MICRONUTRIENTS

Micronutrients are required by plants in small amounts. They are zinc (Zn), boron (B), chloride (Cl), iron (Fe), copper (Cu), manganese (Mn), molybdenum (Mo), and. nickel (Ni). Micronutrients are just as essential for plant growth as the primary and secondary nutrients, but are required in smaller amounts by plants and are less frequently deficient in soils.

While micronutrients are used in very small amounts, molybdenum, boron, and copper can be toxic with minor over application. For example, molybdenum is recommended at rates of ½ to 1 oz. per acre if deficient. Rates of 3 to 4 pounds per acre may be toxic. Micronutrients should not be used indiscriminately.

Micronutrients are found in soil minerals similar to phosphorus and potassium. However, most of these nutrients are converted to inorganic, plant available forms by microbial mineralization soil of organic matter.

Most Kansas soils contain adequate quantities of micronutrients. Supplemental additions of micronutrients containing fertilizers are generally not needed or recommended. However, some soils are deficient in some micronutrients.

The total content of a soil nutrient is not a good measure of availability to plants. Certain soil properties reduce the availability of micronutrients to plant roots. In addition, certain crop species are more susceptible to deficiency than others. The following summarizes some of the soil conditions and crops where micronutrient problems are most likely to occur. This does not imply that deficiencies cannot occur with other crops and soils.

Soil pH has a major effect on the plant availability of micronutrients. In general, solubility and plant availability of micronutrients are greatest in slightly acid to neutral pH soils while availability is lowest in high pH, calcareous soils. The exception is molybdenum which is most available to plants in higher pH soils.

In some acid soils, high levels of soluble iron, aluminum and manganese may be toxic to plants. In acid soils, liming may improve plant growth by reducing the solubility of these elements while increasing the availability of molybdenum.

Soil Conditions and Crops Where Micronutrient Deficiencies Most Frequently Occur		
Micronutrient	Conditions Most Conducive	Susceptible Crops
Zinc (Zn)	Exposed subsoils, recently leveled, low organic matter, high pH calcareous soils	Corn, soybeans, grain and forage sorghums
Iron (Fe)	Calcareous, exposed subsoils, low organic matter soils in western half of Kansas	Grain and forage sorghums, soybeans, field beans, sudangrass,
Chlorine (Cl)	Well drained soils in central and eastern Kansas with no history of potassium applications	Wheat, grain sorghum, corn
Boron (B)	Alkaline, well leached soils in southeastern Kansas, dry soil conditions	Alfalfa, sugar beets, soybeans, corns
Molybdenum (Mo)	Soil pH less than 5.5, deficiencies very rare	Alfalfa, legumes
Copper (Cu)	Deficiencies not observed in Kansas	- - - -
Manganese (Mn)	Deficiencies not observed in Kansas	- - - -
Nickel (Ni)	Deficiencies not observed in Kansas	- - - -

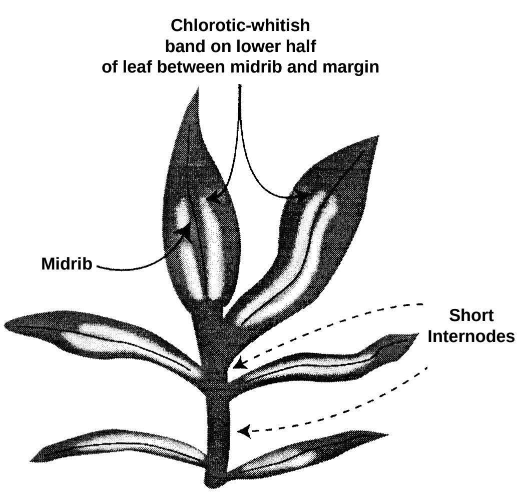
The ideal soil pH range for maximum availability of micronutrients is:

Micronutrient	Soil pH Range For Maximum Availability
Iron	4.0 - 6.5
Manganese	5.0 - 6.5
Boron	5.0 - 7.0
Copper	5.0 - 7.0
Zinc	5.0 - 7.0
Molybdenum	7.0 - 8.5

ZINC (Zn)

Zinc is absorbed through plant roots as the Zn^{++} cation and is involved in production of chlorophyll, protein, and several plant enzymes involved in growth regulation.

The most distinctive symptoms occur in corn. Symptoms occur first in new leaves coming out of the whorl of young plants. Leaves turn yellow /bronze to white in a band between the leaf midvein and margin. Symptoms are most severe at the base while the leaf tip may remain green. Symptoms, once developed, do not disappear and remain on older leaves. Internodes are shortened, resulting in a stunted plant. In soybeans, stunting with general chlorosis to bronzing between the leaf veins occurs.



Zn Deficient Corn Leaves

The major reservoir of zinc in soils is organic matter. Since it is a cation in it's inorganic form, the Zn^{++} ion is adsorbed on cation exchange sites. By understanding how zinc reacts in the soil and used by crops, we can predict where zinc deficiencies are most likely to occur. Some factors favoring zinc deficiency include:

- High pH, calcareous soils. As pH increases, zinc is less soluble in soil solution. Most zinc deficiencies occur in calcareous soils or in acid soils that are over limed. Zinc is 100 times less soluble at pH 8 than at pH 5.

- Low Organic Matter. Zinc deficiency is most common in lower organic matter soils. Crops grown on eroded soils or subsoils exposed by terracing or land leveling often have Zn deficiencies largely because of low organic matter levels found in the subsoil.

- Susceptible Crops. Corn, edible beans, sugar beets, soybeans and grain sorghum, are most responsive to low soil zinc levels. Wheat response to applied zinc on low testing soils has not been documented in Kansas.

- Wet, Cold Soil Conditions. Early season zinc deficiencies occur more frequently in cold soils because of slow root growth and slow release of zinc from organic matter.

- Sugar beet Rotation. For some reason, sensitive crops following sugar beets often are zinc deficient – even if soil test levels are judged to be adequate.

Soil tests are useful to measure the availability of Zn in a soil, but the factors listed above should also be considered when determining Zn needs. Do not collect samples in a metal container.

Zinc deficiencies are more widespread than other micronutrients. As a result, considerable work with examining zinc nutritional needs of crops has been conducted at Kansas State University over the years.

The following conclusions can be drawn from this research:

- Severe cases of zinc deficiency are more likely to be encountered under irrigation;
  - Increased yields under irrigation increase the need for zinc. Sufficient zinc for crop production under dry land conditions may not be adequate for maximum production under irrigation.
  - When land is leveled for irrigation, top soil is removed. The top soil contains a large part of the zinc which is available for use by crops.
  - If leveled, exposed subsoils may have a higher pH than surface soil. The solubility of zinc compounds decreases with an increased pH.

- Zinc deficiency occurs more frequently when top soil has been removed by leveling, erosion or construction of erosion control structures.

- Heavy applications of phosphorus to phosphorus deficient soils often results in the crop expressing a severe zinc deficiency if the soil is also low in soil test extractable zinc.

- Corn, soybeans, and grain sorghum are the three major agronomic crops grown in Kansas that are most susceptible to zinc deficiency. Generally, zinc deficiency is more severe with the corn and soybeans crops. Recent work has shown grain sorghum to be less sensitive to low soil Zn levels.

- Corn and sorghum hybrids differ in their susceptibility to zinc deficiency. There is a good possibility that the same is true for other crops.

- Because of seasonal and climatic variability, the incidence and severity of zinc deficiency varies from year to year. Late or cold springs adversely affect zinc availability in soils and/or zinc uptake by plants. As weather warms up and the soil dries out, deficiency symptoms may disappear.

“P Induced” Zinc Deficiency:

Applications of phosphorus to P deficient soils, particularly if banded, may induce a zinc deficiency in soils which are low in available zinc. Examples of the affect of phosphorus are presented in Tables 2 and 3. In all cases the land had been leveled the previous year and was very low in extractable zinc in the surface soil.

At the St. Mary’s location, the banded starter fertilizer, without zinc, decreased yield 14 bushels per acre below the check plot yield while additions of 10 pounds of zinc with the starter fertilizer increased yields 32 bushels per acre over the check plot yield.

At Belvue, applications of 80 pounds of P_2O_5 per acre without zinc decreased yields 12 bushels per acre when the phosphorus was banded. Yields of corn were increased 44 bushels per acre when 20 pounds of zinc were combined with 80 pounds of P_2O_5.

P and Zn Effects On Corn Yields

P_2O_5	Zn	B’cast	Starter
Lb / A		Corn Yield (Bu/A)	
0	0	107	
0	10	121	115
40	0	121	93
40	10	139	140

St. Mary’s, KS –Kansas State University

P and Zn Effects On Corn Yields

P_2O_5	Zn	B’cast	Starter
Lb / A		Corn Yield (Bu/A)	
0	0	131	
0	20	122	109
80	0	125	119
80	20	143	175

Belvue, KS – Kansas State University

While this effect is commonly referred to as ‘phosphorus induced zinc deficiency’, these locations were clearly phosphorus deficient and zinc deficient. If the soil had adequate levels of soil test zinc, the starter applications of fertilizer phosphorus would not have resulted in an induced zinc deficiency.

Sources of Zinc

Zinc fertilizers are applied at relatively low rates compared to primary nutrient fertilizers. Rates of actual zinc range from less than a pound up to about 10 lb/acre. Since excessive rates may decrease the availability of other micronutrients such as Fe, Zn should not be applied indiscriminately.

There are several common sources of zinc fertilizer. The table below shows several common zinc containing materials and their approximate zinc content:

Zinc Source	Zn (%)
Inorganic:	
Zinc Sulfates (hydrated)	23-36
Zinc Oxy-sulfate	20-40
Zinc-Ammonia Complexes	10-20
Organic:	
Zinc Chelates	7-14
Other Organics (complexes)	5-20

Zinc sulfate is a good source for dry blends, true fluids, and suspensions. It is 100% water soluble.

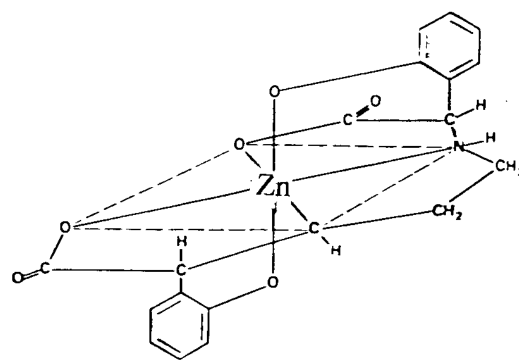
Zinc oxide is less soluble than zinc sulfate and must be finely divided such as in fluid suspensions to be effective, particularly on high-pH soils. Granular oxide materials are less effective than finely divided sources. Not commonly found in the marketplace.

Zinc Oxy-sulfate contains oxide and sulfate forms of zinc. It is produced by treating zinc oxide with sulfuric acid. The water solubility varies greatly with the degree of acidification. A minimum water solubility of 40% to 50% is recommended for best crop response, especially on alkaline soils.

Zinc ammonia complexes, such as 10-0-0-10Zn and 13-0-0-15Zn, are generally produced by ammoniating zinc sulfate or zinc chloride. These products contain free ammonia which complexes the zinc.

The primary advantage of these complexes is that they are very compatible with fluid fertilizers made from ammonium polyphosphate. When these inorganic complexes are mixed with liquid phosphate, the zinc is “sequestered” by the polyphosphate and provides response similar to true chelates. Zinc-ammonia complex materials are the product of choice with fluid fertilizer systems.

Zinc chelates are organic compounds that form a claw-like ring around metal ions such as Zn^{++} .A common chelating agent used for zinc materials is EDTA. In theory, zinc ions are protected by the chelate from soil fixation, yet plant roots are able to absorb zinc . This chelating effect doesn’t last through the season, however. At higher soil pH values (when zinc deficiency is most likely) the EDTA molecule has a greater affinity for calcium and magnesium. Also, over time, chelates serve as a food source for soil microbes. Chelates are more compatible than inorganic zinc sources in orthophosphate fluid mixes.



Chelates are often presented as being much more effective than inorganic sources and as a result are recommended at much lower rates. The difference in effectiveness between chelates and inorganic sources is dependent on several factors. Crop sensitivity, application method, and application rate all influence the performance of inorganic and chelate zinc sources.

Chelates would provide the greatest efficiency as compared to inorganic sources when applied at very low rates on very deficient soils planted to sensitive crops. At higher soil test values or higher application rates differences would be less. For example, at zinc application rates of greater than about 0.25 lb Zn/A applied with ammonium polyphosphate as a starter band, chelates and inorganic sources provide similar results. However, at rates of less than 0.1 lb Zn/A broadcast applied, chelates have provided greater response.

Organic Complexes are derived from organic by-products and micronutrient metal ions. While sometimes referred to as 'partially chelated', these materials do not perform the same as true chelates. These materials can be mixed with fluid phosphate fertilizers made from ammonium polyphosphate.

In general, complexed sources fit well with "rescue" applications applied as a foliar treatment to crops exhibiting deficiency symptoms, while inorganic sources fit best for starter or broadcast applications applied at or prior to planting. Further, any type of material is normally more efficient at low application rates if band applied, as compared to broadcast.

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Application Methods

Broadcast. applications are preferred to correct a low zinc soil test. Five to 10 lb/acre of actual zinc will build soil to non-limiting values for a number of years. Inorganic zinc is more economical than chelates at these rates.

Band application is a very efficient method of applying zinc at low rates. A rate of 0.5 to 1.0 lb Zn/acre is generally sufficient. Annual applications will be needed for low testing soils since the rates normally are not high enough to build zinc soil test values very quickly. All sources of zinc are equally effective when applied with fertilizer materials high in polyphosphate such as 10-34-0.

For use in season, zinc should be limited to 1 lb Zn per 22 lbs. P_2O_5 from 10-34-0. If longer storage is required, only 0.5 lb Zn per 22 lbs. P_2O_5 should be added.

Foliar applications are sometimes effective, especially for spot treatments, but they should be viewed as a rescue operation only. Zinc should be applied at or before planting for the succeeding sensitive crop.

IRON (Fe)

Iron is a catalyst in the production of chlorophyll and is involved in several plant enzyme systems. Plants absorb iron as Fe^{++} cation.

Iron deficiency symptoms are expressed as a yellow to white leaf color (chlorosis) between the veins while the veins often remain green. Symptoms occur first on younger leaves near the top of the plant.

There is a wide variation in susceptibility to iron chlorosis of different crops, and even different varieties of the same crop. Pin oaks, certain fruit trees, shrubs, and ornamental vines are very sensitive to iron chlorosis. Crops such as sorghum, field beans, and soybeans can show severe iron chlorosis, where corn or alfalfa may appear normal. Certain varieties of soybeans are able to utilize iron more effectively than others. In general, proper selection of crop species and variety is an important.

Iron in the Soil

Deficiencies of iron occur quite frequently in the central United States. However, iron fertilization is a relatively rare practice because of:

- Patchy or irregular occurrence of the problem within a field.
- Difficulty in correcting Fe deficiency with soil-applied fertilizer.

Iron is the most abundant element on earth with many tons/acre present in the plow layer. Several factors render most of the soil iron unavailable to plants. These factors include:

- *High Soil pH*. The solubility of iron decreases 1,000 times for every unit increase in soil pH. Most iron chlorosis occurs on alkaline soils, particularly calcareous soils or soils with high bicarbonate (HCO_3) levels. Under such conditions, roots lose the ability to reduce iron to an available form. Iron deficiencies are very rare on acid soils.
- *Poor Soil Drainage and Aeration*.

- *Excess Sodium, Salts*.

Soil organic matter has less effect on availability of Fe than on zinc. In fact, severe iron chlorosis occurs with soybeans on certain high-pH, black soils in Minnesota and Iowa that contain over 5% organic matter.

Sources Of Iron

The same factors that render native soil iron unavailable tend to cause rapid tie-up of iron fertilizers. Thus, soil applications of iron are relatively ineffective. Applications of iron with polyphosphates in a band at planting time have occasionally been effective. Certain iron chelate carriers have been effective as soil-applied iron fertilizers, but they are frequently uneconomical. Broadcasting iron is ineffective.

Foliar applications of iron can be relatively effective in correcting Fe deficiency problems. However, applications must be started *before* plants are severely damaged by chlorosis and may need to be repeated. Ferrous sulfate (1% to 1.5% solution) plus a wetting agent or one of several iron chelates may be used for foliar treatments. Iron chlorosis of trees can be corrected by injections of dry iron salts directly into the trunk or branches.

Guidelines for the critical timing of foliar iron fertilizer applications include:

a. *Soybeans*. Apply by the first trifoliate leaf stage.

b. *Sorghum*. Apply by the sixth leaf stage.

Iron deficiency has been a problem on calcareous western Kansas soils for many years. Grain sorghum is the agronomic crop most susceptible to iron chlorosis problems. Iron deficiency can be corrected by spraying the crop with solutions containing a soluble source of iron or by soil applications of some of the new iron chelates. Spraying the crop is time consuming because the crop must be sprayed two or three times during the growing season in order to control the chlorosis problem. Soil applications of the chelates are relatively expensive. It has taken at least 8 to 10 pounds of iron metal in the form of chelates to control the chorosis problem in most experiments.

Application of manure may be the most practical way to address iron deficiency in areas where manure is accessible. Manure is an excellent source of iron and tends to increase soil organic matter levels. The other way to address the iron problem is to plant crops less susceptible to iron chlorosis. Grain sorghum and soybeans (except for tolerant varieties) are very susceptible, corn is less susceptible and wheat is very tolerant to iron chlorosis.

BORON (B)

Plants absorb B in the $BO_3^{=}$ form. Boron is essential for germination of pollen grains and growth of pollen tubes. It is also essential for formation of seed, cell walls, and protein. Boron is immobile in the plant; thus deficiencies are first expressed in the young actively growing parts of the plant. An exception is cotton where boron is translocated to new tissue. Symptoms are:

Common Boron Fertilizer Sources	
Fertilizer Source	B (%)
Borax	11
Sodium Tetraborate:	
Granubor	14.3-15.0
Boric Acid	17
Solubor	20-20.5

- Alfalfa: A rosetting or bushy appearance of the top of the plant. Tops turn yellow and may die.

- Corn: Barren plants.

- Beets: Brown heart and dark spots on roots.

- *Cotton*: Rosetting at top of plant and thick green leaves that stay green until frost. Excessive square and boll shedding.

Crops most commonly affected by B deficiency are sugar beets, alfalfa, clover, celery, beets, cauliflower, apples, grapes, pears, walnuts, and a few ornamentals. Deficiencies in vegetable crops may produce an unmarketable product.

Boron In The Soil

Boron exists as the plant available borate anion ($BO_3^{=}$) and as organic boron in soil organic matter. Borate is a mobile nutrient in soil. Boron deficiencies are not common, but there are certain soils and conditions where boron deficiencies are more likely to occur including:

- *High Rainfall Areas*. Like nitrate, borate is soluble and easily leached.
- *High pH Soils Containing Free Calcium Carbonate*. Avoid over liming acid soils
- *Low Organic Matter Soils*. Organic matter is the "storehouse" of boron.
- *Dry Soil*. Decomposition of organic matter is reduced and root growth is limited.

Soil tests for B are not well calibrated in Kansas or the Great Plains. Therefore, soil type, crop sensitivity, and deficiency symptoms should also be used as indicators of the need for boron.

Kansas Boron Research

Experiments were conducted in the late 1960's through the early 1970's which showed that boron deficiency could be a problem in southeastern Kansas under certain conditions. The response to boron in the long time rotation experiment at the Columbus Experiment Station is shown below.

Some of the increases in yield of corn, wheat and soybeans by the application of boron could have been due to the influence of the boron on the alfalfa crop. However, response to direct applications of boron on corn in 1972 was obtained in an experiment with corn on another Cherokee county field testing low in available soil test boron.

Response To Boron. Cherokee County, KS - 1963-1972

	Crop Yields			
Crop	Alfalfa	Corn	Wheat	Soybean
	Ton/A	- - - -	Bu/A	- - - -
Control	0.72	43	21	22
Lime	1.08	43	27	25
Lime P	2.95	54	38	28
Lime P, K	3.28	67	43	30
Lime, P, K, B	3.72	73	44	34

Fertilizer Sources of Boron

The indiscriminate use of B fertilizers is discouraged because there is a narrow range between boron deficiency and toxicity. Boron application guidelines include:

- Relatively *low* rates of B should be used. No more than 1-2 lbs B/A per year.
- Never place B in direct contact with seed or in band applications.
- Broadcast dry sources of boron with PK blends in order to achieve uniformity of application. Since very low rates are applied and the potential for toxicity exists, uniform distribution of boron is essential.

Chloride (Cl)

Chloride (Cl) is one of 8 micronutrients essential for crop growth. Chloride is a micronutrient because it is needed in small quantities. Deficiencies of chloride in crops in Kansas and the Great Plains have been identified and confirmed. The purpose of this publication is to discuss chloride in terms of plant, soil, and fertilizer considerations.

Plant Considerations

Chloride is taken up by plants as the Cl^- ion. Chloride was proven to be an essential nutrient in 1954. A major function of chloride in plants is as a counter ion for cation (Ca^+, K^+, Mg^+, NH_4^+) transport and as an osmotic solute. As a counter ion, chloride maintains electrical charge balance for the uptake of essential cations. In addition, chloride serves an essential role in maintaining cell hydration and turgor. A critical role of chloride is as a cofactor in the oxidation of water in photosynthesis and as an activator of several enzymes. Although some chlorinated organic compounds exist in plants, no evidence exists that these compounds are essential.

Even with this early work identifying chloride as an essential plant nutrient, little concern existed about supplying this element as part of a complete fertilization program. However, by the early 1980's research conducted in several states indicated responses to chloride fertilization when soil chloride levels were low. In addition, chloride application has been shown to suppress or reduce the effects of numerous diseases on a variety of crops. The exact mechanism of this effect is not well defined, but may be related to the role of chloride in osmotic regulation. In wheat, chloride has been shown to suppress take-all root rot, tan spot, stripe rust, leaf rust and Septoria while in corn and grain sorghum has suppressed stalk rot.

Physical symptoms of chloride deficiency on plants vary and are not always consistent. In wheat, some varieties will show a characteristic leaf spotting, best described as random chlorotic spots on the leaves. The spots resemble tan spot lesions, but are smaller and don't have the characteristic "halo" at the edge of the spot. In Kansas work on low chloride soils, some varieties consistently show the leaf spotting while other varieties never spot. Montana research also verified variety differences. Other Kansas research indicates that no obvious visual deficiency symptoms occurred on corn or grain sorghum, even where chloride fertilization increased yields.

Excessive levels of chloride in the soil can result in chloride sensitive crops accumulating excessive amounts of Cl^- which can be toxic. For example, in the southeastern United States where large amounts of potassium chloride have been applied to supply needed potassium, high soil chloride levels exist. Chloride sensitive soybean varieties can show toxicity on these soils. In Kansas, the only situation where chloride toxicity may be a factor is on saline soils. In this case, the major detrimental effect of chloride results from its contribution to osmotic stress caused by excessive salts in the root zone.

Soil Considerations

Chloride is normally present in the soil in sizeable quantities, particularly in coastal areas where chloride deposition is high. Estimates of chloride levels in soils range from near zero to over 1000 pounds per acre. Limited evaluation in Kansas indicates fairly low soil chloride levels. This could be due to low chloride deposition (distance from oceans) and the relatively high indigenous potassium levels of the majority of our soils which means very little potassium chloride fertilizer has been applied. Summaries of soil test data in Kansas show a majority of the samples had chloride levels below 40 pounds per acre, with a significant number of samples less than 10 pounds per acre (on 0-24" samples).

As an anion, chloride is not readily adsorbed on the soils exchange complex and is subsequently not attached. Because of this, chloride moves readily with soil water. Chloride is quite leachable, even more so than nitrate. In fact, leaching of chloride is often used as a tracer for movement of other soluble anions such as nitrate or sulfate. The oxidation state of chloride in the soil is not changed by soil microorganisms.

The Kansas State University Soil Testing Laboratory and most commercial labs offer a chloride soil test. Because of the leaching potential of chloride, we recommend sampling to a depth of 24 inches to best assess soil chloride status (just like nitrogen and sulfur). When testing for pH, P, K, organic matter and Zn plus any of the mobile nutrients (N, S or Cl) a 0 to 6 inch and 6 to 24 inch sample is recommended. The 0-6 inch sample will be used for testing routine analyses while the mobile nutrients (N, S and Cl) will be tested on both the 0-6 inch and 6-24 inch samples.

Fertilizer Considerations

Several potential sources of chloride exist, including man-made fertilizers, atmospheric deposition and naturally occurring chloride already in the soil. The atmospheric deposition of chloride in Kansas is quite low and many Kansas soils are low in naturally occurring chloride. Thus, fertilizers become an important chloride source. Potassium chloride (KCl) or muriate of potash is the most common and readily available chloride containing fertilizer in Kansas. On an elemental basis, KCl fertilizer is 53% K and 47% Cl. For ease of calculating, we assume it to be roughly 50-50 K:Cl. For example, if 50 pounds of KCl fertilizer is applied, about 25 pounds of chloride would be furnished. Since P and K in fertilizer are reported on an oxide basis (P_2O_5 and K_2O), it can be confusing as many fertilizer dealers know KCl or muriate of potash fertilizer as 0-0-60 or 0-0-62.

Other chloride containing fertilizers include: ammonium chloride (NH_4Cl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$) and sodium chloride (NaCl). These fertilizers contain 66%, 65%, 74% and 60% Cl, respectively. Calcium chloride, ammonium chloride and magnesium chloride are sometimes available as liquid fertilizer.

Research in Kansas has evaluated all of these sources of chloride and show all to be equally effective in supplying chloride.

Chloride Research in Kansas

Since the early 1980's, considerable research with chloride fertilization has been conducted in Kansas on wheat, corn and grain sorghum. Positive yield responses have been noted on these crops. To date chloride fertilization on other crops has been limited.

Wheat Chloride research on wheat in Kansas has been ongoing for 20 years. Early work clearly showed that chloride fertilization not only increased wheat grain yields on low Cl soils, but also suppressed the progression of leaf rust. Research has also clearly shown that differences exist among wheat varieties in terms of responsiveness to chloride fertilization. For example the variety Cimarron, which consistently exhibits leaf spotting on low Cl soils, averaged 16 bushels/acre response to chloride fertilization at five sites that had soil Cl levels below 20 pounds/acre. At the same sites, the variety Ogallala yielded exactly the same with or without chloride fertilizer.

The following information summarizes this chloride fertilization/wheat variety research. Averaged across all seven varieties, chloride fertilization increased grain yields by 8 bushels/acre. An 8 bushel per acre yield response to a micronutrient is quite impressive, but this was with outstanding wheat yields (70-90 bu/ac). Yield responses of this magnitude would not be expected at lower overall yields, though our research has shown a 7-10% yield increase on low Cl soils, regardless of yield level. Applying chloride consistently and dramatically increased leaf tissue Cl concentrations on all varieties.

Corn and Grain Sorghum Several site-years of chloride research on corn and grain sorghum are summarized below. Overall, results are very similar to wheat. All sites with low soil Cl levels (< 25-30 lb Cl/a) responded to Cl application. The nonresponsive sites had soil Cl levels of 40 lb Cl/a or higher. As with wheat, leaf tissue Cl concentrations of the check (no chloride added) treatments at responsive sites were generally 0.15% or lower.

Over the many years of work on Cl fertilization, we evaluated several chloride rates and sources. In most cases application of 10-20 lbs Cl/a was sufficient to achieve optimum response. We have evaluated ammonium chloride, magnesium chloride, calcium chloride, potassium chloride and even sodium chloride as sources. All chloride sources performed equally. Potassium chloride is the most readily available source. When potassium chloride is used as a Cl source, there is the possibility that the potassium could be the cause of any response. All of our research was conducted on sites with high soil potassium levels and we measured potassium concentrations in leaf tissue samples. We are convinced the responses noted are due to chloride, particularly since other Cl sources also provided yield increases. Other crops have not been evaluated.

Table 3. Chloride fertilization on corn in Kansas.

Chloride Rate	Riley Co.			Brown Co.			Osage Co.	
	Site A	Site B	Site C	Site A	Site B	Site C	Site A	Site B
lb/a	bu/a							
0	70	64	107	188	123	87	133	79
20	84	69	111	191	130	93	133	81
Soil test Cl, lb/a (0-24")	9	16	24	28	14	28	40	61

(Grain Yield)

Table 2. Chloride fertilization on wheat.

Chloride Rate	Marion Co.		Saline Co				Stafford Co.		
	Site A	Site B	Site A	Site B	Site C	Site D	Site A	Site B	Avg.
lb/a	bu/a								
0	45	80	51	89	83	70	73	64	69
20	47	85	54	89	90	75	80	70	74
	7	7	14	22	7	14	7	15	12

(Grain Yield*)

*Average over either 12 or 16 varieties. Soil test Cl, lb/a (0-24")

Table 4. Chloride fertilization on grain sorghum in Kansas

Chloride Rate	Marion Co.				Brown Co.		Osage Co.	
	Site A	Site B	Site C	Site D	Site A	Site B	Site A	Site B
lb/a	bu/a							
0	87	117	63	92	102	87	125	88
10	94	139	71	113	106	95	126	92
20	97	135	72	126	111	96	125	96
Soil test Cl, lb/a (0-24")	9	7	9	43	7	9	52	29

(Grain Yield)

COPPER (Cu)

Plants absorb Cu as Cu^{++}. Copper is necessary in chlorophyll formation and is a catalyst for several plant processes, including protein synthesis. It is required in very small amounts (5 to 20 ppm) in plants. Copper deficiency symptoms occur very rarely and have not been observed in Kansas. Small grains and vegetables are among the crops most sensitive to deficiency. In small grains, leaf tips wilt then die and may resemble frost symptoms. Youngest leaves may be chlorotic.

Copper (Cu^{++} or Cu^{+++}) is held more tightly by organic matter than are most micronutrients. As a result, most copper deficiencies occur in soils that are high in organic matter such as peat and mucks. Very high pH or very sandy soils have shown deficiencies in other areas. Soil tests for copper are largely unreliable and should be used only where they have been calibrated through field research.

Copper has a long residual effect in the soil and over application can be toxic to plants.

MANGANESE (Mn)

Plants absorb manganese or Mn^{++}. Manganese is important in several enzymatic reactions and is involved in the synthesis of chlorophyll. Manganese is relatively immobile in plants, thus deficiency symptoms appear first in youngest leaves. In oats, the symptom is called "gray speck." It starts as gray oval-shaped spots on the margin of the leaf and enlarges into yellow spots. In wheat, barley, and corn, the upper leaves develop yellow streaks running the length of the leaf (interveinal chlorosis).

Manganese deficiency in crops is rare in the Great Plains and have not been observed in Kansas.

MOLYBDENUM (Mo)

Plants absorb Mo as MoO_4^- ions. Although most plants absorb N as nitrate, the plant must convert it to ammonium before it is utilized. Molybdenum is vital for the conversion of nitrates to ammonium within the plant. It is also essential for the process of N fixation by legume nodules; therefore, Molybdenum deficient legumes appear N deficient. Molybdenum is required in smaller amounts than any other essential plant nutrient.

Molybdenum deficiencies are not a concern in Kansas .

Nickel (Ni)

Nickel was only recently recognized as being an essential nutrient. Deficiencies have not been observed in Kansas or the Great Plains.