Potassium management effects on chloride cycling and potato yield and quality

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Summary

Potato production requires large amounts of potassium (K), without which low yield, poor bulking, and other issues may arise. Due to a recent, prolonged peak in K prices, there is strong interest in whether banded K application could reduce K fertilizer requirements in potato crops. Alternatively, K use efficiency might be improved by using split applications of K, reducing losses of K to fixation and leaching before the crop is done taking it up. There are also concerns that fertilization with potassium chloride (KCl), which is affordable and therefore widely used, may result in reduced tuber specific gravity, and whether this effect is due to excessive chloride (Cl) application. The objectives of this study were to (1) evaluate the effects of K rate on tuber yield and quality, (2) determine whether banded K application decreases potato crop K requirements, (3) evaluate the effectiveness of split K application in improving K use efficiency, (4) determine whether using K_2SO_4 in place of KCl improves tuber specific gravity, and (5) evaluate the effects of Cl application on potato crop performance and Cl leaching concentrations. Among broadcast KCl treatments, the highest total yield and specific gravity were observed at 80 lbs/ac K_2O, while the highest yields of U.S. No. 1 and total marketable potatoes were seen at 160 lbs/ac K_2O. Total and marketable yields tended to decrease as broadcast rates increased above 160 lbs/ac as K_2O. Banded application of K increased the yield of U.S. No. 2 tubers, but decreased tuber specific gravity. Split application of KCl produced significantly higher total, marketable, and U.S. No. 1 yields than a single broadcast application at the same total rate (240 lbs/ac K_2O). Using potassium sulfate (K_2SO_4) in place of KCl did not improve tuber specific gravity, nor did a treatment receiving calcium chloride without K have lower tuber specific gravity than the check treatment, suggesting that Cl^- did not reduce specific gravity in this study. At equivalent K_2O rates (160 or 240 lbs/ac), yields with K_2SO_4 were higher than KCl. Banded application of KCl increased the concentration of Cl^- in soil water sampled at the 4 ft depth compared to broadcast applications of KCl or K_2SO_4 at the same K rate. It is possible that banded applications would have produced better yield and less Cl^- leaching if applied at lower rates than broadcast applications. The negative effect of high KCl rates was likely due to lack of rainfall/leaching with low Cl^- concentrations during the growing season coupled with high concentrations of Cl^- in irrigation water, which supplied more than 150 lbs/ac Cl^- over the growing season.

Background

Potassium (K) is required in large quantities in potato agriculture. Low K in potato production results in low yield, poor tuber bulking, and black spot bruising. Deficiency symptoms include scorching of the leaves and, in severe cases, early vine dieback resembling *Verticillium* wilt. Irrigated potatoes are generally grown on sandy soils with low to medium K, so K fertilizer is usually applied to this crop, with the amount determined largely by yield goals. Current practice is to broadcast apply K to potato fields in the fall or spring before planting. An approach to improving K use efficiency may be to apply K in split applications, which may provide more available K during tuber bulking and maturation, reducing the amount of K lost to fixation and leaching.

Potassium prices increased dramatically in 2021 and remained high for over a year before decreasing in 2023. This price increase has stirred interest in banded K application as a possible way to decrease required K application rates in potato crops. Potassium chloride (KCl, also called muriate of potash or MOP: 0-0-60) is the most economical and commonly used K fertilizer in agriculture, which means that chloride (Cl) is co-applied with K. As an essential plant nutrient, Cl has been shown to improve disease resistance in some plants. However, fertilizing with KCl can reduce tuber specific gravity, possibly because of the high application rate of Cl, and using K_2SO_4 (0-0-50) instead of KCl may therefore mitigate these symptoms.

Because Cl is highly leachable and can be environmentally detrimental in large quantities, there is also interest in understanding the fate of Cl in the soil following KCl application. Suction lysimeters at a depth of four feet were used to collect soil water samples from two weeks after planting until six weeks after harvest. These were analyzed for Cl concentration as a measure of how much Cl was leached from the soil throughout the season.

The overall objectives for the potato study were to (1) evaluate the effects of K rate on potato tuber yield and quality, (2) determine whether banded K application decreases potato crop K requirements, (3) evaluate the effectiveness of split K application in improving K use efficiency, (4) determine whether using K_2SO_4 in place of KCl improves tuber specific gravity, and (5) evaluate the effects of Cl application on potato crop performance and Cl leaching concentrations.

Methods

The study was conducted at the University of Minnesota's Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil, in 2023 following a previous crop of soybeans. Initial soil characteristics from samples taken in April 2023 are presented in Table 1. Rainfall and irrigation rates during the season are presented in Figure 1.

Eleven treatments were applied to Russet Burbank potatoes in a randomized complete block design with four replicates. These treatments are summarized in Table 2. Each experimental plot was four rows (12 feet) wide and 20 feet long. Eighteen feet of the central two rows were used for the end-of-season vine and tuber harvest samples, and the ends of these rows were demarcated with one red potato at each end. The field was three plots wide and 16 plots long (four plots duplicated the check treatment and were not included in the analyses). A 3-foot buffer was planted on all sides of the field to reduce edge effects.

Broadcast applications of KCl in treatments 2-5 and 8, K_2SO_4 in treatments 9 and 10, and $CaCl_2$ in treatment 11 were applied by hand according to treatment and worked in with a field cultivator on May 3. On May 4, rows were opened mechanically with 36-inch spacing and a mixture of whole "B" and cut "A" seed potatoes were planted by hand with 12-inch spacing within rows. Belay was applied in-furrow at planting for beetle control, along with the systemic fungicide Quadris. KCl was banded at planting into the rows in treatments 6 and 7 approximately 2 inches below and 3 inches to either side of the seed potatoes. At the same time, a planting fertilizer blend was banded in all treatments, supplying 40 lbs/ac N, 100 lbs/ac P_2O_5, 0.5 lbs/ac S, 1 lb/ac Zn, and 0.5 lbs/ac B in the form of 1.9 lbs/ac urea (46-0-0), 217 lbs/ac DAP (18-46-0), 2.8 lbs/ac $ZnSO_4$ (17.5% S, 35.5% Zn), and 3 lbs/ac Boron 15 (15% B). Weeds, diseases, and insects were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling.

Just before hilling on May 22, the rows in treatment 8 were side dressed with KCl at 120 lbs/ac K_2O. All treatments except for treatments 9 and 10 were side dressed with ammonium sulfate (21-0-0-24S) to provide 54.4 lbs/ac S and 47.6 lbs/ac N. Treatments 9 and 10 were side dressed with 47.6 lbs/ac N as 103 lbs/ac urea (46-0-0).

Lysimeters were installed in all plots from treatments 1, 4, 7, 10, and 11 on May 16 to sample soil water at a depth of 4 feet. Soil water samples were collected on May 19, 24, and 30, June 7, 14, 22, and 26, July 3, 10, 17, and 24, August 22 and 29, September 5, 12, 19, and 26, October 16, 20, and 23, and November 15. In addition, irrigation water and rainwater were periodically sampled during the season and analyzed for chloride. The chloride concentration of lysimeter water, irrigation and rainwater samples were determined using a chloride ion-selective electrode (ISE).

Plant stand in the two harvest-sample rows was assessed on May 31 and June 7. On June 8, the number of stems per plant was determined from a 10-plant sample in one of the harvest-sample rows. On June 14-15 and 27 and July 10, petiole samples and leaflet chlorophyll readings were taken in all plots. Foliar chlorophyll was measured using a SPAD-502 Chlorophyll Meter (Konica Minolta) on the terminal leaflet of the fourth mature leaf from the shoot tip for 20 shoots per plot. Petioles were then collected from the fourth mature leaf from the shoot tip for 20 shoots per plot. The petiole samples were dried at 140°F to constant weight, ground, and sent to Agvise (Benton, MN) to be analyzed for K, Cl, S, and NO_3^--N concentrations. Canopy cover was assessed in each plot using the Canopeo app on June 12, 21, and 26, July 3, 12, 17, and 24, August 1, 8, 14, 21, and 28, and September 7 and 11.

Vines were sampled from 10 feet of the two harvest rows on September 21. The full samples were weighed, then subsamples were collected, weighed, dried at 140°F to constant weight, and weighed again to determine dry matter content. Tubers were harvested on October 2 and sorted by size and grade on October 9. Weights and counts were determined for each size and grade category. Culls were not sorted by size. Total yield was calculated as the sum of yield in all categories, including culls. Marketable yield was the sum of yield in all size categories over 4 oz., excluding culls. The percentage of yield over 6 and 10 ounces were calculated as the sum of all tubers over the threshold size divided by the sum of all tubers in all size categories, excluding culls from both sums. A subsample of 25 tubers was taken from each plot's tuber sample and used to assess the prevalence of hollow heart, brown center, and common scab, as well as tuber specific gravity and dry matter content. Total Cl was determined in subsamples of vines and tubers that were dried at 140 F and then ground using the Cl titration method.

On October 18, soil samples to a depth of 6 inches were collected from each plot. These were dried at 95°F to a constant weight and sent to the University of Minnesota's Research Analytical Laboratory (St. Paul, MN) to be analyzed for chloride content with a Lachat QuikChem 8500 Flow Injection Analyzer. In addition, samples from treatments 1, 4, and 11 were analyzed by the same laboratory for ammonium acetate extractable K.

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.

For all data except lysimeter data and the end-of-season soil K data, five contrast statements were applied to compare (1) the check treatment (treatment 1) versus the treatments receiving broadcast KCl (treatments 2-5), (2) the linear and (3) the quadratic response to KCl rate (among treatments 1-5), (4) broadcast versus banded KCl application (treatments 3 and 4 versus 6 and 7), and (5) broadcast KCl versus broadcast K_2SO_4 (treatments 3 and 4 versus 9 and 10). No contrasts were evaluated for end-of-season soil K concentration, which was only measured in 3 treatments.

Because there were numerous gaps in the lysimeter data, soil water chloride readings were analyzed as average values across four time spans: May 19 – June 14 (vegetative growth to tuber initiation), June 22 – July 24 (initiation to bulking), August 22 – September 26 (bulking to harvest), and October 16 – November 15 (post-harvest), as well as across the full season (May 19 – November 15).

Results

Tuber yield, size, and grade

Results for tuber yield, grade, and size are presented in Table 3. Total and marketable tuber yield and U.S. No. 1 tuber yield were higher in treatments receiving broadcast KCl (treatments 2-5) than in the check treatment (treatment 1). However, among the treatments receiving broadcast KCl, all three yield metrics decreased with increasing application rate, so that the overall relationship between the application rate of broadcast KCl and yield followed a negative quadratic curve. The highest total, marketable, and U.S. No. 1 yields among these treatments were achieved at 160 lbs/ac K_2O. The treatments receiving broadcast K_2SO_4 (treatments 9 and 10), as a group, had non-significantly higher total, marketable, and U.S. No. 1 yields than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4), and the treatment with the highest marketable yield was the treatment receiving K_2SO_4 at 160 lbs/ac K_2O. The treatments receiving banded KCl (treatments 6 and 7) had lower total, U.S. No. 1, and marketable yields than those receiving broadcast KCl (treatments 3 and 4) or K_2SO_4 (treatments 9 and 10) at the same rates, but the difference was only significant for total and U.S. No. 1 yields versus broadcast K_2SO_4 at 240 lbs/ac K_2O.

The yield of U.S. No. 2 tubers was higher in the treatments receiving KCl in a banded application (treatments 6 and 7) than in the treatments receiving broadcast KCl at the same rates (treatments 3 and 4). The treatments receiving broadcast K_2SO_4 (treatments 9 and 10) had marginally significantly higher U.S. No. 2 yield than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4). In both contrasts, the differences were driven by the low yield of U.S. No. 2 tubers in the treatment receiving broadcast KCl at 160 lbs/ac K_2O.

The linear and quadratic contrasts of the percentage of yield represented by tubers over six ounces and ten ounces on the application rate of broadcast KCl (treatments 1-5) were significant. Both percentages increased with K rate between 0 and 160 lbs/ac K_2O, but not between 160 and 300 lbs/ac K_2O. The number of tubers per plant was not related to treatment, indicating that differences in yield among treatments were primarily due to differences in tuber bulking rather than initiation or retention.

The treatments receiving banded KCl were expected to perform similarly to treatments receiving broadcast KCl at higher rates due to improved K use efficiency. The treatment receiving 160 lbs/ac K_2O as banded KCl did perform as if it had received broadcast KCl at a higher rate, since yield tended to decrease with K rate, and this treatment had lower yield than the treatment receiving broadcast KCl at the same rate. However, at 240 lbs/ac K_2O, the banded application treatment produced numerically higher U.S. No. 1 and marketable yield than the broadcast application treatment. Thus, the banded application treatments did not simply yield as though they had received broadcast KCl at a higher rate.

Tuber quality

Results for tuber quality are presented in Table 4. The prevalences of hollow heart, brown center, and common scab were low and unrelated to treatment. Tuber specific gravity was higher among the treatments receiving broadcast KCl (treatments 2-5), as a group, than in the check treatment (treatment 1). However, among the treatments receiving broadcast KCl, tuber specific gravity decreased as the application rate of KCl increased, especially between 240 and 300 lbs/ac K_2O, resulting in a significant quadratic contrast of specific gravity on KCl rate. The treatments receiving banded KCl (treatments 6 and 7), as a group, had lower tuber specific gravity than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4). Although the treatment receiving 160 lbs/ac K_2O as K_2SO_4 (treatment 9) had the highest tuber specific gravity, there was no net effect of applying K_2SO_4 (treatments 9 and 10) in place of KCl (treatments 3 and 4). Tuber dry matter content was significantly related to treatment, but the effect of treatment did not correspond to KCl rate, the use of broadcast versus banded application of KCl, or the use of K_2SO_4 in place of KCl. The treatment receiving split applications of KCl (treatment 8) had significantly lower dry matter content than the treatment receiving the same rate of KCl in a single broadcast application (treatment 4). The treatment receiving $CaCl_2$ (treatment 11) did not differ significantly from the check treatment (treatment 1) in terms of tuber quality.

Plant stand and stems per plant

Results for plant stand and the number of stems per plant are presented in Table 5. Plant stand on May 31 was higher in treatments that received KCl (treatments 2-5) than it was in the check treatment (treatment 1). Based on pairwise comparisons, so long as the K_2O rate was greater than zero, it did not affect plant stand. Treatments receiving banded KCl (treatments 6 and 7), as a group, had marginally significantly lower stand on May 31 and significantly lower stand on June 7 than treatments receiving broadcast KCl at the same rates (treatments 3 and 4).

The number of stems per plant on June 8 was marginally significantly related to treatment, but it was not related to any of the contrasts, and there was no clear pattern in how differences in the number of stems per plant related to differences among treatments.

Leaflet chlorophyll content

Results for leaflet chlorophyll content as measured by a SPAD meter are presented in Table 6. On June 15, aside from a marginally significant tendency for treatments receiving banded KCl (treatments 6 and 7) to have lower leaflet chlorophyll content than treatments receiving broadcast KCl at the same rates (treatments 3 and 4), leaflet chlorophyll was unrelated to treatment. On June 27, there was a negative relationship between the application rate of KCl and leaflet chlorophyll content among the treatments receiving broadcast KCl and the check treatment (treatments 1-5). On July 10, leaflet chlorophyll content was highest in the check treatment (treatment 1), as reflected in a significant linear contrast on KCl rate (among treatments 1-5) and a significant contrast between the check treatment (treatment 1) and the treatments receiving broadcast KCl (treatments 2-5). The treatment receiving $CaCl_2$ without K (treatment 11) had the highest leaflet chlorophyll content on June 27 and the second highest (behind the check treatment, treatment 1) on July 10. Overall, leaflet chlorophyll content decreased over time, and it tended to decrease more the more K_2O a treatment received. K source (KCl vs K2SO4) had no effect on SPAD readings.

Canopy cover

Results for canopy cover are presented in Table 7. On June 12, treatments receiving K_2SO_4 (treatments 9 and 10), as a group, had marginally significantly higher canopy cover than treatments receiving KCl at the same rates (treatments 3 and 4) on that date. Among the treatments receiving broadcast KCl and the check treatment (treatments 1-5), canopy cover significantly or marginally significantly increased with K_2O rate on June 12, July 12, August 8, and September 7 and 11. Among the same treatments, the treatments receiving KCl (treatments 2-5), as a group, had significantly or marginally significantly higher canopy cover than the check treatment on August 8 and 28 and September 7. These findings suggest that K_2O rate, at least as broadcast KCl, has some potential to affect a potato crop's photosynthetic capacity, although this may be tempered by the tendency for leaflet chlorophyll content per unit area to decrease with increasing KCl rate.

The treatment receiving split applications of KCl (treatment 8) had higher canopy cover than the treatments receiving single applications of KCl at the same total rate (treatments 4 and 7) on June 12. The same was true on June 26, though the difference between the split-application treatment and the treatment receiving a single broadcast application (treatment 4) was not significant on that date.

Petiole nutrient concentrations

Results for petiole nutrient concentrations are presented in Table 8. Petiole K concentration showed a consistent positive linear relationship to the application rate of broadcast KCl (among treatments 1-5). On June 14, treatments receiving broadcast K_2SO_4 (treatments 9 and 10), as a group, had marginally significantly lower petiole K concentrations than those receiving broadcast KCl at the same rates (treatments 3 and 4). On July 10, treatments receiving banded KCl (treatments 6 and 7), as a group, had higher petiole K concentrations than those receiving broadcast KCl at the same rates (treatments 3 and 4). The treatment receiving $CaCl_2$ without K (treatment 11) had a higher petiole K concentration than the check treatment on June 14, but this difference had disappeared by July 10. The treatment receiving split applications of KCl (treatment 8) had numerically lower petiole K concentrations than those receiving single applications of KCl, either broadcast (treatment 4) or banded (treatment 7), and the difference with the banded application treatment was significant on June 14 and July 10.

Like K concentration, petiole Cl concentrations consistently increased linearly with the application rate of broadcast KCl (among treatments 1-5). Treatments receiving broadcast K_2SO_4 (treatments 9 and 10), as a group, had significantly lower petiole Cl concentrations than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4) on all three sampling dates. The treatments receiving banded KCl (treatments 6 and 7) had marginally lower Cl concentrations on June 27, but significantly higher Cl concentrations on July 10, than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4). The treatment receiving $CaCl_2$ (treatment 11) had a consistently higher petiole Cl concentration than the check treatment (treatment 1). The treatment receiving split applications of KCl (treatment 8) had significantly lower petiole Cl concentrations than the treatment receiving banded KCl at the same total rate (treatment 7) on June 14 and July 10, while this difference was not significant on June 27. The split-application treatment had lower petiole Cl concentrations than the treatment receiving broadcast KCl at the same total rate (treatment 4) on all three dates.

Petiole S concentration decreased linearly with the application rate of KCl (among treatments 1-5) on June 14 and July 10. The treatments receiving banded KCl (treatments 6 and 7), as a group, had a lower petiole S concentration than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4) on July 10.

Petiole NO_3^--N concentration showed a negative relationship to the application rate of K_2O among the treatments receiving broadcast KCl and the check treatment (treatments 1-5) on June 14 and July 10. On July 10, the treatments receiving broadcast K_2SO_4 (treatments 9 and 10) had a higher petiole NO_3^--N concentration, as a group, than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4).

Vine biomass at vine kill

Results for vine biomass at vine kill are presented in Table 9. Vine fresh and dry biomass per acre was higher among treatments receiving broadcast KCl (treatments 2-5), as a group, than it was in the check treatment (treatment 1). Vine dry matter content showed a marginally significant negative relationship with the application rate of broadcast KCl (among treatments 1-5), indicating that the increase in fresh biomass with KCl rate was disproportionately due to differences in vine water content rather than vine dry biomass. Based on this result and the positive relationship between canopy cover and KCl rate in the last two canopy evaluation dates, it appears that treatments receiving more KCl tended to die back more slowly at the end of the season. This is consistent with the symptoms of K deficiency, which can resemble potato early dying from *Verticillium* wilt.

Tuber and vine element concentrations

Results for tuber and vine K, Cl, S, and Ca concentrations are presented in Table 10. Both tuber and vine K concentrations increased with the application rate of broadcast KCl (among treatments 1-5). Treatments receiving banded KCl (treatments 6 and 7), split-applied KCl (treatment 8), or broadcast K_2SO_4 (treatments 9 and 10) did not have significantly different tuber or vine K concentrations than those receiving broadcast KCl at the same rates (treatments 3 and 4). The lowest K concentrations were observed in the check treatment (treatment 1) and the treatment receiving broadcast $CaCl_2$ (treatment 11).

Like K, tuber and vine Cl concentrations increased with the application rate of broadcast KCl (among treatments 1-5). Additionally, tuber Cl concentrations were higher in the treatments receiving banded KCl (treatments 6 and 7) than those receiving broadcast KCl at the same rates (treatments 3 and 4). Both tuber and vine Cl concentrations were lower in the treatments receiving broadcast K_2SO_4 (treatments 9 and 10) than those receiving broadcast KCl at the same rates (treatments 3 and 4). The treatment receiving split applications of KCl (treatment 8) had a similar tuber Cl concentration, but a significantly lower vine Cl concentration, than the treatment receiving a single broadcast application of KCl at the same rate (treatment 4). The check treatment (treatment 1) had lower tuber and vine Cl concentrations than the treatment receiving broadcast $CaCl_2$ (treatment 11).

Tuber S concentration was not related to treatment. Vine S concentration decreased as the application rate of KCl increased (among treatments 1-5). Since the application rate of S among these treatments was constant, this suggests that KCl either promoted vine growth, producing a dilution effect on S concentration, or interfered with S uptake in some way. Since vine dry yield was not positively related to KCl rate (even tending to decline with increasing rate among treatments 2-5), a dilution effect does not explain the effect of KCl rate on vine S concentration.

It is therefore likely that KCl interfered with S uptake. The treatments receiving broadcast K_2SO_4 (treatments 9 and 10) had significantly higher vine S concentrations than those receiving KCl at the same rates (treatments 3 and 4). This is consistent with Cl^- interfering with SO_4^{2-}-S uptake, but also with the K_2SO_4 treatments simply having received a higher application rate of S. The treatment receiving split applications of KCl (treatment 8) and the treatments receiving banded applications of KCl (treatments 6 and 7) had similar vine S concentrations to treatments receiving broadcast KCl at the same rates (treatments 3 and 4). The check treatment (treatment 1) and the treatment receiving broadcast $CaCl_2$ (treatment 11) did not have significantly different vine S concentrations.

Tuber Ca concentration showed a quadratic relationship to the application rate of KCl (among treatments 1-5), being higher at rates of 0 and 300 lbs/ac K_2O than intermediate rates. Tuber Ca concentration was higher in the treatments receiving broadcast K_2SO_4 (treatments 9 and 10) than in the treatments receiving broadcast KCl at the same rates (treatments 3 and 4). The treatment receiving split applications of KCl (treatment 8) had the highest tuber Ca concentration in the study, significantly higher than the treatments receiving a single application of KCl (treatments 3, 4, 6, and 7). It is not clear why applying K_2SO_4 resulted in a higher tuber Ca concentration than applying KCl, nor why split applications of KCl produced a higher tuber Ca concentration than a single application. The check treatment (treatment 1) and the treatment receiving broadcast $CaCl_2$ (treatment 11) did not have significantly different tuber Ca concentrations. Vine Ca concentration was not related to treatment.

Tuber and vine element uptake

Results for tuber and vine element uptake are presented in Table 11. Tuber, vine, and combined K uptake were positively related to the application rate of KCl (among treatments 1-5). The treatments receiving broadcast KCl (treatments 2-4), as a group, had higher tuber, vine, and combined K uptake than the check treatment (treatment 1). The relationship was only marginally significant for tuber uptake, which also showed a marginally significant quadratic effect of KCl rate, peaking at 240 lbs/ac K_2O.

Tuber, vine, and total Cl uptake increased with the application rate of KCl (among treatments 1-5). Tuber, vine, and combined Cl uptake were higher in treatments receiving KCl at 160 or 240 lbs/ac K_2O (treatments 3 and 4) than in treatments receiving K_2SO_4 at the same K rates (treatments 9 and 10). Tuber Cl uptake was also higher in treatments receiving KCl in a banded application (treatments 6 and 7) than those receiving a broadcast application at the same rates (treatments 3 and 4).

The effect of treatment on S uptake was marginally significant in tubers but not in vines. Tuber S uptake decreased as the application rate of broadcast KCl increased (among treatments 1-5), suggesting that Cl^- competes with S uptake. Consistent with this, tuber S uptake was marginally significantly higher in treatments receiving K_2SO_4 (treatments 9 and 10) than treatments receiving KCl at the same rates (treatments 3 and 4).

Tuber Ca uptake was marginally significantly related to treatment, but vine and combined Ca uptake were not. Tuber Ca uptake was higher in the treatments receiving broadcast K_2SO_4 (treatments 9 and 10) than in the treatments receiving broadcast KCl at the same rates (treatments 3 and 4). It did not differ significantly between the check treatment (treatment 1) and the treatment receiving $CaCl_2$ (treatment 11).

Soil water and irrigation water Cl^- concentrations

Results for soil water Cl^- concentrations are presented in Table 12. Concentration was unrelated to treatment in the first three sampling periods, covering May 19 through September 26. In the post-harvest period, soil water Cl^- concentration was marginally significantly related to treatment. The treatment receiving 240 lbs/ac K_2O as KCl banded at planting (treatment 7) had a significantly higher average soil water Cl^- concentration in this period than the check treatment (treatment 1) or the treatment receiving 240 lbs/ac K_2O as K_2SO_4 (treatment 11). Results were similar for the average soil water Cl- concentration across the entire growing season, except that the treatment receiving 240 lbs/ac K_2O as broadcast KCl (treatment 4) also had a significantly lower mean soil water Cl^- concentration than the treatment receiving banded application.

Irrigation water Cl^- concentrations averaged 40 ppm throughout the growing season. With 17.5 inches of irrigation water supplied to supplement 10.6 inches of rainfall (figure 1), a total of 150 lbs/ac Cl^- was applied with irrigation. Rainwater had less than 1 ppm Cl^-. The lack of rainfall coupled with high Cl^- in irrigation may have contributed to the negative effects of high KCl rates on yield.

End-of-season soil K and Cl concentrations

Results for end-of-season soil K and Cl concentrations are presented in Table 13. Soil K concentration in the top 6 inches was measured in the check treatment (treatment 1), the treatment receiving 240 lbs/ac K_20 as broadcast KCl (treatment 4), and the treatment receiving $CaCl_2$ (treatment 11). The treatment receiving broadcast KCl had a higher soil K concentration after harvest than either of the treatments not receiving K fertilizer.

Soil Cl concentration in the top 24 inches was measured in all treatments. Among the treatments receiving broadcast KCl and the check treatment (treatments 1-5), the soil Cl concentration increased with the application rate of KCl. A similar trend was evident between the two treatments receiving banded KCl (treatments 6 and 7). These two treatments, as a group, had a higher mean soil Cl concentration than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4). The difference was especially pronounced when KCl was applied at 240 lbs/ac K_2O. Applying K as K_2SO_4 instead of KCl (treatments 9 and 10 versus treatments 3 and 4) had no significant effect on end of season soil Cl concentration. Similarly, the treatment receiving $CaCl_2$ (treatment 11) did not have a higher soil Cl concentration than the check treatment (treatment 1).

Conclusions

Several lines of evidence under the conditions of this study suggest that the Cl^- component of KCl was detrimental to potato plants. Among treatments receiving broadcast KCl, total and marketable yields and tuber specific gravity generally decreased as the application rate of KCl increased. Using K_2SO_4 as the K source resulted in numerically higher yields than KCl when applied at 160 lbs/ac K_2O and significantly higher yields at 240 lbs/ac K_2O. Petiole S and NO_3^--N concentrations decreased as the application rate of broadcast KCl increased, and treatments receiving K_2SO_4 in place of KCl had higher petiole NO_3^--N concentrations in July than those receiving broadcast KCl at the same rates. Vine S concentrations at harvest also decreased with increasing KCl application rate. This suggests that Cl^- may compete with SO_4^{2-}-S and NO_3^--N for plant uptake, as has been found in previous studies.

Not all results of this study were consistent with the interpretation that the Cl^- component of KCl was harmful. For example, plant canopy cover in September increased with the application rate of broadcast KCl. Since early vine dieback is a symptom of K deficiency, this may suggest that most of the treatments were somewhat K deficient, and the effect of KCl rate on yield may reflect delayed tuber maturation rather than Cl^- excess.

Applying Cl^- to potato crops is also a concern because excess Cl^- can be harmful to surface waters, which are fed in part by groundwater. The chloride concentration of soil water at a depth of four feet was significantly higher in the treatment receiving banded KCl at 240 lbs/ac K_2O than the treatments receiving broadcast KCl or K_2SO_4 at the same rates, indicating that banded application of KCl may increase leaching of Cl^-. However, the banded application is expected to reduce K fertilizer requirements, and it is possible that applying the optimum rate of KCl for banded application would result in similar Cl^- loss to applying the optimum rate for broadcast application. To the degree that excess Cl^- had a negative impact on the potato crop, this was likely due in part to a combination of high Cl^- concentrations in the irrigation water, which supplied more than 150 lbs/ac Cl^- over the growing season, and a lack of low-Cl^- rainfall, which limited leaching of Cl^- from the soil.

Table 1. Initial soil characteristics in the study field at the Sand Plain Research Farm in Becker, MN, in 2023.

0 - 6 inches												0 - 2 feet
pH	Organic matter (%)	Bray P (mg/kg)	NH_4OAc-K (mg/kg)	NH_4OAc-Ca (mg/kg)	NH_4OAc-Mg (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Fe (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)	Hot water B (mg/kg)	SO_4^{2-}-S (mg/kg)	NO_3^--N (mg/kg)
6.8	1.2	56	92	652	119	6	11	1.2	0.6	0.2	9	1.4

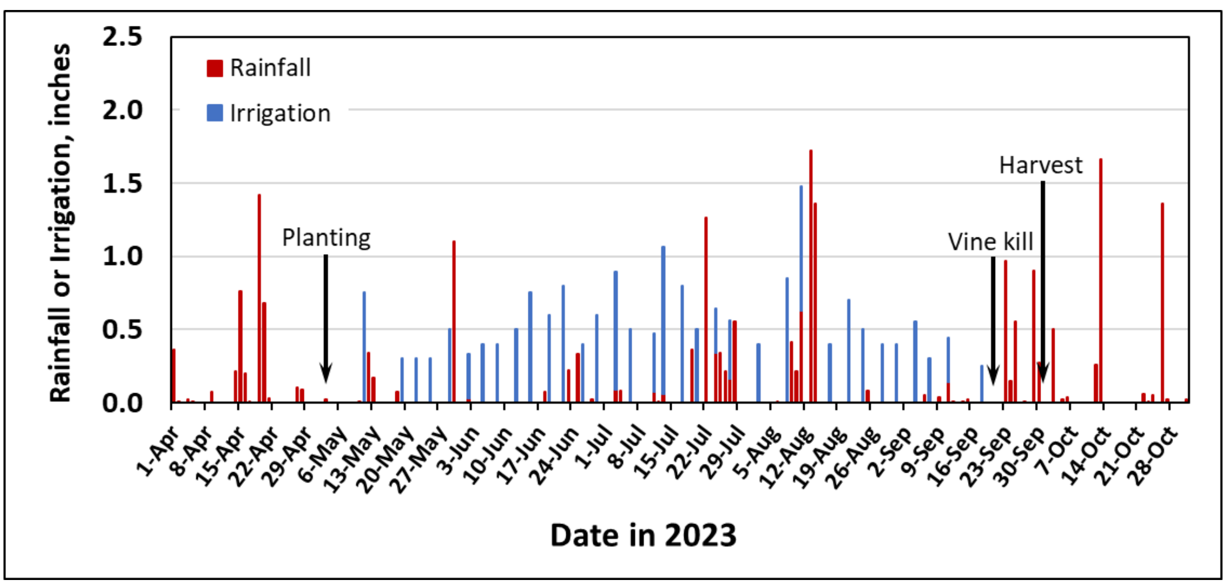

Figure 1. Rainfall and irrigation on each day from April 1 through October 31, 2023. The field received 21.4 inches of rain and 17.5 inches of irrigation during this period, with 10.6 inches of rain between planting (May 4) and vine kill (September 21).

Table 2. K treatments applied to Russet Burbank potatoes. S was applied as ammonium sulfate to the treatments that did not receive K_2SO_4.

Treatment #	Product applied	Method of application	K_2O rate (lbs/ac)	Cl rate (lbs/ac)	S rate (lbs/ac)	S as $(NH_4)_2SO_4$ at emergence (lbs/ac)
1	None	NA	0	0	0	54
2	KCl	Broadcast preplant	80	60	0	54
3	KCl	Broadcast preplant	160	120	0	54
4	KCl	Broadcast preplant	240	180	0	54
5	KCl	Broadcast preplant	320	240	0	54
6	KCl	Banded at planting	160	120	0	54
7	KCl	Banded at planting	240	180	0	54
8	KCl	Half broadcast preplant, half sidedressed at hilling	240	180	0	54
9	K_2SO_4	Broadcast preplant	160	0	54	0
10	K_2SO_4	Broadcast preplant	240	0	82	0
11	$CaCl_2$	Broadcast preplant	0	180	0	54

Table 3. Effects of K and Cl treatment on tuber yield, grade, size, and grade. 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	Application and source	K_2O rate (lbs/ac)	Cl^- rate (lbs/ac)	Yield (cwt/ac)										% yield in tubers over:	
				Culled	0-4 oz.	4-6 oz.	6-10 oz.	10-14 oz.	Over 14 oz.	Total	U.S. No. 1	U.S. No. 2	Marketable	6 oz.	10 oz.
1	No product	0	0	3	101	135	175 bcd	59	28	499 e	378 d	21	398 e	51	17
2	Broadcast, KCl	80	63	5	97	125	208 a	93	60	583 ab	458 ab	27	486 abc	62	26
3		160	126	6	76	115	196 abc	117	67	571 abc	486 a	8	495 abc	66	32
4		240	190	5	93	113	177 bcd	95	66	544 bcd	432 bc	18	450 cd	61	29
5		320	253	7	83	95	164 d	98	87	528 cde	419 bcd	25	445 cde	65	34
6	Banded, KCl	160	126	7	81	94	172 cd	118	93	559 abcd	455 ab	22	477 abc	68	36
7		240	190	6	74	101	171 cd	101	88	535 cde	435 bc	26	461 bcd	67	35
8	Broadcast+side, KCl	240	190	4	82	110	202 ab	128	69	591 a	494 a	16	509 ab	67	33
9	Broadcast, K_2SO_4	160	0	5	79	101	215 a	114	88	597 a	496 a	22	518 a	70	34
10		240	0	4	86	110	202 ab	125	74	598 a	490 a	21	512 ab	67	32
11	Broadcast, $CaCl_2$	0	180	2	96	110	157 d	97	62	522 de	396 cd	30	426 de	59	29
	Treatment effect (P-value)			0.4252	0.8257	0.3292	**0.0248**	0.1879	0.1767	**0.0035**	**0.0007**	0.2219	**0.0061**	0.1293	0.1914
Contrasts	Effect of KCl (1 vs. 2-5)			0.1201	0.3313	*0.0770*	0.4359	**0.0269**	**0.0183**	**0.0079**	**0.0025**	0.8733	**0.0058**	**0.0112**	**0.0124**
	KCl rate, linear (1-5)			0.1053	0.3139	**0.0146**	0.1824	0.1246	**0.0129**	0.7479	0.3520	0.9940	0.3967	**0.0434**	**0.0149**
	KCl rate, quadratic (1-5)			0.6612	0.5792	0.8629	**0.0437**	*0.0827*	0.6231	**0.0034**	**0.0008**	0.1237	**0.0053**	0.1586	0.3336
	Broadcast v banded (3&4 v 6&7)			0.5326	0.5692	0.1515	0.2447	0.8100	0.1158	0.5672	0.4640	**0.0388**	0.8738	0.3724	0.2246
	KCl v K_2SO_4 (3&4 v 9&10)			0.3263	0.8807	0.4753	*0.0863*	0.3872	0.3409	**0.0326**	*0.0944*	*0.0987*	*0.0568*	0.2652	0.5038

Table 4. Effects of K and Cl treatment on tuber quality. 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	Application and source	K_2O rate (lbs/ac)	Cl^- rate (lbs/ac)	Tuber defects (% of tubers) Disqualifying hollow heart	Disqualifying brown center	Common scab	Specific gravity	Dry matter content (%)
1	No product	0	0	5	3	1	1.0798 bc	20.4 ab
2	Broadcast, KCl	80	63	2	2	0	1.0820 ab	20.0 ab
3		160	126	1	1	1	1.0812 abc	21.1 a
4		240	190	3	3	3	1.0806 abc	20.0 ab
5		320	253	2	2	1	1.0771 d	19.5 bc
6	Banded, KCl	160	126	3	2	2	1.0794 c	20.1 ab
7		240	190	4	3	1	1.0745 e	19.6 bc
8	Broadcast+side, KCl	240	190	4	3	0	1.0791 dc	18.5 c
9	Broadcast, K_2SO_4	160	0	1	1	1	1.0823 a	20.5 ab
10		240	0	0	0	1	1.0796 c	21.1 a
11	Broadcast, $CaCl_2$	0	180	1	1	0	1.0796 c	19.5 bc
			Treatment effect (P-value)	0.6335	0.8462	0.6422	**<0.0001**	**0.0303**
Contrasts			Effect of KCl (1 vs. 2-5)	0.1371	0.5331	0.8261	0.6966	0.6670
			KCl rate, linear (1-5)	0.3752	0.8251	0.3546	**0.0249**	0.2371
			KCl rate, quadratic (1-5)	0.2953	0.5761	0.7929	**0.0040**	0.1830
			Broadcast v banded (3&4 v 6&7)	0.3999	0.7269	0.6238	**0.0003**	0.1708
			KCl v K_2SO_4 (3&4 v 9&10)	0.3999	0.2987	0.3296	0.9130	0.5468

Table 5. Effect of K and Cl treatment on plant stand and the number of stems per plant. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Comparisons are presented only for effects where $P \leq 0.10$.

Treatment	Application and source	K_2O rate (lbs/ac)	Cl^- rate (lbs/ac)	% plant stand May 31	June 7	Stems / plant June 8
1	No product	0	0	94 c	99	3.5 abc
2	Broadcast, KCl	80	63	99 ab	100	3.3 bcd
3		160	126	100 a	100	4.1 a
4		240	190	100 a	100	2.9 d
5		320	253	98 ab	100	3.2 bcd
6	Banded, KCl	160	126	98 ab	99	3.7 ab
7		240	190	98 ab	96	3.2 bcd
8	Broadcast+side, KCl	240	190	100 a	100	3.3 bcd
9	Broadcast, K_2SO_4	160	0	99 ab	100	3.5 abc
10		240	0	97 b	99	3.1 cd
11	Broadcast, $CaCl_2$	0	180	98 ab	99	3.2 bcd
			Treatment effect (P-value)	**0.0378**	0.1894	***0.0874***
Contrasts			Effect of KCl (1 vs. 2-5)	**0.0004**	0.2372	0.8649
			KCl rate, linear (1-5)	**0.0341**	0.4005	0.1601
			KCl rate, quadratic (1-5)	**0.0012**	0.4766	0.3051
			Broadcast v banded (3&4 v 6&7)	***0.0651***	**0.0114**	0.9144
			KCl v K_2SO_4 (3&4 v 9&10)	0.1210	0.7384	0.3925

Table 6. Effects of K and Cl treatment on leaflet chlorophyll content (SPAD-502 readings). Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Comparisons are presented only for effects where $P \leq 0.10$.

Treatment	Application and source	K_2O rate (lbs/ac)	Cl^- rate (lbs/ac)	Leaflet cholorphyll content (SPAD-502)		
				June 15	June 27	July 10
1	No product	0	0	55.6	50.4 ab	49.7
2	Broadcast, KCl	80	63	55.2	50.2 ab	47.4
3		160	126	56.2	49.8 abc	47.5
4		240	190	55.3	48.4 cd	47.1
5		320	253	55.6	48.4 cd	47.2
6	Banded, KCl	160	126	53.8	48.9 bcd	47.4
7		240	190	55.1	47.9 d	46.6
8	Broadcast+side, KCl	240	190	55.8	49.0 bcd	47.3
9	Broadcast, K_2SO_4	160	0	54.9	48.3 cd	47.9
10		240	0	54.3	48.1 d	46.9
11	Broadcast, $CaCl_2$	0	180	55.7	50.8 a	48.7
	Treatment effect (P-value)			0.5927	**0.0255**	0.3211
Contrasts	Effect of KCl (1 vs. 2-5)			0.9590	0.1088	**0.0116**
	KCl rate, linear (1-5)			0.9669	**0.0081**	**0.0429**
	KCl rate, quadratic (1-5)			0.8607	0.8146	0.1686
	Broadcast v banded (3&4 v 6&7)			***0.0866***	0.2897	0.7037
	KCl v K_2SO_4 (3&4 v 9&10)			0.1341	0.1703	0.8865

Table 7. Effects of K and Cl treatment on canopy cover, as measured by the Canopeo app. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Comparisons are presented only for effects where $P \leq 0.10$.

Treatment	Application and source	K_2O rate (lbs/ac)	Cl^- rate (lbs/ac)	Percent canopy cover (Canopeo)													
				12-Jun	21-Jun	26-Jun	3-Jul	12-Jul	17-Jul	24-Jul	1-Aug	8-Aug	14-Aug	21-Aug	28-Aug	7-Sep	11-Sep
1	No product	0	0	30 bc	51	79 ab	95	96	96	96	97	92	97	95	85	55	47
2	Broadcast, KCl	80	63	36 a	58	83 ab	97	95	96	96	97	96	98	97	90	65	53
3	Broadcast, KCl	160	126	31 bc	51	78 b	91	96	96	95	97	93	97	96	91	64	55
4	Broadcast, KCl	240	190	28 c	56	79 ab	97	97	97	97	98	96	98	97	91	69	60
5	Broadcast, KCl	320	253	28 c	50	82 ab	94	97	97	96	98	95	98	96	91	75	64
6	Banded, KCl	160	126	32 abc	51	81 ab	95	96	94	95	98	94	97	93	90	76	67
7	Banded, KCl	240	190	28 c	47	70 c	90	95	97	96	97	94	98	97	90	72	60
8	Broadcast+side, KCl	240	190	35 ab	56	86 a	97	95	96	96	98	95	97	86	87	64	56
9	Broadcast, K_2SO_4	160	0	33 ab	56	81 ab	96	96	96	96	98	96	97	97	93	75	62
10	Broadcast, K_2SO_4	240	0	33 ab	61	84 ab	97	97	96	95	98	95	97	96	89	69	57
11	Broadcast, $CaCl_2$	0	180	32 abc	48	78 b	96	96	96	97	97	95	97	95	87	65	52
Treatment effect (P-value)				***0.0639***	0.4316	***0.0769***	0.1121	0.1834	0.4872	0.7072	0.4273	0.1099	0.9440	0.4724	0.6558	0.3144	0.7694
Contrasts	Effect of KCl (1 vs. 2-5)			0.8129	0.5967	0.6184	0.8884	0.6254	0.6550	0.8700	0.6381	**0.0151**	0.2724	0.6283	***0.0527***	**0.0441**	0.2088
Contrasts	KCl rate, linear (1-5)			**0.0432**	0.7605	0.7284	0.8475	***0.0864***	0.3573	0.5021	0.1814	***0.0726***	0.3044	0.8160	0.1241	**0.0213**	***0.0915***
Contrasts	KCl rate, quadratic (1-5)			0.1541	0.4173	0.7085	0.6173	0.4873	0.6489	0.4524	0.7883	0.5218	0.7681	0.7302	0.2457	0.9220	0.9760
Contrasts	Broadcast v banded (3&4 v 6&7)			0.8753	0.2784	0.2899	0.6054	0.1074	0.4950	0.7427	0.3920	0.9836	0.8042	0.6584	0.6890	0.2056	0.3784
Contrasts	KCl v K_2SO_4 (3&4 v 9&10)			***0.0762***	0.2724	0.1630	0.1368	0.7738	0.3838	0.5013	0.6212	0.3584	0.7820	0.9660	0.9756	0.3264	0.7076

Table 8. Effects of K and Cl treatment on petiole K, Cl, S, and NO_3^--N concentrations. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Comparisons are presented only for effects where $P \leq 0.10$.

Treatment	Application and source	K_2O rate (lbs/ac)	Cl^- rate (lbs/ac)	Petiole K (%)			Petiole Cl (%)			Petiole S (%)			Petiole NO_3-N (%)		
				14-Jun	27-Jun	10-Jul	14-Jun	27-Jun	10-Jul	14-Jun	27-Jun	10-Jul	14-Jun	27-Jun	10-Jul
1	No product	0	0	7.18 f	5.88	4.78 g	0.58 f	1.04 f	1.34 f	0.23 bc	0.22	0.24 abc	2.20	2.00	2.07
2	Broadcast, KCl	80	63	8.25 e	7.55	6.03 f	1.22 e	1.71 e	1.90 e	0.25 a	0.25	0.24 a	1.98	2.27	2.06
3		160	126	8.63 bcde	8.93	6.48 ef	1.87 cd	2.26 bcd	2.30 d	0.22 cde	0.22	0.24 ab	2.03	2.07	1.74
4		240	190	9.23 ab	7.70	7.60 abc	2.18 bc	2.45 b	2.74 b	0.23 bcd	0.21	0.22 de	2.05	1.96	1.99
5		320	253	9.03 abc	10.00	8.23 a	2.63 a	2.94 a	3.00 a	0.21 e	0.23	0.21 e	1.88	1.91	1.74
6	Banded, KCl	160	126	8.93 abcd	7.38	7.30 bcd	1.96 bc	2.07 cd	2.62 bc	0.22 de	0.21	0.22 cde	2.02	1.90	1.97
7		240	190	9.33 a	8.60	8.00 ab	2.13 bc	2.24 bcd	3.17 a	0.22 cde	0.24	0.21 e	2.05	1.79	2.05
8	Broadcast+side, KCl	240	190	8.63 bcde	7.40	6.98 cde	1.57 d	2.00 d	2.42 cd	0.23 bcd	0.22	0.23 abcd	2.02	1.97	1.80
9	Broadcast, K_2SO_4	160	0	8.35 de	8.33	6.53 def	0.61 f	1.30 f	1.37 f	0.23 bcd	0.24	0.23 abcd	2.22	2.32	2.11
10		240	0	8.45 cde	7.58	7.45 abc	0.65 f	1.26 f	1.42 f	0.24 ab	0.23	0.24 abc	2.07	2.00	2.14
11	Broadcast, $CaCl_2$	0	180	8.23 e	6.18	4.78 g	2.27 b	2.29 bc	2.50 cd	0.24 ab	0.21	0.23 bcde	1.95	1.71	1.96
	Treatment effect (P-value)			**0.0006**	0.1075	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0106**	0.9688	**0.0081**	0.2221	0.8971	0.2060
	Effect of KCl (1 vs. 2-5)			**<0.0001**	**0.0110**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.5096	0.6989	0.3031	**0.0286**	0.7698	0.1378
	KCl rate, linear (1-5)			**<0.0001**	**0.0052**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0042**	0.8107	**0.0009**	**0.0416**	0.2872	*0.0626*
Contrasts	KCl rate, quadratic (1-5)			**0.0344**	0.6849	0.6398	0.1672	0.1137	0.1090	0.1489	0.8394	**0.0455**	0.8088	0.3327	0.8309
	Broadcast v banded (3&4 v 6&7)			0.4811	0.7146	*0.0693*	0.8848	*0.0927*	**0.0002**	0.2106	0.7455	**0.0399**	0.9261	0.3553	0.2279
	KCl v K_2SO_4 (3&4 v 9&10)			*0.0709*	0.6834	0.8788	**<0.0001**	**<0.0001**	**<0.0001**	0.2949	0.4834	0.5624	0.2166	0.3201	**0.0372**

Table 9. Effects of K and Cl treatment on vine fresh and dry yield per acre and dry matter content. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Comparisons are presented only for effects where $P \leq 0.10$.

Treatment	Application and source	K_2O rate (lbs/ac)	Cl^- rate (lbs/ac)	Vine biomass (T/ac)		Vine dry matter content (%)
				Fresh	Dry	
1	No product	0	0	3.79	0.93	29.2
2	Broadcast, KCl	80	63	6.75	1.63	26.2
3		160	126	8.08	1.59	20.6
4		240	190	6.70	1.32	20.3
5		320	253	7.65	1.38	18.8
6	Banded, KCl	160	126	8.89	1.59	19.7
7		240	190	5.92	1.55	27.7
8	Broadcast+side, KCl	240	190	6.59	1.48	24.7
9	Broadcast, K_2SO_4	160	0	7.19	1.45	21.1
10		240	0	7.24	1.24	19.4
11	Broadcast, $CaCl_2$	0	180	5.07	0.96	28.7
			Treatment effect (P-value)	0.3664	0.3509	0.5780
Contrasts			Effect of KCl (1 vs. 2-5)	**0.0241**	**0.0360**	0.1222
			KCl rate, linear (1-5)	*0.0761*	0.4066	*0.0613*
			KCl rate, quadratic (1-5)	0.1826	*0.0842*	0.6147
			Broadcast v banded (3&4 v 6&7)	0.9935	0.6222	0.4629
			KCl v K_2SO_4 (3&4 v 9&10)	0.8953	0.6342	0.9605

Table 10. Effects of K and Cl treatment on tuber and vine concentrations of K, Cl, S, and Ca at harvest. 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	Application and source	K_2O rate (lbs/ac)	Cl^- rate (lbs/ac)	Tuber element concentrations (%)				Vine element concentrations (%)			
				K	Cl	S	Ca	K	Cl	S	Ca
1	No product	0	0	1.35 c	0.14 f	0.13	0.023 ab	0.62 d	1.44 f	0.20 ab	1.85
2	Broadcast, KCl	80	63	1.53 abc	0.17 ef	0.14	0.015 c	1.25 cd	2.03 de	0.19 ab	1.91
3		160	126	1.43 bc	0.19 de	0.12	0.015 c	1.80 bc	2.67 bc	0.16 d	1.84
4		240	190	1.65 a	0.23 bcd	0.13	0.015 c	2.30 b	2.95 ab	0.17 cd	1.63
5		320	253	1.68 a	0.25 ab	0.12	0.020 bc	3.28 a	3.44 a	0.16 d	1.67
6	Banded, KCl	160	126	1.58 ab	0.24 bc	0.12	0.015 c	2.28 b	2.92 ab	0.19 abcd	1.82
7		240	190	1.70 a	0.28 a	0.12	0.020 bc	2.08 b	3.22 a	0.16 d	1.75
8	Broadcast+side, KCl	240	190	1.65 a	0.22 cd	0.12	0.028 a	2.28 b	2.38 cd	0.17 bcd	1.76
9	Broadcast, K_2SO_4	160	0	1.55 ab	0.14 f	0.13	0.020 bc	1.95 bc	1.73 ef	0.21 a	1.98
10		240	0	1.58 ab	0.15 f	0.13	0.023 ab	2.54 ab	2.08 de	0.20 ab	1.80
11	Broadcast, $CaCl_2$	0	180	1.35 c	0.26 ab	0.12	0.025 ab	0.84 d	2.44 bcd	0.18 bcd	1.88
			Treatment effect (P-value)	**0.0142**	**<0.0001**	0.2921	**0.0416**	**<0.0001**	**<0.0001**	**0.0369**	0.7825
Contrasts			Effect of KCl (1 vs. 2-5)	**0.0135**	**0.0002**	0.5004	*0.0657*	**0.0002**	**<0.0001**	**0.0302**	0.5610
			KCl rate, linear (1-5)	**0.0026**	**<0.0001**	0.2791	0.5929	**<0.0001**	**<0.0001**	**0.0112**	0.1284
			KCl rate, quadratic (1-5)	0.9292	1.0000	0.6447	**0.0296**	0.5942	0.4936	0.3355	0.7084
			Broadcast v banded (3&4 v 6&7)	0.1898	**0.0031**	0.2847	0.3996	0.6990	0.2468	0.3672	0.7047
			KCl v K_2SO_4 (3&4 v 9&10)	0.7397	**0.0003**	0.5183	**0.0409**	0.5522	**0.0002**	**0.0013**	0.2445

Table 11. Effects of K and Cl treatment on tuber, vine, and combined uptake of K, Cl, S, and Ca at harvest. 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	Application and source	K_2O rate (lbs/ac)	Cl^- rate (lbs/ac)	Tuber element uptake (lbs/ac)				Vine element uptake (lbs/ac)				Combined element uptake (lbs/ac)			
				K	Cl	S	Ca	K	Cl	S	Ca	K	Cl	S	Ca
1	No product	0	0	137 c	14 e	13 bc	2.3 abcd	12 d	27 c	3.6	34	149 b	41 e	17	36 c
2	Broadcast, KCl	80	63	179 ab	19 cd	16 a	1.8 d	43 bcd	68 ab	6.2	61	221 a	88 bcd	22	63 a
3		160	126	171 b	23 bc	14 abc	1.8 d	55 abc	83 a	5.2	59	226 a	105 ab	19	61 a
4		240	190	180 ab	24 b	14 abc	1.7 d	66 ab	77 ab	4.5	42	246 a	101 abc	19	44 abc
5		320	253	171 b	25 ab	13 c	2.1 cd	89 a	95 a	4.5	47	260 a	120 a	17	49 abc
6	Banded, KCl	160	126	179 ab	26 ab	13 bc	1.7 d	80 ab	94 a	6.0	56	259 a	121 a	19	58 ab
7		240	190	178 ab	29 a	12 c	2.1 bcd	60 ab	94 a	5.1	57	237 a	122 a	17	60 ab
8	Broadcast+side, KCl	240	190	180 ab	24 b	13 bc	3.0 a	70 ab	73 ab	5.1	52	250 a	97 abcd	19	55 abc
9	Broadcast, K_2SO_4	160	0	188 ab	17 de	15 ab	2.5 abcd	56 abc	50 bc	6.2	57	244 a	67 de	22	60 ab
10		240	0	200 a	18 d	16 a	2.9 ab	71 ab	52 bc	5.0	41	271 a	70 cde	21	44 abc
11	Broadcast, $CaCl_2$	0	180	139 c	27 ab	13 c	2.6 abc	18 cd	50 bc	3.4	36	157 b	77 bcd	16	39 bc
Treatment effect (P-value)				**0.0198**	**<0.0001**	*0.0938*	*0.0783*	*0.0526*	**0.0061**	0.5223	0.3346	**0.0281**	**0.0015**	0.2601	0.3373
Contrasts	Effect of KCl (1 vs. 2-5)			**0.0069**	**<0.0001**	0.4524	0.2853	**0.0092**	**0.0005**	0.1979	*0.0716*	**0.0043**	**0.0002**	0.2538	*0.0767*
	KCl rate, linear (1-5)			*0.0726*	**<0.0001**	0.3124	0.6378	**0.0018**	**0.0009**	0.9739	0.8093	**0.0051**	**0.0002**	0.5541	0.8225
	KCl rate, quadratic (1-5)			*0.0627*	0.1378	0.1064	0.2429	0.8034	0.1572	0.1915	*0.0774*	0.3068	0.1238	0.1025	*0.0834*
	Broadcast v banded (3&4 v 6&7)			0.8217	**0.0214**	0.2094	0.6472	0.5722	0.2567	0.4773	0.5133	0.6440	0.1657	0.7490	0.4585
	KCl v K_2SO_4 (3&4 v 9&10)			0.1230	**0.0027**	*0.1000*	**0.0111**	0.8460	**0.0274**	0.4430	0.8648	0.4038	**0.0130**	0.1744	0.9453

Table 12. Effects of K and Cl treatment on soil water Cl^- concentration, with values averaged across monthlong periods and the entire season (May 19 through November 15). 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	Application and source	K_2O rate (lbs/ac)	Cl^- rate (lbs/ac)	Soil water Cl^- (ppm) by developmental phase				
				5/19 - 6/14	6/22 - 7/24	8/22 - 9/26	10/16 - 11/15	All season
1	No product	0	0	29	7	46	80 b	34 b
4	Broadcast, KCl	240	190	40	24	70	107 ab	54 b
7	Banded, KCl	240	190	51	24	167	241 a	108 a
10	Broadcast, K_2SO_4	240	0	39	22	27	36 b	32 b
11	Broadcast, $CaCl_2$	0	180	33	21	166	157 ab	65 ab
			Treatment effect (P-value)	0.2966	0.3053	0.1263	***0.0954***	***0.0908***

Table 13. Effects of K and Cl treatment on soil K to a depth of 6 inches and Cl concentrations to a depth of 24 inches. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Comparisons are presented only for effects where $P \leq 0.10$.

Treatment	Application and source	K_2O rate (lbs/ac)	Cl^- rate (lbs/ac)	End-of season soil:	
				K (ppm)	Cl (ppm)
1	No product	0	0	38 b	70 cde
2	Broadcast, KCl	80	63	.	64 cde
3		160	126	.	42 e
4		240	190	87 a	119 bc
5		320	253	.	134 b
6	Banded, KCl	160	126	.	58 de
7		240	190	.	195 a
8	Broadcast+side, KCl	240	190	.	77 bcde
9	Broadcast, K_2SO_4	160	0	.	65 cde
10		240	0	.	70 cde
11	Broadcast, $CaCl_2$	0	180	44 b	102 bcd
			Treatment effect (P-value)	**0.0037**	**0.0067**
Contrasts			Effect of KCl (1 vs. 2-5)	.	0.4827
			KCl rate, linear (1-5)	.	**0.0264**
			KCl rate, quadratic (1-5)	.	0.1408
			Broadcast v banded (3&4 v 6&7)	.	***0.0747***
			KCl v K_2SO_4 (3&4 v 9&10)	.	0.6083