Chloride Fertilization and Soil Testing – Update for Major Crops in Kansas

By David Mengel, Ray Lamond, Vic Martin, Stu Duncan, David Whitney, and Barney Gordon

Chloride (Cl^-) is the ion form of chlorine (Cl). It is an essential, but sometimes overlooked, nutrient in crop production. Years of work have shown that wheat and other crops can show substantial response to Cl^- application. This article discusses Cl^- nutrition and summarizes Kansas research results for major crops from the 1990s through 2006.

Although crop response to Cl^- application was suspected as early as the mid-1800s, Cl was first identified as an essential plant nutrient for growth and development in 1954 (Broyer et al., 1954). While Cl is classified as a micronutrient, the quantities of Cl^- taken up and present in the plant are comparable to many macronutrients. Concentrations of Cl^- in corn earleaf and wheat flagleaf at flowering are commonly found to range from 0.25 to 1%.

Plants take up Cl as the Cl^- ion from the soil solution, and the primary form of Cl in plants is Cl^-. Like nitrate (NO_3^-), Cl^- acts as a counter-ion for the transport and uptake of essential cations such as calcium (Ca^{2+}), potassium (K^+), magnesium (Mg^{2+}), and ammonium (NH_4^+). Chloride also plays important roles in enzyme activation (Broyer et al., 1954; Grant et al., 2003) and osmotic regulation (Kafkafi and Xu, 2002).

Perhaps one of the most important roles of Cl in plant growth is in the suppression of plant disease. Suppression of disease through Cl fertilization has been reported in many crops including corn, millet, wheat, and barley (Heckman, 2006). In Kansas, the suppression of leaf rust in wheat and stalk rots in sorghum are important.

In the Great Plains, the most commonly observed visual symptoms from Cl^- deficiency are seen on wheat. The deficiency symptoms appear as leaf spotting and are referred to as physiological leaf spot. Visible Cl deficiency symptoms have not been defined for most agronomic crops, including corn and sorghum, though yield responses have been obtained.

Most of the Cl in soils is present in the soil solution as Cl^-, and arrives from rainfall, marine aerosols, volcanic emissions, irrigation water, and fertilizers (Havlin et al., 2005). Most references cite deposition values from precipitation of 10 to 35 lb Cl^-/A per year, with higher values in coastal areas. However, recent reports from the U.S. Atmospheric Deposition Program show much lower values, ranging from 0.5 to 1 kg/ha (0.45 to 0.9 lb/A) across much of the Great Plains and >10 kg/ha (9 lb/A) in coastal areas. Substantial amounts of Cl can be found in irrigation water, often enough to meet crop needs (Mikkelsen, 2005). In areas that have low levels of K, Cl is typically added as muriate of potash (KCl) fertilizer, thus increasing Cl^- concentration in the soil (Engel et al., 1997; Lamond and Leikam, 2002).

Comparing wheat leaves from plot which received Cl^- (left) and untreated plot (right).

Bear (1929), in discussing K fertilizers, noted that KCl fertilizer secured better yields than sulfate of potash in areas of heavy rainfall that are far from the seashore. He later explained that Cl is generally deficient in "interior regions" where rainfall causes runoff and underground drainage.

Two excellent reviews on Cl^- in plants and soils are: Chapter 9, "Chlorine", by Dr. Joseph Heckman in *The Handbook of Plant Nutrition*, 2007 and "Crop Responses to Chloride" by Dr. Paul Fixen in *Advances in Agronomy*, volume 50, 1993.

Chloride Fertilization Research in Kansas

The earliest Cl^- field research results found for Kansas

Cimmaron variety wheat at Sandyland Experiment Field, Kansas, showed deficiency symptoms when no Cl^- was applied (left). With 24 lb Cl^-/A, leaf spotting was eliminated (above).

Abbreviations and notes: ppm = parts per million.

Table 1. Response of wheat to Cl^- fertilization in Kansas (derived from 34 experiments conducted from 1990-2006).

Cl^- applied, lb/A	Grain yield, bu/A	Leaf Cl^- at boot, %
0	48.4 b	0.29 c
10	51.7 a	0.38 b
20	52.5 a	0.43 a
LSD 0.05	1.3	0.03
n	34	30

Table 2. Response of dryland grain sorghum to applied Cl^- fertilizer in Kansas (derived from 20 site-years of data from 1996-2006).

Cl^- applied, lb/A	Grain yield, bu/A	Leaf Cl^- at boot, %
0	98.5 b	0.10 c
20	108.2 a	0.24 b
40	109.9 a	0.33 a
LSD 0.05	2.4	0.05
n	20	11

Table 3. Response of dryland corn to applied Cl^- fertilizer in Kansas (derived from 11 studies conducted from 1990-2006).

Cl^- applied, lb/A	Grain yield, bu/A	Leaf Cl^- at tassel, %
0	104.4 b	0.17 c
20	108.9 a	0.27 b
40	111.6 a	0.36 a
LSD 0.05	3.4	0.05
n	11	11

was from studies conducted in the early 1980s. Much of this work was sparked by reports of effects of Cl^- on plant disease. Bonczkowski (1989) and co-workers conducted a series of studies in Northeast Kansas comparing the use of KCl to fungicides on suppression of wheat rust. Work was also conducted at several locations, primarily with wheat, focused on nutrient response. Early results suggested that the greatest potential for response would be in dryland production in areas with no history of potash fertilization.

The following is a summary of Kansas Cl^- work conducted from 1990 to 2006. More details on the majority of these studies can be found in the Kansas Fertilizer Research Reports, published annually and available on-line at the K-State Research and Extension website: >www.ksre.ksu.edu/library<.

Wheat. In the period from 1990 to 2006, 39 field experiments were conducted, primarily in the eastern half of the state, looking at the response of hard red winter wheat to Cl^- fertilization. Nearly all these experiments were conducted under dryland conditions, in areas of high native soil K levels with no history of potash application. Various treatments were compared in these studies, with a focus on Cl^- application rate, Cl^- source, and time and/or method of application. Of the 39 studies, 23 showed a statistically significant response to Cl^- fertilization when analyzed individually.

The results from 34 of those experiments, all of which included common treatments of Cl^- fertilizer rates of 0, 10, and 20 lb/A applied as KCl broadcast in the spring, were combined and analyzed using each location as a replication and the treatment means at that location as individual observations. In each of these studies, non-K sources were included, allowing the separation of K response from Cl^- response. The results are summarized in **Table 1**.

A significant wheat yield response to Cl^- fertilization was found in the combined analysis of these studies. The addition of 10 lb of Cl^- increased wheat yield 3.3 bu/A across all sites, and no additional response to the 20 lb/A Cl^- rate was seen. Chloride fertilization increased the Cl^- content of the top leaves at boot, with an increase in leaf Cl^- seen as rates increased.

Of the individual experiments, 21 used four rates of Cl^-: 0, 10, 20, and 30 lb/A. Again, a significant response in grain yield was seen with the first increment of Cl^- applied, with no additional response to higher rates.

A number of different materials were used as Cl^- sources in these studies, with comparisons of Cl^- fertilizers included at most sites. The most commonly used materials were KCl and sodium chloride (NaCl), with ammonium chloride (NH_4Cl), magnesium chloride ($MgCl_2$), and calcium chloride ($CaCl_2$) also used. While slight differences were observed in leaf Cl^- content between sources, no differences were observed between sources in yield response.

Sorghum. During the period of 1996 through 2006, 23 field trials were conducted examining the response of grain sorghum to applied Cl^- fertilizers. Of the 23 sites, 19 showed a significant yield response to Cl^- fertilization. Using the same process, a combined analysis was made of 20 site-years of data, looking at the response of sorghum to 0, 20, or 40 lb/A Cl^- applied broadcast pre-plant or pre-emerge as KCl or NH_4Cl **(Table 2)**.

As with wheat, a statistically significant yield response was seen to the first rate of Cl^- when data were combined across locations. In this case, the lowest rate was 20 lb/A Cl^-, with no additional response to the higher rate. Leaf Cl^- level went up with increased level of fertilization. Source comparisons were made in many of these studies, with no difference in effectiveness seen between KCl, NaCl, $CaCl_2$, and NH_4Cl.

Corn. Less work has been done examining the response of corn to Cl^- in Kansas, in part due to the large portion of the corn crop under irrigation (most of irrigation water in the state contains significant amounts of Cl^-) or in areas naturally low in soil K with a history of KCl applications. Eleven studies were conducted on dryland corn in the south central, north central, and north east portions of Kansas between 1996 and 2001. Only six of the 11 sites gave a significant yield response to Cl^- fertilization. The results from the 11 trials were combined and reported in **Table 3**. As with sorghum and wheat, a significant yield response was obtained to the first 20 lb/A of added Cl^-, with no additional response to additional Cl^-. Corn earleaf Cl^- levels increased with increasing rates of Cl^-. Some source comparisons were made with corn, and no differences were seen between sources tested. The number of source comparisons was too low to do a combined analysis.

Bromegrass. Chloride fertilization on bromegrass was also recently studied. A total of 10 experiments were conducted in 2004-2006. As with wheat, corn, and sorghum, increasing rates of Cl^- fertilizer increased the concentration of Cl^- in

Table 4. Soil test Cl^- interpretations and fertilizer recommendations for Kansas.

Category	Soil Cl^- in a 0 to 24 in. sample, lb/A	Soil Cl^- in a 0 to 24 in. sample, ppm	Cl^- recommended,[1] lb/A
Low	<30	<4	20
Medium	30-45	4-6	10
High	>45	>6	0

[1]Recommendations for corn, sorghum, and wheat only.

the plant tissue. However, no increases in forage yield were obtained at any of the sites. No recommendations for Cl^- fertilization of bromegrass are made in Kansas.

Soil and Plant Testing for Chloride

Based on this body of work, routine Cl^- soil tests and Cl^- fertilizer recommendations for wheat, sorghum, and corn have been offered by the Kansas State Soil Testing Lab since the mid-1990s. Plant analysis is also offered for research or diagnostic purposes. As with nitrate and sulfate, Cl^- soil testing is recommended using a 0 to 24 in. "profile" sample.

The interpretation of the Cl^- test and corresponding fertilizer recommendations for corn, sorghum, and wheat are given in **Table 4**. Chloride fertilizer is recommended for these crops at soil tests below 6 ppm, or 45 lb soil Cl^- in the 24 in. sample depth.

Summary

Chloride fertilization based on soil testing is gradually becoming an established practice in dryland wheat, sorghum, and corn production. More field testing is needed, particularly in western Kansas, to determine the breadth of the Cl^- deficient area, and to improve soil test correlations and calibrations. However, based on current data, the probability of a response to Cl^- in dryland wheat and sorghum production in central Kansas is high. BC

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