# Effects of potassium management on chloride cycling and corn yield and element uptake

Carl Rosen, James Crants, Matt McNearney, Daniel Kaiser, Melissa Wilson, and Mudassar Iqbal
Department of Soil, Water, and Climate, University of Minnesota
crosen@umn.edu

## Summary

Corn production covers a vast area in Minnesota, and large quantities of potassium (K) fertilizer are applied to this crop each year when a need is indicated by a soil test. The most common K fertilizer is potassium chloride (KCl, 0-0-60-48Cl). With KCl, the application of large amounts of K implies the application of large amounts of chloride ($Cl^-$). $Cl^-$ is an essential plant nutrient, but excessive soil $Cl^-$ can impact crop yields. Due mostly to increasing use of road salt, $Cl^-$ contamination of surface waters is a growing problem. However, the use of KCl as a K source potentially contributes to this issue. Any costs or benefits of applying $Cl^-$ to corn as KCl would be eliminated by substituting a non-$Cl^-$ K source such as potassium sulfate ($K_2SO_4$). To evaluate the effects of the $Cl^-$ fraction of KCl on corn crop health and soil water $Cl^-$ concentrations, nine treatments were applied to plots of DeKalb 4375 corn at the Rosemount Research and Outreach Center in Rosemount, MN: (1) a check treatment receiving no K or $Cl^-$; (2, 4, and 6) KCl applied at 50, 100, and 150 lbs/ac $K_2O$, respectively; (3, 5, and 7) $K_2SO_4$ applied at the same K rates; (8) liquid dairy manure applied at 150 lbs/ac $K_2O$ and 68 lbs/ac $Cl^-$, and (9) $CaCl_2$ applied at 75 lbs/ac $Cl^-$. Grain yield was unrelated to treatment. Unexpectedly, the treatment receiving 100 lbs/ac $K_2O$ as KCl had higher stover dry yield than any other treatment. The concentrations of K, Cl, and S in grain were unrelated to treatment. In contrast, the concentrations of K and Cl in stover increased with their application rates. Although the application rate of S was held constant across all treatments except the manure treatment by applying gypsum ($CaSO_4$) as needed to bring the rate to 51 lbs/ac S, stover concentrations of S increased with the application rate of $K_2SO_4$. Results for grain and stover element uptake, considered separately, were similar to those for their respective element concentrations, except that high stover yield in the treatment receiving 100 lbs/ac $K_2O$ as KCl resulted in a significant quadratic response for K and Cl uptake. Elemental uptake into grain and stover combined showed similar patterns to those seen in stover alone, except that combined S uptake was unrelated to treatment. Soil water $Cl^-$ concentrations at a depth of six feet were unrelated to treatment. In contrast, end-of-season soil K to a depth of six inches and soil $Cl^-$ to a depth of two feet were related to the application rates of K and $Cl^-$, respectively. These results suggest that the $Cl^-$ supplied by KCl was neither beneficial nor harmful to the corn crop in this study, and that, in this dry year, $Cl^-$ did not leach to a depth of six feet into the soil. Furthermore, The S content of $K_2SO_4$ was apparently more available to the crop than that of gypsum.

## Background

Corn production requires large quantities of potassium (K) to optimize yields and is taken up in amounts similar to nitrogen. Potassium chloride (KCl, 0-0-60-48Cl) is the most common K fertilizer, so chloride ($Cl^-$) is often co-applied with K. $Cl^-$ is an essential plant nutrient that has generally been neglected in K fertilizer research. It is not yet clear how often crops can benefit from $Cl^-$ application. $Cl^-$ has been shown to improve disease resistance in some plants, but it can also compete with other anions, such as $SO_4^{2-}$-S and $NO_3^-$-N, for plant uptake. Detrimental effects of excess $Cl^-$ on corn growth, kernel set, and yield have also been demonstrated, but $Cl^-$ excess does not appear to be a common problem in this crop. Any benefits or problems due to $Cl^-$

application are less likely to occur if K is supplied by $Cl^-$-free sources such as potassium sulfate ($K_2SO_4$, 0-0-50-17S).

$Cl^-$ is highly leachable and increasingly recognized as a contaminant in surface waters, with the primary source being road salt. It is not clear to what degree the use of KCl as a K source in agriculture contributes to this problem. Because corn is among the most widely grown crops in Minnesota, it potentially contributes to elevated $Cl^-$ concentrations in surface waters.

To determine the effects of the $Cl^-$ fraction of KCl on corn crop yield and soil $Cl^-$ cycling, corn cropping systems are being evaluated at the Rosemount Research and Outreach Center in Rosemount, MN. The objectives of the study are to evaluate the effects of (1) KCl rate, (2) $K_2SO_4$ rate, (3) manure as a source of K, $Cl^-$, and S, and (4) $Cl^-$ applied without K (as $CaCl_2$), on corn yield, stover biomass, uptake of $Cl^-$, K, and S, and soil water $Cl^-$ concentrations.

**Methods**

The study was conducted at the Rosemount Research and Outreach Center in Rosemount, MN, on a Waukegan silt loam soil. The previous crop was soybeans. Initial soil characteristics based on samples collected on May 13, 2023, are presented in Table 1. Daily rainfall during the season is presented in Figure 1. The field was not irrigated.

A total of 11 treatments were applied in a randomized complete block design with four replicates. However, two pairs of treatments were identical in 2023 and will become distinct in 2024. Each of these pairs was treated as a single treatment in the analysis of 2023 results, leaving 9 distinct treatments in this year. These treatments are presented in Table 2. Each plot was 15 feet (6 rows) wide by 30 feet long. The plots were marked out within a field 260 feet long and 235 feet wide divided by a 20-foot alley into two, 235-by-120-foot stands of corn.

Preplant fertilizer, including manure (treatment 8), was broadcast on May 17 according to treatment. The manure application rate was based on a desired N application rate of 150 lbs/ac, which resulted in the application of 150 lbs/ac $K_2O$, 68 lbs/ac $Cl^-$, and 30 lbs/ac S. Gypsum (17% S, 24% Ca) was applied as needed to provide a total S application rate of 51 lbs/ac except in the manure treatment, which did not receive gypsum. Thus, treatments 1, 2, 4, 6, and 9 each received gypsum at 300 lbs/ac; treatments 3 and 11 received 200 lbs/ac gypsum; and treatments 5 and 7 received 100 and 0 lbs/ac gypsum, respectively.

On May 18, DeKalb 4375 seed was planted at 32,500 seeds/ac, together with an application of 6 lbs/ac N and 20 lbs/ac $P_2O_5$ as ammonium phosphate (10-34-0) at 60 lbs/ac. Rows with poor emergence were hand-replanted on June 9. On June 13, all treatments except the one receiving manure (treatment 8) received 150 lbs/ac N sidedressed as urea (46-0-0) applied at 325 lbs/ac.

On September 28, at the R6 growth stage, a six-plant sample was collected from each plot. The ears were separated from the stover. The stover from each sample was weighed fresh in the field. It was then passed through a woodchipper, from which a subsample was collected. Each subsample was weighed, and the subsamples were dried at 140 °F until they reached a constant weight, at which time their dry weights were determined. The ears were weighed, dried at 140 °F until they reached a constant weight and separated into grain and cobs. The dry grain and cob fractions were weighed separately. Element concentrations in the grain and stover were measured using inductively coupled plasma spectrometry (ICP) by Agvise, Inc. The concentrations of K, Cl, and S were used to calculate uptake of these elements by multiplying the per-acre dry yield of grain and stover by the concentrations of K, Cl, and S in each tissue. Per-acre dry yield of stover was estimated based on the dry yield of the six-plant samples and a population density of 32,500 plants/ac. Grain was harvested from the central two rows of each six-row plot by combine on November 8. The per-acre dry yield of grain was estimated based on combine yields at harvest (corrected from 15.5% moisture).

On May 13 and 16, 2022, lysimeters were installed six feet deep in five treatments: the check treatment (treatment 1), the treatments receiving 100 lbs/ac $K_2O$ as KCl (treatment 4) and $K_2SO_4$ (treatment 5), the treatment receiving manure (treatment 8), and the treatment receiving 75 lbs/ac $Cl^-$ as $CaCl_2$ (treatment 9). Water samples were collected on May 15 and 26, June 1, 12, and 28, July 10, 21, and 28, August 7 and 17, September 6, 19, and 28, October 20 and 30, and November 14. On November 9, soil samples to a depth of six inches were collected to measure $NH_4OAc$-extractable K concentrations, and samples to a depth of two feet were collected to measure $CaSO_4$-extractable $Cl^-$ concentrations.

Data were analyzed using the GLIMMIX procedure in SAS 9.4 software (SAS Institute, Inc., 2016). Each response variable was analyzed as a function of treatment and block. Denominator degrees of freedom were determined by the Kenward-Roger method and the data were assumed to be normally distributed. Pairwise comparisons were evaluated where the effect of treatment was at least marginally significant ($P < 0.10$). Pairs of treatments were considered significantly different if the P value of the pairwise comparison was less than 0.10. Lysimeter data were analyzed both at each collection date (not presented) and averaged across the season.

For all data except lysimeter data and the end-of-season soil K data, six CONTRAST statements were applied to compare **1)** the check treatment (treatment 1) versus the treatments receiving KCl or $K_2SO_4$ (treatments 2-7), the **2)** linear and **3)** quadratic responses to KCl rate (treatments 1, 2, 4, and 6), the **4)** linear and **5)** quadratic responses to $K_2SO_4$ rate (treatments 1, 3, 5, and 7), and **6)** the treatments receiving KCl (treatments 2, 4, and 6) versus those receiving $K_2SO_4$ (treatments 3, 5, and 7). No CONTRAST statements were applied to lysimeter and end-of-season soil K data, neither of which included the full suite of treatments.

## Results and discussion

*Grain and stover yield*

Results for grain and stover yield are presented in Table 3. Grain yield was not related to treatment, but stover yield was. The treatment receiving 100 lbs/ac $K_2O$ as KCl (treatment 4) had significantly higher stover dry yield than any other treatment, resulting in a significant quadratic response to KCl rate.

*Corn grain and stover element concentrations*

Results for grain and stover elemental concentrations are presented in Table 4. Grain K, Cl, and S concentrations were not significantly related to treatment. In contrast, stover concentrations of all three elements were significantly related to treatment to treatment.

Stover K concentrations increased with the application rates of both KCl and $K_2SO_4$. The difference in K concentration between the check treatment (treatment 1) and the treatments receiving 50 lbs/ac $K_2O$ (treatments 2 and 3) was greater than the difference among all treatments receiving KCl or $K_2SO_4$ (treatments 2-7).

Stover Cl concentration was strongly positively related to the application rate of KCl. This relationship was approximately linear between 0 and 100 lbs/ac $K_2O$ (treatments 1, 2, and 4), but the treatment receiving 150 lbs/ac $K_2O$ (treatment 6) did not have a significantly higher stover Cl concentration than the one receiving 100 lbs/ac $K_2O$ (treatment 4). Stover Cl concentration was not related to the application rate of $K_2SO_4$ and was higher in treatments receiving KCl than those receiving $K_2SO_4$. It was similar in the treatment receiving manure (treatment 8) to the other treatments receiving 150 lbs/ac $K_2O$ (treatments 6 and 7).

Stover S concentrations were higher in treatments receiving $K_2SO_4$ (treatments 3, 5, and 7) than those receiving KCl (treatments 2, 4, and 6). There was a positive relationship between K rate and stover S concentration among the treatments receiving $K_2SO_4$ (treatments 3, 5, and 7). Since all treatments received the same total S rate, these results suggest that the S in $K_2SO_4$ may be more available for uptake than the S in gypsum. The treatment receiving manure (treatment 8), which had the lowest S application rate in the study, also had the lowest stover S concentration.

*Corn aboveground element uptake*

Results for aboveground element uptake are presented in Table 5. The uptake of K, Cl, and S into the grain was not related to treatment. However, the uptake of all three elements into stover varied with treatment.

Stover K uptake increased with increasing application rate of either KCl (treatments 1, 2, 4, and 6) or $K_2SO_4$ (treatments 1, 3, 5, and 7). With both sources, the highest stover K uptake was observed at 100 lbs/ac $K_2O$. (treatments 4 and 5). This peak was higher in KCl, which had high stover dry yield at 100 lbs/ac $K_2O$ (treatment 4), than in $K_2SO_4$ (treatment 5), resulting in a significant quadratic contrast on KCl rate. K uptake was marginally significantly higher in treatments receiving KCl (treatments 2, 4, and 6) than in treatments receiving $K_2SO_4$ at the same K rates (treatments 3, 5, and 7). The difference in K uptake between KCl and $K_2SO_4$ is partially due to the high stover dry yield in treatment 4 and would likely not be significant without it.

The treatments receiving KCl produced significantly higher Cl uptake than those receiving $K_2SO_4$ (treatments 3, 5, and 7). Among treatments receiving KCl (treatments 2, 4, and 6), but not among the treatments receiving $K_2SO_4$, Cl uptake increased with increasing $K_2O$ application rate. Like K uptake, Cl uptake was highest when KCl was applied at 100 lbs/ac $K_2O$ (treatment 4), resulting in a significant quadratic contrast on KCl rate. High Cl uptake in this treatment was attributable to its high stover dry yield.

S uptake into stover increased with the application rate of $K_2SO_4$, resulting in a marginally significant linear contrast on $K_2O$ rate. The treatment receiving manure (treatment 8) had the lowest stover S uptake in the study. The uptake of each element into grain and stover combined reflected uptake into stover, except that total uptake of S was unrelated to treatment.

*Soil water $Cl^-$ and end-of-season soil K and $Cl^-$ concentrations*

Results for soil water $Cl^-$ at a depth of 6 feet, soil K concentration to a depth of six inches, and soil $Cl^-$ concentration to a depth of two feet are presented in Table 6. Soil water $Cl^-$ concentration, averaged across the season, was unrelated to treatment. This was also true of soil water $Cl^-$ concentration on each of the 16 sampling dates (not shown). This suggests that little of the $Cl^-$ applied in fertilizer leached from the soil to a depth of six feet, likely due to lack of leaching rainfall during the growing season.

End-of season soil $Cl^-$ concentration to a depth of two feet was related to treatment. Soil in plots receiving KCl had a significantly higher $Cl^-$ concentration than soil in plots receiving $K_2SO_4$. Soil $Cl^-$ concentration increased with the application rate of KCl. This indicates that much of the $Cl^-$ applied in fertilizer was still near the soil surface after harvest. Soil K concentration to a depth of six inches was significantly related to treatment, with the treatments receiving K (treatments 6 and 8) having higher soil K concentrations than the check treatment (treatment 1) or the treatment receiving $CaCl_2$ (treatment 9). Like $Cl^-$, much of the K applied in fertilizer apparently remained near the soil surface after harvest.

**Conclusions**

The treatments applied had no significant effects on grain yield or the concentrations or uptake of K, Cl, or S. In contrast, elemental concentrations and uptake into stover did respond to treatment. As expected, the tissue concentration and uptake of K and Cl increased with the application rates of these elements. The S in $K_2SO_4$ was apparently more readily taken up by corn stover than the K in gypsum or manure. The treatment receiving manure had the lowest stover S uptake in the study, reflecting a lower S rate applied. We did not find evidence that $Cl^-$ competed with $SO_4^{2-}$ for uptake. Based on results for soil water $Cl^-$ concentrations at six feet below the soil surface and soil $Cl^-$ concentration in the top two feet of soil, the $Cl^-$ from KCl or $CaCl_2$ largely remained near the surface over the course of this study, with little of it leaching down to six feet below the surface during a year with below average rainfall during the growing season.

**Table 1.** Soil characteristics before planting in the corn field in Rosemount, MN, in 2023.

| 0 - 12 inches | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bray P (ppm) | K (ppm) | $Cl^-$ (ppm) | pH | Organic matter (%) | Total organic C (%) | Sand (%) | Silt (%) | Clay (%) |
| 23 | 130 | 15 | 5.6 | 3.9 | 1.8 | 21 | 54 | 25 |

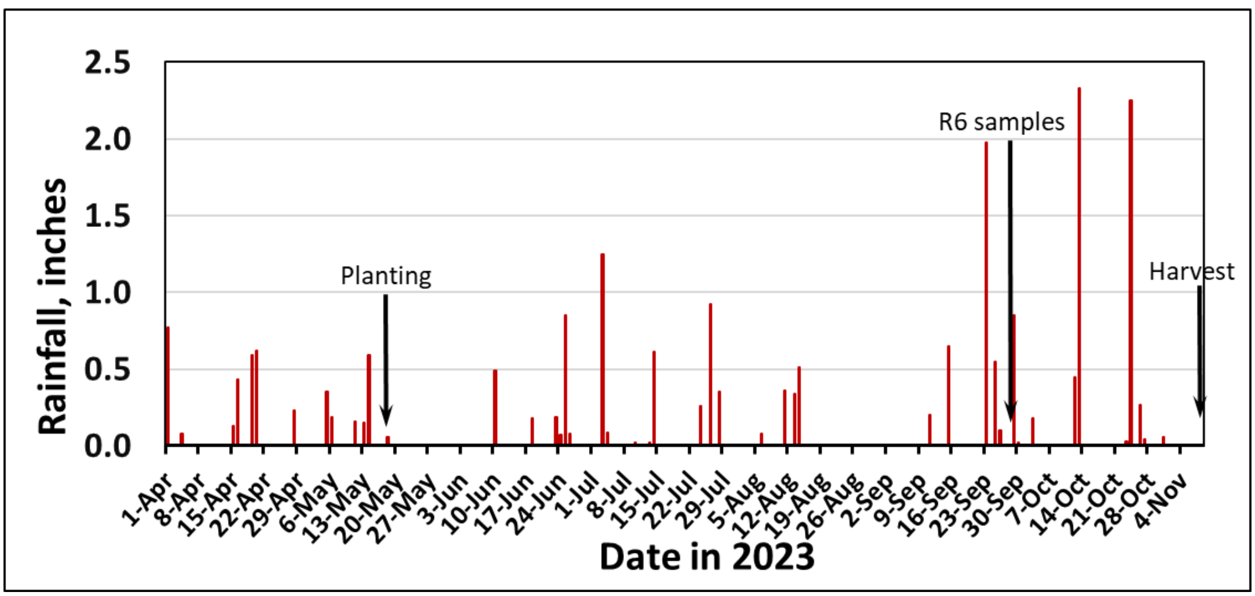


**Figure 1.** Rainfall on each day from April 1 through October 31 in 2023. The field was not irrigated. The field received a total of 21.0 inches of rain during this period, with 16.7 inches falling between planting (May 18) and harvest (November 8).

**Table 2.** Treatments applied to corn plants in Rosemount, MN, in 2023.

| Treatment # | $K_2O$ rate (lbs/ac), source | $K_2O$ rate (lbs/ac) | $Cl^-$ rate (lbs/ac) | S rate (lbs/ac) | | |
|---|---|---|---|---|---|---|
| | | | | Treatment | Gypsum[6] | Total |
| 1 | 0 lbs/ac | 0 | 0 | 0 | 51 | 51 |
| 2[1] | 50 lbs/ac as KCl[2] | 50 | 40 | 0 | 51 | 51 |
| 3[1] | 50 lbs/ac as $K_2SO_4$[3] | 50 | 0 | 17 | 34 | 51 |
| 4 | 100 lbs/ac as KCl | 100 | 79 | 0 | 51 | 51 |
| 5 | 100 lbs/ac as $K_2SO_4$ | 100 | 0 | 34 | 17 | 51 |
| 6 | 150 lbs/ac as KCl | 150 | 119 | 0 | 51 | 51 |
| 7 | 150 lbs/ac as $K_2SO_4$ | 150 | 0 | 51 | 0 | 51 |
| 8 | 150 lbs/ac as manure[4] | 150 | 68 | 30 | 0 | 30 |
| 9 | 0, $CaCl_2$[5] | 0 | 75 | 0 | 51 | 51 |

[1]Treatment has 8 plots, half of which will receive the same $K_2O$ rate and source in 2024.

[2]Potassium chloride: 0-0-60-47.4Cl

[3]Potassium sulfate: 0-0-50-17S

[4]Manure had 22 lbs $K_2O$, 10 lbs Cl, and 4.4 lbs S per 1000 gal and was applied at 6800 gal/ac.

[5]Calcium chloride: 60% Cl

[6]Gypsum ($CaSO_4 \cdot 2H_2O$): 17%S

**Table 3.** Effects of K and Cl treatments on corn grain yield and dry stover yield. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Pairwise comparisons are presented only for effects where $P \leq 0.10$.

| Treatment | Source | $K_2O$ rate (lbs/ac) | $Cl^-$ rate (lbs/ac) | Grain yield @ 15.5% moisture (bu/ac) | Stover dry yield (T/ac) |
|---|---|---|---|---|---|
| 1 | Check | 0 | 0 | 199 | 3.4 b |
| 2 | KCl | 50 | 40 | 198 | 3.6 b |
| 3 | $K_2SO_4$ | 50 | 0 | 197 | 3.4 b |
| 4 | KCl | 100 | 79 | 195 | 4.2 a |
| 5 | $K_2SO_4$ | 100 | 0 | 198 | 3.6 b |
| 6 | KCl | 150 | 119 | 208 | 3.3 b |
| 7 | $K_2SO_4$ | 150 | 0 | 200 | 3.5 b |
| 8 | Manure | 150 | 68 | 185 | 3.2 b |
| 9 | $CaCl_2$ | 0 | 75 | 190 | 3.5 b |
| | Treatment effect (P-value) | | | 0.7262 | **0.0484** |
| Contrasts | Effect of K (1 vs. 2-7) | | | 0.9540 | 0.2331 |
| | KCl rate, linear (1, 2, 4, 6) | | | 0.4941 | 0.5593 |
| | KCl rate, quadratic (1, 2, 4, 6) | | | 0.3445 | **0.0036** |
| | $K_2SO_4$ rate, linear (1, 3, 5, 7) | | | 0.9136 | 0.4726 |
| | $K_2SO_4$ rate, quadratic (1, 3, 5, 7) | | | 0.8447 | 0.6570 |
| | KCl v $K_2SO_4$ (2, 4, 6 v 1, 3, 7) | | | 0.7901 | 0.1696 |

**Table 4.** Effects of K and Cl treatments on concentrations of K, Cl, and S in corn grain and stover. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Pairwise comparisons are presented only for effects where $P \leq 0.10$.

| Treatment | Source | $K_2O$ rate (lbs/ac) | $Cl^-$ rate (lbs/ac) | Grain element concentrations (%) | | | Stover element concentrations (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | K | Cl | S | K | Cl | S |
| 1 | Check | 0 | 0 | 0.29 | 0.040 | 0.078 | 0.56 d | 0.10 c | 0.055 bc |
| 2 | KCl | 50 | 40 | 0.29 | 0.043 | 0.076 | 0.73 abc | 0.25 b | 0.053 cde |
| 3 | $K_2SO_4$ | 50 | 0 | 0.28 | 0.043 | 0.079 | 0.68 bc | 0.14 c | 0.054 bcde |
| 4 | KCl | 100 | 79 | 0.31 | 0.053 | 0.080 | 0.76 ab | 0.34 a | 0.050 de |
| 5 | $K_2SO_4$ | 100 | 0 | 0.26 | 0.048 | 0.073 | 0.74 abc | 0.10 c | 0.060 ab |
| 6 | KCl | 150 | 119 | 0.27 | 0.040 | 0.075 | 0.79 a | 0.38 a | 0.058 bc |
| 7 | $K_2SO_4$ | 150 | 0 | 0.29 | 0.040 | 0.078 | 0.74 abc | 0.09 c | 0.065 a |
| 8 | Manure | 150 | 68 | 0.31 | 0.040 | 0.073 | 0.76 ab | 0.35 a | 0.048 e |
| 9 | $CaCl_2$ | 0 | 75 | 0.29 | 0.045 | 0.075 | 0.64 cd | 0.36 a | 0.058 bc |
| | | | Treatment effect (P-value) | 0.6411 | 0.5767 | 0.5187 | **0.0407** | **<0.0001** | **0.0122** |
| Contrasts | | | Effect of K (1 vs. 2-7) | 0.7406 | 0.4170 | 0.7884 | **0.0011** | **0.0018** | 0.6641 |
| | | | KCl rate, linear (1, 2, 4, 6) | 0.5955 | 0.6367 | 0.7704 | **0.0017** | **<0.0001** | 0.7189 |
| | | | KCl rate, quadratic (1, 2, 4, 6) | 0.2786 | 0.1010 | 0.4923 | 0.1171 | ***0.0900*** | ***0.0961*** |
| | | | $K_2SO_4$ rate, linear (1, 3, 5, 7) | 0.8773 | 0.8131 | 0.6272 | **0.0070** | 0.6434 | **0.0129** |
| | | | $K_2SO_4$ rate, quadratic (1, 3, 5, 7) | 0.2148 | 0.2687 | 0.4923 | 0.1777 | 0.3998 | 0.2920 |
| | | | KCl v $K_2SO_4$ (2, 4, 6 v 1, 3, 7) | 0.3811 | 0.6409 | 0.7010 | 0.2934 | **<0.0001** | **0.0113** |

**Table 5.** Effects of K and Cl treatments on K, Cl, and S uptake into corn grain, stover, and grain and stover combined. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Pairwise comparisons are presented only for effects where $P \leq 0.10$.

| Treatment | Source | $K_2O$ rate (lbs/ac) | $Cl^-$ rate (lbs/ac) | Grain element uptake (lbs/ac) | | | Stover element uptake (lbs/ac) | | | Combined element uptake (lbs/ac) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | K | Cl | S | K | Cl | S | K | Cl | S |
| 1 | Check | 0 | 0 | 27 | 3.8 | 7.3 | 39 c | 6 c | 3.7 bcd | 66 c | 10 c | 11.0 |
| 2 | KCl | 50 | 40 | 27 | 4.0 | 7.1 | 52 b | 18 b | 3.7 bc | 79 b | 22 b | 10.9 |
| 3 | $K_2SO_4$ | 50 | 0 | 26 | 4.0 | 7.4 | 47 bc | 10 c | 3.7 cd | 73 bc | 14 c | 11.0 |
| 4 | KCl | 100 | 79 | 28 | 4.8 | 7.4 | 62 a | 28 a | 4.1 abc | 90 a | 33 a | 11.5 |
| 5 | $K_2SO_4$ | 100 | 0 | 25 | 4.6 | 6.8 | 53 ab | 7 c | 4.3 ab | 78 b | 12 c | 11.1 |
| 6 | KCl | 150 | 119 | 27 | 3.9 | 7.4 | 54 ab | 26 a | 3.8 bc | 80 ab | 30 a | 11.2 |
| 7 | $K_2SO_4$ | 150 | 0 | 28 | 3.8 | 7.3 | 52 b | 7 c | 4.5 a | 79 b | 10 c | 11.8 |
| 8 | Manure | 150 | 68 | 27 | 3.5 | 6.4 | 49 bc | 23 ab | 3.1 d | 75 bc | 26 ab | 9.5 |
| 9 | $CaCl_2$ | 0 | 75 | 26 | 4.1 | 6.7 | 45 bc | 25 a | 4.0 abc | 71 bc | 29 a | 10.7 |
| | | | Treatment effect (P-value) | 0.9120 | 0.7222 | 0.5375 | **0.0321** | **<0.0001** | **0.0401** | **0.0293** | **<0.0001** | 0.3274 |
| Contrasts | | | Effect of K (1 vs. 2-7) | 0.7649 | 0.4555 | 0.8945 | **0.0030** | **0.0027** | 0.2951 | **0.0053** | **0.0035** | 0.6893 |
| | | | KCl rate, linear (1, 2, 4, 6) | 0.9388 | 0.5394 | 0.7677 | **0.0061** | **<0.0001** | 0.6263 | **0.0084** | **<0.0001** | 0.6734 |
| | | | KCl rate, quadratic (1, 2, 4, 6) | 0.7129 | 0.2624 | 0.8321 | **0.0094** | **0.0157** | 0.4848 | **0.0085** | **0.0149** | 0.8545 |
| | | | $K_2SO_4$ rate, linear (1, 3, 5, 7) | 0.9369 | 0.7780 | 0.8045 | **0.0204** | 0.8905 | **0.0179** | **0.0265** | 0.9368 | 0.3301 |
| | | | $K_2SO_4$ rate, quadratic (1, 3, 5, 7) | 0.1911 | 0.3078 | 0.5453 | 0.2437 | 0.4440 | 0.6636 | 0.5207 | 0.3742 | 0.5466 |
| | | | KCl v $K_2SO_4$ (2, 4, 6 v 1, 3, 7) | 0.3296 | 0.7008 | 0.6500 | ***0.0997*** | **<0.0001** | 0.1732 | ***0.0534*** | **<0.0001** | 0.7362 |

**Table 6.** Effects of K and Cl treatments on soil water $Cl^-$, end-of-season soil K to a depth of 6 inches, and end-of-season soil $Cl^-$ to a depth of 2 feet. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Pairwise comparisons are presented only for effects where $P \leq 0.10$.

| Treatment | Source | $K_2O$ rate (lbs/ac) | $Cl^-$ rate (lbs/ac) | Soil water $Cl^-$ (ppm) | End of season soil: K 0-6" (ppm) | End of season soil: $Cl^-$ 0-2' (lbs/ac) |
|---|---|---|---|---|---|---|
| 1 | Check | 0 | 0 | 7 | 111 b | 47 d |
| 2 | KCl | 50 | 40 | 15 | . | 61 cd |
| 3 | $K_2SO_4$ | 50 | 0 | . | . | 51 d |
| 4 | KCl | 100 | 79 | 16 | . | 81 ab |
| 5 | $K_2SO_4$ | 100 | 0 | 17 | . | 54 d |
| 6 | KCl | 150 | 119 | . | 134 a | 80 ab |
| 7 | $K_2SO_4$ | 150 | 0 | . | . | 54 d |
| 8 | Manure | 150 | 68 | 10 | 139 a | 73 bc |
| 9 | $CaCl_2$ | 0 | 75 | 5 | 115 b | 94 a |
| | | | Treatment effect (P-value) | 0.3477 | **0.0162** | **0.0004** |
| Contrasts | | | Effect of K (1 vs. 2-7) | . | . | ***0.0551*** |
| | | | KCl rate, linear (1, 2, 4, 6) | . | . | **0.0012** |
| | | | KCl rate, quadratic (1, 2, 4, 6) | . | . | 0.3350 |
| | | | $K_2SO_4$ rate, linear (1, 3, 5, 7) | . | . | 0.5308 |
| | | | $K_2SO_4$ rate, quadratic (1, 3, 5, 7) | . | . | 0.7905 |
| | | | KCl v $K_2SO_4$ (2, 4, 6 v 1, 3, 7) | . | . | **0.0006** |