UNDERSTANDING CROP RESPONSE TO MICRONUTRIENTS

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INTRODUCTION

There are many factors that affect crop response to micronutrients, and response to micronutrients is often less predictable than response to N, P, and K. Responses to micronutrients may be dramatic if the nutrient is deficient, but more often, responses are incremental yield increases or even only maturity or quality improvements. Micronutrient chemistry in the soil is complex and there are numerous interactions with other nutrients and environmental conditions. While predictability of micronutrient response may be less than some other nutrients, it can be improved by considering the interactions with some of the factors affecting crop nutrient response.

DETERMINING MICRONUTRIENT NEEDS

Micronutrient need is evaluated first by soil testing. Appropriate soil testing provides an indicator of the probability of crop response to a given nutrient. Because of the complexity of micronutrient interactions with other production factors, the predictability of micronutrient response is often somewhat less than for other nutrients. Responses to micronutrients can be observed when soil test levels are adequate. Conversely, a low soil test does not guarantee crop response when other factors are limiting. Nevertheless, soil test information should not be ignored. Crop history and field scouting records help to pinpoint previous problem areas and gain some insight as to how the crop responded to treatments. Plant analysis provides a good evaluation of the micronutrient status of a plant when soil tests and field scouting are not conclusive. For best results, soil and plant analysis should be used together to detect shortages and to develop effective micronutrient management programs.

SOIL pH

Soil pH is a major determinant of micronutrient availability in the soil. Availability of boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) decreases sharply as soil pH increases. Soil pH governs the reaction products of fertilizers applied to the soil and is a major reason most of what we apply as fertilizer becomes fixed or “tied up” as insoluble minerals in the soil. The chemistry of high pH soils makes them prone to deficiencies of most micronutrients. Over-liming can actually induce micronutrient deficiencies. Conversely, acid soils are less likely to be deficient in available micronutrient.

SOIL CONDITIONS AND ROOT GROWTH

Adverse soil conditions such as cold temperatures, wet soils, poor drainage, compaction, root pruning, and disease all decrease rooting volume and therefore negatively affect nutrient availability. Some nutrients, such as zinc are well known for being less available under adverse conditions. Starter fertilizers are often applied to overcome some of these conditions. Addition of micronutrients in the starter fertilizer can produce additional response even when soil test levels are high and response is not expected. For example, studies in Wyoming with dry edible beans demonstrated response to starter zinc in very high testing soils (Blaylock, 1995b and 1996). Other studies have shown similar responses in other crops.

TIMING AND METHODS OF APPLICATION

Broadcast applications are often most convenient, but require higher rates for response and sometimes, such as with Fe on alkaline soils, are rendered ineffective by the soil conditions which originally created the need for treatment. Soils that are low in a particular nutrient may benefit from broadcast applications at higher rates to build available nutrient levels. Broadcast applications of B are usually more effective than for other nutrients because it is mobile in the soils and moves more easily to plant roots.

Band placement is usually superior on alkaline soils because of the propensity for micronutrients to be tied up with other soil minerals. The micronutrient metals, Cu, Fe, Mn, and Zn, are immobile in the soil and are supplied to plant roots primarily by diffusion. Band applications frequently produce the desired response at one-fourth to one-half the rate needed with a broadcast application. In a band application, soil pH can sometimes be manipulated as a tool for improving micronutrient availability. Several studies have documented better performance of micronutrients applied in a band with other acid or acid-forming fertilizers (Miner et al, 1986; Petrie and Jackson, 1984a; Petrie and Jackson, 1984b). A summary of Kentucky field trials evaluating methods of Zn application to corn (Table 1) showed band placement to be better than either broadcast or foliar methods.

Table 1. The effect of application methods of Zn on corn grain yields.

Application method,	Corn Response (bu/A)			
(sites)	0-4	5-10	11-15	15+
	Percent of trials showing response			
Broadcast (31 sites)	55	6	19	20
Row (28)	29	21	29	21
Foliar (31)	26	36	6	32

Kentucky.

Foliar sprays allow for the use of a minimum of product and rapid absorption and correction of deficiencies. Foliar applications should be made as soon as the deficiency is observed. By the time visual symptoms are observed, some yield potential may have been lost. Rescue foliar applications may be less effective because they are often made after deficiencies are observed and yield potential has been lost. For some situations, foliar applications may be the best method of correcting micronutrient deficiency. For example, Fe and Mn deficiencies on alkaline soils are difficult to correct with soil applications, but can be readily corrected with timely foliar treatments. Only small amounts of product are needed, but repeated applications may be necessary to maintain proper nutrient supply. Foliar applications should be made in consideration of plant nutrient demand and soil supplying capacity. Foliar feeding strategies should be accompanied by regular field scouting and knowledge of the soil, environment, and production system. Plant tissue analysis can be useful in diagnosing nutrient status before symptoms appear.

Seed coating fits best with Mo applied with the inoculation for legume crops. Seed coatings have been used with some success with some other micronutrients, but it may be difficult to supply sufficient amounts of some nutrients to provide the entire crop need.

NUTRIENT INTERACTIONS

Levels of other nutrients can affect micronutrient response. Interactions of the metals Cu, Fe, Mn, and Zn with P have been well documented. One of the best-known interactions is the Zn-P interactions. High levels of soil or fertilizer P have been shown to reduce the uptake and utilization of Zn. This usually occurs when Zn is marginal to deficient and rarely is observed with high soil Zn levels. High N supply may also increase Zn demand. High N levels stimulate vegetative growth and delay crop maturity; Zn often hastens crop development and maturity. Dry bean studies in Wyoming have demonstrated this response, even on high-Zn soils (Blaylock, 1995a. The following are some examples that have been noted in the published literature. High levels of exchangeable bases, such as calcium and magnesium, sometimes reduce uptake of the micronutrient metals (Cu, Fe, Mn, and Zn); high soil N and P are often associated with Cu deficiency and high N levels delay translocation of Cu to growing points; and high levels of one metal can induce a deficiency of another. Balanced plant nutrition is the best way to avoid problems resulting from interactions with other nutrients; avoid excess levels of other nutrients while maintaining adequate supply of the micronutrients.

FIELD VARIABILITY

Natural or man-caused field variability often affects crop response to micronutrients. Frequently, soil micronutrient levels will vary dramatically across a field. These differences may be associated with changes in soil pH, soil organic matter, topsoil thickness, drainage, and landscape position. Grid sampling has identified significant areas of fields that are deficient in one or more micronutrients when field-average samples otherwise indicate adequate levels. When this occurs producers lose potential profits in these areas by inadequate fertilization. These profits can be captured by properly accounting for natural or man-made variability.

Figure 1 shows data representing samples from several Iowa corn fields sampled on a one-acre grid and analyzed for various nutrients. The distribution of Zn soil test levels is shown in the bars. The line indicates the percentage of samples below a given soil-test level. The field average of 1.4 ppm would be near or above commonly used critical values for DTPA-Zn. However, it can be seen that about 50% of the acres represented by these samples would be below a critical level of 1.0 ppm DTPA-Zn. At this level, some yield loss from Zn deficiency could be expected. Field average sampling and recommendation would unlikely advise additional Zn fertilizer on these acres, but it is apparent a

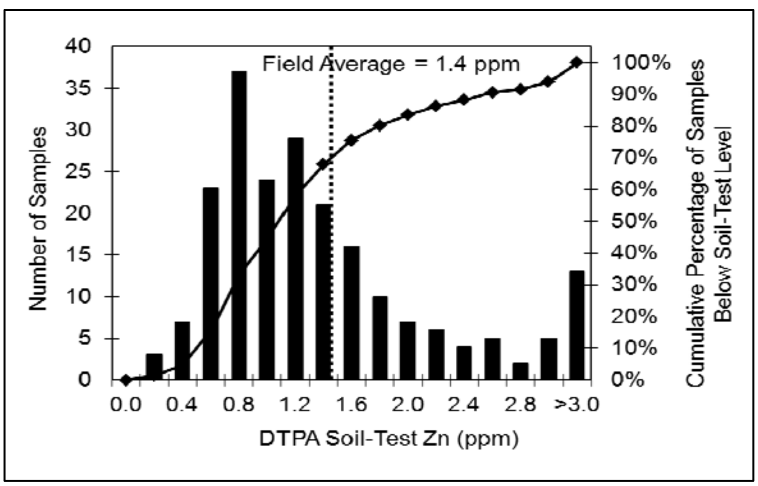

Figure 1. Distribution of DTPA soil-test values in several Iowa corn fields in 1998.

field-average strategy would not be the best management for these acres. A site-specific strategy would more accurately represent the actual nutrient needs and make better use of micronutrient resources. Similar examples can be shown for soils throughout North America.

CROP SENSITIVITY

Crops vary greatly in sensitivity to micronutrients. Understanding a crop's specific nutrient requirements will help improve prediction of micronutrient needs and maximize economic benefits of the nutrient management program. Table 2 contains a listing compiled from a variety of sources of some common crops considered to be most responsive to specific micronutrients.

Table 2. Crops considered most responsive to various micronutrients.

Boron	Copper	Iron	Manganese	Zinc
Alfalfa	Corn	Sorghum	Soybean	Corn
Clover	Onion	Soybean	Sugarbeet	Dry bean
Cotton	Tomato	Dry bean	Wheat	Sorghum
Sugarbeet	Small grains	Sugarbeet	Oat	Onion
Brassicas	Alfalfa	Turf	Corn	Soybean

SOIL ORGANIC MATTER AND TEXTURE

Excesses in soil organic matter and texture are often associated with micronutrient deficiency. Very high soil organic matter results in organic complexation of the micronutrient metals, especially copper and manganese. Low organic matter, especially when resulting from topsoil loss by soil erosion or leveling when a calcareous subsoil is present, often causes micronutrient deficiencies. Organic matter decomposition is an important soil source of these nutrients. Natural chelators that can make micronutrients more available are present at much lower levels when soil organic matter is low. Very sandy soils have low cation-exchange capacity and are easily leached. In very clayey soils, diffusion, the mechanism by which many of these nutrients move to roots, is slower. Although soil levels of the nutrient may be high, movement to the roots may be inadequate to supply the plant during periods of peak demand.

FERTILIZER SOURCE

Micronutrient source is another factor determining crop response. Unlike many N, P, and K fertilizers, there is much differentiation among available products. Micronutrient sources vary considerably in their physical state, chemical reactivity, cost and availability to plants. Available micronutrient fertilizers can be grouped into three main classes – inorganic compounds, synthetic

Product sizing and blending uniformity are even more important for micronutrients than for N-P-K fertilizers because of the small amounts applied. Poor blending of a few pounds of micronutrient carrier in a bulk blend can result in poor product performance and lost profits.

Inorganic compounds may be in the form of oxides, carbonates, oxysulfates, or metallic salts, such as sulfates, chlorides, or nitrates. Sulfates are the most common of the metallic salts and are commonly available in a granular form. Ammoniated $ZnSO_4$ or $ZnCl_2$ solutions are also available and are usually applied in polyphosphate starter fertilizers. Oxides are sometimes used as fine powders. They may be effective if finely ground and thoroughly mixed with the soil, but their immediate effectiveness for crops is very low in granular form. Micronutrient fertilizers must supply the nutrient in a form that is water soluble or becomes soluble in the soil.

Oxysulfates are the most common form used for granular fertilizers. Oxysulfates are commonly available as either single-nutrient products or as multi-nutrient homogenous granular fertilizers. They are oxides, usually industrial by-products, which have been partially reacted with sulfuric acid. The percentage of water-soluble metal (Cu, Fe, Mn or Zn) in oxysulfates is directly related to the degree of acidulation. Research results have shown that at least 35 to 50% of the total metal in granular metal-oxysulfates should be in water-soluble form to be immediately effective for crops. Products that do not meet minimum solubility requirements have been shown to produce less than maximum crop response (Amrani, 1997; Mortvedt, 1992; Mascagni and Cox, 1985).

Figure 2 shows the results of a Colorado State University study comparing inorganic Zn fertilizers. Materials with low water solubility produced little effect on plant growth in soil of pH 7.4, even at very high rates. Materials that exceeded the recommended 35-50% water solubility produced the maximum plant response and were not significantly different from each other. Materials that had water solubility less than 50% produced a response that was proportional to solubility and application rate. Inorganic sources usually are the least costly sources per unit of micronutrient, but they may not always be the most effective for crops. Materials with greater water solubility are usually more expensive than materials with low solubility because of greater manufacturing costs.

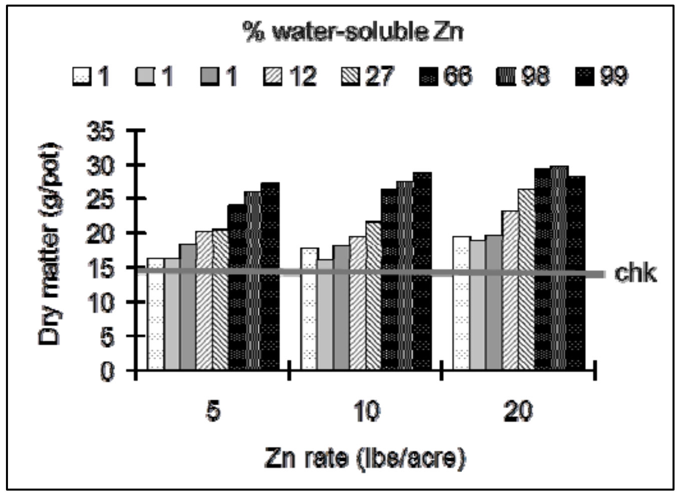

Figure 2. Corn response to inorganic Zn fertilizers of varying water solubility. Amrani et al. 1997.

Synthetic chelates are formed by combining a chelating agent with a metal through coordinate bonding. Chelates are much more costly and claims of greater effectiveness are often exaggerated. Stability of the metal-chelate bond affects availability of the micronutrient metals to plants. An effective chelate is one in which the affinity of the chelating agent for the micronutrient metal is greater than for other cations in the soil. The micronutrient will thereby be maintained in its chelated form in the soil solution and be less reactive with soil minerals. Weaker or less stable chelates that do not maintain the metal in the chelated form may provide little or no advantage over inorganic sources. Relative effectiveness per unit of micronutrient for soil applications of the most stable chelates (EDTA, for example) may be from two to five times greater than that of inorganic sources, but chelate costs may be five to 100 times higher. Claims of greater effectiveness are often exaggerated. Several chelates are available at various prices and relative effectiveness values depend on the specific chelates and inorganic products compared.

Organic complexes are made by reacting metallic salts with organic by-products of the wood pulp industry or other related industries. While organic complexes are less costly per unit of micronutrient than the synthetic chelates, they are also usually less effective. For soil applications, the relative effectiveness of organic complexes is usually similar to the inorganic products. These sources may be more suitable for foliar sprays and mixing with some fluid fertilizers.

Micronutrient fertilizers should be chosen to apply or blend accurately within the management system of the grower and with other fertilizer applications. Products that do not blend uniformly with other fertilizers will not be uniformly applied in the field. This is even more important for micronutrients than for N-P-K fertilizers because of the small amounts applied. Poor blending of a few pounds of micronutrient carrier in a bulk blend can result in poor product performance, improper fertilization, and lost profits. Chelates and foliar applications are effective means of supplying micronutrients if used properly.

SUMMARY

Confident diagnosis of micronutrient needs requires more than a scan of laboratory results from a 0-6" soil sample. Success increases dramatically when considering overall fertility management, management level of the producer, soil type and conditions, crop sensitivity, and past observations of crop response, quality, or deficiency symptoms. Responsible agronomists can give better recommendations and improve the probability of economic return if this additional information is used in making micronutrient recommendations.

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