Micronutrients

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Introduction

Increased interest in micronutrients as limiting factors in crop growth and yield is due to the following reasons:

- Today's crop yields require larger amounts of these nutrients.
- Long-time cropping has removed measurable amounts of these nutrients.
- Widespread use of animal manures has decreased and use of high-analysis fertilizers low in nutrient impurities has increased.
- Topsoil has been removed through erosion, land leveling, or terrace construction resulting in deficiency of certain micronutrients.
- More information is available on crop responses, availability of nutrients in various soils, soil testing and plant analysis.
- More attention is being given to crop quality and nutritional value of todays crops.
- Variability of nutrients across fields has been recognized and the technology to manage variability continues to develop.

It is reasonable, therefore, to pay more attention to the adequacy of micronutrients in crop production. Although used in smaller quantities than other essential nutrients, they are just as important for proper plant nutrition. With the exception of chlorine, the total uptake of micronutrients by corn and soybean, e.g., range from a few pounds to a fraction of a pound per acre (Table 1).

Table 1. Approximate amounts of micronutrients contained in above ground plant material in an acre of 160 bu/acre corn, 40bu/acre, and 60bu/acre soybean.

	Pounds of element per acre				
Element	Corn		Wheat		Soybean
	Grain	Stover	Grain	Straw	Grain
Boron	0.04	0.13	0.1	0.5	0.08
Chlorine	4.0	72.0	--	--	--
Copper	0.02	0.09	0.03	0.01	0.06
Iron	0.11	1.9	0.19	0.50	0.90
Manganese	0.05	0.27	0.09	0.16	0.08
Molybdenum	0.005	0.003	--	--	0.01
Zinc	0.18	0.18	0.14	0.05	0.06

Essential Plant Nutrients

Micronutrients are essential for plant growth, but plants require relatively small amounts of them, hence, the term “micro”. They include boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), Molybdenum (Mo), and zinc (Zn). These elements may be referred to as minor or trace elements, but micronutrients is the preferred term.

Sixteen elements are generally considered essential for plant growth, i.e., plants can complete their life cycle. In addition to the above seven micronutrients; three organic elements, carbon (C), hydrogen (H), and oxygen (O); three primary nutrients, nitrogen(N), phosphorus (P), and potassium (K); and the three secondary nutrients, calcium (C), magnesium (Mg), and sulfur (S) are essential.

Among additional elements found in plants are sodium (Na), vanadium (Va), cobalt (Co), and silicon (Si). These are termed functional which means they function in the plant in a non-specific manner. For now they are not considered essential micronutrients for the economic crops commonly grown.

Soil Sources

The micronutrients in the soil and their availability to plants are determined by the minerals contained in the original parent material and by the weathering processes that have taken place over the years. In general, the leached highly-weathered soils of warm, moist regions contain smaller amounts of micronutrients than soils in cool, dry regions. There are exceptions, however, and the total amount of an element in soils is usually a poor indication of the amount available for plant uptake. The amount of each micronutrient in soil varies considerably. As shown in Table 2, there is also a very large difference among the micronutrients in the amounts in soils.

Table 2. Average amount of micronutrients found in soils.

Element	Average amount lbs/acre*/0-6 inch depth
Boron (B)	40
Chlorine (Cl)	?
Copper (Cu)	20
Iron (Fe)	75,000
Manganese (Mn)	1,200
Molybdenum (Mo)	4
Zinc (Zn)	100

The amounts may vary by more than 100 percent.

Table 3 shows the original sources and the chemical forms in which micronutrients exist in the soil. In addition, almost every soil contains some of each of these elements within the structure of organic matter and in soluble organic acids.

Table 3. Sources of micronutrients in soils and primary chemical forms in soils.

Element	Major sources of micronutrients in soils*	Predominant chemcial forms in soils
Boron (B)	Minerals-tourmaline	Borosilicates, borates
Chlorine (Cl)	Salts-oceanic, volcanic	Chlorides
Copper (Cu)	Minerals-sulfides	Hydroxy-carbonates, silicates
Iron (Fe)	Minerals-oxides, hydroxides	Oxides, hydrous oxides, Silicates
Manganese (Mn)	Minerals-oxides, hydroxides	Oxides, silicates
Molybdenum (Mo)	Minerals	Molybdates
Zinc (Zn)	Minerals-sulfides	Oxides, silicates, Carbonates

*Organic matter also contains micronutrients, but the original source was a mineral except for chlorine.

Factors Affecting Availability

Micronutrient deficiencies usually occur because sufficient amounts are not soluble and available to the crop and not because of insufficient amounts in the soil.

There are many soil and environmental factors that affect the availability of micronutrients to plants. The primary factors include soil pH, organic matter content, soil texture which affects leaching and organic matter content, soil water content, nutrient interactions, and temperature.

Soil pH is the most important factor influencing the availability of micronutirents. As soil pH increases the availability of iron, manganese, copper and zinc decreases, boron availability also decreases as soil pH increases up to above 8.5 where the availability increases due to sodium. Molybdenum is the only element whose availability increases as soil pH increases. The effect of soil pH on chloride availability is neutral.

Coarse textured soils, i.e., sandy soils, tend to be low in boron, and copper is often low in leached calcareous soils. Poorly drained soils usually have poor aeration that contributes to iron, zinc and manganese deficiencies.

Cool weather combined with poorly drained soils accentuates iron and zinc deficiency occurrences because of poor root growth. Under dry soil conditions boron deficiencies are increased and molydenum deficiencies tend to be more severe because less mineralization occurs and less soluble B is available.

Low organic matter soils are low in boron and often low in zinc, especially sandy soils. Organic matter may form natural chelates aiding in maintaining iron in a soluble form. High organic matter content provides more available boron to plants, but decreases copper availability due to strong bonding of copper to organic matter and may tie up manganese into unavailable organic complexes.

Other elements may affect the availability of most micronutrients. High amounts of phosphorus in soils borderline in copper, zinc, iron and manganese may reduce their availability and/or uptake by plants. Applications of: iron and zinc may reduce copper availability; copper, manganese and zinc may reduce iron availability; and copper, iron and zinc may reduce manganese availability. Applications of potassium may increase boron deficiency on soils low in boron, but high calcium availability increases the capacity of plants for boron. Soils high in iron and aluminum oxides tend to be low in molybdenum, but these soils also are highly weathered and frequently acidic.

Chlorine deficiencies tend to occur in areas of low rainfall and on soils that have had little or no history of potassium fertilizer applications. The most commonly used potassium fertilizer is potassium chloride (KCl).

Plants and varieties are frequently different in their sensitivity to a particular micronutrient deficiency. Some crops are more sensitive than others and some varieties within a crop may exhibit a particular micronutrient deficiency while others do not even though the growing conditions are the same.

Soil Analysis

Soil testing can aid in verifying a suspected plant nutrient deficiency that would limit crop yield, and provides a basis for recommending additions of a nutrient source.

Ideally a soil test meets these requirements:

1. The extraction solution and procedure should solubilize a proportionate part of the available forms of a nutrient in soils with variable properties.
2. The amount of nutrient in the extract should be measurable with reasonable accuracy and speed.
3. The amount extracted should be correlated with crop response to that nutrient under various conditions.

The development of an acceptable soil test on which recommendations can be based with some degree of confidence for their profitability is a three-step process.

1. Identification of an extractant that will extract and, for some nutrients, solubilize a proportionate part of labile forms (forms readily available and that will become easily available) of the nutrients from soils with different properties.
2. Evaluate if amounts of nutrients extracted are related to the quantities taken up by plants from different soils. This is the "correlation" process and is accomplished in the greenhouse. If there is a good correlation between the chemical analysis and the plant analysis, this provides confidence that the soil test provides an index of nutrient availability. Because this research is done in the greenhouse, it is not known with any certainty whether the soil test will be a satisfactory prediction for field situations. Greenhouse environments are artificial growth

conditions, plant roots are restricted to the soil containers, and the soil medium is usually from the surface soil horizon.

3. Calibration of the soil test in the field is the determination of a critical level that is the soil test value that separates soils into responsive and non-responsive categories. The critical level is based on yield response to applications of the nutrient under field conditions. If sufficient rates of the nutrient are applied and the research is done on a broad range of nutrient availability across soils, it is possible to interpret soil test values in the responsive range into categories, e.g., very low, low, etc. and to make recommendations for the amount of nutrient to apply.

Ideally, it is desirable to have a single extractant for two or more nutrients. Because of the large difference in the chemistry of soils and the chemistry of each nutrient, there has been limited success in the development of "universal soil extractants". The DTPA extractant for the micronutrient cations, zinc, iron, manganese and copper has been reasonably successful, but there are other extractants also used for these micronutrients. The Mehlich extractants are being researched as potential extractants for some of the primary, secondary, and micro nutrients. Ammonium acetate is a widely accepted extractant for the exchangeable cations, potassium, magnesium, calcium and sodium. There are individual extractants for the nutrient elements, phosphorus nitrogen, sulfur, boron, chlorine and molybdenum that exist as anions in the soil. With the exception of phosphorus, all form relatively soluble compounds and are relatively mobile in the soil.

Because of the differences among the nutrients for acceptable soil analysis, soil analysis for each will be discussed in its section.

Diagnosing Plant Symptoms

A deficiency of an essential element will result in a decrease in the normal growth of the plant and decrease the yield. When sufficiently low, the deficiency of a nutrient will be shown in some manner (symptoms) by the plant. These symptoms are either: 1) chlorosis, which is a yellowing, either uniform or interveinal, of plant tissue due to a reduction in the chlorophyll formation processes; 2) necrosis, or death of plant tissue; 3) lack of new growth or terminal growth resulting in rosetting at the top of the plant; 4) an accumulation of anthocyanin and an appearance of a reddish color; or 5) stunting or reduced growth with either normal or dark green color or yellowing.

Perhaps the most useful concept of plant nutrition for diagnosing nutrient deficiency symptoms is the principle of nutrient mobility in plants. Where and how a deficiency is first expressed is influenced by how easily the nutrient is translocated in the plant.

Mobile nutrients move readily in the plant. Under deficient conditions the plant is able to move nutrients from older developed plant parts into young developing tissue. As a result, deficiencies are more severe in the older, usually lower, leaves. If the deficiency is severe, the entire plant may develop symptoms but the symptoms will occur first and in greatest severity in the older leaves. Mobile nutrients include nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg). Zinc (Zn) is considered to be slightly mobile in the plant and sulfur (S) is somewhat mobile.

Immobile nutrients are held as relatively permanent constituents of plant compounds and are not easily moved to new growth areas under deficient conditions. As a result, early symptoms occur in the youngest leaves and stems, whereas, older leaves tend to appear normal. Immobile nutrients include iron (Fe), manganese (Mn), copper (Cu), molybdenum (Mo), boron (B), and calcium (Ca).

Diagnosis of a nutrient deficiency can be narrowed considerably by evaluating: a.) type of symptom (i.e., chlorosis, stunting, coloration, etc.) and, b.) location of the symptom on the plant (i.e., uppper or lower leaves). Also, consider soil properties such as soil pH and organic matter, which can aid in eliminating some possible nutrients. **Soil tests and plant analysis of normal and deficient plants should be used to confirm the diagnosis if there is any doubt.** Acceptable or sufficiency nutrient concentrations for several crops are given in Table 4. The values for vegetables are very general and should only be used as guidelines.

Table 4. Nutrient sufficiency ranges for corn, soybeans, alfalfa, wheat, sugar beets, potatoes and vegetables.

ELEMENT	CORN	SOYBEANS	ALFALFA	WHEAT	SUGAR BEETS	VEGETABLES	POTATOES
	Ear leaf sample of initial silk	Upper fully developed leaf sampled prior to initial flowering	Top 6 inches sampled prior to initial flowering	Upper leaves sampled prior to initial bloom	Center fully developed leaf sampled in midseason	Top fully developed leaves	Petioles from most recently matured leaf sampled in midseason
				Percent (%)			
Nitrogen	2.76-3.50	4.26-5.50	3.76-5.50	2.59-3.00	3.01-4.50	2.50-4.00	2.50-4.00
Phosphorus	0.25-0.50	0.26-0.50	0.26-0.70	0.21-0.50	0.26-0.50	0.25-0.80	0.18-0.22
Potassium	1.71-2.50	1.71-2.50	2.01-3.50	1.51-3.00	2.01-6.00	2.00-9.00	6.00-9.00
Calcium	0.21-1.00	0.36-2.00	1.76-3.00	0.21-1.00	0.36-1.20	0.35-2.00	0.36-0.50
Magnesium	0.16-0.60	0.26-1.00	0.31-1.00	0.16-1.00	0.36-1.00	0.25-1.00	0.17-0.22
Sulfur	0.16-0.50	0.21-0.40	0.31-0.50	0.20-0.40	0.21-0.50	0.16-0.50	0.21-0.50
				Parts per million (ppm)			
Manganese	20-150	21-100	31-100	16-200	21-150	30-200	30-200
Iron	21-250	51-350	31-250	11-300	51-200	50-250	30-300
Boron	4-25	21-55	31-80	6-40	26-80	30-60	15-40
Copper	6-20	10-30	11-30	6-50	11-40	8-20	7-30
Zinc	20-70	21-50	21-70	21-70	19-60	30-100	30-100
Molybdenum	0.1-2.0	1.0-5.0	1.0-5.0	0.03-5.0	.15-5.0	0.5-5.0	0.5-4.0

Nutrient – Root Contact

Nutrients must reach the root surface before uptake by the plant. The three methods by which nutrients reach the root surface are root interception, mass flow, and diffusion. The relative importance of these methods can provide guidance for the most efficient method of application of each micronutrient. Whether one method predominates depends on many factors that includes; concentration of the nutrient, physical and chemical characteristics of the soil, root system of the plant, water regime in the soil, and transpiration of the plant. A dominant method for a nutrient to reach a root surface is most important when it is deficient because this can guide placement.

Root interception is the growth of the root into contact with ions that are held on the exchange complex of clays and organic matter. Copper and iron are usually held on the exchange complex. This also applies to some extent for zinc. Root interception is important for these essential nutrients.

Mass flow (or convection) is the movement of soil water and nutrients in solution to the root. Water movement through soils, carrying those ions freely mobile in solution, primarily occurs as a result of a suction gradient resulting from increased suction at the root surface due to transpiration (water loss) by the plant. Mass flow is important in getting water-soluble nutrients to plant roots for uptake.

Diffusion is the movement of ions from a higher concentration to one of lower concentration. Diffusive movement of ions does not necessarily involve water movement. Whether nutrients arrive at the root surface by root interception or mass flow and are taken up by the plant, the concentration of those nutrients is lowered and diffusion can occur. Uptake of manganese, zinc, and to some extent iron and molybdenum if limiting has been shown to be related to movement by diffusion in the soil.

The relative amounts of the micronutrients reaching the root surface by root interception, mass flow, and diffusion as well as suggested placement, are shown in Table 5.

Table 5. Primary mechanism by which micronutrients arrive at the plant root surface for uptake.

	Relative amounts*			
Nutrient	Root interception	Mass flow	Diffusion	Suggested** Application
Boron	+	++++	+	Broadcast
Chlorine	+	++++	+	Broadcast
Copper	+++	+	++	Broadcast
Iron	++	+	+++	Band or Foliar
Manganese	+	+	++++	Band or Foliar
Molybdenum	+	+++	++	With Seed***
Zinc	++	+	+++	Band or Broadcast

* + = very low, ++++=very high importance

** These are typically suggested methods of application. Foliar applications have also been used for rescue treatments or for early season applications where field history has shown a need for the element.

*** Such a small amount, i.e. ounces, is required, this is the feasible method to apply.

Plant uptake

The exact process by which nutrients are taken into (absorbed) the plant is still being researched. There is general agreement that nutrient uptake is a two-step process. A portion of the root is readily available to the external solution and ions may move by diffusion and mass flow into these areas. This space has been defined as "free space" and is outside the xylem, which is a conduit in the plant through which materials move. Movement of ions into the "free space" is considered passive.

The second step in nutrient uptake is the active transport of ions from the free space across a membrane into interior cells and into the xylem. Active transport implies that energy is expended by the plant and is, thus, a metabolic process. Ions do not cross membranes as ions but combine with a carrier that facilitates their passage. The initial binding by the carrier occurs at the outer surface of the membrane. The ion-carrier complex crosses the membrane, where it dissociates and releases the ion on the inside of the cell. The carrier then can return to combine with another ion. Carriers are apparently selective in which ion it will carry because concentrations of a particular nutrient in a plant can be greater or less than the concentration of that nutrient in the solution external to the root. There is competition among some ions for a carrier site. This can partially explain the inhibition of uptake of a particular ion by another ion, particularly if the concentration of a competing ion in solution is much greater than the other ion.

Plants take up nutrients in a particular ionic form that is shown in Table 6. Because of this, choice of fertilizer source can be important for some micronutrients.

Table 6. Forms of micronutrients taken up by plants.

Element	Ionic form(s) taken up by plant
Boron (B)	$B(OH)_3$
Chlorine (Cl)	Cl^-
Copper (Cu)	Cu^{2+}
Iron (Fe)	Fe^{2+}, Fe^{3+}
Manganese (Mn)	Mn^{2+}
Molybdenum (Mo)	MoO_4^{2-}
Zinc (Zn)	Zn^{2+},$Zn(OH)_2$

General Role of Micronutrients in the Plant

Micronutrients are generally considered to be enzyme activators in plants. Enzymes are small protein clusters that carry out a specific and necessary function in the plant. Each enzyme requires a specific micronutirent to activate it. The micronutrient is sometimes referred to as a catalyst. All the micronutrients, B, Cu, Fe, Mn, Mo, and Zn, except chlorine (Cl) are activators of specific enzymes. Chlorine is involved in the capture and storage of light energy and in the regulation of osmotic pressure within the plant. Because it is an anion, it counterbalances cations in the plant.

Micronutrient Fertilizer Sources

There are several materials available to choose from for copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn). Although there are fewer materials available for boron (B), chlorine (Cl) and molybdenum (Mo), the available materials are commonly used and are very effective.

Inorganic Sources. There are several inorganic sources of micronutrients including sulfates, chlorides, oxides and oxysulfates (mixtures of sulfates and oxides).

Sulfates ($SO_4^=$) of Cu, Fe, Mn, and Zn are probably the most commonly used sources. Whether in powdered or granular form, they are completely water soluble and are quickly available to the plant after soil application. Sulfates can also be foliar applied.

Chloride (Cl^-)sources of Cu, Fe, Mn, and Zn are available mainly as liquids for use in liquid applications.

Oxides of Cu, Mn and Zn in granular form are water insoluble and their availability depends on their reaction in the soil, method of placement, and reaction with fertilizer carrier if applied with a fertilizer material. Fine powers of oxides are more water soluble because as the size of particle decreases the total surface area increases and chemical reaction in soil increases.

Oxysulfates are compounds of oxides that have been partially acidulated with sulfuric acid. The degree of acidulation determines the degree of water soluble micronutrient in the product. Water solubility is reported to range from three percent to 30 percent or more. Some researchers suggest Mn and Zn sources should be 50 percent or more water soluble to be effective the season of application. Depending on the original feedstock, oxysulfates may contain various concentrations of "heavy metals", e.g. cadmium, lead, and copper.

Frits are noncrystalline substances of variable composition. Their solubility depends on the composition of the carrier glass in terms of its oxide constituents. The element is embedded in the glass carrier or stuck on its surface.

Zinc- ammonia complexes (ammoniated zinc sulfate solution) are common to the fluid fertilize industry and mix easily with ammonium polyphosphate solutions. These are considered to be intermediate between zinc sulfate and chelates in their availability.

Organic sources are synthetic or natural organic chelated compounds of the metallic micronutrients Cu, Fe, Mn, and Zn. The chelating agents tend to keep the micronutrients in solution and being available under soil pH conditions in which the nutrients normally form insoluble compounds. They may be more efficient than inorganic micronutrients under certain soil conditions. Estimates of their efficiency compared to an inorganic source range from 10 to 1 to being equal. This efficiency ratio is usually related directly to the recommended rate of application. Chelated compounds, in general are more costly than the inorganic compounds.

The primary synthetic chelates are EDTA(ethylenediaminetetraacetic acid), EDDHA (ethylenediamine di (o-hydroxyphenylacetic acid), DTPA (diethylenetriaminepenataacetic acid), and HEDTA (hydroxyethylethylenediaminetriacetic acid). Of these EDTA is probably the most commonly used chelate.

The natural organic complexes are usually ligninsulfonates and polyflavinoids, and are usually derived from the wood pulp industry.

Crop species and some crop varieties within species vary greatly in their sensitivity to micronutrient deficiencies and to their response to applications of micronutrient fertilizers. The relative response of crops to micronutrients (Table 7) can be used to guide expectations on crop yield increase or crop quality improvement.

Table 7. Relative response of selected crops to micronutrient fertilizers.[1]

	Response to micronutrient						
Crop	**Mn**	**B**	**Cu**	**Zn**	**Mo**	**Fe**	**Cl**
Alfalfa	low	high	high	low	medium		
Asparagus	low	low	low	low	low	medium	
Barley	medium	low	medium	low	low	medium	high
Blueberry	low	low	medium				
Broccoli	medium	high	medium		high	high	
Cabbage	medium	medium	medium	low	medium	medium	
Carrot	medium	medium	medium	low	low		
Cauliflower	medium	high	medium		high	high	
Celery	medium	high	medium		low		
Clover	medium	medium	medium	low	high		
Corn	medium	low	medium	high	low	medium	
Cucumber	high	low	medium				
Dry edible bean	high	low	low	high	medium	high	
Grass	medium	low	low	low	low	high	
Lettuce	high	medium	high	medium	high		
Oats	high	low	high	low	low	medium	medium
Onion	high	low	high	high	high		
Parsnip	medium	medium	medium		low		
Pea	high	low	low	low	medium		
Pepper	medium	low	low		medium		
Peppermint	medium	low	low	low	low	low	
Potato	high	low	low	medium	low		
Radish	high	medium	medium	medium	medium		
Rye	low	low	low	low	low		
Snapbean	high	low	low	high	medium	high	
Sorghum	high	low	medium	high	low	high	
Soybean	high	low	low	medium	medium	high	
Spearmint	medium	low	low	low	low		
Spinach	high	medium	high	high	high	high	
Sudangrass	high	low	high	medium	low	high	
Sugar beet	high	medium	medium	medium	medium	high	
Sweet corn	high	medium	medium	high	low	medium	
Table beet	high	high	high	medium	high	high	
Tomato	medium	medium	high	medium	medium	high	
Turnip	medium	high	medium		medium		
Wheat	high	low	high	low	low	low	high

[1] Highly responsive crops will often respond to micronutrient fertilizer additions if the micronutrient concentration in the soil is low. Medium responsive crops are less likely to respond, and low responsive crops do not usually respond to fertilizer additions even at the lowest soil micronutrient levels.

Boron (B)

Function in Plant

Boron influences cell development and elongation. It is involved in the transport of sugars across cell membranes and in the synthesis of cell wall material. Boron regulates the carbohydrate metabolism in plants and plays a role in amino acid formation and synthesis of proteins.

Boron in Soils

Soil organic matter is the major source of B in soils. As a result most of the available B is in the surface horizon of soils where organic matter is highest. Soils low in organic matter are deficient in B more than soils high in organic matter. During periods of low rainfall, the surface soil dries out, plants are unable to take up B and B deficiency is more likely to occur during dry weather, especially in alfalfa. In the drier areas of the western regions of the U.S., there are fewer B deficiencies because less B is leached out of the soils.

Boron is not readily held by soil particles and, like nitrate, can be leached down through coarse-textured soils and below the root zone of several crop plants. Sandy soils are more likely to be B deficient than fine-textured silts and clays because of their leaching potential and because they usually are lower in organic matter.

Alkaline soils with a pH of 7.0 and above are more likely to be B deficient than acid soils. Care should be taken to not overlime soils, which is more likely to occur on sandy soils, and to not apply lime to soils when soil pH is above 6.8.

Deficiency Symptoms

Boron deficiency symptoms appear on young actively growing tissue because it is immobile in plants and is involved in cell division and cell-wall synthesis. When deficient, the plants' growing points stop growing and may die if the deficiency persists. This results in rosetting of alfalfa and breakdown and corky, dark discoloration of root crops such as beets and turnips.

Crops most commonly affected are alfalfa, sugar beets, cauliflower, clover, celery, beets, apples, grapes, pears, walnuts, and a few ornamentals. Deficiency symptoms for specific crops are:

Alfalfa-	Death of growing tip, rosetting at the top of the plant, and yellowing of top leaves. (can be confused with leafhopper damage that shows as a V-shaped yellowing of leaves and may appear on all parts of plants. Both tend to occur in dry periods.)
Beet-	Brown heart and dark spots on roots.
Sugar beet-	White, netted, chapping of upper blade surfaces or wilting of tops. If severe deficiency, crosswise cracking of petioles develops, growing point dies and root heart rots.

Cauliflower-	Darkening of head and hollow and darkened stems.
Cabbage-	Yellow, stunted and head breakdown.
Celery-	Stem cracked, brownish mottling of bud leaves, heart blackened.
Apples-	Pitting, skin discolored, cracking, corking.
Pears-	Blossom blast, pitting, internal corking, bark cankers.
Grapes-	Dying of main shoots.
Walnuts-	Die back from shoot tips, leafless branches.

Soil Analysis

The most widely used B soil test is the hot water extraction method. Reliability of test is less than for phosphorus and potassium. The difficulty is in predicting how much B will be available from the organic matter during the growing season.

Boron nutrient requirements depend on the crop to be grown. For most crops requirements are usually met when soils contain 0.5 to 1.0 ppm of hot water soluble B. Interpretation of B soil test results, however, should depend on research of the crops and soils of the area.

Plant Analysis

Analysis of plant tissue gives a good indication of the B nutrition of plants. It is important to indicate the stage of plant development at sampling and the plant part sampled, because B levels in the plant change with age. Table 4 gives sufficiency ranges of B for selected plant parts of selected crops.

Fertilizer Sources and Application of Boron

Sodium borate is the most commonly used source of B. "Solubor" is a trade name for the sodium borate commonly used in foliar sprays or in liquid fertilizers. Sources of B are listed in Table 8.

Table 8. Sources of boron

Material	Percent B
Borax	11
Boric acid	17
Sodium pentaborate	18
Sodium tetrabrate	
Fertilizer borate –48	14
Fertilizer borate –65	20
Solubor	20

Recommended rates of actual B applied for crops and method of application should rely on local research information for crops and soils of the area. Applications should only be made where a deficiency is indicated or has been documented.

In general, for alfalfa 0.5 to 1.0 lb B/acre broadcast as a topdressing annually or 2.0 lb. B/acre once in a rotation for legumes is sufficient. For highly responsive specialty crops soil applications of 1.5 to 3 lb B/acre may be needed and 0.5 to 1.0 lb B/acre for medium responsive crops. The B source should be thoroughly mixed when blended with other fertilizer materials. Segregation and toxic effects when over applied can be a problem.

Although rarely needed, B can be broadcast and thoroughly incorporated into the soil for corn, beans, or oat. Never use a borated fertilizer in the row for corn or soybean, or in a drill for oat. If previously applied to a forage, it is sufficient for grain crops in the rotation.

Boron Toxicity

Boron toxicity is usually caused by applications at planting time on highly sensitive crops, e.g., beans, corn, small grains and grass. High rates of B in starter fertilizer can cause toxicity in sensitive crops.

Symptoms of B toxicity are yellowing of leaf tips, interveinal chlorosis and progressive scorching of the leaf margins. In soybeans the leaves may have a rust-like appearance. High levels of calcium may increase B tolerance of plants. Concentrations of over 200 ppm B in mature leaf tissue is indicative of toxic levels of B in plants.

Chlorine (Cl)

Function in Plant

Chlorine (chloride) takes part in the capture and storage of light energy through its involvement in photophosphorylation reactions in photosynthesis. It is not present in the plant as a true metabolite but as a mobile anion. It is involved with K in regulation of osmotic pressure, acting as an anion to balance cations.

Chlorine in Soils

The element chlorine exists in nature as chloride salts of calcium, magnesium, potassium and sodium. Chloride (Cl^-) is frequently confused with chlorine gas (Cl_2). Chlorine gas, which is used for water purification, is manufactured from chloride salts and it is reactive and unstable. The non-reactive chloride is the form present in soils, the form in fertilizer salts, and the form of concern in agriculture. It does not convert to chlorine gas in soils.

Chloride is not strongly combined with minerals or organic matter and exists primarily in a dissolved form in the soil solution. Availability of chloride to plants is influenced very little by soil acidity (soil pH), aeration, or organic matter except by their effect on plant root development that affects nutrient uptake in general.

Chloride salts accumulate in saline soils where rainfall is insufficient to leach the salts out of the root zone of crops. Because it is mobile in the soil, chloride can be leached as nitrate can be leached.

In the Great Plains area of the United States where rainfall is less, deposition from ocean salts is non-existent, soils are naturally high in potassium, and there is no or little history of potash (KCl) fertilizer application, chloride deficiency has been identified on small grains.

Deficiency Symptoms

Deficient plants wilt more readily. Bronzing of leaves can occur. Chloride suppresses some diseases on small grains and can reduce the impact of diseases such as take-all root rot, stripe rust, leaf rust, tan spot and Septoria leaf spot.

Soil Analysis

Chloride can be extracted from soils by water or a weak electrolyte because chloride salts are highly water soluble. The extractant calcium nitrate has been calibrated for some small grains. The critical soil test level for chloride is not well defined. A chloride amount of 60 lb/acre in a two foot sample is considered sufficient by some states for wheat, barley and rye. Some evidence exists that corn and sorghum will respond to chloride.

Plant Analysis

There is insufficient information to specify any optimum level of chloride concentrations in plants. Healthy plants may contain an extremely wide range of chloride.

Fertilizer Sources and Application of Chlorine

All fertilizer sources of chlorine are chloride salts. The most common source is potassium chloride (KCl, 0-0-60), which contains 45 percent chloride and 50 percent K. Broadcast application of any chloride source would be adequate because of its mobility in the soil.

Recommended rates of actual Cl should rely on local research on crops and soils of the area. Applications should be made only where a deficiency is indicated or has been documented.

One approach to determine a recommended rate of Cl is to subtract the soil test result for a 2-foot sample in lbs/acre from 60. If the soil test result is less than 60, the difference is the amount of chloride to apply per acre.

Chlorine Toxicity

Toxicity from chloride results from excessive application of chloride salts or from high chloride levels in irrigation water. Usually, the effect is a "salt effect" from the high concentration of soluble materials, including cations, in the soil solution, which inhibits the uptake of water by plants causing them to wilt. The salt effect is more prevalent than plant uptake of excess chloride. Broadcast applications of chloride salts rather than row or band placement greatly reduces the potential for salt injury to seedlings and plant roots.

Copper (Cu)

Function in Plant

Copper is involved in the activation of several enzyme systems and apparently cannot be replaced by other metal ions. It is involved in cell wall formation. It is necessary for protein synthesis and a deficiency causes a buildup of soluble nitrogen compounds.

Copper in Soils

Available Cu in soils is held mainly as the cation Cu^{++} on the cation exchange complex in soils. Organic matter and soil pH are the dominant factors affecting availability to plants.

Organic matter binds Cu more tightly than other micronutrients. In general, as organic matter increases, Cu availability decreases. Although binding with organic matter reduces fixation by soil minerals and leaching, availability of Cu to plants is also reduced. As a result most Cu deficiencies occur in soils that are high in organic matter such as peats and mucks.

Increasing the soil pH by liming increases the amount of Cu held by clay and organic matter, decreasing Cu availability. Soils with a pH above 7.5 are more likely to be Cu deficient. Copper deficiency may occur, although unlikely, on very acid mineral soils that have been heavily cropped and fertilized with N, P and K.

Deficiency Symptoms

Copper deficiency in many plants shows up as wilting or lack of turgor and development of a bluish green tint before leaf tips become chlorotic and die.

Crops most commonly affected are wheat, oat, sudan grass, onion, table beet, spinach, lettuce, and alfalfa. Deficiency symptoms for specific crops are:

Wheat, Oat-	Leaves are yellowish and leaf tips look like frost damage; aborted heads on shriveled grain; excessive tillering with high mortality rate of late tillers.
Carrot roots, Onion bulbs-	Poor pigmentation.
Corn-	Bluish green leaves and wilting or lack of turgor; tips of leaves may later become chlorotic and die.

Soil Analysis

Because Cu deficiencies are not common, research to calibrate a soil test for Cu is somewhat lacking. The DTPA soil test for Cu provides some indication of sufficiency. Canadian researchers suggest 0.4 to 0.5ppm DTPA extractable Cu to be a critical level for wheat and barley. Other reserch suggests 1.1 ppm DTPA extractable Cu for barley and oat.

Plant Analysis

Normal plants usually contain 8 to 20ppm Cu, whereas, deficient plants contain less than 6ppm. It is important to sample the appropriate plant part at the stage of plant development for which information exists. Table 4 gives sufficiency ranges of Cu for selected plant parts of selected plants.

Fertilizer Sources and Application of Copper

Common sources of Cu are the sulfate, the oxides, chelates and complexes. Sources of Cu are listed in Table 9.

Table 9. Fertilizer sources of copper

Material		Percent Cu
Copper chelate	Na_2Cu EDTA	13
Copper sulfate	$CuSO_4 \cdot 5H_2O$	25
Cupric oxide	CuO	75
Cuprous oxide	Cu_2O	89
Copper complexes	Organic	Variable

Copper can be broadcast or banded in soils or applied as a foliar spray. Broadcasting with other nutrients is most common. Recommended rates of actual Cu should rely on local research on crops and soils of the area. Applications should only be made where a deficiency is indicated or has been documented.

In general broadcast rates are usually 3 to 6 lb Cu/acre, but can range from 4 to 13 lb Cu/acre depending on the crop and soil. Banded rates of Cu are approximately one-fourth of that recommended for broadcast and range from 1 to

4 lb Cu/acre depending on crop and soil. Because Cu is essentially immobile in the soil, it is suggested that recommended rates are good for 5 to 8 years, depending on the soil and crop. When 30 lb Cu/acre has been applied, discontinue applications.

Copper Toxicity

The potential for Cu toxicity exists where Cu is applied annually for some specialty crops or as a component of some fungicides. Copper toxicity often results in plant stunting, a bluish tint to leaf color, and leaf cupping followed by leaf chlorosis or necrosis. Toxic levels in soil reduce seed germination, shoot vigor, and iron availability.

Copper is tightly adsorbed by most soils and will not leach. Once a Cu toxicity problem develops, it may be very difficult, if not impossible, to alleviate it. The situation persists for many years.

Hog manure and some sewage sludges may contain high levels of Cu. If these materials are applied repeatedly, soil Cu levels should be monitored to avoid toxicity problems.

Iron (Fe)

Function in Plant

Iron is essential for the synthesis of chlorophyll, the green color of plants which functions in photosynthesis but it is not part of the chlorophyll molecule. Iron is involved in N fixation, photosynthesis, electron transfer, respiratory enzyme systems as a part of cytochrome and hemoglobin and in other enzyme systems.

Iron in Soils

Iron deficiency is widespread throughout the Great Plains states and on calcareous soils of Iowa and Minnesota. One estimate is over eight million acres of iron-deficient soils in the seven Great Plains states.

Iron exists as the ferrous (Fe^{++}) and ferric (Fe^{+++}) forms in soils. The ferrous form is available for plant uptake. Soil pH and aeration status of the soil determine which form predominates. Ferric iron compounds have low solubility in the soil solution and conditions that favor formation of ferric iron compounds decrease iron availability. Soil pH, soil aeration, reactions with organic matter, and some plant adaptations influence Fe availability.

As soil pH increases, the concentration of Fe in the soil solution decreases, with a minimum at pH 7.4 to 8.5. This is the soil pH range that most Fe deficiencies occur.

Flooding and compaction reduce soil aeration and, thus, the oxygen level. This can decrease or increase Fe availability depending on soil condition. Iron deficiencies usually occur early in the growth season when soils tend to be wet and cool and root growth and microbial activity are limited. As soils warm, microbial activity and root growth increase, allowing plants to absorb more Fe. In acid soils rapid microbial activity can reduce Fe to more soluble Fe^{++} compounds. In alkaline or calcareous soils rapid microbial activity may produce enough carbon dioxide to react with water to form bicarbonate ions, which when absorbed by plants immobilize Fe within plants resulting in Fe deficiency.

Organic matter improves Fe availability by combining with Fe, reducing chemical fixation or precipitation, resulting in more Fe in the soil solution available for plant uptake. Organic matter is a source of Fe that becomes available when the organic matter is decomposed.

Some plants excrete sufficient hydrogen ions (H^+) from roots, which lowers the pH at the root surface and increases Fe availability. Other plants excrete organic compounds that reduce ferric iron (Fe^{+++}) to the more soluble and available ferrous iron (Fe^{++}). Some varieties of a species, e.g. soybean, have been bred to be more efficient.

Deficiency Symptoms

Because Fe is immobile in the plant, deficiency symptoms appear on newly formed leaves or terminal growth. Severe deficiency results in yellowing of the youngest leaves. Moderate Fe deficiency appears as interveinal chlorosis, with the veins remaining green. The symptoms of Fe and manganese (Mn) deficiencies are similar and difficult to distinguish from each other.

Alfalfa, small grains and corn are tolerant of low Fe availability but Fe deficiency in corn can occur on low organic matter, calcareous soils. Some soybean varieties, grain sorghum, many fruits, pin oaks, pines, roses, certain ornamentals and acid-demanding plants such as azaleas, blueberries and rhododendrons are sensitive to low Fe availability and many need iron. Lawns, particularly putting greens on golf courses, sometimes show Fe deficiency because of high pH and high levels of phosphorus.

Soil Analysis

The DTPA soil extractant developed at Colorado State University provides a measure of Fe availability in soils. Knowledge of soils and soil pH is useful in predicting where the potential of Fe deficiency is likely. A critical level of DTPA extractable Fe for some soils in 2.5 ppm. Most crops will respond to Fe additions if DTPA extractable Fe is less than 2.5 ppm. Iron-inefficient crops may respond to Fe additions on soils in the medium range between 2.5 and 4.5 ppm.

Interpretation of Fe soil test results, however, should depend on research of the crops and soils of the area.

Plant Analysis

Although plant analysis is useful to confirm or detect a nutrient deficiency for most essential nutrients, it is not as reliable for Fe because of contamination by iron-containing soil or dust. Special care should be taken to be sure the plant part sampled has not been contaminated. There is a question whether total Fe in plant tissue is a useful measure of the Fe status of a plant. Visible symptoms may be a better criterion for whether a crop or plant will respond to Fe additions. Table 4 gives sufficiency ranges of Fe for selected plant parts of selected crops.

Fertilizers Sources and Application of Iron

Common Sources of Fe are the sulfate and chelates. Sources of Fe are listed in Table 10.

Table 10. Fertilizer sources of iron.

Material		Percent Fe
Chelates	Fe EDDHA	6
	Fe DTPA	10
	Fe EDTA	9-12
Ferrous sulfate	$FeSO_4 \cdot 7H_2O$	20
Ferrous ammonium sulfate	$(NH_4)_2Fe(SO_4)_2 \cdot 6H_2O$	20
Iron frits	Glass (Silicate)carrier	Varies
Organic iron complexes	Organic	6-11

Broadcast applications of Fe sources are seldom successful because of the reactivity of Fe in soil rendering it unavailable and is not recommended. Iron chelates applied in a band with other fertilizer materials at planting time have given yield increases of soybean. Not all chelates remain stable over a wide range of soil pH. Iron EDDHA maintains Fe in a soluble form from pH 4.0 to 9.0, iron DTPA is selective for Fe up to pH 6.3. Suggested rates should be those of the manufacturer but usual rates are 0.5 to 2.0 lb Fe/acre. Iron frits should only be applied to acidic soils.

Foliar applications usually range from 0.10 to 0.15 lb Fe/acre, but may need to be applied more than once to correct Fe deficiency in some crops or plants. Ferrous sulfate, ferrous ammonium sulfate, and chelates are suitable sources for foliar applications. The foliage should be wet thoroughly and if recommended by manufacturer a surfactant may be needed. Foliar applications of Fe to Fe deficient soybean should be made when the first trifoliolate leaf is fully emerged and no later than two emerged trifoliolates because the plant is permanently injured at later stages of growth and will seldom respond to foliar treatments. Foliar applications of ferrous sulfate to turf has been somewhat successful because there is limited contact with the soil.

Acidification of calcareous soils for field crops to reduce iron deficiency is very expensive and is rarely appropriate. For individual plants, e.g., ornamentals, shrubs, and trees, it is possible to acidify the root zone with sulfur or aluminum sulfate.

Where Fe deficiency of a crop is common, select varieties, e.g., possible for soybean, that are Fe-efficient and tolerate the soil situation.

Iron Toxicity

Iron toxicity is not common under neutral or higher soil pH conditions. It has occurred on very acid soils of pH lower than 5.0 and where excess soluble Fe salts have been applied to the foilage or soil. Necrotic spots on leaves are the first symptom of iron toxicity.

There are specific soil situations where excessive Fe has interfered with manganese (Mn) uptake causing a Mn deficiency. Soil applications of either Fe or Mn chelates aggravates the situation because available Fe is increased.

Manganese (Mn)

Function in Plant

Manganese functions as an activator of an enzme that is involved in the evolution of oxygen in photosynthesis. It is a component of several enzyme systems. It also functions as part of oxidation-reduction reactions and electron transport systems. It is a structural component of certain metalloproteins.

Manganese in Soils

The amount of manganse (Mn) in soils varies greatly depending on the soil parent material and the environment in which the soils exist. Some soils may have up to 3,000 ppm of Mn, but most is unavailable for plant use. Most available Mn occurs as exchangeable Mn, Mn associated with organic matter, or Mn oxides. It is also a component of ferro-magnesium silicate minerals.

The amount of available Mn in soils is affected by soil pH, organic matter content, soil moisture, and soil aeration. The dominant form taken up by plants is the Mn^{++} ionic form.

Manganese availability to plants decreases as soil pH increases and may become deficient in soils with a pH above 6.5. Conversely, Mn availability increases as soil pH decreases and may become toxic in soils with a soil pH below 5.5. The amount of soluble Mn increases 100 fold for each unit decrease in soil pH, e.g., pH 5.0 down to 4.0. The converse occurs as soil pH increases.

As soil organic matter increases, organic Mn complexes increase and exchangeable Mn decreases. Soils high in organic matter with a pH above 6.5 are conducive to Mn deficiency occuring. Microbial activity can oxidize Mn to less available forms reducing the available supply for crops.

Excess soil moisture and high microbial activity causes poor soil aeration and thus low oxygen in the soil. High organic matter and warm temperatures favor high microbial activity that consumes or reduces the supply of oxygen. As a result, manganese oxide is reduced to soluble manganese (Mn^{++}), increasing the available supply. Temporary waterlogged conditions are conducive to Mn toxicity. Prolonged excessively wet conditions, under which leaching of soluble Mn can occur, can result in Mn deficiency.

Excessive soil levels of phosphorus, calcium (high pH), zinc, and copper may cause or induce a Mn deficiency.

Deficiency Symptoms

Most crops deficient in Mn become yellowish to olive green, but the pattern of symptoms varies among species. Because Mn is immobile in the plant, deficiency symptoms tend to be on the new young growth but may occur more generally over the plant.

Oat-	Gray oval shaped spot starts on edge of leaf at 3- to 4- leaf

	stage; it may spread across leaf; or many such spots may appear. Known as gray speck.
Barley, Wheat-	Yellow parallel streaks on upper leaves that run the length of leaf, but yellowing does not start at tip. Plants may have soft, limber growth and may show colorless spots.
Corn-	Interveinal chlorosis of leaves showing as light yellow-green pinstriping.
Soybeans, Beans, celery, Cucumbers, Cabbage-	For most non-grain crops, interveinal chlorosis with veins remaining green. Can be confused with Fe deficiency in soybeans.
Sugar beets, Potatoes-	Chlorosis begins on younger leaves. Later, gray and black freckling may develop along veins.

Soil Analysis

The DTPA extractant is used by some states to provide a measure of Mn availability. A dilute phosphoric acid extracting solution is used by some for acid soils. A critical level of 1.0 ppm for DTPA extractable Mn can be used as a guideline above which no crop response is expected. For the dilute phosphoric acid extractable Mn a critical level of 10 ppm is suggested.

Plant Analysis

Plant tissue analysis is useful in determining the Mn status of the plant. Normal plants usually contain 30 to 200 ppm, whereas, values below 20 ppm are usually considered deficient. It is important to sample the appropriate plant part at the stage of plant development for which information exists. Table 4 gives sufficiency ranges of Mn for selected plant parts for selected plants.

Fertilizer Sources and Applications of Manganese

Common sources of Mn are the sulfate, oxides, and chelates. Sources of Mn are listed in Table 11.

Table 11. Fertilizer sources of manganese.

Material		Percent Mn
Manganese chelate	Mn EDTA	12
Manganese sulfate	Mn $SO_4 \cdot 3\ H_20$	26-28
Manganese oxide	Mn O	41-68
Manganese dioxide	Mn O_2	63
Manganese chloride	Mn Cl_2	17
Manganese carbonate	Mn CO_3	31
Manganese frits	Glass (silicate) carrier	10-25
Manganese complexes	Organic	7-9

Broadcast applications of Mn are not recommended because soils fix Mn rapidly rendering it unavailable to plants. Banding a Mn source other than a chelate, with an acid forming fertilizer is satisfactory because this reduces contact with the soil and the acidic band improves availability. In some instances banding a Mn chelate has intensified the Mn deficiency because Fe replaced the Mn in the chelate making the Mn unavailable and the Fe more available for uptake accentuating the iron-manganese imbalance.

Manganese sulfate and manganese chelate are the most commonly used sources of Mn and are effective as foliar treatments because both are soluble. Suggested rates of Mn chelate should be that of the manufacturer. Rates of Mn for a foliar application provided by a chelate range from 0.10 to 0.15 lb Mn/acre. Rates greater than 0.25 lb Mn/acre provided by a chelate may be phytotoxic. If Mn sulfate is the source for a foliar application, usual rates are 0.75to 1.0 lb Mn/acre. For soil application usual rates are 3.0 to 5.0 1b Mn/acre if Mn sulfate or Mn oxide are the source and 0.5 to 0.8 lb Mn/acre if chelates are the source. Depending on the cause of the Mn deficiency, a soil applied chelate may not be effective. For the higher listed rates, these would be appropriate for oat, wheat, soybean, sudan grass dry beans, snap beans, lettuce, spinach, onions, radishes, and raspberry. The lower listed rates are suggested for other crops.

Manganese Toxicity

Excess available Mn occurs in acid soils with a a pH of 5.5 or less, especially for soils low in organic matter and temporarily waterlogged. High Mn levels are most likely to occur in acid, sandy soils.

Distorted leaves and dark specks on leaves are symptoms of Mn toxicity. As severe toxicity increases, leaf tissue begins to die at the leaf margins and progresses inward on the leaf. On soybean in the early stages of growth, interveinal chlorosis similar to a deficiency is a symptom. Plant tissue analysis is helpful in diagnosis of Mn toxicity. Concentrations over 300 ppm are considered excessive or toxic.

Plants sensitive to Mn toxicity are; alfalfa, cabbage, cauliflower, clover, dry edible beans, potatoes, small grains, sugar beets, and tomatoes. Liming acidic soils to the appropriate pH for the crop to be grown should eliminate potential Mn toxicity.

Molybdenum (Mo)

Function in Plant

Molybdenum is a part of the nitrate reductase enzme that is involved in the reduction of nitrate to ammonium after nitrate is taken up by the plant. It is also a structural component of the enzyme nitrogenase, which is involved in the fixation of atmospheric nitrogen into ammonium in a symbiotic relationship with legumes. The amount required by plants is very small.

Molybdenum in Soils

Molybdenum content in soils is very low, usually around 2ppm. As soils become acid, Mo availability decreases because iron and aluminum solubility increases and they react with Mo making it unavailable. Increasing soil pH increases Mo availability and usually liming acid soils is sufficient to maintain adequate Mo availability for all crops. Soils derived from sands tend to be low in Mo. Most Mo deficiencies occur on the older weathered and acidic soils in the Southeastern United States, but have occurred in the Midwest. Plants take up Mo as the molybdate ($MoO_4^{=}$) ion. High levels of soil sulfate ($SO_4^{=}$) can suppress its uptake.

Deficiency Symptoms

The first symptom of Mo deficiency is shown as a N deficiency (light yellow green leaves) because Mo is required for N fixation by leguminous plants and for conversion of nitrate to organic N in all plants. If the deficiency is severe, the leaf edges of some crops may turn brown and curl upward, termed cupping.

Soil Analysis

Because Mo deficiency is infrequent and proper soil management requires maintaining soil pH in a satisfactory range for crop growth, no reliable soil test has been developed for available Mo in soils.

Plant Analysis

Molybdenum is required in very small amounts by plants. Normal plant tissues contain 0.8 to 5.0ppm. Deficient plants usually contain less than 0.5ppm, but certain non-responsive crops such as corn and grass may contain only 0.1ppm. Table 4 gives sufficiency ranges of Mo for selected plant parts for selected plants.

Fertilizer Sources and Application of Molybdenum

Common sources of Mo are listed in Table 12.

Table 12. Fertilizer sources of molybdenum.

Material		Percent Mo
Sodium molybdate	$Na_2MoO_4 \cdot 2H_2O$	39
Ammonium molybdate	$(NH_4)_6 Mo_7O_{24} \cdot 2H_2O$	54
Molybdenum trioxide	MoO_3	66

The most common and satisfactory treatments are to the seed and a foliar application to correct a deficiency, but liming the soil to soil pH 6.0 or above should provide a correction. Seed treatment of 0.5 oz/acre is usually sufficient. For an existing deficiency on a crop a foliar spray of 2 to 3 oz/acre of sodium or ammonium molybdate is effective.

Molybdenum Toxicity

Plants are tolerant of high soil Mo concentrations and toxicity to plant growth would be rare. Plants high in Mo content, however, can cause problems for ruminant animals. An antagonism for Mo on copper metabolism can occur in the animal. Supplemental copper in the animal's diet counteracts the Mo and overcomes the problem.

Zinc (Zn)

Function in Plant

Zinc is a metal component of several enzyme systems that function as electron transfer mechanisms and in protein synthesis and degradation. Zinc is part of auxin, one of the well-known enzymes regulating plant growth. It is necessary for chlorophyll synthesis and carbohydrate formation.

Zinc in Soils

Available Zn is held on the cation exchange complex of soils, i.e., it is held on the surface of clay and organic matter. Most of the Zn in soils exists in unavailable forms in iron and manganese oxides. Soils may contain 2 to 25ppm of exchangeable and organic Zn.

The amount of available Zn in soils is affected by soil pH, soil texture, soil phosphorus, and weather conditions. The dominant form taken up by plants is the Zn^{++} ionic form.

Zinc availability to plants decreases as soil pH increases and may become deficient in soils with a pH above 6.5. Soil pH affects Zn availability more than any other factor. Care should be taken to not overlime soils, especially sands, so that Zn deficiency is not induced. Exposure of calcareous subsoils by erosion, terrace construction, or land leveling frequently causes Zn deficiency to occur on the affected areas.

Coarse textured soils e.g., sands and sandy loams, and organic soils are more likely to be zinc deficient than fine textured soils, e.g., silt loams and silty clay soils, because the coarse textured soils and organic soils were originally low in zinc.

High soil phosphorus levels can induce Zn deficiency in sensitive crops such as corn when available soil Zn is borderline sufficient or low. There has been some controversy on why this occurs. The current accepted explanation is that high levels of phosphorus in plants restrict Zn movement in plants resulting in an accumulation in the roots and deficiency in the top of plants. Care should be taken to not over fertilize with phosphorus on crops responsive to Zn.

Zinc deficiencies are more likely to occur early in the growing season during wet, cool, cloudy weather because plant uptake of Zn is low under these conditions. When soil temperatures increase and the soil dries out, plants frequently grow out of the deficiency. Crops grown on poorly drained organic soils probably show a deficiency because of restricted root growth.

Deficiency Symptoms

Zinc deficiency of corn appears as interveinal chlorosis, yellow striping, or as chlorotic bands starting at the base of the leaf and extending outward towards the tip. This usually occurs on the upper leaves first and unless very severe the margins of the leaf and the area next to the midrib will remain green. Plants are often stunted, i.e., shortened internodes and the nodal tissues show a reddish to brown discoloration when the stalk is split.

Dry edible beans deficient in zinc first become light yellow and leaves become deformed, dwarfed and crumpled. As severity increases the interveinal area becomes pale green and then yellow near the tips and margins of leaves. Pods abort in the terminal area of a Zn deficient plant. In snap beans interveinal chlorosis develops and is similar to manganese deficiency. Leaves of soybean have stunted stems and chlorotic interveinal areas on younger leaves. Later, the leaves may turn brown giving the plant a bronze appearance. Fewer pods are set and seed number is reduced.

Onions are sensitive to Zn deficiency and show yellow striping, bending, and twisting of the tops.

Soil Analysis

The DTPA extractant is used by most states that have calcareous soils. States that have very few if any high pH soils tend to use a 0.1 M HCl extraction for Zn. The procedures for the DTPA test are more standard for soil test laboratories than the HCl test. As a consequence, it is advisable to check the information on what is a critical level of soil zinc in states where the HCl test is used.

For the DTPA extractant a critical value of 0.75 to 0.80ppm Zn is used by some states for corn, sorghum, edible beans, flax and potatoes. Above this value, little or no response to applied Zn is expected. The interpretation for soil test values obtained by the HCl extractant may vary, but a critical value of 3.0ppm Zn is used by some.

Plant Analysis

Plant tissue analysis is useful in determining the Zn status of the plant and confirming if a Zn deficiency exists. Normal plants usually contain 30 to 100ppm Zn. Tissues containing less than 20ppm are often deficient. It is important to sample the appropriate plant part at the stages of plant growth for which information exist. Table 4 gives sufficient ranges of Zn for selected plant parts of selected plants.

Fertilizer Sources and Applications of Zinc

Common sources of Zn are the sulfates, oxides, combinations of oxides and sulfates (oxysulfates) and chelates. Sources of Zn are listed in Table 13.

Table 13. Fertilizer sources of zinc.

Material		Percent Zn
Zinc sulfate	$ZnSO_4 \cdot H_2O$	36
Zinc oxide	Zn O	77-80
Zinc oxysulfate	Oxides plus sulfates	varies
Zinc chelate	Na_2Zn EDTA	14
Zinc polyflavonoid	Organic	10
Zinc ligninsulfonate	Organic	5
Zinc frits	Glass (silicates) carrier	varies
Zinc-ammonia complexes		10

Zinc may be applied in a band at crop planting, broadcast or foliar. Foliar applications are appropriate for some speciality crops, e.g. tree fruits or to correct a known Zn deficiency that might occur unexpectedly on young plants.

General recommendations for a broadcast application of inorganic Zn are in the ranges of 4 to 10 lb. Zn/acre. If banded the recommendation of inorganic Zn is about one-half the rate broadcast, i.e., 2 to 5 lb. Zn/acre. Zinc chelates can be more effective than the inorganic sources because the chelating compound can protect the Zn from fixation by soil yet plant roots are able to take up Zn from the chelate. It is somewhat controversial on how effective zinc chelates are compared to inorganic sources. In some cases only 20 to 30 percent as much zinc chelate is needed as inorganic sources, and in many cases there is little difference in the effectiveness of the sources. In general, recommended rates of chelated zinc are one-third to one-fourth of those for inorganic sources.

Water solubility of the inorganic sources is an issue. A general suggestion is that 50 percent of the total Zn should be in the water-soluble form to be fully effective for the immediate crop. Water solubility of zinc oxide is very low and that of the oxysulfates can be very variable. If a water insoluble source such as zinc oxide is used it must be finely ground to be effective, but this poses a problem in blending with traditional dry fertilizer materials. There is a good relationship between immediate availability of Zn to plants and the percentage of water-soluble Zn in the fertilizer. Zinc sulfate, liquid zinc ammonia complexes, and zinc chelates are water soluble. Zinc sulfate and liquid zinc ammonia complexes are comparable in their effectiveness.

Zinc Toxicity

Excessive soil Zn levels may occur on extremely acid soils, i.e., soil pH less than 5.0 or in areas were Zn-enriched municipal sludge or industrial waste has been applied to the land. In general, plant tissue concentrations exceeding 300ppm Zn may be considered toxic but there is a great difference among crop species and varieties. Corn may tolerate the higher level of 300ppm Zn but in some varieties of dry edible beans 40 to 50ppm Zn in the tissue may result in toxicity. Vegetable crops are generally sensitive to high Zn levels, whereas, grasses tolerate high levels. Most small grains and soybean are intermediate between corn and dry edible beans in their sensitivity. Specific Zn soil test values have not been established for occurrence of toxicity because of the great range in plant tolerance to Zn. Liming acid soils will reduce the potential for Zn toxicity.

Secondary Nutrients

The secondary nutrients, calcium (Ca), magnesium (Mg), and sulfur (S), are major essential nutrients in addition to nitrogen (N), phosphorus (P), and potassium (K). The secondary nutrients are required in relatively large amounts but are less likely to be deficient. The total secondary nutrient content of some selected crop yields is shown in Table 14. The highest nutrient removal occurs when the whole plant is harvested such as with alfalfa and corn silage.

Table 14. Approximate secondary nutrient content for selected crops and yields.

			Lbs/acre	
Crop	Acre yield	Calcium	Magnesium	Sulfur
Corn grain	150 bu	2	8	10
Corn silage	15 tons	25	23	25
Oat grain	80 bu	2	3	5
Wheat grain	40 bu	1	6	3
Barley grain	40 bu	1	2	3
Soybean grain	40 bu	7	7	8
Alfalfa	4 tons	112	21	23

Although calcium deficiency per se is rare, there are crops that will respond to calcium additions. Sulfur deficiencies are more common than magnesium deficiencies. As plant genetics continues to rapidly change and commodity crops are developed with specific characteristics and qualities, interest increases in the adequate nutrition of crops by all essential nutrients. In addition:

- Higher crop yields and continuous cropping requires and removes larger amounts of these nutrients.
- More attention is being given to crop quality parameters, especially identity preserved crops.

- Use of high-analysis fertilizers low in nutrient impurities has increased while widespread use of animal manures has decreased.
- The decrease in sulfur emissions by industry has decreased the amount of sulfur deposited on the soil by precipitation.
- Increased use of nitrogen fertilizer and high soil potassium levels can cause low magnesium in some plants that causes grass tetany problems in livestock.

Calcium (Ca)

Function in Plant

Calcium is a component of every cell wall and is involved in cell elongation and cell division. It influences the structural stability and permeability of cell membranes. It acts as an activator for only a few enzymes. Calcium is credited for its beneficial effect on plant vigor and grain and seed formation. It is absorbed as the Ca^{++} ion.

Calcium in Soils

Calcium is a component of several soil minerals. Also, soil parent material usually contains more Ca than magnesium and potassium. Calcium is the dominant cation (Ca^{++}) held on the cation exchange capacity of soil clay and organic matter because it is held more tightly than magnesium (Mg^{++}) or potassium (K^{+}) and other exchangeable cations. As a consequence, soils normally have large amounts of exchangeable Ca in the range of 300 to 5,000ppm. Because of its strong attraction to the cation exchange complex, Ca movement by water in soils is extremely slow. But, because of the large amounts usually found in soils some Ca is probably lost by leaching except from very acid soils. Sufficient Ca to meet plant needs arrives at plant roots by mass flow except in very acid soils.

Deficiency Symptoms

Terminal buds and crop roots fail to develop when Ca is deficient. Symptoms show up first at the growing points because Ca is immobile in the plant. Blossom end rot of peppers and tomatoes, blackheart in celery, cavity spot in carrot and internal tip burn in cabbage are attributed to Ca deficiency.

In corn, the tips of new leaves do not emerge from the whorl because of a sticky, gelantous material. This gives the plant a "ladder" appearance. The leaf tips are also very chlorotic. Calcium deficiencies are usually related to the inability of the plant to translocate (move) Ca to the affected plant part rather than insufficient Ca in the soil.

Soils that are adequately limed are high in Ca. Moderately acid soils (soil pH 5.0 to 6.0) generally contain sufficient Ca for plants. Poor plant growth on these soils may be due to excess soluble aluminum, manganese or iron rather than lack of Ca. Very acid soils (soil pH less than 5.0) and soils that have received very excessive amounts of potassium and/or magnesium are conducive to Ca deficiency.

Soil Analysis

The same extractant, ammonium acetate, is used for calcium, potassium and magnesium. For non-calcareous soils the Mehlich 3 extractant may be used as a substitute for ammonium acetate.

An approximation for sufficient exchangeable Ca is 400 to 600ppm for sandy soils and 600-1000ppm for silty, clayey and organic soils. For most areas that have acidic soils, soil pH is used to determine if liming is necessary and another test, e.g., the SMP buffer method, is used to determine the lime requirement to increase soil pH to a given level. Where acidic soils are limed, sufficient calcium is present, whether calcitic or dolomitic limestone is used.

Calcium/magnesium ratios in soils have not been shown to be a problem except when exchangeable magnesium exceeds exchangeable Ca. This is difficult to achieve. Dolomitic limestone has a calcium/magnesium ratio of 2:1. Research has shown that crops are tolerant to a wide range of calcium/magnesium ratios and appear to be insensitive to this ratio if Ca is equal to or exceeds magnesium.

Plant Analysis

Calcium concentration of plant tissue tends to increase as plants mature. It is important to designate the stage of growth (maturity) when selecting plant tissue for analysis. There is a wide range in sufficiency values for Ca among and within crop species as shown in Table 4. For plants with storage organs, e.g., apples and potatoes, leaf tissue analysis is not useful because sufficient Ca might move to the leaves but not to the storage organs.

Fertilizer Sources and Application of Calcium

Agricultural limestone applied to correct soil acidity is the dominant source of applied Ca. Dolomitic or calcitic limestone is suitable, but calcitic limestone is preferred for soils with a calcium/magnesium ratio less than one. Table 15 lists the amount of Ca in some common liming and fertilizer materials.

Table 15. Sources of calcium.

Material		Percent Ca
Calcitic lime	$Ca CO_3$	40
Dolomitic lime	$Ca CO_3 + Mg CO_3$	22
Gypsum	$Ca SO_4 \cdot 2H_2O$	22
Slaked lime	$Ca (OH)_2$	54
Ordinary superphosphate	$Ca(H_2PO_4)_2 + Ca SO_4$	20
Triple superphosphate	$Ca (H_2PO_4)_2$	14
Calcium chloride	$Ca Cl_2$	36
Calcium nitrate	$Ca (NO_3)_2$	24

A soil application of a Ca material, other than an acid neutralizing material, such as gypsum can be appropriate for soils with a low cation exchange capacity supporting crops that require an acidic soil. Potatoes grown in such an environment can benefit.

Foliar applications to Ca deficient plants should cover the young terminal growth. Applications to older leaves are of little or no benefit. A suggested rate for foliar application is 1 to 2 pounds of Ca in 30 gallons of water, using either calcium chloride or calcium nitrate. Both are water soluble.

Recommended rates of Ca as a liming source or as a nutrient per se should be based on research conducted on soils and crops of the area.

Calcium Toxicity

Calcium toxicity is essentially unknown, but excessive calcium carbonate in soils can cause reduced availability of other nutrients, which is associated with high soil pH. Foliar application of some calcium materials can cause burning of foliage if soluble sources are applied in excessive amounts.

Magnesium (Mg)

Function in Plant

Magnesium is an essential part of the chlorophyll molecule. It activates many enzymes and aids in the formation of sugars, oils, and fats. Magnesium is mobile in the plant and is readily translocated from older to younger plant parts. It is absorbed as the Mg^{++} ion.

Magnesium in Soils

Magnesium is a component of several common soil minerals. Soils developed from coarse-grained rocks low in Mg containing minerals tend to be low in Mg. Most fine-textured soils and soils developed from rocks high in Mg contain adequate amounts of available Mg.

Magnesium is held on the cation exchange complex, and this exchangeable Mg is available to plants but is not easily leached through the soil. Acid soils, especially sands, frequently contain low levels of Mg. Soils neutral or high in pH usually contain adequate Mg.

Soils that may be deficient in Mg are: soils limed with materials low in Mg, such as paper-mill waste, marl or calcitic limestone; acid sandy soils; and organic soils containing free calcium carbonate or marl. In sandy soils high concentrations of potassium or ammonium in the soil solution due to fertilization interfere with Mg uptake by plants and can induce a Mg deficiency. If exchangeable Mg exceeds exchangeable potassium in the soil, Mg deficiency does not usually occur.

Deficiency Symptoms

Because Mg is mobile in the plant, deficiency symptoms first appear in the older leaves. In corn, Mg deficiency symptoms first appear as interveinal chlorosis of the older lower leaves. Symptoms may appear early in a cold, wet growing season and then disappear when soils warm up.

In wheat and oats, the older leaves show a distinctive chainlike yellow streaking. In potatoes, chlorosis begins at the tips and margins of the older leaves and progresses between the veins toward the centers of the leaves. Leaves become brown or reddish and very brittle during advanced stages of deficiency.

For other vegetables crops, chlorosis begins on the tips or edges of the leaves, veins remain green, and interveinal tissue may become brown. For some crops, older leaves are mottled and lighter green than new leaves.

Soil Analysis

The same extractant, ammonium acetate, is used for magnesium, potassium, and calcium. For non-calcareous soils the Mehlich 3 extractant may be used as a substitute for ammonium acetate.

An approximation for sufficient exchangeable Mg is 51 to 250ppm for sandy soil, 75 to 250ppm for organic soils and 101 to 500 ppm for all other soils. Other criteria to consider that could warrant a Mg application are: if the equivalents of potassium exceed Mg; if the soil Mg (as a percent of total bases) is less than 3 percent; or if the equivalent ratio of calcium to Mg is greater then 10.

Calcium/magnesium ratios in soils have not been shown to be a problem exept when exchangeable Mg exceeds exchangeable calcium. This is difficult to achieve unless: soils were developed from minerals high in Mg and low in other bases; or application of high rates of a straight Mg source. Dolomitic limestone has a calcium/magnesium ratio of 2:1 and applications of this limestone will not cause exchangeable Mg to exceed exchangeable calcium. Many soils in the Midwest have levels of exchangeable Mg that exceed "ideal" levels. There is no known way to selectively remove Mg to reduce these levels in the soil. Additions of acidifying materials, calcitic limestone on non-acid soils, or calcium sulfate are not warranted and there is no research base for these practices. Midwest research has shown that plant growth is not affected by a wide range of calcium /magnesium ratios as long as calcium and Mg levels are not deficient and the calcium /magnesium ratio is greater than one.

Plant Analysis

Magnesium concentration in plant tissue tends to decrease as plants mature and, within a plant, decreases from top to bottom because it is mobile in the plant. It is important to designate the stage of growth and the plant part selected for analysis. There is a wide range in sufficiency values for Mg among and within crop species as shown in Table 4.

Fertilizer Sources and Application of Magnesium

An application of dolomitic limestone to acid soils is the most economical and practical way to correct a Mg deficiency. On non-acid soils or if the crop requires an acid soil a Mg deficiency may be corrected with 50 to 100 lb/acre of soluble Mg broadcast or 10 to 20lb Mg/acre in a band alongside the row. Epsom salts (magnesium sulfate), potassium magnesium sulfate, or finely ground magnesium oxide are satisfactory sources of Mg. If excessive potassium has induced a Mg deficiency, either Epsom salts or magnesium oxide should be used.

Magnesium can be applied as a foliar spray. Some plants are not able to take up sufficient Mg from the soil. Suggested rates are 10 to 20 pounds of Epsom salts in 30 gallons of water.

Common Mg sources are listed in table 16.

Table 16. Sources of Mg

Material		Percent Mg
Dolomitic lime	$CaCO_3 + Mg\,CO_3$	8-20
Epsom salts	$Mg\,SO_4 \cdot 7\,H_2O$	10
Kieserite	$Mg\,SO_4 \cdot H_2O$	18
Potassium magnesium sulfate	$K_2SO_4 \cdot 2MgSO_4$	11
Magnesium oxide	$Mg\,O$	60

Low levels of Mg in lush grass pastures can lead to the development of hypomagnesemia (grass tetany) in grazing livestock. Feeding legume hay, which is higher in Mg content than grass, or adding a Mg source to the feed ration are corrective measures. An animal nutritionist should be consulted to adjust the feed ration. Soil testing should be the basis for correcting the soil problem.

Magnesium Toxicity

Because plants tolerate a wide range of exchangeable Mg in soils and more than a sufficient amount in a plant doesn't seem to cause a nutrient imbalance in the plant, Mg toxicity per se is not a problem.

Sulfur (S)

Function in Plant

Sulfur is a constituent of the amino acids, cysteine, methionine, and cystine that are essential for protein formation. It is also involved in the formation of vitamins and synthesis of hormones and chlorophyll. Sulfur is part of an important structural material of chloroplast membranes and of ferredoxins involved in photosynthesis reactions and in N-fixation by legumes. Sulfur is present in glycosides, which give the characteristic odors and flavors to mustard, onion and garlic plants. Sulfur is taken up by plants from the soil solution as the sulfate ($SO_4^=$) ion.

Sulfur in Soils

Sulfur transformations in the soil are very similar to those of nitrogen. In soil, S is present primarily in the organic form, which becomes available when organic matter decomposes. The process of mineralization of organic S to sulfate –S is similar to mineralization of organic nitrogen to nitrate –N. And, similar to nitrogen S can be immobilized by bacteria during the decomposition of crop residues rich in carbon but low in S. The amount of S mineralized each year from organic matter is small relative to nitrogen mineralized. Available sulfate –S can be changed to unavailable sulfide –S in water-logged soils. As aeration improves the sulfide –S combines with oxygen to re-form available sulfate –S.

Sulfate –S is subject to leaching because it remains in soil solution, but it is not quite as leachable as nitrate. Although it is not held on the cation exchange complex, it is attracted and absorbed on the surface of acid clays. Some acid, clayey subsoils contain sizeable amounts of available sulfate –S that can be taken up by plants. These subsoil pools of subsoil sulfate –S are seldom analyzed for, but they can account for no crop response to fertilizer –S when a surface soil test for S indicates a crop response would occur.

Deficiency Symptoms

Sulfur deficient plants are generally light green resembling a slight nitrogen deficiency, but the symptoms tend to be over the plant or on the upper leaves. It is not mobile in the plant. A sulfur compound is involved in nitrogen metabolism in the plant and a S deficiency interferes with this, resulting in the appearance of a slight N deficiency. Legumes, especially alfalfa, have a high S requirement, so deficiencies appear on these crops first. Corn, small grains, and grasses are less likely to show S deficiency. When it occurs in corn, sulfur deficiency causes interveinal chlorosis of the upper leaves and small plants may be light green overall. Plants may grow out of the deficiency as the roots penetrate into the subsoil.

Sulfur deficiency is most likely to occur on coarse – textured soils low in organic matter and on crops with a high S requirement.

Soil Analysis

The soil test used for S measures sulfate –S. This does not account for that released from organic matter and manure or that deposited in rainfall. Soil sampling is usually for phosphorus and potassium and therefore, doesn't account for subsoil sulfate –S. (Some states suggest a 2-foot sample for S.) The soil test for S is not as precise as tests for phosphorus and potassium.

Monocalcium phosphate is a preferred common extractant for sulfate –S because it depresses the solubility of organic matter and produces a clearer filtrate than if potassium phosphate is used. Other possible extractants are calcium chloride, lithium chloride and sodium chloride.

Predictability of a crop response to S additions based on S soil test results is poor. Some researchers have combined estimates of S in precipitation, S mineralization, S in manure, and subsoil S with soil test S to produce an index that improves the predictability of a response to S additions.

Plant Analysis

It may be necessary to request a S analysis if a laboratory does not do this routinely on samples. Many crops have S concentrations very similar to phosphorus. If a soil test indicates a S need and plant symptoms are non-existent or questionable, a plant analysis should be used to verify a S need. Sulfur sufficiency values are given in Table 4 for selected plant parts of selected crop species. It is important to designate the growth stage and the plant part selected for analysis.

Fertilizer Sources and Application of Sulfur

Naturally occurring S sources, e.g., organic matter, manure, precipitation and irrigation water usually meet or exceed the S requirements of the crop grown.

There are, however, S deficient soils where addition of inorganic S sources will benefit the crop grown. Sandy soils or well drained soils may require annual additions of sulfate –S because it is readily available, but it leaches through these soils. Where irrigation is used on these sandy soils the irrigation water may supply sufficient S.

All sulfate forms of S fertilizer are equally effective when surface applied or incorporated (Table 17). Elemental S should be incorporated in the soil to be effective because it must be transformed into sulfate –S by bacteria to be available to plants. The rate of this transformation depends on fineness of the particle size, the degree of incorporation, and soil environmental conditions affecting the activity of the bacteria. To be effective for the intended crop elemental S should be applied well in advance of crop needs. In some cases crop response to elemental sulfur occurs several months after application.

Table 17. Common fertilizer sources of sulfur.

Material		Percent S
Ammonium sulfate	$(NH_4)_2 SO_4$	24
Potassium sulfate	K_2SO_4	18
Potassium magnesium sulfate	$K_2SO_4 \bullet 2MgSO_4$	23
Calcium sulfate (gypsum)	$CaSO_4 \bullet 2H_2O$	17
Magnesium sulfate (Epsom salts)	$MgSO_4 \bullet 7H_2O$	14
Ammonium thiosulfate solution	$(NH_4)_2 S_2O_3 + H_2O$	26
Ordinary superhposphate	$Ca(H_2PO_4)_2 + Ca SO_4$	14
Zinc sulfate	$Zn SO_4$	18
Elemental sulfur	S	88-98

Row crops and small grains generally require 10 lb S/acre on sulfur deficient soils. Suggested rates for alfalfa are 25 to 50 lbs S/acre in the seeding year and 15 to 25 lb/acre if topdressed to an established stand. These rates should last 2 to 3 years unless on a very sandy soil. Ammonium thiosulfate, a very commonly used source in fluid fertilizers, should NEVER be placed with a crop seed. It is toxic to the seed and will drastically reduce crop stand.

Sulfur Toxicity

Sulfate/sulfur toxicity symptoms begin as an interveinal chlorosis and scorching of the leaf margins, which gradually proceeds inward. Potential areas for occurrence would be those using irrigation water high in sulfates.

Sulfur dioxide in the atmosphere can injure plants. Relatively sensitive crops are soybeans, dry edible beans, alfalfa, small grain crops, and several vegetable crops. Symptoms of sulfur dioxide injury are similar to frost damage, herbicide injury or injury from other aerial contaminants. It is difficult to make an accurate diagnosis of sulfur dioxide injury. The potential for this injury should decline as sulfur emissions from burning fossil fuels are reduced.

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