrogen. Split nitrogen applications are one way to improve nitrogen utilization by the plant. For example, when fall planting a small grain crop, only 20 to 30 pounds nitrogen per acre are recommended, with the balance of the crop nitrogen requirement being top-dressed in the following February. Likewise for corn, 30 pounds nitrogen per acre is recommended at planting with the balance of the nitrogen requirement being side-dressed when the plants are 18 to 30 inches tall. Such procedures maximize fertilizer-use efficiency, thereby reducing the potential plant nitrogen stress as well as possible loss through runoff and percolation into either surface or ground water supplies.

Nitrogen fertilizer is not recommended for legume crops, except when a small amount of nitrogen will assist in plant establishment. Most legumes benefit from the fixing of atmospheric nitrogen (N_2) by microorganisms functioning symbiotically on the roots of the legume plant. This symbiotic association between the legume plant and nitrogen -fixing microorganisms performs best on fertile soils that have been adequately limed and fertilized. Seeds of all leguminous crop plants should be inoculated before sowing unless that legume species has been grown in the field within the past two years. Inoculation ensures optimum nodule formation, resulting in effective nitrogen fixation. Specific *Rhizobium* strains may be required for some legumes, such as cowpea and Southern peas. When nitrogen fertilizer is applied to legumes, or the soil has a substantial residual nitrogen level, both nodule formation and biological N_2 fixation can be significantly reduced.

When a non-legume crop follows a legume crop, the nitrogen fertilizer recommendation is reduced by 25 pounds nitrogen per acre since the nitrogen in legume-plant residues can contribute considerable nitrogen to the following crop. The level of nitrogen credit will be determined by several factors, the quantity of residue left behind in the soil, the carbon:nitrogen (C:N) ratio of the residue, and the degree of microbial activity occurring during the time of decomposition and nitrogen release. Therefore, the 25 pounds nitrogen per acre is an average expected credit that can be more or less, depending on the conditions mentioned above.

When high carbon:nitrogen (C:N) ratio crop residues are incorporated into the soil, additional nitrogen fertilizer may be needed to prevent a possible nitrogen deficiency from occurring in a high nitrogen-requirement crop, since soil microorganisms are more efficient in nitrogen utilization than most crop plants.

Sizeable quantities of nitrogen can be lost from the soil by denitrification, the conversion of inorganic soil nitrogen forms into nitrogen (N_2) gas. Denitrification, being a biological process, rapidly occurs under anaerobic conditions (when a soil is water saturated) and under warm soil temperature conditions.

List of Nitrogen-containing Commercial Fertilizers:

Source	**Formula**	**Form**	**%N**
	Inorganic		
Ammonium nitrate (34-0-0)	NH_4NO_3	Solid	34
Ammonium sulfate (21-0-0)	$(HN_4)_2SO_4$	Solid	21
Ammonium thiosulfate (12-0-0)	$(NH_4)_2SO_3$	Liquid	12
Anhydrous ammonia (82-0-0)	NH_3	Gas	82
Aqua ammonia (20.5-0-0)	NH_4OH	Liquid	2-25
Calcium cyanamide	$CaCN_2$	Solid	21
Calcium nitrate (15.5-0-0)	$Ca(NO_3)_2.4H_2O$	Solid	16
Diammonium phosphate (18-46-0)	$(NH_4)_2HPO_4$	Solid	18
Monoammonium phosphate (12-51-0; 11-52-0; 10-50-0)	$NH_4H_2PO_4$	Solid	11
Nitrogen solutions	Varies	Liquid	19-32
Potassium nitrate (13-0-44)	KNO_3	Solid	13
Sodium nitrate (16-0-0)	$NaNO_3$	Solid	16
	Synthetic organic		
Urea (46-0-0)	$CO(NH_2)_2$	Solid	45
Sulfur-coated urea (40-0-0)	$CO(NH_2)_2$-S	Solid	40
Urea formaldehyde (38-0-0)	$CO(NH_2)_2$-CH_2O	Solid	38
	Natural Organic		
Animal Waste		Solid	~1 – 4
Animal Waste		Liquid	~0.1 – 0.5
Poultry Waste		Solid	~2.5
Cotton Seed Meal		Solid	12 – 23
Milorganite		Solid	12

Sewage Sludge	Solid	10 – 20

Major Nitrogen Fertilizer Sources Used in South Carolina (2005-2006)
(1,000 tons or more in order of use, largest to least)

30-0-0 liquid
25-0-0 liquid
32-0-0 liquid
46-0-0 (urea) solid
34-0-0 (ammonium nitrate) solid
21-0-0 (ammonium sulfate) solid
28-0-0 liquid
24-0-0 liquid

b. Phosphorus (P)

Phosphorus is included in the Standard Soil Test. The phosphorus level in the soil is determined by the Mehlich No.1 extraction procedure. A phosphorus fertilizer recommendation is based on:

- amount of phosphorus extracted from the soil
- soil group
- crop to be grown
- expected likelihood of an economic crop yield response to applied phosphorus

The soil test-based phosphorus fertilizer recommendation is designed to maintain the soil phosphorus test level within the “sufficient” range, thereby keeping the soil phosphorus level from reaching the “high” test level, thereby creating a potential plant imbalance and/or environmental hazard, or slipping back into the “medium” or less test levels, resulting in reduced crop yields.

When applied as fertilizer, phosphorus usually remains in the surface soil horizon at the point of contact. A major portion of soil phosphorus is not readily available to the plant since it is tightly bound to soil particles as well as existing as aluminum, iron and calcium phosphate compounds that are relatively insoluble. In course textured soils, some phosphorus may move downward when surface soil available phosphorus reaches the “high” test level. However, significant amounts of phosphorus are not readily leached from most surface soil into the subsoil. Most downward phosphorus movement into the subsoil occurs as a result of tillage, and root growth into the subsoil.

Soil test phosphorus levels in native soils normally decline with depth, while for a cropped soil, the extent of decline will be determined by the frequency and depth of tillage. Declining phosphorus soil test levels with soil depth may eventually begin to adversely affect crop yields. Therefore, turning the soil to mix applied phosphorus fertilizer into the soil profile is a highly desirable procedure. A surface soil (6 to 8 inches in depth) testing “high” in phosphorus may test “medium” or “low” following deep tillage to a depth of 8 to 12 inches, the result of bringing into the now deeper surface soil zone, “low” testing phosphorus soil material.

While the leaching of phosphorus through the soil profile does not commonly occur, surface losses of phosphorus can be significant as a result of soil erosion. Phosphorus attached to eroding soil particles can contribute to excessive levels of phosphorus in surface waters.

Soils that have been fertilized for several years using only or primarily, poultry litter, dairy wastes and other animal manures, can begin to test “high” or “excessive” in phosphorus, since application rates of these substances are generally based on their nitrogen content. Animal manures commonly have similar nitrogen and phosphorus contents, and most crops will utilize 5 to 10 times more nitrogen than phosphorus, therefore, phosphorus will begin to accumulate in the soil under such management practices.

Soil acidity as well as soil moisture and temperature levels are associated with phosphorus crop availability. Corn seedling response to phosphorus is likely to occur in cool spring weather (low soil temperature) conditions. When purple coloration of corn leaves occurs, the effect is not due to low phosphorus availability, but to slow root growth (reduced soil-root contact) and a lower rate of phosphorus absorption by plant roots that occurs when such climatic conditions exist.

Three crop conditions that will benefit from the banding of phosphorus fertilizer are

- for transplants when phosphorus is recommended
- when planting in cold soils in late winter or early spring when the phosphorus soil test level is “medium” or less
- under soil conditions when the phosphorus soil test level is “very low” or “low”

When the phosphorus soil test level is “high” and no phosphorus fertilizer is applied, the soil should be tested the following year to determine if that high status still exists.

Additional phosphorus may not be needed for soybeans or peanuts if a soil test recommended amount of phosphorus had been applied to the preceding crop.

Phosphorus exists in the soil solution as either the monohydrogen phosphate (HPO_4^{2-}) or dihydrogen phosphate ($H_2PO_4^-$) anions, depending on the soil pH.

List of Phosphorus-containing Commercial Fertilizers:

Source	**Formula**	**% Available P_2O_5 Citrate Soluble**	**Water Soluble**
Ammonium polyphosphate (10-34-0)	$(NH_4)_3HP_2O_7 \cdot H_2O$	55	100
Basic slag (0-9-0)	$3CaOP_2O_5 \cdot SiO_2$	2 – 16	--
Concentrated superphosphate (0-45-0)	$Ca(H_2PO_4)_2$	44 - 52	
Diammonium phosphate (18-46-0)	$(NH_4)_2HPO_4$	46 – 48	100
Monoammounium phosphate (12-51-0; 11-52-0; 10-50-0)	$NH_4H_2PO_4$	48	100
Phosphorus acid (0-54-0)	H_3PO_4	55	100

Rock phosphate, fluo- and chloro-apatites	$3Ca_3(PO_4)_2CaF_2$	3 – 26	0
Superphosphate, 20% (0-20-0)	$Ca(H_2PO_4)_2$	16 – 22	9
Superphosphoric acid, polyphosphate	$H_3PO_4 + H_4P_2O_7$	76 – 85	100

Major Phosphate Fertilizer Sources Used in South Carolina (2005-2006)

Basic slag (0-9-0) 4,566 tons; triple superphosphate (0-46-0) 432 tons; triple superphosphate (0-45-0) 70 tons	22 – 28	--

c. Potassium (K)

Potassium is included in the Standard Soil Test. Potassium extracted by the Mehlich No. 1 extraction reagent is that existing in the soil solution plus that on the soil cation exchange sites. The quantity of potassium extracted is used in the calculation for determining the cation exchange capacity (CEC) of the soil.

A potassium fertilizer recommendation is based on

- amount of potassium extracted from the soil
- crop to be grown
- expected likelihood of an economic crop yield response to applied potassium
- adjustment based on subsoil potassium test level

Potassium can be leached from the sandy surface soil into the subsoil on those soils typically found in the Coastal Plain region. This loss by leaching makes it nearly impossible to build the potassium soil test level above the “medium” category for most sandy soils. By applying potassium fertilizer just prior to planting, this loss by leaching should not be sufficient to reduce yield under normal rainfall/irrigation conditions. However, in those years when rainfall amounts are high, leaching of potassium from the surface soil may be sufficient to affect crop yields for Soil Groups 1 and 2 but not for the other soil groups.

When the soil potassium test category is “high,” potassium not removed by the crop will tend to leach into the lower soil horizon when the soil is fallow. If a subsoil test for potassium is conducted for Soil Group 2 (having a clay layer within 20 inches of the surface) and Soil Group 3 soils and the test category is “high,” the recommended potassium fertilizer rate based on the surface soil test potassium level can be reduced.

It is not uncommon for the plant to take up more potassium than needed if a potassium-containing fertilizer is applied at a rate greater than that recommended. This phenomenon is known as “luxury consumption,” a condition that can significantly affect plant yield and quality. In addition, due to luxury consumption, a considerable amount of potassium will be removed if the entire plant is harvested. Therefore, for a following crop, more potassium than what might be expected will need to be applied.

When the level of magnesium in the soil tests "low," a high potassium fertilizer rate may induce a magnesium deficiency. In the event that the K soil category is "high" or above, no potassium fertilizer should be applied. However, the soil should be tested the following year for potassium to determine if the "high" category status still exists.

For some South Carolina soils, the presence of potassium-containing minerals (i.e., mica and feldspars) may release sufficient potassium to satisfy the crop potassium requirement, even though a potassium soil test result may indicate insufficient potassium.

Potassium exists in the soil solution as the potassium (K^+) cation.

List of Potassium-containing Commercial Fertilizers:

Source	**Formula**	**%K**
Potassium chloride (muriate of potash) (0-0-60)	KCl	60 - 63
Potassium hydroxide	KOH	83
Potassium magnesium sulfate (SUL-PO-MAG)	$K_2SO_4.MgSO_4$	22
Potassium nitrate (13-0-44)	KNO_3	44
Potassium sulfate (0-0-50)	K_2SO_4	50 - 52

Major Potash Fertilizer Sources Used in South Carolina (2005-2006)

Potassium chloride (0-0-60) 5,429 tons; 83
potassium sulfate (0-0-50) 1,116 tons;
potassium chloride (0-0-62) 593 tons

d. Calcium (Ca)

Calcium is included in the Standard Soil Test. Calcium extracted by the Mehlich No. 1 extraction reagent is that existing in the soil solution and on the soil cation exchange sites. The quantity of calcium extracted is used in the calculation for determining the cation exchange capacity (CEC) of the soil.

If lime has been recently applied (less than 6 months), a portion of unreacted lime may be dissolved by the Mehlich extractant, thereby adding calcium found in the filtrate that can affect both the interpretation of the calcium test result and CEC calculation.

The calcium requirement for most crops is satisfied if the soil pH is within the desired range for that crop and the soil is regularly limed, using either calcitic or dolomitic limestone, based on a soil test lime recommendation. When the calcium test category is "low," a small amount of a liming material (500 to 1,000 pounds per acre) can be soil applied to supply sufficient calcium to satisfy the crop requirement even if the soil pH is within the recommended range (>6.0 or 6.5). Another option for supplying calcium when the soil pH is within or above the desired range is to apply a commonly-used source of calcium, gypsum ($CaSO_4{\cdot}H_2O$).

Those crops commonly grown in South Carolina and most sensitive to low soil calcium are: tomato, pimento, peanut, and fruit and nut trees.

Calcium exists in the soil solution as the calcium (Ca^{2+}) cation.

List of Calcium-containing Commercial Fertilizers:

Source	**Formula**	**%Ca**
Calcium nitrate (15.5-0-0)	$Ca(NO_3)_2$	19
Gypsum	$CaSO_4 \cdot H_2O$	23
Gypsum (by product)	$CaSO_4 \cdot H_2O$	17
Gypsum (impure)	$CaSO_4 \cdot H_2O$	15
Superphosphate, normal (0-20-0)	$Ca(H_2PO_4) + CaSO_4 \cdot 2H_2O$	20
Superphosphate, triple (0-45-0)	$Ca(H_2PO_4)_2$	14

e. Magnesium (Mg)

Magnesium is included in the Standard Soil Test. Magnesium extracted by the Mehlich No. 1 extraction reagent is that existing in the soil solution and on the soil cation exchange sites. The quantity of magnesium extracted is used in the calculation for determining the cation exchange capacity (CEC) of the soil.

Normally when the soil magnesium test category is “low”, the soil will also have a low soil pH. Therefore, broadcasting dolomitic limestone that contains magnesium, based on a soil test lime recommendation, will at the same time increase the magnesium soil test level and correct the soil acidity. When the soil is acidic and liming is required, and the soil magnesium test category is “medium” or higher, any source of lime can be used. The selection of dolomitic limestone each time the soil is limed will not result in magnesium toxicity or cause a cation imbalance in the soils typically found in South Carolina. When the soil test magnesium category is “low” and liming to correct soil acidity is not required, an application of 10 to 15 pounds magnesium per acre as either magnesium sulfate ($MgSO_4 \cdot 7H_2O$) or sulfate of potash-magnesia (SUL-PO-MAG) is recommended to satisfy the magnesium crop requirement.

If the soil magnesium test category in the subsoil is “medium” or higher, a magnesium recommendation based on the surface soil magnesium test level can be disregarded when growing most crops, but not for those crops sensitive to magnesium. This assumption from subsoil magnesium assumes that there will be normal expected root growth into the subsoil.

Vegetable crops, such as beets, broccoli, cabbage, carrot, cauliflower, collards, eggplant, onions, pepper, pole beans, spinach or greens are very susceptible to magnesium deficiency when either the soil magnesium test category is “low” and/or the soil pH is below that recommended for best plant growth.

Magnesium deficiency can occur when:

- the soil pH is less than 5.5

- there is an imbalance among the other major cations, potassium (K^+) and calcium (Ca^{2+})
- plants are under moisture stress for an extended period of time

Some crop species and varieties will develop magnesium deficiency symptoms, even though sufficient magnesium exists in the soil, due to a combination of moisture and temperature stresses.

Magnesium exists in the soil solution as the magnesium (Mg^{2+}) cation.

List of Magnesium-containing Commercial Fertilizers:

Source	**Formula**	**%Mg**
Magnesium oxide	MgO	50 – 55
Magnesium sulfate (Epsom Salts)	$MgSO_4 \cdot 2H_2O$	10
Potassium magnesium sulfate	$K_2SO_4 \cdot MgSO_4$	11
Pro/Magnesium	$3MgOSiO_2 \cdot 2H_2O$	22

f. Sulfur (S)
A determination for sulfur is not included in the Standard Soil Test, but its determination can be requested.

The use of ammonium phosphates and concentrated superphosphate (triple superphosphate, 0-45-0) rather than superphosphate (0-20-0) fertilizers has resulted in an increase in the potential for sulfur deficiency in South Carolina soils. A major source of sulfur is found in the soil organic matter, but most soils in the Coastal Plain of South Carolina contain too little organic matter for it to be an adequate sulfur source. Between 8 to 11 pounds sulfur per acre per year are deposited on South Carolina soils from precipitation. In the Piedmont, sulfur deposited from the atmosphere is retained on soil clay surfaces due to anion adsorption and can be sufficient to satisfy most crop requirements. For this reason there is no need to apply a sulfur-containing fertilizer for soils in Group 4.

For Coastal Plain soils, sulfur will leach from the surface soil, but then be retained in the lower clay layer. In Soil Group 2, if the clay layer is within 20 inches of the surface, and for Soil Group 3, testing their subsoils for sulfur is recommended. The test will indicate if the level of sulfur in the subsoil is sufficient to satisfy the crop requirement. If the test result indicates an insufficiency, then the fertilizer recommendation should include a fertilizer source that will add at least 10 pounds sulfur per acre. For a crop to utilize subsoil sulfur, their roots must be capable of growing into the subsoil. In-row subsoiling or chisel plowing may be necessary for some soils if plant roots are to reach this source of sulfur.

During periods of low temperature and/or when excessive rainfall occurs in the spring, sulfur deficiency (lack of overall plant green foliage color) may occur in some crop plants, especially corn growing in sandy soils. However, this deficiency symptom will disappear when roots reach the subsoil where sulfur has accumulated. Side-dressing with a nitrogen-sulfur solution may be desirable when a sulfur deficiency is expected.

It may be possible to obtain good crop yields on Soil Groups 1 and 2 for a few years without adding a fertilizer sulfur source. However, sulfur fertilization of these soils is recommended:

- when organic matter content is low (<1.0%)
- on course-textured soils where sulfur will be readily leached from the surface soil
- when the depth to the clay layer is greater than 20 inches

Until a practical soil test procedure for predicting the sulfur status in Soil Groups 1 and 2 is developed, an annual application of 10 pounds sulfur per acre as either fertilizer or in a pesticide application is recommended for all crops grown in these two Soil Groups.

For Soil Group 5 the amount of subsoil sulfur determined by the sulfur soil test is considered "insufficient" if that found is less than 40 pounds sulfur per acre. For Soil Groups 1, 2, 3, 4, or 6, determined soil test sulfur is considered "insufficient" when less than 20 pounds sulfur per acre.

Sulfur exists in the soil solution as the sulfate (SO_4^{2-}) anion.

List of Sulfur-containing Commercial Fertilizers:

Source	**Formula**	**%S**
Ammonium sulfate (21-0-0-24)	$(NH_4)_2SO_4$	24
Ammonium thiosulfate (12-0-0-26)	$(NH_4)_2S_2O_3$	26
Gypsum	$CaSO_4 \cdot 2H_2O$	19
Magnesium sulfate (Epsom Salts)	$MgSO_4 \cdot 7H_2O$	13
Nitrogen-S solution	$CO(NH_2)_2\text{-}NH_4NO_3\text{-}(NH_4)_2SO_4$	2 – 5
Potassium magnesium sulfate (SUL-PO-MAG)	$K_2SO_4 + MgSO_4$	23
Potassium sulfate (0-0-50-18)	K_2SO_4	18
Sulfur (S)	S	90 – 100
Sulfur-coated urea	$CO(NH_2)_2\text{-}S$	10
Superphosphate (0-20-0)	$CaSO_4$ + calcium phosphate	12