k-state extension
Agronomy e-Updates

Number 70
February 23, 2007

1. Soil and plant testing for chloride in Kansas

Chloride (Cl^-) fertilization based on soil testing is slowly becoming an established practice in dryland wheat, grain sorghum, and corn production in central and northeast Kansas. More field testing is needed, particularly in western Kansas, to determine the extent of the chloride-deficient areas, and to improve soil test correlations and calibrations. But based on current data, the probability of a response to Cl^- in dryland wheat and sorghum production in central Kansas is high.

Routine Cl^- soil tests and Cl^- fertilizer recommendations for wheat, grain sorghum, and corn have been offered by the K-State Soil Testing Lab since the mid-90's. Plant analysis is also offered for research or diagnostic purposes only. As with nitrate and sulfate, chloride soil testing is recommended using a 0-24" profile sample.

The interpretation of the Cl^- test and corresponding fertilizer recommendations for corn, grain sorghum, and wheat are given in the table below. Chloride fertilizer is recommended for these crops at soil tests below six ppm, or 45 pounds soil chloride in the 24-inch sample depth. Potassium chloride and ammonium chloride are the most commonly available and widely used fertilizer products.

Soil Test Chloride Interpretations and Fertilizer Recommendations for Kansas			
	Soil Chloride in a 0-24 inch sample		Chloride Recommended
Category	lbs/acre	ppm	lbs/acre
Low	<30	<4	20
Medium	30-45	4-6	10
High	>45	>6	0

Plants take up Cl as the Cl^- ion from the soil solution. The primary form of chlorine found in plants is Cl^-. Like nitrate, Cl^- helps with the transport and uptake of essential cations such as Ca, K, Mg, and NH_4. Chloride also plays important roles in enzyme activation and osmotic regulation.

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. 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.

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2. Chloride fertilization research on wheat, grain sorghum, and corn

The earliest field research on chloride (Cl^-) in Kansas was conducted in the early 1980's. Much of this work was sparked by reports of effects of Cl^- on plant disease. Larry Bonczkowski and co-workers conducted a series of studies in northeast Kansas comparing the use of KCl to fungicides for suppression of wheat rust. Work was also conducted at several locations, primarily with wheat, on yield 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 work conducted from 1990 to present. The individual crop summaries are averaged across all soil chloride levels in the experiments. Reports on the majority of these studies can be found in the Kansas Fertilizer Research Reports, published annually and available on-line at http://www.oznet.k-state.edu/library

Wheat: From 1990 to 2006, 39 field experiments were conducted, primarily in the eastern half of the state, looking at the response of 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 (or 59 percent) showed a statistically significant response to Cl^- fertilization.

The results from 34 of those experiments (the ones which included Cl^- fertilizer rates of 0, 10 and 20 pounds per acre -- applied as KCl broadcast in the spring) were combined and analyzed using each location as a rep 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 the table below.

Response of Wheat to Chloride Fertilizer: Summary of K-State Research 1990-2006		
Chloride Application Rate (lbs Cl^-/acre)	Grain Yield (bu/acre)	Percent Chloride (in top leaves at boot)
0	48.4	0.29
10	51.7	0.38
20	52.5	0.43
LSD	1.3	0.03
n	34	30

A small but significant wheat yield response to Cl^- fertilization was found in the combined analysis of these studies. Chloride fertilization also increased the Cl^- content of the top leaves at boot.

A number of different materials were used as Cl^- sources in these studies, with comparisons of chloride fertilizers included at most sites. The most commonly used materials were KCl and NaCl, with NH_4Cl, $MgCl_2$, and $CaCl_2$ 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. These studies were conducted under dryland conditions, and primarily in central Kansas. Of the 23 sites, 19 (or 82 percent) showed a significant yield response to chloride fertilization. A combined analysis was made of 20 site-years of data (the ones which included Cl^- fertilizer rates of 0, 20, and 40 pounds per acre -- applied broadcast pre-plant or pre-emerge as KCl or NH_4Cl).

Response of Grain Sorghum to Chloride Fertilizer: Summary of K-State Research 1996-2006		
Chloride Application Rate (lbs Cl^-/acre)	Grain Yield (bu/acre)	Percent Chloride (in top leaves at boot)
0	98.5	0.10
20	108.2	0.24
40	109.9	0.33
LSD	2.4	0.05

n	20	11

As with wheat, a statistically significant yield response was seen when combined across locations to the first rate of Cl^-, in this case 20 pounds per acre. There was no additional response to the higher rate. Leaf Cl^- level went up with increased level of fertilization. There were no difference in effectiveness between KCl, NaCl, $CaCl_2$, and NH_4Cl.

Corn: Less work has been done examining the response of corn to Cl^- in Kansas. Most of the corn in the state is either irrigated (irrigation water often contains significant amounts of Cl^-) or is grown in areas with a history of KCl applications. Eleven studies were conducted on dryland corn in the SC, NC and NE portions of Kansas between 1996 and 2001. Only six or the 11 sites gave a significant yield response to Cl^- fertilization.

Response of Corn to Chloride Fertilizer: Summary of K-State Research 1990-2006		
Chloride Application Rate (lbs Cl^-/acre)	Grain Yield (bu/acre)	Percent Chloride (in top leaves at boot)
0	104.4	0.17
20	108.9	0.27
40	111.6	0.36
LSD	3.4	0.05
n	11	11

In addition to these crops, Cl^- fertilization on bromegrass has also studied in recent years. Ten experiments were conducted in 2004-2006. Increasing rates of Cl^- fertilizer increased the concentration of Cl^- in the plant tissue. However, no increases in forage yield were obtained at any of the sites. No recommendations for fertilization of bromegrass with Cl^- are made in Kansas.

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3. Soil nitrogen: Understanding an increasingly valuable commodity

Nitrogen (N) is a valuable commodity for producers. Nitrogen makes up 78 percent of the atmosphere, but unfortunately it is in a gaseous form (N_2) that plants cannot use directly. It is also present in the soil, but much of that N is tied up in organic matter and not readily available for plant use. What producers have to provide to crops is N in the plant available form of nitrate or ammonia within the soil.

Crop producers have to find ways to work with the natural processes that occur in the soil to maximize the amount of N that exists as nitrate or ammonia during the time when crops need it most. To accomplish this, the producer first must understand the basic processes involved in soil nitrogen (the soil nitrogen cycle), and what happens to applied fertilizer N. It is virtually inevitable that part of the N a producers pays for and applies to the soil will be lost, either through volatilization, denitrification, leaching, or surface runoff. Another part may be unavailable for the current crop because of immobilization. A successful N fertilization program, in which the producer gets the most yield response per dollar spent on N fertilizer, depends on the right combination of cropping systems, N sources, application timing, and application methods.

Organic matter is the storehouse of most of the N in soil. This N is not available for plant uptake until mineralization occurs. The most important factors to understand are mineralization, N fixation, immobilization, leaching, denitrification, and volatilization.

* *Mineralization* refers to the microbial breakdown of complex organic N-containing compounds to nitrate-N, which is available to plants. This breakdown occurs in several steps, through the formation of amines and amino acids (aminization) to ammonium (ammonification) to nitrate (nitrification). Because this is a microbial-mediated process, soil temperature, moisture, pH, and aeration all affect the rate of mineralization. At soil temperatures below 50 degrees, the rate of mineralization is quite slow. Mineralization rapidly increases as soil temperatures reach the 65-90 F degree range. A soil with a near neutral pH (6.5 to 7.5), and that is moist and well aerated, would be ideal for rapid mineralization. Ammonification can occur in wet, poorly aerated soils, but not nitrification.

* *N fixation* is the biological process in which microorganisms in the soil convert elemental N in the soil air into organic N compounds, which in turn are converted through further microbial activity into plant available nitrate or ammonium. Symbiotic N fixation by legumes is the principal means of biological fixation, but some fixation does occur by free-living organisms. N fixation by legumes in crop rotations can be substantial and fertilizer application rates should be adjusted for legume credits.

* *Immobilization* can occur as organic matter is decomposed. The nitrogen content of the organic matter or crop residue is an important factor in determining the rate of mineralization. Soil organic matter typically has a carbon-to-nitrogen (C:N) ratio of roughly 10:1. Organic residue such as wheat straw with a much wider C:N ratio of 80:1, for example, will be mineralized at a much slower rate than residue from soybean or alfalfa, which has a much narrower C:N ratio. In fact, an immobilization or tie-up of available nitrate-N in the soil may occur during the decomposition process of wheat straw, and other residue with a high C:N ratio, such as corn and grain sorghum. This is generally short-term immobilization, with release of the “tied-up” N as the decomposition process progresses. However, a crop planted during this period of tie-up may show N deficiency if no supplemental N is supplied.

* *Nitrogen leaching* occurs with nitrate-N on sandy soils where excess rainfall and/or irrigation water causes rapid movement of water below the root zone. Nitrogen in the form of the ammonium ion will not leach because it has a positive charge and is held by negatively charged clay particles and organic matter.

* *Denitrification* is the breakdown of nitrate or nitrite ions by anaerobic organisms under waterlogged soil conditions to gaseous forms (N_2, N_2O, or NO), with loss to the atmosphere. Ideal soil temperature and pH conditions for denitrification are similar to conditions that favor mineralization. The soil generally has to be waterlogged for several days for substantial losses to occur. Ammonium-N is not subject to denitrification.

* *Volatilization* is the loss of N from the soil as ammonia (NH_3) to the atmosphere. This may occur from improper application of anhydrous ammonia (not sealing the ammonia in the soil), or from manure or urea-containing fertilizers left on the soil surface. Urease enzymes in the soil-residue complex convert urea to ammonia, which is volatile. Conditions that favor volatilization losses include surface application of manure or urea on moist to wet soils covered with high amounts of residue under rapid drying conditions. Incorporation of manure or urea eliminates volatilization losses. Also, rainfall shortly after application of a half-inch or more will move the urea into the soil, minimizing volatilization.

Producers should utilize agronomic practices that maximize mineralization and N fixation, and minimize volatilization, denitrification, and leaching.

-- David Whitney, Former Soil Fertility Specialist

(Note: This article by David Whitney originally appeared in the February 24, 2006 issue of Agronomy e-Update. The information remains timely and important.)

These e-Updates are a regular weekly item from K-State Extension Agronomy. All of the Research and Extension faculty in Agronomy will be involved as sources from time to time. If you have any questions or suggestions for topics you'd like to have us address in this weekly update, contact Jim Shroyer, Research and Extension Crop Production Specialist and State Extension Agronomy Leader
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