FROM THE GROUND UP
agronomy news

INSIDE THIS ISSUE:

Metals And Micronutrients

Weighing environmental hazards and economic benefits

This newsletter focuses on metals and micronutrients from two points of view: environmental hazards and agronomic benefits. The newsletter starts with an introductory article to refresh all of our memories with the basics. The next several articles focus on environmental concerns, specifically, heavy metal contamination of fertilizers, soil copper accumulation due to its use in footbaths for livestock, and arsenic in groundwater. After that, we switch focus to agronomic utilization of micronutrients with several articles on zinc that cover sources, application methods, and interactions with phosphorus.

The last three articles focus on iron in corn, boron in alfalfa and potatoes, and sulfur in wheat. Numerous outside authors contributed to this issue including: Terry Tindall from Simplot, Alan Blaylock from Agrium, Bryan Hopkins from the University of Idaho, Bart Stevens from the University of Wyoming, and Gary Hergert from the University of Nebraska. I'm grateful to all of the contributing authors and hope this newsletter is helpful in weighing both the hazards and benefits of metals and micronutrients.

Jessica Davis
Soil Specialist
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Colorado State University
Knowledge to Go Places

Micronutrients In Crop Production

An understanding of micronutrient deficiency symptoms, common conditions leading to deficiencies, and sources of micronutrients is essential to understanding the role of micronutrients in agronomy.

Questions are often raised about the relative importance of micronutrients in crop production. It has been well established that optimum yields generally are not possible without N, P and K fertilizers, and the secondary nutrients to a lesser extent. Most growers and dealers follow the recommended rates and methods of application to achieve top yields, but they may not consider that one or more micronutrients also may be limiting their yields.

Micronutrients are those elements which are essential for plant growth, but are required in much smaller amounts than those of N, P and K. The micronutrients are boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), zinc (Zn), and chloride (Cl). Because Cl deficiencies rarely occur, this report will discuss the other six micronutrients.

Micronutrient deficiencies have been verified in many soils through increased use of soil testing and plant analyses. Soil tests should be included in all micronutrient fertilization programs, first to assess the level of available micronutrients and later to determine possible residual effects (buildup). Plant analyses give an indication of the micronutrient status of crops during the growing season.

Boron
Boron deficiency symptoms first appear at the growing points. This results in a stunted appearance (rosetting), barren ears due to poor pollination, hollow stems and fruit (hollow heart), brittle discolored leaves, and loss of fruits and nuts.

Boron deficiencies are mainly found in acid soils, on sandy soils in regions of high rainfall or under irrigation, and those soils with low soil organic matter. Borate ions are mobile in soil and can be leached from the root zone. Boron deficiencies are more pronounced during drought periods when root activity is restricted. Crops that are susceptible to B deficiency are alfalfa, sugar beets, clovers, and some vegetable crops. There have been few reported crop responses to applied B in Colorado.

Copper
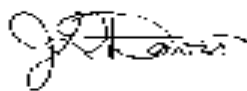Deficiency symptoms of Cu are dieback of stems and twigs, yellowing

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of leaves, stunted growth, and pale green leaves that wither easily. Cereal crops are especially susceptible to low Cu levels, with curled leaves at tillering, head and stem bending, shriveled grain, and delayed maturity.

Copper deficiencies are mainly reported on organic soils (peats and mucks), and on sandy soils which are low in organic matter. Copper uptake decreases with increases in soil pH and increased P and Fe availability in soils. Some crops that are sensitive to Cu deficiency are alfalfa, barley, corn, oats, wheat and some vegetable crops. Copper deficiencies have not been observed in Colorado crops.

Iron

Iron deficiency is expressed as yellow leaves due to low levels of chlorophyll (chlorosis), which first appears on the younger upper leaves in interveinal tissues. Severe Fe deficiencies may cause leaves to turn completely yellow or almost white, and then brown as leaves die.

Iron deficiencies are found mainly on calcareous (high pH) soils. Cool, wet weather enhances Fe deficiencies, especially on soils with marginal levels of available Fe. Poorly aerated or compacted soils also reduce Fe uptake by plants. Uptake of Fe decreases with increased soil pH, and is adversely affected by high levels of available P, Mn and Zn in soils. Some crops which are sensitive to Fe deficiency are corn, sorghum, wheat and ornamentals. Iron chlorosis has been widely observed in grain sorghum and on ornamentals in Colorado.

Manganese

Interveinal chlorosis on dry beans, and whitish-gray spots on leaves of cereal crops are Mn-deficiency symptoms. Brown necrotic spots appear on leaves with very severe Mn deficiencies, resulting in premature leaf drop.

Deficiencies of Mn mainly occur on organic soils, and sandy soils low in organic matter, and on over-limed soils. Toxicity of Mn can result in some acidic, high-Mn soils. Crops which are susceptible to Mn deficiency are dry beans and some vegetable crops. There have been no reported Mn deficiencies in Colorado crops.

Molybdenum

Molybdenum deficiency symptoms in legumes are mainly exhibited as N-deficiency symptoms because of the primary role of Mo in N_2 fixation. Deficiency symptoms of Mo in some vegetable crops are irregular leaf blade formation (known as whiptail), interveinal mottling and marginal chlorosis of older leaves. Molybdenum deficiencies are found mainly on acid, sandy soils in humid regions. Plant uptake of Mo increases with increased soil pH, which is opposite that of the other micronutrients. Crops which are sensitive to Mo deficiency are alfalfa, clovers and some vegetable crops. There have been no reported Mo deficiencies in Colorado crops.

Zinc

Some zinc deficiency symptoms are short internodes (rosetting), a decrease in leaf size, chlorotic bands along the midribs of corn, mottled leaves of dry beans, narrow yellow leaves in the new growth of citrus, and delayed maturity.

Zinc deficiencies are mainly found on sandy soils low in organic matter and on organic soils. They occur more often during cold, wet spring weather and are related to reduced root growth and activity. Uptake of Zn decreases with increased soil pH, and is adversely affected by high levels of available P and Fe in soils. Some crops which are susceptible to Zn deficiency are corn, dry beans, lettuce and onions. Zinc application is recommended for corn grown on Colorado soils testing low (<1.5 ppm) in available Zn.

Micronutrient sources

Micronutrient sources vary considerably in their physical state, chemical reactivity, cost, and availability to plants. The main classes are inorganic products, synthetic chelates and organic complexes.

Inorganic sources include oxides and carbonates and metallic salts such as sulfates, chlorides, and nitrates. The sulfates are the most common of the metallic salts and are sold in crystalline or granular form. An ammoniated $ZnSO_4$ solution usually is applied in polyphosphate starter fertilizers. Oxides of Mn and Zn are also sometimes used as fine powders, but their immediate effectiveness for crops is rather low in granular form.

Oxysulfates are oxides, usually industrial by-products, which have been partially acidulated with sulfuric acid, and generally are sold in granular form. The percentage of water-soluble 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 Zn in granular Zn-oxysulfates should be in water-soluble form to be immediately effective for crops. Similar results would be expected for Mn-oxysulfate. Inorganic sources usually are the least costly sources per unit of micronutrient, but they may not always be the most effective for crops.

Synthetic chelates are formed by combining a chelating agent with a metal through coordinate bonding. Stability of the metal-chelate bond affects availability of the micronutrient metals to plants. An effective chelate is one in which the rate of substitution of the chelated micronutrient for other cations in the soil is quite low, thus maintaining the applied micronutrient in chelated form.

Relative effectiveness for crops per unit of micronutrient as soil-applied chelates may be from two to five times greater than that of inorganic sources, but chelate costs may be five to 100 times higher. Several chelates are sold, so relative effectiveness values depend on the sources of chelates and inorganic products compared.

Organic complexes are made by reacting metallic salts with some organic by-products of the wood pulp industry or other related industries. The types of chemical bonding of the metals to the organic components are not well understood. While organic complexes are less costly per unit of micronutrient, they usually are less effective than synthetic chelates. They also are more readily decomposed by microorganisms in soil. These sources are more suitable for foliar sprays and mixing with some fluid fertilizers.

Summary

Micronutrients are as important as the primary and secondary nutrients in plant nutrition. However, the amounts of micronutrients required for optimum crop yields are much lower. Soil tests and plant analyses are excellent diagnostic tools to monitor the micronutrient status of soils and crops. Visual deficiency symptoms of these nutrients also are well recognized in most economic crops. Micronutrient recommendations are based on soil and plant tissue analyses, the crop species and expected yield, management level, and research results.

Because recommended rates usually are low, most micronutrients are applied with NPK fertilizers, but foliar sprays also are frequently applied. Choice of micronutrient source depends on the method of application, compatability with the NPK fertilizer, convenience of application, and the relative agronomic effectiveness and cost per unit of micronutrient.

John Mortvedt
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Heavy Metals In Commercial Fertilizers

Risk assessments of the use of cadmium, lead, and arsenic in fertilizer focus on public health and safety.

Most commercial phosphate, potassium, and micronutrient fertilizers originate from natural resources. The J.R. Simplot Company, for example, has a modern mining operation on the Idaho/Wyoming border from which we extract phosphorus ore. Simplot's mine sits at about 7000 feet in elevation, but was at one time an inland ocean. Sediments associated with this body of water had a high concentration of phosphorus in the form of a mineral called apatite (also known as rock phosphate). The ocean sediments (which are now rock) also contained small concentrations of other elements. Some of these elements provide nutrition for growing plants and others have no nutritional value (such as cadmium, lead, and arsenic). All of the elements contained in the phosphorus fertilizer are also naturally occurring in the soil to which the fertilizers are being applied.

Public concern over heavy metals in commercial fertilizer has decreased recently as understanding of these elements has improved. Concern with public health, as well as environmental degradation, had surfaced over the past few years. Most of the concern came about due to popular articles that were written to generate interest and public discussion. Much public discussion, thousands of dollars spent, many hours of deliberation and new laws initiated have been the final results of this information. I guess the question to ask is: Are we a better world for the time and exposure? Maybe we are.

The fertilizer industry is more closely monitored and the total amount of nutrient (especially P) is restricted to agronomic rates (in some areas). Proposed laws in California have moved closer to accepting Risk-Based Concentrations for the above mentioned elements through the California Dept. of Food and Agriculture (CDFA). The U.S. EPA has also conducted an extensive fertilizer risk assessment to provide direction regarding additional regulations of commercial fertilizers relative to non-nutritive elements. They adapted assessments for bio-solids used as a soil amendment and cement kiln dust used as an agriculture liming material. The EPA was interested in NPK fertilizers, all micronutrient fertilizers, and some soil amendments. Nine metals were evaluated which included arsenic, cadmium, and lead. It is interesting to note that the EPA did not evaluate Risk-Based Concentrations but asked three yes or no questions:

1) Are commercially available phosphate materials safe for humans and the environment?
2) Are micronutrients safe? and
3) Are NPK blended fertilizers safe?

To answer these questions, the EPA evaluated exposure routes using farm families (adults and children) as their receptors. The exposure routes were as follows:

◆ Direct ingestion of fertilizer products during application
◆ Incidental consumption of soil
◆ Inhalation of particles or fertilizer vapors during application
◆ Ingestion of plant and animal products produced on fertilized soil
◆ Ingestion of fish from streams adjacent to fertilized fields

The EPA evaluated hundreds of commercially available products and found only four materials that had elevated levels of metals above an accepted standard of concern. The materials of concern included one liming material, and one each of iron, boron, and zinc micronutrient fertilizers. The standard of concern was not a cancer risk, but listed as a hazard index. The hazard index separates products that are "safe"

from those that need further evaluation.

Two additional risk assessments have also been conducted evaluating heavy metals contained in fertilizers. One was conducted for The Fertilizer Institute and the other by the California Department of Food and Agriculture (CDFA). Both of the studies had primary concern for public health and safety in association with exposure to fertilizer materials. The CDFA study not only looked at exposure to humans from handling or ingesting the fertilizer, but also evaluated heavy metal uptake in vegetable crops, root crops and grains. The CDFA study has resulted in a new regulation restricting levels of arsenic, cadmium, and lead in phosphate and micronutrient fertilizers. The new regulation will be implemented in California in 2002.

A more interesting study (from an agronomic viewpoint) is currently being conducted by Washington State University under the direction of Drs.

Bob Stevens and Shiou Kuo and other researchers in Washington. Their study included the application of both raw rock phosphate, treble super phosphate (0-45-0) from two sources, and a zinc micronutrient fertilizer. These fertilizer materials were applied at both agronomic rates and as much as eight times agronomic rates to field plots, which were planted to wheat or potatoes. The primary goal was to determine how fertilizer-loading rates would impact cadmium and lead levels of these two crops. At the end of the 2000 growing season there were no effects on yield.

Cadmium and lead concentrations increased in both the soil and the potato tuber and wheat grain relative to increased application rates. However, even at the high rate (8 x agronomic rate), the tissue concentration was far below any of the Risk-Based Concentrations established by EPA or CDFA. The most interesting results from their work were relative to the use of raw rock phosphate. This material surprisingly decreased grain yield in the first year of the study. Unless raw rock P is treated with sulfuric acid and processed into 0-45-0 it is difficult for crop P demands to be met.

Results of several risk assessments, as well as the above field study and other published research, have shown that commercial fertilizers are safe when used at agronomic rates.

Terry Tindall
Manager of Agronomy
J.R. Simplot Co.

Is Copper In Dairy Footbaths A Problem For Crops And Cows?

Copper sulfate used in dairy footbaths can lead to soil copper buildup.

Most dairies in Colorado use copper sulfate in foot baths to control hoof infections. After use, the foot baths are usually channeled into the wastewater lagoons along with the runoff water and flush water from the milking parlors. Then, the lagoon effluent is usually applied to forage crops being grown to feed the cows.

An article in Hoard's Dairyman by E.D. Thomas in July 2001 brought this issue to the forefront with special concern for copper accumulation in forage crops and subsequent toxicity to dairy cows.

Regulations

At this time, there are no regulations that pertain to copper applications to crops in the form of dairy effluent. However, both the biosolids and hog regulations require regular soil sampling and analysis for copper. In addition, The Colorado Department of Health and Environment limits the annual and cumulative application of metals in biosolids, including copper. The annual limit for copper application in this form is 67 lbs/acre, and the cumulative or lifetime loading limit is 1340 lbs copper per acre. Officially, these limitations do not apply to dairies, unless they use biosolids. However, the wise milk producer will pay attention to these regulations as possible precedents for dairy regulation in the future.

Copper quantities

We calculated typical copper usage by Colorado dairies and found a range from about 1000 lbs Cu/year up to over 10,000 lbs Cu/year. This calculation is based on the following information: 5-10 lbs copper sulfate is dissolved in 25 gallons of water, copper sulfate is 25% copper, footbaths hold 25-75 gallons of water and are changed about nine times per day and used two to three times per week. So is 1000-10,000 lbs Cu/yr a problem? Obviously, the answer will depend on how much acreage the effluent is spread on. If the effluent is all applied through one center pivot onto 125 acres, this is equivalent to 9 to 84 lbs Cu/yr. The high end of the range is over the biosolids annual loading limit, so these values are high enough to warrant further consideration.

Toxicity to bacteria in lagoons

The first potential hazard of the copper could be to bacteria in the wastewater lagoons. Some copper may re-precipitate or settle out into the lagoon sludge, thus reducing the copper levels in the effluent itself. However, effluent copper levels may still be toxic to bacteria, and this is important because most lagoons are sites for either aerobic or anaerobic treatment of waste by bacteria. One large Colorado dairy recently had difficulty with low bacterial populations and determined that this

was probably due to the copper sulfate footbaths.

Toxicity to crops

When copper is applied to our soils, it is strongly bound to clay minerals. Exchangeable copper is held much more tightly than other cations, and is not readily available to plants. Organic matter also binds copper, so the more organic matter and clay that a soil has, the greater the potential for copper adsorption will be. In addition, increasing soil pH reduces copper availability to plants, allowing greater soil copper accumulation without subsequent plant toxicity in our high pH soils. Because of its strong binding, copper leaches very little, and accumulates in the soil surface.

Copper is not readily mobile in plants, resulting in higher copper levels in roots than in shoots. Therefore, copper toxicity often results in decreased root growth and damage to root cell membranes. Researchers have found that high levels of calcium can alleviate copper's toxic effects on membranes, which is fortunate for Coloradoans who generally have high soil calcium levels. Copper toxicity may also induce iron deficiencies or general chlorosis in plants.

There is tremendous variability in plants' ability to tolerate high copper levels. In general, a level of 20-30 parts per million (ppm) in the leaves may be considered toxic, but this is a broad generality across all plant species and should not be applied to specific crops without additional information. Some researchers have

noted that legumes, such as alfalfa, are more sensitive to copper toxicity than grasses, so care should be taken when growing alfalfa on soils that receive Cu-enriched effluent.

Toxicity to livestock

The maximum tolerable level of copper in diets of lactating dairy cows is 100 ppm, while the minimum is 10 ppm. Therefore, when copper sulfate is being used in footbaths and the waste is channeled to the lagoon and applied to land, producers should have copper analyzed in their forages before feeding them, as part of their normal forage testing program. Be aware that other types of livestock have different critical levels; for example, 20 ppm copper can be toxic to sheep.

Actions to consider

- Calculate your copper use and land application rate.
- Consider alternatives to copper sulfate (tetracycline or more soluble coppers that allow lower copper use rates).
- Divert the footbath water, so it does not enter the lagoons.
- Analyze the copper content of forage grown on land that receives effluent with copper in it. Monitor forage copper levels annually to see if they are increasing.
- Increase the acreage of crops receiving the lagoon effluent, in order to dilute the copper over more area.

Jessica Davis and Bill Wailes
Extension Soils and Dairy Specialists
Colorado State University

meet Dwayne Westfall

Dwayne Westfall is a Professor in the Department of Soil and Crop Sciences. His research areas include soil fertility management, dryland cropping systems management and precision agriculture. He also teaches "Soil Fertility Management" and a course for graduate students "Presentation of Scientific Information". Dwayne grew up on a potato and small grain farm in Idaho. He received his B.S. degree from the University of Idaho and Ph.D. from Washington State University. He has held positions at Texas A&M University, Great Western Sugar Company and worked for two years in Pakistan on CSU's On-Farm Water Management Project. His favorite pastime is spoiling his 10 grandchildren and then turning them over to their parents!

Is There Arsenic In Your Drinking Water?

Hot spots of arsenic exist in groundwater on the West Slope, San Luis Valley, and northeastern Colorado.

Shortly after President George W. Bush took office, he suspended one of the last acts of the Clinton administration, a tightening of the federal standard for arsenic levels in drinking water. President Clinton had lowered the federal standard from 50 parts per billion (ppb) down to 10 ppb. In March, the EPA asked for a study which the National Academy of Sciences (NAS) completed in September. This study concluded that an arsenic standard of 10 ppb still results in a cancer risk (1 in 500) that far exceeds what EPA usually considers acceptable (1 in 10,000). These cancer risks are based on consuming 2 liters (about eight 8 oz glasses) of this contaminated water source per day over a lifetime. Arsenic in drinking water is known to cause bladder, lung, and skin cancers. On October 31, the Bush administration announced that it is adopting the 10 ppb standard, based upon the NAS study. However, some people argue that the NAS study supports the need for an even lower standard of 3 ppb in drinking water (a 1 in 1,667 cancer risk).

Where does it come from?
Arsenic is a naturally occurring element in rocks, soils, and water in contact with them. Widespread high concentrations of arsenic in groundwater are generally attributed to natural sources, such as dissolution of rocks and minerals. However, arsenic is used in many industrial products. About 90% of industrial arsenic is used as a pesticide in wood preservation. Arsenic is also used in mining, smelting, and some agricultural uses, specifically, growth promotion in swine and poultry. These uses could also lead to pollution of groundwater.

Colorado levels
The U.S. Geological Survey has collected and analyzed arsenic in nearly 20,000 wells across the U.S. (reported by Sarah J. Ryker in the November 2001 issue of Geotimes). In general, they found that the highest groundwater arsenic levels are in the western U.S. Specifically, in Colorado there are a few hot spots on the West Slope where arsenic levels in groundwater exceed 50 ppb (the old standard). In addition, there are a few locations in northeastern Colorado and the San Luis Valley where groundwater arsenic levels exceed 10 ppb (the new standard).

In Colorado, only 18% of people rely on groundwater for drinking water. Most of these people are located largely in the Eastern plains, but an increasing number of foothills and mountain homes rely on groundwater. Nineteen of Colorado's 63 counties rely almost exclusively on groundwater for a drinking water source.

The U.S. Geological Survey developed county maps that show county-by-county arsenic distribution. Twenty-five percent of well samples from Logan, Sedgwick, and Saguache counties had arsenic concentrations of at least 5 ppb. Phillips, Alamosa, Rio Grande, Rio Blanca, and Garfield had 25% of samples that exceeded 3 ppb.

Community implications
Water systems across the country will have to be in compliance with the 10 ppb standard by 2006. Almost 97% of the affected water systems serve fewer than 10,000 people each. Therefore, many small communities

Arsenic

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will be affected by the new standard. These communities will be forced to either upgrade their water filtration systems or find alternative water supplies. This changes are likely to increase water costs for consumers, while reducing their cancer risk.

Homeowners with private wells are not regulated under water quality standards. However, homeowners who have excessive arsenic levels in their water and do not filter their water or find another water source, will potentially be putting their health at risk.

Actions to consider

If you get water from a public water system, ask for the results of their arsenic analysis. If you drink from a private well, take a water sample and have it analyzed. You can then decide whether to purchase a home filtration system to remove arsenic from your drinking water.

Jessica Davis and Troy Bauder
Extension Soil and Water Quality Specialists
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meet
Kathy Corwin Doesken

Kathy Corwin Doesken is the new research associate for Jessica Davis. Kathy started October 15th, just in time to help with fall field work. She is a graduate of Colorado State University, Department of Soil and Crop Sciences, and is pleased to return to work in the department, where some folks remember her. She is interested in soil fertility and nutrient resource management. Kathy has experience teaching and is looking forward to bringing together her interests in education and agriculture as Davis' research assistant.

She is married to Nolan, who is also employed by CSU in the Department of Atmospheric Science. Kathy, Nolan, and their two teen-aged children, Gail and Joel, live northwest of town on an old farm. Kathy has been involved in small-scale farming, raising horses, and making lots of compost.

Kathy fills the position vacated by Kirk Iversen, who left CSU in August to take a position at Auburn University.

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Zinc Fertilizers, Is There A Difference?

Plant availability of zinc depends on water solubility of fertilizers.

Zinc (Zn) is one of the micronutrients required for plant growth and the most common micronutrient that is deficient in Colorado soils. One of the main reasons for this is that our soils are generally alkaline in pH and contain free lime ($CaCO_3$), which ties up the Zn in unavailable forms. The Zn sensitive crops grown in Colorado include corn, sorghum, sudan, sorghum X sudan hybrids, dry beans and potatoes. These crops respond to Zn fertilization if the soil Zn levels are low. The next logical question is "are my soils low in available Zn?" - only a soil test can tell you this. All soil testing laboratories operating in this region can perform this test for you. So, I get a soil test performed, and sure enough, the soil tests low in Zn! What's next? Well, the application of a Zn fertilizer of course. The question we would like to address is "are all Zn fertilizers equally effective in correcting Zn deficiencies?". In the market place, disagreement exists regarding the effectiveness of the many Zn fertilizers that are being sold.

Some people question the importance of water solubility of a granular Zn fertilizer and its relationship to Zn availability to plants. What is water solubility and why should it matter? Water solubility indicates how much of the fertilizer will dissolve in water. Why does it matter? Most nutrients are taken up from the soil solution by the plant; therefore, if a fertilizer will not dissolve in the soil solution, it will probably not be an effective fertilizer.

Solubility is related to the process used in fertilizer manufacturing and the primary product used as a Zn source. Many Zn fertilizers in the market place are manufactured from industrial by-products such as zinc oxide (ZnO). Unfortunately, ZnO is not water soluble and not an effective Zn fertilizer on our alkaline soils. To prepare granular Zn fertilizer from ZnO, it is reacted with sulfuric acid (H_2SO_4) to improve solubility and promote granulation. The final product will be a mixture of ZnO, and zinc sulfate ($ZnSO_4$). Zinc sulfate is essentially 100% water soluble and a good Zn source for plants. The more acid that ZnO is reacted with, the more $ZnSO_4$ that is formed, and the higher the water solubility of the final fertilizer material. Fertilizers that are mixtures of ZnO and $ZnSO_4$ are called Zn oxysulfates.

We conducted some studies to determine if the percent water solubility of a granular Zn fertilizer is a measure of its ability to supply Zn to the plant. Corn plants were grown in the greenhouse on a Zn-deficient soil. Six Zn fertilizer materials were evaluated ranging from 99.9% to 0.7% water solubility. The fertilizers included $ZnSO_4$ and five Zn oxysulfate fertilizers ranging in water solubility from 98.3 to 0.7% water solubility: Zn20 (98.3%), Zn27 (66.4%), Zn40 (26.5%), ZnOxS (11%), and ZnOS (0.7%). The first number is the total Zn content of the fertilizer and the number in parenthesis is the water solubility. The $ZnSO_4$ contains 36% Zn and is about 100% water soluble. We use $ZnSO_4$ as our reference to which we compare all other fertilizers. Fertilizer rates used were equivalent to 0 (control), 5, 10 and 20 lb Zn/A. Plants were harvested about 6 weeks after emergence. Previous work has shown that there is no need to grow corn plants to maturity to evaluate the effectiveness of different fertilizer sources, as results will be similar to those during early growth stages. Plant growth (dry matter production) and Zn uptake were measured. We only present the plant growth data here.

Zinc-deficiency symptoms were observed on the corn plants grown with the two fertilizers with the lowest water solubility, ZnOxS (11%) and ZnOS (0.7%). These symptoms were evident as early as 5 days after emergence. Pronounced bands of chlorosis appeared on the leaves, starting near the leaf whorl and extending up the leaf. These bands turned white with time. As plant growth progressed, Zn-deficiency symptoms also occurred with the Zn40 (26.5%). Plants fertilized with these three materials were stunted in growth. Slight Zn deficiencies were also observed with Zn27 (66.4%),

but the reduction in plant growth was very small.

The dry matter production for the various Zn fertilizers is shown in Figure 1. Based on the plant growth response, three groups of Zn fertilizer materials were identified: (i) ZnOS (0.7%) resulted in no significant growth increase with Zn application (Fig. 1), (ii) Zn40 (26.5%) and ZnOxS (11%) resulted in a small increase in corn growth as Zn rate increased and (iii) $ZnSO_4$ (99.9%), Zn20 (98.3%), and Zn27 (66.4%) all increased growth substantially. The very low agronomic effectiveness of ZnOS (0.7%), ZnOxS (11%), and Zn40 (26.5%) is related to their lower water solubilities and the inability of these fertilizers to release Zn to the plant. The application of high rates of Zn from fertilizers containing low water soluble Zn did not satisfy the plant's needs.

A Zn application rate of 5 lb/A was sufficient to maximize dry matter production when Zn was applied as Zn20 (98.3%), Zn27 (66.4%), and $ZnSO_4$ (99.9%). In fact, no significant differences were observed between 5 as compared to 10 and 20 lb Zn/A. In contrast, Zn40 (26.5%) required 20 lb/A to obtain optimum dry matter production (Fig. 1). This clearly shows that water solubility of granular Zn fertilizer was related to availability.

Conclusions

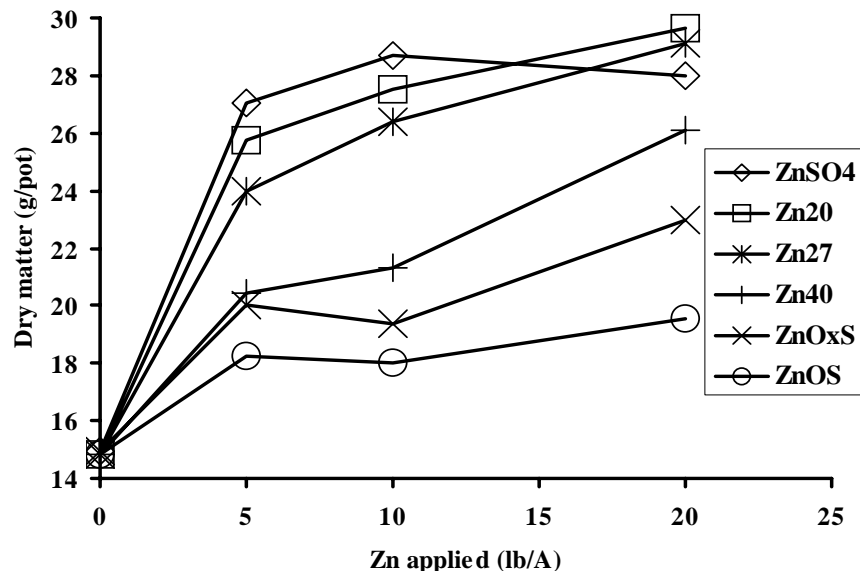The agronomic effectiveness of the six granular Zn fertilizers studied decreased as the percent water-

Figure 1. Corn dry matter production as affected by Zn fertilizer application rates and sources.

soluble Zn decreased: $ZnSO_4$ (99.9%) > Zn20 (98.3%) > Zn27 (66.4%) > Zn40 (26.5%) > ZnOxS (11%) >ZnOS (0.7%). High correlations were found between water solubility of Zn in the fertilizer material and plant response. We conclude that granular Zn fertilizers should have water-soluble Zn levels of at least 50% to be effective in supplying adequate Zn levels for the current crop. Knowing the total Zn content of a fertilizer is not enough to determine which fertilizer you should use. You need to know the degree of water solubility of granular Zn fertilizers before you purchase them. Ask your fertilizer dealer for this information and if the water solubility is not at least 50%, use a different material that satisfies this requirement.

Do these greenhouse results apply to field conditions?

Many people ask this question. Under some circumstances the answer is NO. However, when a greenhouse study is

used to evaluate the availability of micronutrients to plants the results are directly applicable to field conditions. In fact, many researchers have reported that "if a micronutrient doesn't do the job in the greenhouse, it won't work in the field". The reason is that in a greenhouse study plant roots are confined to a small volume as contrasted to a very large rooting volume that occurs in the field. This results in a much higher density of roots in the soil in the greenhouse and a greater chance for the plant's roots to come in contact with the fertilizer granule, or its diffusion zone. Consequently, this is an advantage to fertilizers that have a low water solubility. SO, if a fertilizer doesn't work in the greenhouse, it won't work under field conditions!

Dwayne Westfall and Bill Gangloff
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Zinc Application Methods

Band or starter applications of zinc are best.

The primary methods of applying zinc (Zn) fertilizer to beans are broadcast, banding, and foliar sprays. Each method has advantages and disadvantages. A Zn fertilizer can be blended into other fertilizers being broadcast. While this is rapid and convenient, broadcasting zinc has not produced consistent responses, even on low-testing soils. Many Colorado soils have high Zn-fixing capacity. In other words, much of the zinc applied reacts with other soil minerals and becomes unavailable to plants. Availability is reduced further if soil conditions, such as compaction, restrict root growth.

Banding concentrates Zn in the root zone, improves the probability of root contact, and reduces fixation. Greater efficiency of band applications means that lower rates can be used to get the same crop response. Broadcast applications usually call for 5-10 lbs Zn/acre while 1-5 lbs Zn/acre is adequate for banded application. Research studies comparing band and broadcast applications of Zn have demonstrated more consistent responses to banding than to broadcasting. In some cases, banding has produced crop responses even on high-Zn soils.

Foliar applications are usually used to correct an unanticipated deficiency that occurs during the growing season. A water-soluble fertilizer such as a Zn chelate or Zn sulfate is dissolved in water and applied at about 0.5 to 1.0 lbs Zn/acre in enough water to wet foliage, about 20-30 gal of solution per acre. Repeated applications are often necessary to maintain healthy plants when soils are deficient in available Zn.

A discussion of Zn application on dry beans should include the use of starter fertilizers. Starter fertilizers have been shown to improve early growth and development of many crops. In Colorado, dry beans are often planted into cold, high-pH, low organic matter soils. Compaction is often present. Under these conditions, early plant growth and development are slow and many nutrients, especially Zn, are less available.

Yield potential of beans is established during early vegetative growth. Flower cells are being formed at this time. Stress during this formative period reduces the number of flower cells that are formed and thereby reduces yield potential. By applying Zn in a starter fertilizer, early vegetative growth is increased, the photosynthetic factory is greater, and yield potential increases.

While starters are not commonly used on beans, Wyoming research has demonstrated significant profit opportunities with the use of starters. As little as 1 lb Zn/acre in a starter containing N and P was effective in producing an additional 130 lbs bean yield/acre, hastening maturity by two days, and increasing profit by more than $20/acre over a starter containing only N and P. This response was observed on soils with very high soil Zn. Be aware that starters should not be placed in direct contact with bean seed. Beans are very sensitive to salts, and stand loss will result from seed-placed fertilizer.

Band or starter application of Zn on beans in Colorado is highly recommended if soil pH is high, N and/or P supply is high, soil compaction is present, or yield potential is high. The advantages outweigh the inconvenience.

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Dry Bean Response To Zinc

Foliar application on irrigated dry beans in southwestern Colorado increased yield in one out of two years.

Dry bean is an important crop in Colorado. It ranks fifth in acreage and total value in Colorado and fourth in the U.S. in production. In southwestern Colorado, dry bean is produced mostly under dryland conditions but much higher yields can be achieved with supplemental irrigation. Most agricultural soils in southwestern Colorado have relatively high pH (7.0 to 8.0) and are low in organic matter and available P. High pH and low organic matter are among the factors that favor the development of Zn deficiency. Zinc deficiency causes chlorosis in bean plants and can delay maturity and reduce seed yield.

Khan and Soltanpour (Khan, A., and P.N. Soltanpour. 1978. Factors associated with Zn chlorosis in dryland beans. Agron. J. 70: 1022-1026) attributed chlorosis in dryland dry bean in southwestern Colorado to high soil P/Zn ratio and a high incidence of root rot disease. The chlorotic bean plants were situated lower on the slope than the green plants, which led the authors to speculate that the higher soil moisture in lower areas may have increased P availability. Soil Zn level was about the same, 0.5 ppm in the areas with green or chlorotic bean plants. Spraying the chlorotic plants with a

1% Zn solution removed chlorosis and increased bean yield by 18 to 92%, but not up to the yield level of the healthy plants. The difference in yield between the green plants and those sprayed with Zn was attributed to the higher incidence of root rot in the chlorotic plants. Root rot resistant pinto bean varieties have been released since 1981 and are now widely grown in southwestern Colorado.

A field experiment was initiated in 1999 to determine the effect of Zn application rate and method on irrigated pinto bean yield in southwestern Colorado. 'Bill Z' pinto bean was planted in early June at approximately 22 seeds m^{-2} in 1999 and 2000 at the Southwestern Colorado Research Center at Yellow Jacket, CO. A second variety, 'Poncho' was included in the 2000 experiment. The soil type was Wetherill silty clay loam. Zinc sulfate was broadcast shortly before planting beans in both years at 5 and 10 lbs Zn/acre and incorporated into the soil with a field cultivator. Foliar spray of

a 7% zinc sulfate solution was made at the same rates with a 3-m boom sprayer four to five weeks after planting.

Bean seed yield was much higher in 2000 (2936 lbs/acre) than in 1999 (2120 lbs/acre), probably due to better irrigation water management in 2000. No symptoms of zinc deficiency were visible before or after the foliar spray in any of the treatments in 1999 or 2000. However, a foliar application of 5 lbs Zn/acre resulted in significantly higher Bill Z seed yield in 1999 compared to the control (over 500 lbs/acre more). The broadcast treatments had no yield effect in 1999. Zinc application rate or method did not affect Bill Z or Poncho seed yield in 2000. Future studies will include shallower soil sampling and a close look at soil spatial variability since chlorosis often occurs in patches in bean fields in southwestern Colorado.

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Table 1. Soil test results

	pH	OM	Soil Zn (ppm)	
			AB-DTPA	Mehlich-3
1999	7.2	1.0 %	0.3	31
2000	7.5	1.1 %	0.6	20

Phosphorus And Zinc Interaction

Banding high rates of P can induce Zn deficiency in high pH soil.

Phosphorus and zinc are essential nutrients for plant growth. Unfortunately, these nutrients can act antagonistically with one another in certain circumstances. This antagonistic reaction is know to cause yield reductions in many crops.

Yield reductions due to this interaction are caused by either phosphorus or zinc deficiencies. Deficiencies typically occur when a nutrient is present in short supply. In this case, the nutrient is present in marginal to normal levels, but the antagonizing nutrient is present in such a large quantity that it forces a deficiency of the other. In other words, excessive phosphorus can cause zinc to become deficient in plant tissue. Similarly, excessive zinc can cause phosphorus deficiency, however, this phenomenon is very rare.

The mechanism of this phosphorus-zinc interaction occurs primarily in the plant root, rather than in the soil, as many people suppose. Excessive concentrations of phosphorus in the plant root tesult in the binding of zinc within root cells. The zinc becomes part of the "fabric" of the root and, therefore, becomes unavailable for transport to leafves, where it is needed for normal plant growth.

Phosphorus-induced zinc deficiencies are more common than zin-induced phosphorus deficiencies. This is because it is much more common for growers to apply substantial amounts

Location	Soil Boron (ppm)	Soil Organic Matter (%)	Soil Texture
Yellow Jacket	0.4	1.1	silty clay loam
Holyoke	0.2	1.2	sandy loam
Center	0.1	1.0	gravelly sandy loam

of phosphorus fertilizer as compared to zinc fertilizer.

Zinc deficiency caused by excessive phosphorus can occur if:
- Zinc concentrations in the soil are low, especially in high pH and/or calcareous (excess lime) soil, and
- High rates of phosphorus fertilizer are applied.

A phosphorus-induced zinc deficiency is uncommon in soils that simply have a high soil-test phosphorus level. In fact, these deficiencies occur just as readily in soils with low soil-test phosphorus levels. In other words, this phenomenon is more related to the amount of fertilizer applied for the current season rather than the level already present in the soil.

The method of phosphorus fertilizer application also impacts the likelihood of inducing a zinc deficiency. Concentrated bands of phosphorus fertilizer tend to induce zinc deficiencies more commonly than broadcast applications. The probability of creating a zinc deficiency increases as the rate of phosphorus in the band increases.

Producers applying substantial

amounts of manure often ask if the very high levels of phosphorus in the manure could induce a siznc deficiency. Although it is true that manure contains a large amount of phosphorus, it also contains organically-complexed zinc, which helps to prevent the deficiencies from occurring.

The manure effect and research on this interaction demonstrate how to prevent phosphorus induced zinc deficiencies:
- Base phosphorus fertilizer rates on prudent soil-test recommendations.
- Apply a moderate amount of zinc if choosing to apply excessive rates phosphorus fertilizer, especially when band applied.
- Include a small amount of zinc (<1.5 lb/acre) in phosphorus-based starter mixes, especially if the zinc concentration is low or marginal based on soil-test data .
- Do not apply zinc fertilzier if soil-test zinc level is above marginal levels and all phosphorus is being applied via broadcast methods.

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Managing Iron Chlorosis In Corn

Ferrous sulfate in the seedrow increased yield of susceptible and tolerant hybrids.

Some soils of the western plains and inter-mountain west have chemical and physical characteristics that cause iron deficiency in corn. Affected corn plants typically are stunted and have yellow (chlorotic) leaves with veins that remain somewhat green, resulting in a striped appearance. The severity of the symptoms varies from year to year depending on the weather; symptoms usually are worse in cool and wet conditions. Mild yellowing may disappear when the weather turns warmer and drier, but moderate to severe yield reductions are usually the result when chlorosis persists for the entire growing season.

We don't know exactly why certain soils cause iron chlorosis to develop, while other soils with similar characteristics produce healthy corn. Soil tests for iron (DTPA or AB-DTPA) do not always show low Fe levels, which complicates prediction of the problem. Affected soils do typically have high pH (7.8 or higher) and contain free lime (calcium carbonate). High sodium, poor drainage, low organic matter and high phosphorus have also been implicated. In some cases the problem lies in the subsoil (16-24 inches deep) rather than in the plow layer. Whatever the cause, iron

availability (not necessarily iron levels per se) in these soils is very low. As a result, it is usually ineffective to try to correct the problem by broadcasting iron fertilizers. Applying soil amendments to modify soil pH is usually not an economical option, either.

The most commonly recommended approach is the use of chlorosis-tolerant corn hybrids. Genetic tolerance levels vary greatly from hybrid to hybrid, and most seed companies can provide information on each hybrid's level of resistance. In many cases, use of tolerant hybrids

Table 2. Results from Nebraska small plot study showing effects of seed-row applied iron fertilizer on corn yield (average of 3 years).

Fertilizer Source	Application Rate	Hybrid	
		Susceptible	Tolerant
	(lbs $FeSO_4 \cdot 7H_2O$ per acre)	—— grain yield, bushels per acre	
Check		24 C	122 B
liquid	50-75	117 B	156 A
dry $FeSO_4 \cdot 7H_2O$	50	133 AB	157 A
dry $FeSO_4 \cdot 7H_2O$	100	146 A	169 A
dry $FeSO_4 \cdot 7H_2O$	150	143 A	157 A

A, B, C Treatments with a common letter are not significantly different within hybrid type ($p < 0.05$).

will provide an acceptable level of correction, but yield-limiting chlorosis will still develop in the most severe soils. In these cases, either foliar or seed-row applications of iron may be beneficial.

A commonly recommended approach for foliar application is to apply a 1% solution of ferrous sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$) every 7 to 10 days beginning when chlorosis first becomes evident and ending when emerging leaves are no longer chlorotic. Iron chelates are also water soluble and produce similar results to the ferrous sulfate without the risk of burning the leaves, but chelates are considerably more expensive than ferrous sulfate. When these guidelines are followed, foliar applications are usually effective, but economical yield increases may not occur if applications are made too late or if they are not repeated at the recommended intervals.

Recent research at the University of Nebraska West Central Research and Extension Center was conducted to evaluate a second option for applying iron. In this study, iron fertilizer placed in the seed row consistently increased corn yield compared to an untreated check. Banding the fertilizer protects it from being tied up by the soil, and the seed-row placement enables the small roots of the corn seedling to access the iron early in the growing season. Dry

ferrous sulfate applied at a rate of 50 to 100 pounds per acre (at a cost of $8.50 to $17.00 per acre) was the most effective treatment evaluated, but chelated iron (FeEDDHA at 2.5 to 4 pounds per acre) and a lower solubility iron sesquioxide (from Agrium U.S. Inc. applied at a rate of 200 pounds per acre) also produced smaller, but significant yield increases. Seed-row applied iron fertilizer produced substantial yield increases with both chlorosis-susceptible and chlorosis-tolerant corn hybrids (Table 1). The yield benefit varied from year to year as the weather influenced chlorosis severity, but a positive response was observed in every year.

Some producers and agronomists may be hesitant to place fertilizer materials in direct contact with the seed at these relatively high application rates because of the risk of salt damage to emerging seedlings. This concern appears to be unwarranted as the Nebraska results showed no evidence of stand reduction, except in 2 of 5 years when ferrous sulfate was applied at a rate of 150 pounds per acre. No stand reduction was observed at application rates of 100 pounds per acre or less.

While the dry iron materials are very effective, many producers feel they are less convenient than liquids. Chelated iron can be dissolved in water and applied as a liquid, but this

is probably not economical due to the high cost of chelates. A liquid formulation of ferrous sulfate is not currently available commercially, and because the solubility of ferrous sulfate limits the concentration of a liquid formulation to 5% iron, a suitable commercial product may not be forthcoming. A 5% iron solution, made by dissolving ferrous sulfate in water, was evaluated in the Nebraska research. While it was effective in both small and large plot trials, its performance did not equal that of the dry ferrous sulfate, probably because the low solubility limited the total amount of iron that could be applied per acre.

Chlorosis development is usually spotty and, while the severity of chlorosis varies from year to year, the location of these areas within a field usually remains consistent. Thus, the most economical approach to managing iron deficiency chlorosis in these fields may be to apply fertilizer materials only to those areas in the field where chlorosis is a consistent problem. Research is now being conducted to evaluate this site-specific approach on a production scale.

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Boron Fertilization Of Potatoes And Alfalfa

Even on sandy soils with low B levels, no yield or quality responses were found.

Boron is an essential plant nutrient for all crops. It plays important roles in cell wall synthesis, sugar transport, and seed production. Alfalfa is considered to be a crop with a high B requirement, while potatoes require lower B levels.

Boron deficiencies are found most often in sandy soils, with low organic matter contents, and high soil pH levels. Deficiency symptoms in alfalfa are described as "yellow-top." The younger leaves turn yellow or red between the veins, rosetting develops due to shortened stems, and, ultimately, the terminal bud dies. In potatoes, symptoms include discoloration and death of the terminal buds, stubby roots, short internodes, and bud and flower drop.

We initiated several studies from 1997-1999 to evaluate the impact of B application on irrigated alfalfa yield and on yield and quality of two potato cultivars. We sought out soils with low B levels, low organic matter levels, and coarse textures and settled on three locations: one in southwestern Colorado near Yellow Jacket (alfalfa), one in northeastern Colorado in the sandhills near Holyoke (alfalfa), and one gravelly soil in the San Luis Valley near Center (potatoes). Each study site was evaluated for two years. Soil properties are given below.

The alfalfa varieties were Pioneer 5454 at Holyoke and Archer at Yellow Jacket. Two potato cultivars were evaluated: Russet Norkotah and Russet Nugget. Solubor™ was applied pre-plant to potatoes at 0, 1, and 2 lbs B/acre. Foliar application of Solubor™ was made to alfalfa in April at rates of 0, 0.5, 1, 2, and 4 lbs B/acre.

There was no significant impact of B fertilizer application on alfalfa yield for any of the cuttings in any of the four site-years. There was also no significant impact on potato yield (total or components), specific gravity, agronomic characteristics, quality traits, or disease ratings in either of the two site-years.

Why were there no yield responses to B fertilization on low B soils in this study? Are there other B sources to consider? Let's take a look at the potential for irrigation water and subsoil to supply B to crops.

Perhaps the irrigation water is supplying the necessary B to crops. A survey of 92 wells in northeastern Colorado revealed an average of 0.52 ppm B in the irrigation water, with a range from 0.03 to 2.30 ppm B. Based on 30 inches (2.5 ft) of consumptive water use by alfalfa, 0.3 ppm B in irrigation water would provide alfalfa's required 2 lbs B/A

(2.5 acre-feet of water x 2.7 million lbs water/acre-foot x 0.3 ppm B = 2.0 lbs B/acre). Therefore, irrigation water may be providing the necessary B, thus preventing a response to B fertilizer, even on soils testing low in available B.

However, the B level in the irrigation water at both Yellow Jacket and Center was only 0.02 ppm (equivalent to 0.1 lbs B/acre-foot of water), a level low enough to suspect that a B fertilizer response could occur. Could subsoil B be supplying the B need for the crops grown in these locations? This is a possibility in the soil at Yellow Jacket; however, the shallow gravelly soils of the San Luis Valley or the deep sands of northeastern Colorado don't have much potential for subsoil storage of B.

At this point, no confirmed B deficiencies have ever been documented in Colorado. Therefore, CSU does not recommend B fertilization even on soils testing low in available B.

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Sulfur Fertilization Of Dryland Winter Wheat

Sulfur increased yield when soil pH was high and OM was low.

In the 1980's, CSU researchers Hunter Follett and Dwayne Westfall studied sulfur fertilization of winter wheat at 15 locations throughout eastern Colorado. Fertilizer treatments were injected about four inches deep at 12-inch spacings as liquid ammonium thiosulfate about two weeks before planting. The nitrogen and phosphorus applications were uniform across the plots. Three of the fifteen locations had significant yield responses. However, the average soil sulfate levels in the responsive sites was higher than the average level in the non-responsive sites.

Many wheat farmers apply sulfur with their pre-plant nitrogen and phosphorus applications. Often the stated purpose of the S is to reduce pH in the fertilizer band (thus increasing the availability of P, Zn, and Fe), not necessarily to supply S as a nutrient. A closer look at the Follett and Westfall dataset reveals that the yield response is related to the soil pH at the 15 study sites. One of the responsive sites had a low pH (6.6), but sulfur decreased yield significantly at this site. The other two responsive sites had yield increases due to S fertilization, and both had soil pH levels of 7.5 or greater. However, there were two other sites with pH of 7.5 or greater which did not respond to S fertilization. Other research has shown that S fertilizer responses are more likely to occur in soils with low organic matter contents. This principle holds true in this case as well. The two sites with positive yield response of 3-4 bu/acre both had soil pH levels > 7.5 and soil organic matter levels $< 1.5\%$. Therefore, S fertilization has the best chance of increasing yield when soil pH > 7.5 and soil OM $< 1.5\%$. Be sure to consider the cost of the additional fertilizer when making your S fertilization decisions.

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Table 3. Wheat yield response to sulfur fertilization.

Soil pH	Yield Response	Details
< 7.0	1/5 responsive sites	The responsive site had a negative yield response.
7.0-7.4	0/6 responsive sites	--
$\geq$ 7.5	2/4 responsive sites	The responsive sites had soil OM $\leq 1.5\%$, and the non-responsive sites had soil OM $= 2.0\%$.

web pages

http://www.epa.gov/epaoswer/hazwaste/recycle/fertiliz/risk/
EPA report on heavy metals in fertilizers.

http://animalscience-extension.tamu.edu/publications/13281133-ashoof.htm
Information on foot disorders in dairy cattle (Texas A&M University).

http://co.water.usgs.gov/trace/arsenic/
USGS report and maps on arsenic in groundwater.

http://www.nrdc.org/water/drinking/qarsenic.asp
Frequently asked questions (and answers) on arsenic in drinking water (Natural Resources Defense Council).

http://www.back-to-basics.net/
Current soil fertility information from IMC and the Potash and Phosphate Institute.

http://www.ext.colostate.edu/pubs/crops/pubcrop.html
Colorado State University soil and fertilizer factsheet no. 0.545 Zinc and iron deficiencies.