3. Micronutrients

There are 7 essential plant nutrient elements defined as micronutrients [boron (B), zinc (Zn), manganese (Mn), iron (Fe), copper (Cu), molybdenum (Mo), chlorine (Cl)]. They constitute in total less than 1% of the dry weight of most plants. The following discussion focuses primarily on the soil characteristics for the micronutrients.

a. Boron (B)

Boron is included in the Standard Soil Test. The level of soil boron is "insufficient" or "low" when extractable boron is less than 0.1 pound per acre. Soil boron is found in both organic and inorganic forms that are made available to plants as either or both soil organic matter is decomposed and/or boron-containing minerals dissolve. There may be between 20 to 200 pounds boron in the surface layer of South Carolina soils, but only a small portion is available to plants. Boron, as the borate (BO_3^{3-}) anion, is mobile in the soil and can be easily leached from the surface soil.

Calcium, potassium, and nitrogen concentrations in both the soil and plant can affect boron availability and plant function, the calcium:boron (Ca:B) ratio relationship being the most important. Therefore, soils high in calcium will require more boron than soils low in calcium. The chance for boron toxicity is greater on low calcium-content soils.

The need to include boron in the fertilizer recommendation is determined by:

- crop requirement
- soil boron test level

For any given crop when boron is recommended, a high rate of boron may be required on:

- clay-type soils
- soils that are high in water pH and/or calcium content
- high organic matter content soils
- soils where boron is broadcast versus boron being either banded or foliar applied

Boron is routinely included in the fertilizer recommendation for the crops cotton, peanut, alfalfa, apple, root crops, cabbage, broccoli, and cauliflower, and when reseeding clover or where clover seeds are to be harvested.

When applied as a part of a soil fertility program, many types of animal manures, superphosphate (0-20-0), and liming materials may contain sufficient boron to meet the boron requirement for some crops.

Crops differ in their sensitivity or tolerance to boron, crops most sensitive being peach, strawberry and soybean; corn, tobacco, tomato and small grains being moderately tolerant to boron; while the crops, cotton, sunflower and alfalfa are the most tolerant.

When boron deficiency symptoms occur, boron is recommended at application rates determined by crop as given below:

Application Rates of Boron Recommended for Correcting Boron Deficiency by Crop

Crop	Amount Applied	Crop	Amount Applied
Alfalfa	2.0 – 4.0	Grapes	0.6 – 1.0
Apple	0.3 – 1.4	Peanut	0.3 – 0.5
Cabbage	1.0 – 4.5	Pea	0.9 – 1.2
Carrot	1.0 – 1.7	Potato	0.6 – 1.0
Clovers	0.6 – 2.3	Strawberry	0.6 – 1.0
Corn	0.6 – 1.0	Sweet Potato	0.6 – 1.7
Cotton	0.6 – 1.0	Tomato	0.6 – 1.7

Care is needed not to exceed both recommended boron soil and foliar application rates since boron toxicity is a definite possibility. A plant analysis is the best method for determining when boron is actually needed. Soil test boron is "excessive" when extractable boron is greater than 3.0 pounds per acre.

Boron exists in the soil solution as the borate (BO_3^{3-}) anion.

List of Boron-containing Commercial Fertilizers:

Source	Formula	% B Content
Borax	$Na_2B_4O_7 \cdot 10H_2O$	11
Boric Acid	H_3BO_3	16
Solubor	$Na_2B_4O_7 \cdot 4H_2O + Na_2B_{10}O_{16} \cdot 10H_2O$	20

b. Zinc (Zn)

Zinc is included in the Standard Soil Test. The level of soil zinc is "insufficient" or "low" when extractable zinc is less than 2.0 pounds per acre and the soil pH is less than 6.1, and when extractable zinc is less than 2.5 pounds per acre and the soil pH greater than 6.0.

Zinc deficiency has been observed on early-planted corn during cool, wet periods, but plants usually recover as the soil dries and warms. Zinc is routinely recommended for corn grown on sandy soils (Soil Groups 1 and 2) when the soil-pH is above 6.5. A zinc application is normally recommended for pecan unless a plant analysis indicates that zinc is not required. A zinc recommendation for peach and apple is not generally made unless a deficiency is verified by means of a leaf analysis. Both soil and plant analyses are to be used to determine if a zinc deficiency exists. When soil zinc is "insufficient", zinc is recommended for certain crops, the treatment rate being between 3 to 5 pounds zinc per acre.

To correct a zinc deficiency in peach, plum or nectarine trees, foliar apply either chelated zinc, following label directions, or apply at three-week intervals a solution containing 3 ounces zinc sulfate ($ZnSO_4 \cdot 7H_2O$) dissolved in 100 gallons of water. If a zinc-containing fungicide is being applied to the foliage, additional zinc as either soil or foliar applied will not be required.

In old peach orchards, zinc soil toxicity can occur following years of applying zinc-containing fungicides. Repeated use of sludge, slag, or poultry litter, all of which can contain high concentrations of zinc, may result in soil zinc toxicity. The potential for a zinc toxicity can be reduced or eliminated by liming the soil to raise the water pH above 6.0 or 6.5, the pH level normally recommended for the crop growing or to be grown.

Peanut is particularly sensitive to zinc and this element can be toxic to peanut at combinations of soil pH and extractable zinc:

Soil pH	**Extractable Zinc lbs per acre**
< 5.9	> 5
< 6.0	> 11
< 6.1	> 21
< 6.2	> 31
< 6.3	> 41
> 6.2	> 51

Soils with these combinations of soil pH and extractable zinc should be planted to another crop.

Zinc toxicity can occur for other crops at levels of greater than 40 lbs per acre.

Zinc exists in the soil solution as the zinc (Zn^{2+}) cation.

List of Zinc-containing Commercial Fertilizers:

Source	**Formula**	**Water Solubility**	**%Zn**
Zinc chelate	$Na_2ZnEDTA$	Soluble	14
	NaZnTA		13
	NaZnHEDTA		9
Zinc Oxide	ZnO	Insoluble	60 – 78
Zinc oxysulfate		Variable	18 – 50
Zinc polyflavonoids	organically bound Zn		10
Zinc sulfate	$ZnSO_4 \cdot 2H_2O$	Soluble	36
	$ZnSO_4$-NH_3-complex	Soluble	10 – 15

c. Manganese (Mn)

Manganese is included in the Standard Soil Test. Manganese deficiency is most likely to occur in soybean, peanut, oat, wheat, and cotton grown on soils in Soil Groups 1, 2 and 3 in Area 5 and on some poorly drained soils in Area 4 when the soil pH is high (>6.0 or 6.5, depending on soil type).

Soil factors that contribute to manganese deficiency are:

- waterlogged conditions occurring during a portion of the crop year
- poorly drained soils, natively low in manganese
- when the soil pH is high (>6.0 or 6.5, depending on soil type)

The level of soil manganese is "insufficient" or "low" when the soil pH and extractable manganese are:

Soil pH	**Extractable Manganese lbs per acre**
< 5.6	< 4.0
> 5.5 and < 5.8	< 6.0
> 5.7 and < 6.0	< 8.0
> 5.9 and < 6.2	< 10.0
> 6.1 and < 6.5	< 12.0
> 6.4 and < 6.7	< 14.0
> 6.6 and < 6.9	< 16.0
> 6.8	< 17.0

Manganese deficiency can be corrected by either soil or foliar applications of manganese. For soybeans, 15 to 75 pounds manganese sulfate ($MnSO_4 \cdot H_2O$ - 26 to 28% manganese) or its equivalent per acre is recommended for optimum yield when the soil pH is greater than 6.4. However on high pH soils (>7.0), correcting a manganese deficiency by a soil manganese application may not correct the deficiency since most of the applied manganese will most likely be converted to an unavailable form in such soils.

For soybean, the best way to correct a manganese deficiency is to apply 1 pound manganese per acre as $MnSO_4 \cdot 4H_2O$ as a foliar spray, making two applications during the growing season. Rotating a crop of soybeans with corn may lower the soil pH sufficiently to prevent a manganese deficiency from occurring in the following soybean crop. Another effective way to correct a marginal manganese deficiency is to row apply a phosphorus-containing fertilizer at planting.

If a manganese deficiency is suspected, both plant tissue and soil samples should be collected for analysis to confirm the deficiency.

Manganese toxicity is not likely to occur on most soils except those that are extremely acidic when the soil pH is less than 5.0. In general, those crops sensitive to manganese deficiency are likely to be sensitive to high levels of soil-available manganese. High soil test manganese levels are easily decreased by bringing the soil pH to the level recommended for the crop.

Manganese exists in the soil solution as the manganeous (Mn^{2+}) cation. Other valance states may also exist under varying soil physical and chemical conditions.

List of Manganese-containing Commercial Fertilizers:

Source	**Formula**	**Water Solubility**	**%Mn**

Manganese chelate	MnEDTA	Soluble	5 – 12
Manganese oxide	MnO	Insoluble	53
Manganese oxysulfate		Variable	30 – 50
Manganese sulfate	$MnSO_4 \cdot 4H_2O$	Soluble	24

d. Iron (Fe)

In most cases, plant iron deficiency is not due to the lack of iron in the soil, but due to soil conditions that reduce its plant availability, such as:

- high soil pH
- low soil oxygen levels caused by either soil compactions or water- logging
- prolonged periods of excessive soil moisture
- high temperatures
- high soil phosphorus, copper, manganese, and zinc levels

Based on these soil influencing factors plus the lack of a correlation between Mehlich No. 1-extractable iron and plant response, the extractable-iron concentration in the soil is not reported.

Crops in South Carolina that may exhibit iron deficiency symptoms are pecan (when over fertilized with zinc), centipede grass, blueberry, and certain ornamentals, such as azalea and camellia. A foliar application of iron is the most effective way to correct an iron deficiency by either applying a 1% solution of ferrous sulfate [$FeSO_4$ - adding a little sulfuric acid (H_2SO_4) to keep the iron in solution], or a 2% solution of chelated iron.

Some plants have been designated as "iron sufficient" due to the ability of their roots to acidify the rhizosphere and/or to secrete phytosiderophores that complex iron at the root-soil interface, and thereby enhance iron uptake.

Iron exists in the soil solution as either the ferrous (Fe^{2+}) or ferric (Fe^{3+}) cation, the valence form being determined by soil conditions.

List of Iron-containing Commercial Fertilizers:

Source	**Formula**	**Water Solubility**	**%Fe**
Ferrous ammonium phosphate	$Fe(NH_4)PO_4 \cdot H_2O$	Soluble	29
Ferrous ammonium sulfate	$NH_4SO_4.FeSO_4 \cdot 6H_2O$		14
Iron chelates	NaFeEDTA	Soluble	5 – 11
	NaFeHPDTA	Soluble	5 – 9
	NaFeEDDHA	Soluble	6
	NaFeDTPA	Soluble	10
	FeHEDTA	Soluble	5 – 9
	FeEDDHA	Soluble	6

Iron polyflavonoids	Organically Bound Fe		9 – 10
Ferrous sulfate	$FeSO_4 \cdot 7H_2O$	Soluble	20
Ferric sulfate	$Fe(SO_4)_3 \cdot 4H_2O$	Soluble	23

e. Copper (Cu)

Copper is included in the Standard Soil Test. Copper deficiency is not a common occurrence on South Carolina soils. However, copper deficiency is likely to occur on organic soils, mineral soils high in organic matter content (>5 %), and on very sandy soils that have been over-limed and thus have a high soil pH (>6.0 or 6.5, depending on soil type).

Copper is retained in available forms in clay soils. Copper can be leached from very sandy soils low in organic matter content. Correcting a copper deficiency from occurring in organic soils requires application rates of 20 to 50 pounds copper sulfate ($CuSO_4 \cdot 5H_2O$) per acre or a foliar application at the rate of 1 to 2 pounds $CuSO_4 \cdot 5H_2O$ per acre. There is a very narrow range between deficiency and toxicity for copper, and either soil or foliar-applied recommendations should be based on a deficiency verified by a plant tissue analysis. Copper exists in the soil solution as the cupric (Cu^{2+}) cation.

List of Copper-containing Commercial Fertilizers:

Source	**Formula**	**Water Solubility**	**%Cu**
Basic copper sulfates	$CuSO_4 \cdot 3Cu(OH)_2$ General formula	Soluble	13 - 53
Copper chelates	$Na_2CuEDTA$	Soluble	13
	NaCuHEDTA	Soluble	9
Copper sulfate (monodydrate)	$CuSO_4 \cdot H_2O$	Soluble	35
Copper sulfate (pentahydrate)	$CuSO_4 \cdot 5H_2O$	Soluble	25
Curpic ammonium phosphate	$Cu(NH_4)PO_4 \cdot H_2O$	Soluble	32
Cupric chloride	$CuCl_2$	Soluble	17
Cupric oxide	CuO	Soluble	75
Cuprous oxide	Cu_2O	Soluble	89
Copper polyflavonoids	Organically bound Cu	Partially soluble	5 – 7

f. Molybdenum (Mo)

Most South Carolina soils contain from 1 to 6 pounds molybdenum per acre; more than sufficient to meet most crop requirements. Therefore, South Carolina soils are not tested for molybdenum availability. However, molybdenum is recommended for legumes growing on acid soils when a deficiency is suspected. Molybdenum is not recommended for application on non-legume crops.

Soil pH is the major soil factor affecting molybdenum plant availability. Generally, if the soil pH is greater than 6.0, a deficiency is not likely to occur. If the soil pH is below 6.0 and molybdenum deficiency is suspected, the recommended application rate for most legume crops is 2 to 8 ounces molybdenum per acre applied as either a seed treatment or foliar spray.

Molybdenum exists in the soil solution as the molybdate (MnO_4^{2-}) anion.

List of Molybdenum-containing Commercial Fertilizers:

Source	Formula	Water Solubility	%Mo
Ammonium molybdate	$(NH_4)_6Mo_7O_{26}$	Soluble	53
Molybdenum trioxide	MnO_3	Soluble	66
Molybdenum dioxide	MnO_2	Soluble	75
Sodium molybdate	$Na_2MoO_4 \cdot 2H_2O$	Soluble	39

g. Chlorine (Cl)

Chlorine is an essential plant nutrient element, existing in the soil as the chloride (Cl^-) anion. This anion is abundant in nature and chloride excesses are more common that its deficiency. Crop quality can be affected by the use of chloride-containing fertilizers. For tobacco as well as potato and tomato, either potassium sulfate (K_2SO_4) or potassium nitrate (KNO_3) is the recommended potassium fertilizer source rather than potassium chloride (muriate of potash, KCl). For blueberries, acid-forming fertilizers that do not contain chloride are preferred.

Chlorine exists in the soil solution as the chloride (Cl^-) anion.

List of Chloride-containing Commercial Fertilizers:

Source	Formula	Water solubility	%Cl
Calcium chloride	$CaCl_2$	Soluble	50
Potassium chloride	KCl	Soluble	48