Timing of K application for corn and soybean production

AFREC Final Project Report 3/31/2024 for

AFREC Project(s) R2023-C

Results through the 2023 Growing Seasons

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Summary Points – Year 2

- Potassium application rate and timing had inconsistent impacts on corn leaf and soybean trifoliate K concentration. When significant, leaf K concentration tended to increase linearly with increasing K application rate.
- Leaf Cl concentration was increased greater with spring application of potash fertilizer. Fall application either did not increase or only slightly increased Cl concentration. Results though 2022 show that increased Cl concentration in the leaf tissue did not result in decreased corn yield.
- Corn grain yield was increased with K application at two corn and two soybean locations. Time of K application seldom, if ever, affected corn grain yield. Corn grain yield was maximized when 80 lbs K_2O was applied across locations.
- Soybean grain yield was significantly lower when K was applied in spring. Across locations, soybean grain yield was not increased by K fertilizer but was 1 bushel per acre less when K rates were applied in spring. The amount of K that could be applied ahead of soybean, and not reduce yield, could not be clearly determined.
- Seed K concentration and K removal with harvested corn or soybean grain were inconsistently impacted by K application rate and timing.
- Soybean seed protein and oil concentration were not impacted by K application rate or timing.

Introduction

Potassium is an important nutrient for crops. The goal of this study is to establish whether corn and soybean yield is impacted by the timing in which potassium fertilizer, applied as potassium chloride, is applied ahead of the crop. Many growers prefer to apply dry fertilizer containing phosphorus and potassium in the fall since both nutrients are immobile and should not leach in most soils. While recent research has been conducted looking at potassium response in corn and soybean none of that work compared timing of fertilizer application to determine whether there is a difference in yield potential for similar rates of potassium applied in the fall versus in the spring.

Application of fertilizer in the fall does give more time for nutrients to react with the soil which can impact nutrient availability. Potassium does not form covalent bonds with other nutrients like phosphorus and should be less impacted by when the fertilizer is applied. Potassium can be fixed in soils high in smectite clays which can reduce availability. Recent increases in the price of potash coupled with greater potassium deficiency induced by dry weather conditions require further research to fine tune potassium guidelines to ensure application is both economical and will increase yield.

Recent research in Minnesota has demonstrated that soybean yield can be reduced by the application of potassium chloride (KCl) fertilizer directly ahead of the soybean crop. The bulk of this research was conducted with KCl applied in the fall the year prior to soybean being grown. In conversations with other researchers and retailers the negative impact of Cl on soybean is generally assumed to be worse with an application in the spring close to when the soybean crop is planted. One goal of this study is to better determine how timing may impact soybean yield both positive and negative. Soybean seed quality will also be assessed to follow up on differences in seed protein and oil concentration commonly found in other research studies. Information is needed if KCl fertilizer does reduce yield as to how much can be applied before the soybean crop and whether the risk for damage is greater based on when the fertilizer is applied.

Additional data on plant tissue K concentration and whether tissue K can predict final grain yield needs to be measured to provide better guidance on the use of tissue sampling and whether tissue concentrations can be predictive of final grain yield. For corn two key timings are commonly sampled, mid-vegetative and early reproductive samples. For soybean only early reproductive samples are commonly collected which will be added to past data collected in Minnesota correlating relative yield response in corn and soybean to plant tissue K concentrations.

Objective

The objectives of this study will be:

1. Determine the optimal rate of K applied as KCl for corn and soybean and determine whether the optimal rate of K varies whether fertilizer is applied in fall compared to spring?
2. Establish If soybean yield is decreased by the application of KCl, is the decrease less if KCl is applied in the fall?
3. Evaluate potassium rate and timing impacts on soybean seed quality.
4. Determine if plant tissue K concentration can be a predictor of final grain yield.
5. Evaluate the impact that fall and spring K application have on soil test change for samples collected in June
6. Assess the impacts of K application timing on fixed potassium as extracted by the sodium tetraphenylboron.

<u>Materials and Methods</u>

Six locations will be established in each of three growing seasons starting in Fall of 2021, 2022, and 2023 (the budget for this proposal only includes year 2 which is the 2023 growing season and further years should be consistent with the budget proposed). Three corn and three soybean trials will be established each year. Sites will be selected based on current soil test values targeting locations testing 150 ppm or less in K by air dried samples. Corn and soybean will be the only crops studied.

Each site is established using a split plot design where larger main plots are established representing one of five K fertilizer rates (0, 40, 80, 120, and 160 lbs K2O per acre). Each main plot is split into two sub-plots four rows wide which represent time of fertilizer application (fall versus spring). All fertilizer is applied as potassium chloride (KCl). Additional nitrogen, phosphorus, and sulfur will be applied as needed such that yield is not limited by any nutrient other than potassium.

Soil samples will be collected from each main block (20 samples per site consisting of 8 to 10 0-6" cores) prior to fall treatment application and in June (all plots) and will be kept in a moist state, sieved, then split. Part of the Fall sample will be air dried, ground, and analyzed for Olsen P, pH, organic matter, and ammonium acetate K. June samples will be run for K only. The remaining moist portion of the soil sample will be analyzed without drying using the "direct sieve" method. Soil moisture will be calculated in order to weigh out 2 g of oven-oven dry equivalent moist soil which will be extracted with 1M ammonium acetate similar to the method used for the air-dried samples. Leaf samples will be collected from each plot for corn at V8-V10 (uppermost fully developed leaf) and R1 (leaf opposite and below the ear) and for soybean at the R1-R2 growth stage (uppermost fully developed trifoliate) and will be analyzed for total K concentration. The fixed potassium fraction will be assessed on air dried samples collected both in the fall and in June following a 7 day incubation with sodium tetraphenylboron.

All soybean plots will be harvested with a small plot combine. Corn will either be harvested with a plot combine or by hand. Grain samples will be collected from each location and analyzed for total K concentration. Soybean grain will be analyzed by NIR for protein and oil content on whole soybean seeds.

Table 1. Soil series information, planted crop at each location, and initial soil test data from potassium studies conducted in 2022. Soil test data was collected in the Fall at trial establishment from each main plot.

			Soil Test K			Soil Test†			
Year	Location	Crop	Air Dry	Moist	5 min TBK	P	pH	SOM	Soil Series
				Ppm				%	
2022	Crookston	Corn	123	54	348	12	8.2	3.4	Wheatville
	Lamberton	Corn	181	102	646	8	6.8	4.7	Normania
	Rosemount	Corn	69	43	294	12	6.3	4.4	Waukegan
	Lamberton	Soybean	131	69	285	15	5.3	4.3	Normania
	Rochester	Soybean	88	52	284	7	6.7	4.5	Mt Carroll
	Rosemount	Soybean	105	83	222	41	7.0	2.6	Waukegan
2023	Lamberton	Corn	115	59	491	9	5.7	4.2	Normania
	Rochester	Corn	95	72	412	7	6.9	4.2	Mt. Carroll
	Rosemount	Corn	105	78	321	15	5.3	3.7	Waukegan
	Crookston	Soybean	186	137	482	15	7.7	3.7	Wheatville
	Faribault	Soybean	107	80	466	18	6.6	2.8	Lester
	Le Sueur	Soybean	148	131	487	35	6.5	3.7	Cordova

† K, Soil test potassium (K-ammonium acetate); P, Bray-P1 phosphorus; SOM, soil organic matter.

Table 2. Summary of non-traditional soil test data collected for the 2022 locations. Data summarized are for samples collected the previous fall before the cropping year at each location.

Year	Location	Crop	Particle Size			CEC	K base Sat	
			Sand	Silt	Clay		Dry	Moist
			--------%--------			meq/100g	%	
2022	Crookston	Corn	29.1	32.2	38.7	21.4	1.47	0.65
	Lamberton	Corn	27.2	28.4	44.4	26.7	1.73	0.98
	Rosemount	Corn	7.2	57.5	35.3	20.0	0.88	0.55
	Lamberton	Soybean	27.8	30.9	41.3	22.3	1.50	0.79
	Rochester	Soybean	2.0	60.2	37.8	20.7	1.09	0.64
	Rosemount	Soybean	35.3	36.3	28.4	11.8	2.28	1.80
2023	Lamberton	Corn	40.9	28.5	30.0	22.9	1.28	0.66
	Rochester	Corn	30.0	46.3	23.8	17.3	1.41	1.07
	Rosemount	Corn	11.6	62.2	26.3	20.9	1.29	0.96
	Crookston	Soybean	41.0	31.9	27.2	22.6	2.10	1.55
	Faribault	Soybean	51.6	25.6	22.8	16.2	1.69	1.26
	Le Seuer	Soybean	47.2	26.6	26.2	21.4	1.77	1.57

CEC, cation exchange capacity

7 Day TBK, Sodium tetraphenylboron K concentration after a 7-day incubation period.

K base Sat based on fall soil test K values for based on extraction of dry or moist soil samples

Table 3. Summary of cultural practices for studies conducted in 2022. Fall fertilization data is for the fall preceding the calendar year the trial was conducted at each location.

Year	Location	Crop	Cultivar†	Date of		
				Fall Fert.‡	Spring Fert.	Planting
2022	Crookston	Corn	DK 29-89	1-Nov	27-May	27-May
	Lamberton	Corn	DK 49-44	27-Oct	4-May	23-May
	Rosemount	Corn	P 9489AM	4-Nov	3-May	16-May
	Lamberton	Soybean	S 19EC12	27-Oct	5-May	24-May
	Rochester	Soybean	AG 17XF2	5-Nov	4-May	6-May
	Rosemount	Soybean	NK 18-J7E3	4-Nov	4-May	23-May
2023	Lamberton	Corn	DK 52-18	3-Nov	4-May	24-May
	Rochester	Corn	DK 50-87	2-Nov	3-May	19-May
	Rosemount	Corn	P 9211	7-Nov	2-May	13-Jun
	Crookston	Soybean	NK 008E3	4-Nov	10-May	13-May
	Faribault	Soybean	P 18A73E	10-Nov	27-Apr	25-May
	Le Seuer	Soybean	P 18A73E	10-Nov	27-Apr	4-May

†AG, Asgrow; DK, Dekalb; NK, Northrup King; P, Pioneer; S, Stine.

‡ Fall fertilizer (fert.) was applied the fall the previous year in which the study was harvested.

Results and Discussion

Location data are summarized in Table 1. Sites were targeted that had soil test K values less than 200 ppm. Sites were preferred if they had soil test K values less than 150 ppm and ideally closer to 100-120 ppm or less. Additional chemical properties are listed in Table 2. Table three summarizes cultural practices used at each location.

2022 Data Summary

Table 4 and 5 summarize main effects and main effect interactions for the ANOVA for the measured variables for the 2022 corn and soybean trials, respectively. Tables 5 and 6 summarize the potassium (K) rate and timing main effects for corn and soybean, respectively. Interactions were generally not significant, and the interaction data are not summarized for most of the measured variables. A lack of a significant interaction is an indication that there is no impact of K timing on fertilizer use by either crop. Exceptions however will be noted.

Soil samples were collected in June to assess potential differences in K availability based on application timing. While samples were analyzed following air drying and on field moist basis, only the field most data are summarized. Potassium application rate impacted soil test K change at four of six locations (two corn and two soybean). Timing itself was not significant but the timing by rate interaction was significant at 2 of the 4 locations where K rate was significant, and one location, Crookston, where rate was not significant. Figures 1 summarizes data for both the corn and soybean locations. Tables 4 and 5 also summarize K extracted by sodium tetraphenyl boron (Na-TBK) but I may need to re-run a portion of the data before I can summarize the results. I have been encountering inconsistencies in the data when comparing extractable K to the Na-TBK values. I will have more discussion in the 2023 year-end project report.

Corn data are summarized in Table 5. Potassium fertilizer rate affected most measured variables at Rosemount and seldom affected variables at Crookston and Lamberton, which one exception, leaf Cl concentration. At Rosemount, there was a general increase in leaf and grain K concentration with increasing K application rate. Corn grain yield was increased when up to 80 lbs K_2O was applied per acre. Time of K application did affect V10 and R1 leaf K concentration at Rosemount. In both cases the concentration of K was greater with spring applied K at Rosemount. Time of application did not affect measured variable at Crookston or Lamberton.

Leaf Cl concentration was affected by both K rate and timing at both V10 and R1 samples at Lamberton and Rosemount. Leaf Cl concentration was only affected for the R1 sampling at Crookston where both Rate and time were significant. In all cases were rate and time were significant, the rate by timing interaction was also significant. Figure 2 summarizes the impact of K rate on leaf Cl concentration. The significant interaction at Lamberton and Rosemount was a result of a greater effect of K applied in the spring on leaf Cl concentration as evident by the greater slope of the line for spring versus fall data. The affect was opposite at Crookston where K application rate impacted leaf Cl concentration at R1 but only for Fall applied K.

Soybean main effect significance data are summarized in Table 6. Potassium application did not affect leaf tissue and grain K concentration and grain yield and quality parameters at Lamberton. For some reason application timing did affect grain yield at Lamberton with Fall application yielding more than spring K application. However, K application rate was not significant so it is unclear why timing was significant at Lamberton but there was no effect of K on soybean grain yield.

Response trends were similar at Rochester and Rosemount. In both sites K application rate affected R1 leaf K concentration and soybean grain yield. At both locations leaf K concentration was increased when up to 120 lbs K_2O per acre were applied. Soybean grain yield responses did differ by site. At Rochester, yield was increased when up to 80 lbs K_2O per acre were applied. At Rosemount, technically the control did not produce a significantly different yield from any of the applied fertilizer rates but the 40 lb K_2O rate did produce yield similar higher application rates. The 120 lb K_2O rate statistically produced the lowest yield at Rosemount but that effect was likely a result of within site variability as the 80 and 160 lb K_2O rates had greater grain yield and did not differ from each other. Time of application did impact leaf K concentration at Rochester where K concentration was greater for spring application. Application timing did not affect soybean grain yield at Rochester or Rosemount. Grain K concentration did increase with increasing K application rate to Rochester and K removal was greater at both Rochester and Rosemount because of greater grain yield with applied K. Seed protein and oil concentration were not affected by K application rate at any of the three locations.

Leaf Cl concentration at R1 was impacted by K application rate at all locations while timing was significant at two of the three locations. All locations showed a significant interaction between K application rate and timing for leaf Cl concentration. The interaction between K application rate and timing are summarized in Figure 3. In all three cases, there was little to no effect of fall applied K on the concentration of Cl in the leaf tissue at all three locations while the spring K tended to result in linear increases in Leaf Cl concentration. Soybean grain yield was not negatively impacted by K application rate at any of the locations so the overall impact of the extra Cl in the plant appeared to be negligeable. The Cl data gathered in this study does begin to answer one question regarding timing and Cl uptake.

Table 4. ANOVA summary for measured variables (potassium rate and timing) for the three corn trials conducted in 2022.

Main Effect	Moist K Change	June TBK	V10 Leaf K	V10 Leaf Cl	R1 Leaf K	R1 Leaf Cl	Grain Moisture	Grain Yield	Grain %K	Grain K Removal
			----------------	----------------	----------------	*P*>F	----------------	----------------	----------------	
					Crookston					
K rate	0.17	0.86	0.34	0.34	*	*	0.63	0.74	0.67	0.86
Timing	0.44	0.55	0.56	0.88	0.85	*	0.42	0.77	0.28	0.34
K rt x Time	*	0.82	0.34	*	*	***	0.80	0.15	0.30	0.08
					Lamberton					
K rate	**	0.32	0.61	**	0.15	***	0.29	0.20	0.29	0.41
Timing	0.17	0.44	0.88	***	0.54	***	0.66	0.94	0.89	0.79
K rt x Time	0.07	0.73	0.72	***	0.28	*	0.99	0.30	0.13	0.12
					Rosemount					
K rate	***	0.29	***	***	***	***	***	***	*	*
Timing	0.67	0.41	*	***	*	***	0.31	0.20	0.31	0.62
K rt x Time	0.11	0.61	0.17	**	*	***	0.17	0.25	0.09	0.13

Asterisks denote significance at $P \leq 0.001$ (***), $P \leq 0.01$ (**), and $P \leq 0.05$ (*) probability levels.

Table 5. ANOVA summary for measured variables (potassium rate and timing) for the three soybean trials conducted in 2022.

Main Effect	Moist K Change	June TBK	R1 Leaf K	R1 Leaf Cl	Grain Yield	Grain %K	Grain K Removal	Grain Protein	Grain Oil
					---------------------------------------*P*>F---------------------------------------				
					Lamberton				
K rate	*	0.13	0.29	***	0.73	0.45	0.99	0.55	0.77
Timing	0.16	0.13	0.49	***	*	0.94	0.08	0.61	0.94
K rt x Time	0.56	0.57	0.71	*	0.64	0.93	0.84	0.49	0.95
					Rochester				
K rate	0.22	0.74	**	0.09	***	*	**	0.38	0.71
Timing	0.91	0.47	**	0.12	0.13	*	*	0.51	0.38
K rt x Time	0.25	0.86	0.21	0.08	*	0.10	0.06	0.77	0.52
					Rosemount				
K rate	0.09	0.65	***	*	0.09	0.71	**	0.87	0.59
Timing	0.69	0.67	0.67	***	0.28	0.88	0.29	*	0.14
K rt x Time	*	0.52	0.19	**	0.39	0.53	0.46	***	0.26

Asterisks denote significance at $P \leq 0.001$ (***), $P \leq 0.01$ (**), and $P \leq 0.05$ (*) probability levels.

Table 6. Summary of treatment main effects for three corn locations where K fertilizer rates were applied in Fall or spring ahead of the 2022 cropping season. Treatments are considered significantly different at $P \leq 0.10$. Numbers followed by the same letter for individual site treatment main effects are not significantly different.

	K application rate (lb K_2O ac^{-1})					Application Time	
Location	0	40	80	120	160	Fall	Spring
	V10 Upper Leaf %K						
Crookston	1.70	1.79	1.79	1.85	1.79	1.77	1.79
Lamberton	1.99	2.00	1.93	2.11	2.03	2.01	2.02
Rosemount	0.55c	0.57c	0.70b	0.86a	0.87a	0.67b	0.74a
	V10 Upper Leaf Cl (ppm)						
Crookston	983	1191	1352	1340	1283	1221	1239
Lamberton	1388c	1645b	1790ab	1841ab	1917a	1543b	1890a
Rosemount	671e	1696d	2552c	3399b	3884a	1909b	2972a
	R1 Leaf %K						
Crookston	1.33b	1.54a	1.61a	1.53a	1.63a	1.53	1.52
Lamberton	1.74	1.71	1.72	1.93	1.88	1.79	1.81
Rosemount	0.92d	1.04c	1.25b	1.34a	1.36a	1.15b	1.21a
	R1 Leaf Cl (ppm)						
Crookston	1175	1306bc	1735ab	1566abc	1945a	1752a	1323b
Lamberton	1434c	2041b	2652a	2502a	2722a	1905b	2608a
Rosemount	571e	1629d	2437c	3144b	3487a	1803b	2668a
	Moisture in harvested grain %						
Crookston	14.1	14.1	14.2	14.0	14.0	14.1	14.0
Lamberton	15.3	15.2	15.4	15.6	15.5	15.4	15.5
Rosemount	14.0c	15.3ab	15.7a	15.1b	15.0b	14.9	15.1
	Corn grain yield at 15.5% bushels per acre						
Crookston	160	165	163	157	165	162	161
Lamberton	182	185	191	191	181	186	186
Rosemount	163b	169b	186a	192a	192a	178	183
	Corn Grain %K						
Crookston	0.33	0.33	0.34	0.35	0.34	0.34	0.33
Lamberton	0.31	0.28	0.30	0.30	0.30	0.30	0.30
Rosemount	0.38a	0.34b	0.38a	0.34b	0.35ab	0.36	0.35
	K Removed in Corn Grain (lb K_2O/ac)						
Crookston	29.9	30.8	31.3	30.8	30.5	31.1	30.3
Lamberton	32.1	29.6	32.6	32.1	30.6	31.3	31.5
Rosemount	33.4bc	32.1c	40.5a	36.6ab	37.6ab	36.4	35.7

Table 7. Summary of treatment main effects for three soybean locations where K fertilizer rates were applied in Fall or spring ahead of the 2022 cropping season. Treatments are considered significantly different at $P \leq 0.10$. Numbers followed by the same letter for individual site treatment main effects are not significantly different.

	K application rate (lb K_2O ac^{-1})					Application Time	
Location	0	40	80	120	160	Fall	Spring
	---------- R1 Leaf %K ----------						
Lamberton	2.41	2.33	2.35	2.43	2.54	2.43	2.39
Rochester	1.96c	2.15b	2.31ab	2.33a	2.45a	2.16b	2.32a
Rosemount	2.39cd	2.34d	2.59bc	2.92a	2.68b	2.57	2.60
	---------- R1 Leaf Cl (ppm) ----------						
Lamberton	511c	563bc	600b	615b	723a	551b	654a
Rochester	535b	535b	580ab	603a	575ab	551	580
Rosemount	383b	478b	702ab	1050a	1003a	415b	1031a
	---------- Soybean grain yield at 13% bushels per acre----------						
Lamberton	57.2	55.2	55.5	55.1	54.4	56.5a	54.4b
Rochester	65.6c	67.8b	69.6a	69.0ab	69.3a	67.9	68.7
Rosemount	57.7ab	61.1a	62.3a	59.8b	62.1a	60.1	58.4
	---------- Soybean Grain %K ----------						
Lamberton	1.58	1.62	1.60	1.62	1.66	1.62	1.61
Rochester	1.65c	1.71bc	1.78a	1.76ab	1.76ab	1.71b	1.75a
Rosemount	1.72	1.75	1.75	1.79	1.78	1.76	1.76
	---------- K Removed in Soybean Grain (lb K_2O/ac)----------						
Lamberton	56.6	56.0	55.4	55.9	56.3	57.1a	55.0b
Rochester	68.1c	72.4b	77.5a	75.9ab	76.2a	72.8b	75.2a
Rosemount	62.1bc	66.9ab	68.4a	58.8c	69.4a	66.1	64.1
	---------- Soybean Grain Protein % ----------						
Lamberton	33.9	33.8	33.7	33.9	34.1	33.9	33.8
Rochester	34.2	34.0	34.0	34.1	33.8	34.0	34.1
Rosemount	35.8	35.6	35.8	36.0	35.7	35.7b	35.9a
	---------- Soybean Grain Oil % ----------						
Lamberton	18.7	19.0	18.8	18.8	18.8	18.8	18.8
Rochester	17.9	17.9	17.9	17.7	17.8	17.8	17.9
Rosemount	17.2	17.1	17.1	17.3	17.0	17.1	17.2

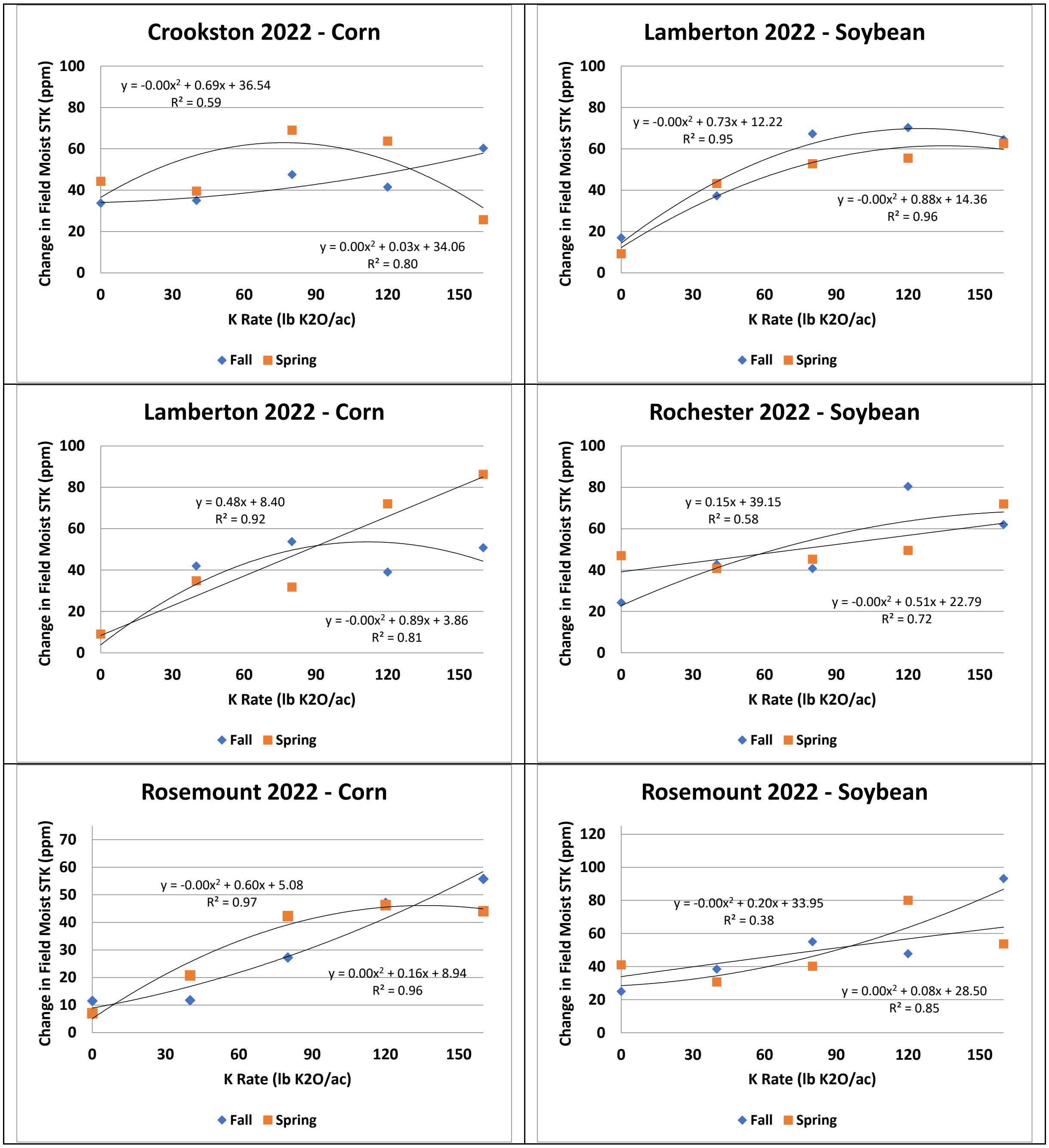

Figure 1. Summary of change in June ammonium acetate K extracted from moist soil samples K application ahead of corn or soybean in Fall 2021 or Spring 2022.

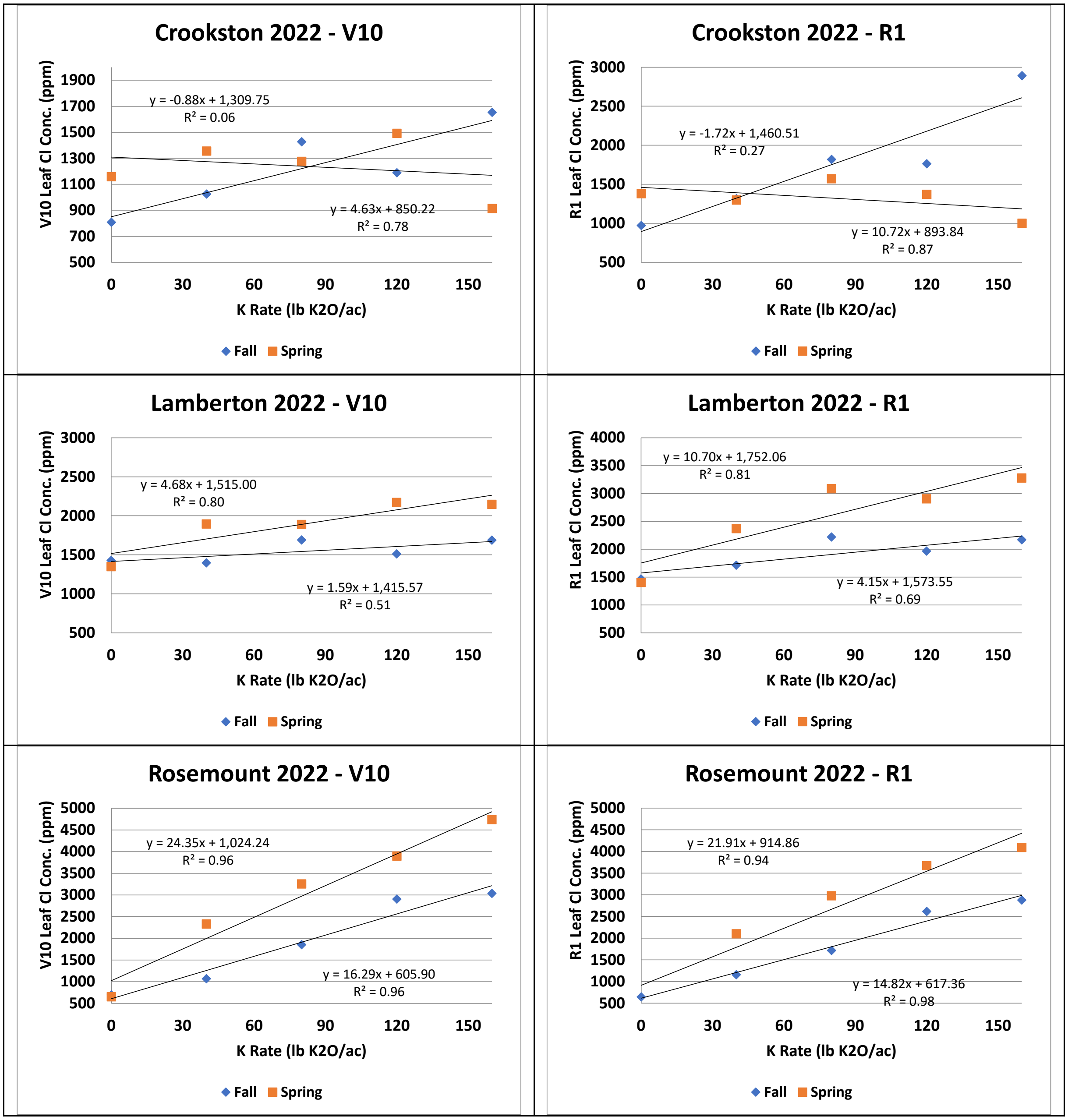

Figure 2. Summary of the impact of potash application in Fall or Spring on V10 or R1 corn leaf Cl concentration for three field sites established in 2022.

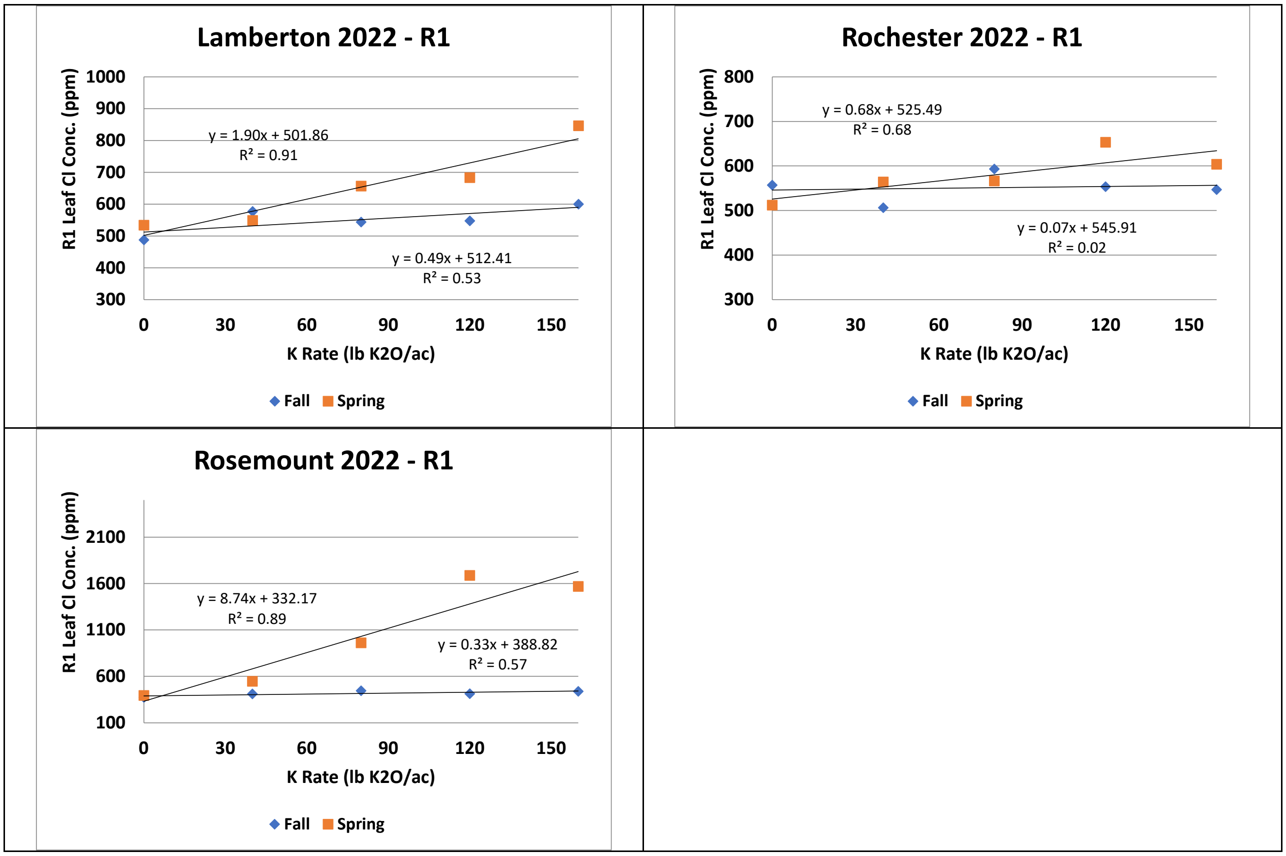

Figure 3. Summary of the impact of potash application in Fall or Spring on R1 soybean trifoliate Cl concentration for three field sites established in 2022.

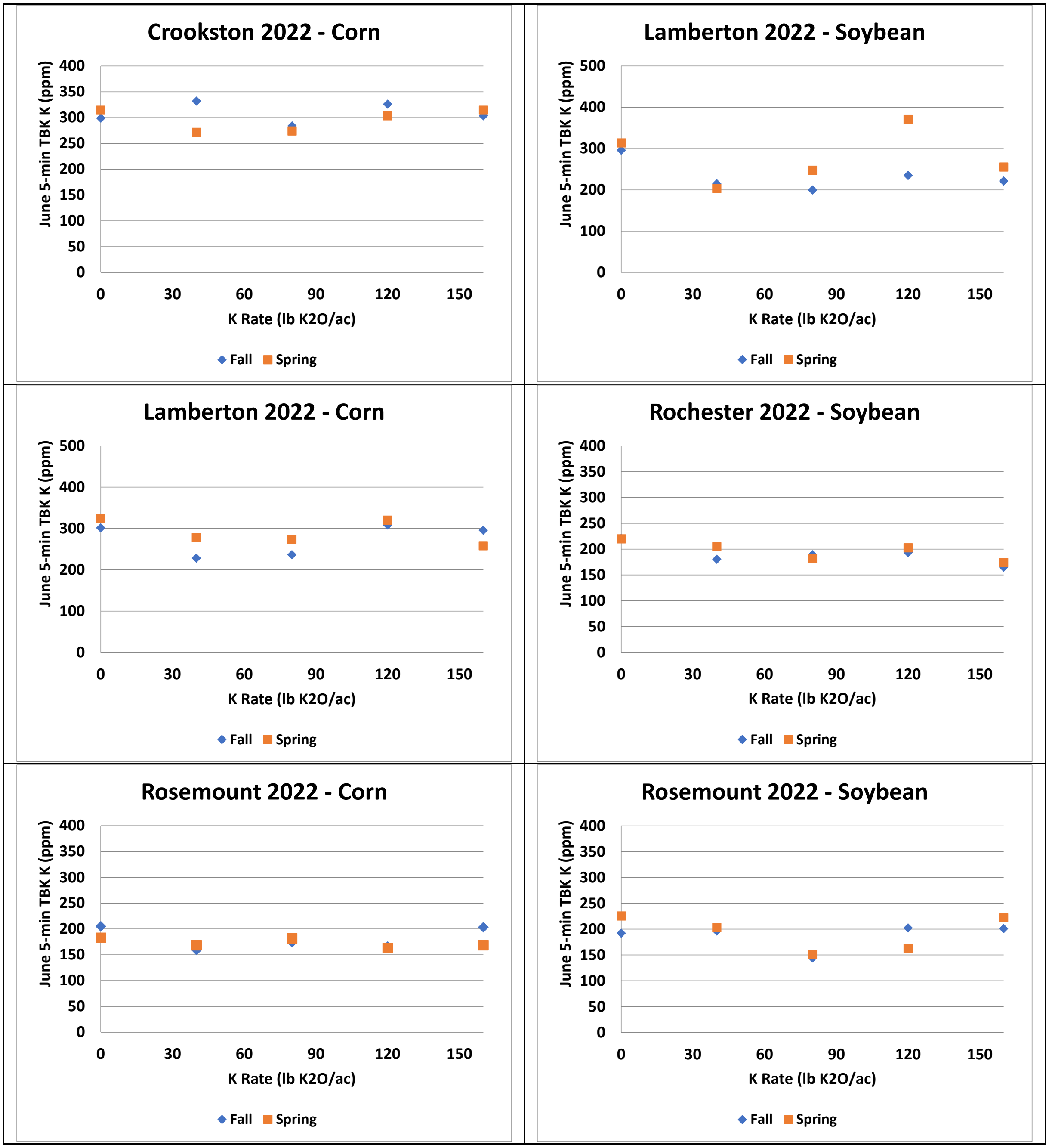

Figure 4. Summary of the amount of K extracted by incubating soil for 5 minutes with tetraphenylboron minus the amount of K extracted by the moist soil ammonium acetate test for samples collected in June of 2022.

2023 Data Summary

Table 8 and 9 summarize main effects and main effect interactions for the ANOVA for the measured variables for the 2023 corn and soybean trials, respectively. Tables 10 and 11 summarize the potassium (K) rate and timing main effects for corn and soybean, respectively. Interactions were generally not significant outside of selected plant tissue measurements. Interaction data are not summarized for most of the measured variables in the tables but are included in separate figures. A lack of a significant interaction is an indication that there is no impact of K timing on fertilizer use by either crop. Exceptions for 2023 will be noted.

Soil samples were collected in June to assess potential differences in K availability based on application timing. While samples were analyzed following air drying and on field moist basis, only the field most data are summarized. Potassium application rate impacted soil test K change at all six locations. Timing itself was not significant but the timing by rate interaction was significant only at Lamberton in 2023. Figure 5 summarizes data for both the corn and soybean locations. Tables 10 and 11 also summarize K extracted by sodium tetraphenyl boron (Na-TBK) using a 5-minute extraction. The 5-minute extraction is thought to represent the most active fraction of non-exchangeable K. The 5-minute extraction includes both exchangeable and non-exchangeable K. Subtracting the moist K values from the data gives an estimate of the actual non-exchangeable K. All locations though showed no impact of K rate and timing on the non-exchangeable K fraction indicating that fertilizer K stayed in the soil solution rather than being “fixed”. There was a mixture of soils dominated by illite and by smectite but not major difference in how the non-exchangeable K fraction was impacted by K application. The same effect was also noted in the 2022 data. Figure 4 as well as Figure 8 summarize non-exchangeable K data.

Corn data are summarized in Table 10. Potassium fertilizer rate affected most leaf K and Cl tissue concentrations. Timing and the time by rate interaction was significant for leaf Cl concentration due to a greater increase in leaf Cl when K was spring applied. Corn grain yield was only increased by K at Rochester even though there were slightly increasing yield trends at Rosemount. Time of application did not have any impact on corn grain yield in 2023.

Soybean main effect significance data for 2023 are summarized in Table 11. Potassium application more commonly impacted leaf K and Cl concentrations across the 3 locations but did not affect soybean grain yield, seed protein, or oil concentration. The time main effect was significant for soybean grain yield at Crookston and Le Center. In both cases fall application outyielded spring. Soybean R1 leaf Cl concentration was similarly impacted by the rate x time interaction as was seen for corn. While trifoliate Cl concentration did increase regardless of timing the increase in trifoliate Cl concentration was greater when KCl was applied in the spring compared to the fall.

Table 8. ANOVA summary for measured variables (potassium rate and timing) for the three corn trials conducted in 2023.

Main Effect	Moist K Change	June TBK	V10 Leaf K	V10 Leaf Cl	R1 Leaf K	R1 Leaf Cl	Grain Moisture	Grain Yield	Grain %K	Grain K Removal
			--		*P*>F	--				
					Lamberton					
K rate	*	0.74	0.37	*	0.07	0.18	0.92	0.48	0.99	0.83
Timing	***	0.33	***	***	***	***	0.74	0.53	0.95	0.68
K rt x Time	**	0.39	0.10	***	*	**	0.44	0.79	0.20	0.21
					Rochester					
K rate	*	0.11	***	***			0.08	***	0.52	*
Timing	0.28	0.08	*	***			*	0.09	*	*
K rt x Time	0.94	0.11	0.09	**			0.09	0.57	0.10	0.39
					Rosemount					
K rate	***	0.13	***	***	***	***	0.08	0.17	0.57	0.20
Timing	0.69	0.53	0.28	***	0.13	***	**	0.18	0.52	0.09
K rt x Time	0.86	0.53	0.28	***	0.06	***	0.13	0.71	0.18	0.06

Asterisks denote significance at $P \leq 0.001$ (***), $P \leq 0.01$ (**), and $P \leq 0.05$ (*) probability levels.

Table 9. ANOVA summary for measured variables (potassium rate and timing) for the three soybean trials conducted in 2023.

Main Effect	Moist K Change	June TBK	R1 Leaf K	R1 Leaf Cl	Grain Yield	Grain %K	Grain K Removal	Grain Protein	Grain Oil
	--				*P*>F	--			
					Crookston				
K rate	*	0.94	*	**	0.44	0.21	0.29	0.63	0.19
Timing	0.66	0.89	0.28	**	*	0.88	0.21	1.00	0.40
K rt x Time	0.68	0.70	0.20	0.25	0.65	0.10	0.62	0.70	0.96
					Faribault				
K rate	*	0.31	**	***	0.34	0.07	0.41	0.49	0.20
Timing	0.92	0.32	0.23	**	0.73	0.44	0.64	0.32	0.38
K rt x Time	0.76	0.18	0.91	0.09	0.27	0.95	0.38	0.94	0.98
					Le Center				
K rate	*	0.52	*	0.21	0.47	0.52	0.73	0.46	0.77
Timing	0.99	0.22	0.74	0.45	*	0.62	0.11	0.10	0.18
K rt x Time	0.92	0.74	0.33	0.18	0.84	0.08	0.69	0.80	0.36

Asterisks denote significance at $P \leq 0.001$ (***), $P \leq 0.01$ (**), and $P \leq 0.05$ (*) probability levels.

Table 10. Summary of treatment main effects for three corn locations where K fertilizer rates were applied in Fall or spring ahead of the 2023 cropping season. Treatments are considered significantly different at $P \leq 0.10$. Numbers followed by the same letter for individual site treatment main effects are not significantly different.

	K application rate (lb K_2O ac^{-1})					Application Time	
Location	0	40	80	120	160	Fall	Spring
	V10 Upper Leaf %K						
Lamberton	1.19	1.06	1.31	1.38	1.30	1.01b	1.48a
Rochester	0.40d	0.48c	0.59b	0.55b	0.76a	0.52b	0.58a
Rosemount	1.01d	1.26c	1.46b	1.57b	1.76a	1.38	1.44
	V10 Upper Leaf Cl (ppm)						
Lamberton	1185b	1899a	2385a	2373a	2387a	1111b	2979a
Rochester	531d	2091c	3020b	3993a	3979a	2037b	3408a
Rosemount	703d	1971c	2452b	2789ab	3148a	760b	3665a
	R1 Leaf %K						
Lamberton	0.97b	0.96b	1.15ab	1.15ab	1.27a	0.92b	1.27a
Rochester	--	--	--	--	--	--	--
Rosemount	1.26c	1.62b	1.65b	1.72b	1.94a	1.60	1.68
	R1 Leaf Cl (ppm)						
Lamberton	1374	1658	2055	2086	2127	1191b	2529a
Rochester	--	--	--	--	--	--	--
Rosemount	491c	1073b	1647a	1862a	1652a	626b	2064a
	Moisture in harvested grain %						
Lamberton	17.8	17.6	18.1	17.8	17.9	17.8	17.9
Rochester	20.9b	21.7a	21.0b	21.8a	21.1b	21.4a	21.1b
Rosemount	23.2b	25.4a	26.5a	25.4a	25.3a	24.7a	25.7a
	Corn grain yield at 15.5% bushels per acre						
Lamberton	193	189	202	193	198	194	197
Rochester	155a	168c	173bc	178ab	184a	168b	174a
Rosemount	166	177	181	181	177	179	174
	Corn Grain %K						
Lamberton	0.29	0.29	0.29	0.30	0.30	0.29	0.29
Rochester	0.30	0.29	0.30	0.30	0.29	0.29b	0.30a
Rosemount	0.35	0.34	0.36	0.35	0.35	0.32	0.35
	K Removed in Corn Grain (lb K_2O/ac)						
Lamberton	32.2	31.5	33.7	32.3	33.4	32.4	32.9
Rochester	25.9b	27.6ab	29.3a	29.9a	29.9a	27.6b	29.5a
Rosemount	32.9	34.4	36.9	35.9	35.2	35.8a	34.4b

Table 11. Summary of treatment main effects for three soybean locations where K fertilizer rates were applied in Fall or spring ahead of the 2023 cropping season. Treatments are considered significantly different at $P \leq 0.10$. Numbers followed by the same letter for individual site treatment main effects are not significantly different.

	K application rate (lb K_2O ac^{-1})					Application Time	
Location	0	40	80	120	160	Fall	Spring
	---------- R1 Leaf %K ----------						
Crookston	2.43c	2.65ab	2.56bc	2.78a	2.77ab	2.61	2.66
Faribault	1.61c	1.62c	1.89b	1.97ab	2.12a	1.87	1.81
Le Sueur	2.02b	2.12b	2.18ab	2.31a	2.31a	2.20	2.18
	---------- R1 Leaf Cl (ppm) ----------						
Crookston	977b	927b	921b	997b	1141a	957b	1028a
Faribault	326b	354b	460a	530a	510a	377b	495a
Le Sueur	384	432	431	479	476	432	451
	---------- Soybean grain yield at 13% bushels per acre----------						
Crookston	45.4	42.5	43.1	43.6	43.4	44.1a	43.0b
Faribault	48.2	41.9	42.9	48.7	41.1	44.3	44.8
Le Sueur	54.2	57.7	52.0	55.7	56.1	55.6a	53.7b
	---------- Soybean Grain %K ----------						
Crookston	1.89	1.84	1.87	1.91	1.93	1.89	1.89
Faribault	1.75b	1.75b	1.83a	1.83a	1.85a	1.80	1.81
Le Sueur	1.88	1.81	1.89	1.82	1.86	1.84	1.86
	---------- K Removed in Soybean Grain (lb K_2O/ac)----------						
Crookston	53.7	49.0	50.5	52.2	52.5	52.3	50.9
Faribault	53.0	45.9	49.2	55.8	47.8	49.9	50.7
Le Sueur	63.6	65.2	61.3	63.6	65.4	65.3	62.3
	---------- Soybean Grain Protein % ----------						
Crookston	32.9	33.0	32.7	33.0	33.2	33.0	33.0
Faribault	33.5	33.4	33.6	32.9	33.4	33.5	33.2
Le Sueur	34.2	34.1	33.9	34.7	33.8	34.0b	34.2a
	---------- Soybean Grain Oil % ----------						
Crookston	19.2	19.3	19.5	19.5	19.3	19.3	19.4
Faribault	20.1	20.3	20.0	20.7	20.4	20.2	20.4
Le Sueur	19.7	19.8	19.7	19.5	20.1	19.8	19.7

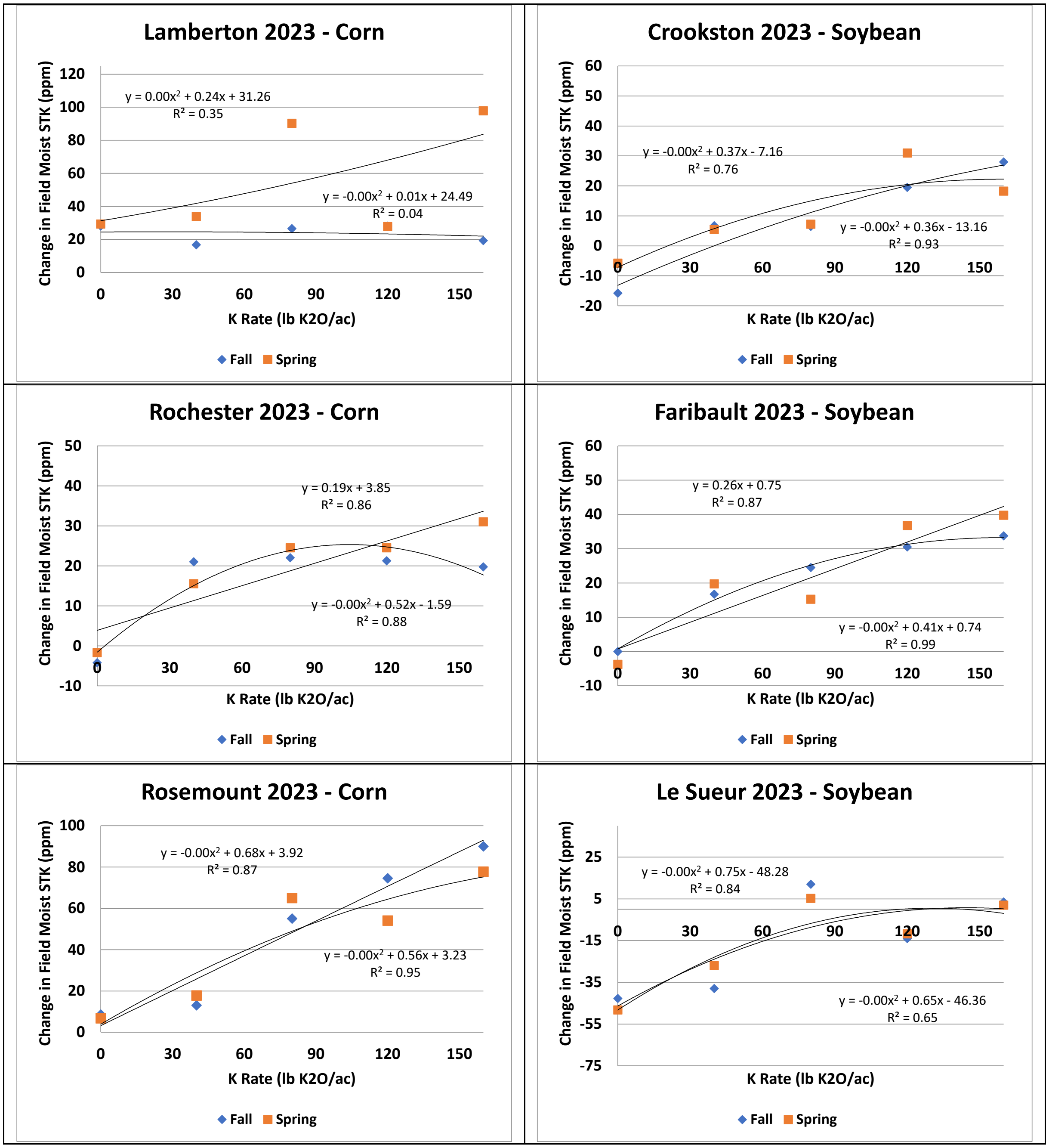

Figure 5. Summary of change in June ammonium acetate K extracted from moist soil samples K application ahead of corn or soybean in Fall 2022 or Spring 2023.

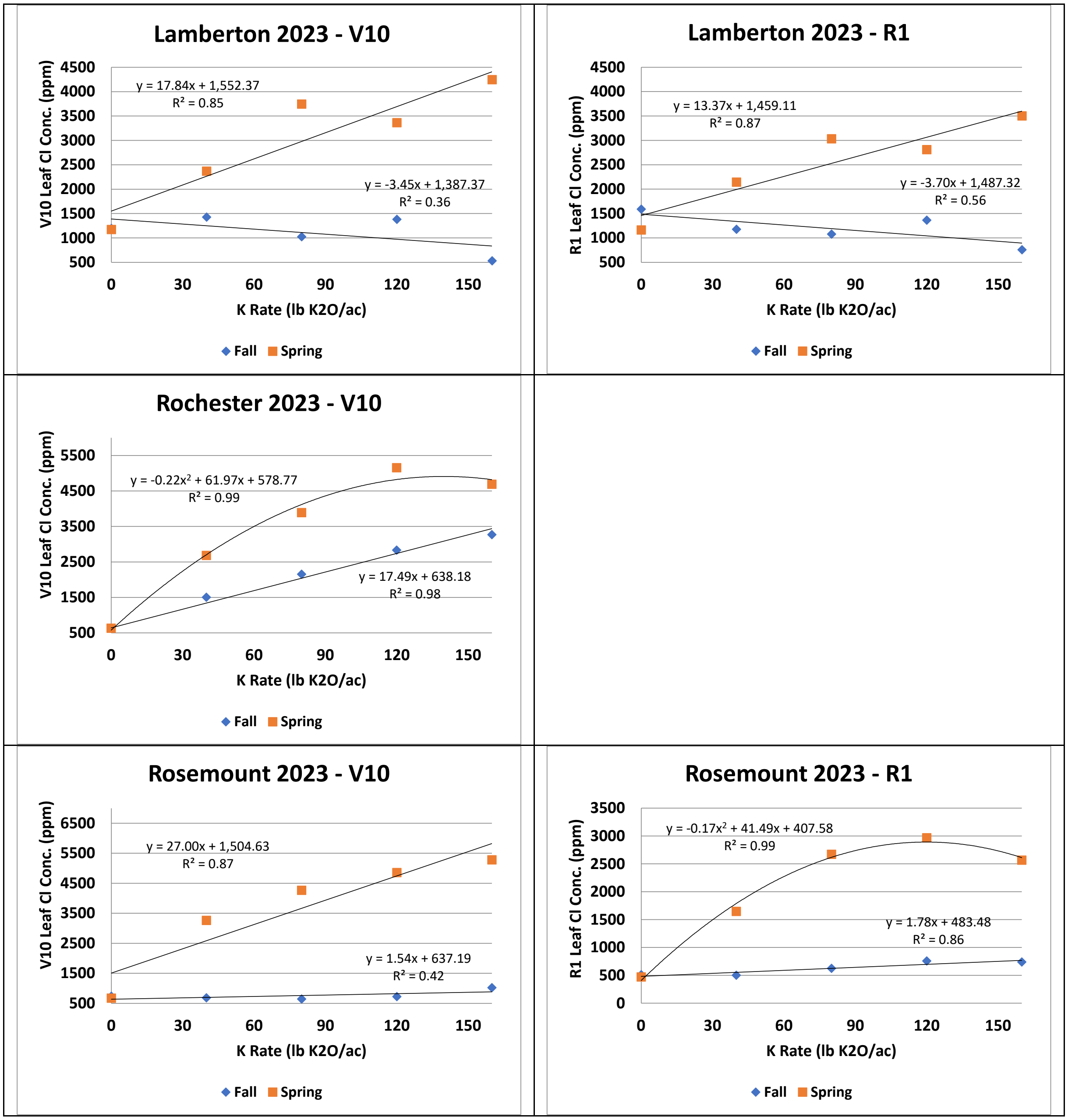

Figure 6. Summary of the impact of potash application in Fall or Spring on V10 or R1 corn leaf Cl concentration for three field sites established in 2023.

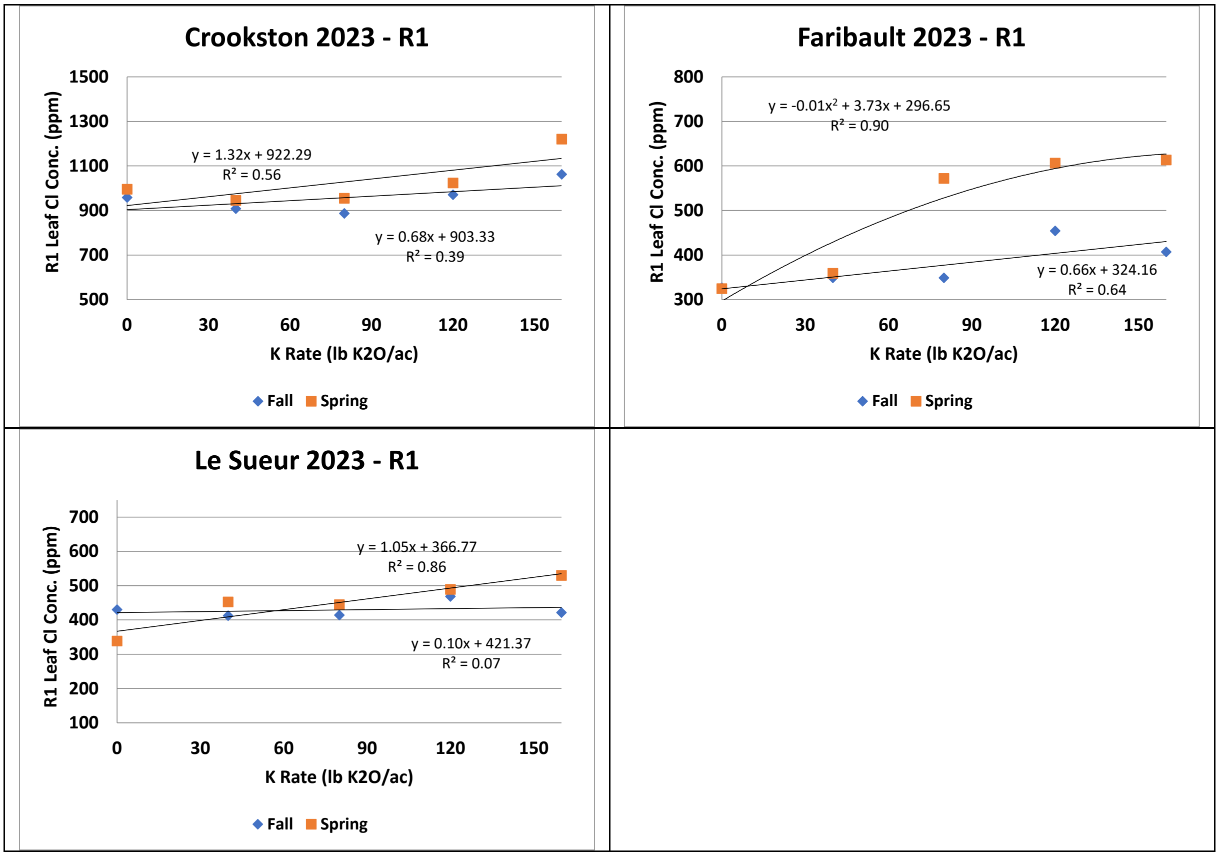

Figure 7. Summary of the impact of potash application in Fall or Spring on R1 soybean trifoliate Cl concentration for three field sites established in 2023.

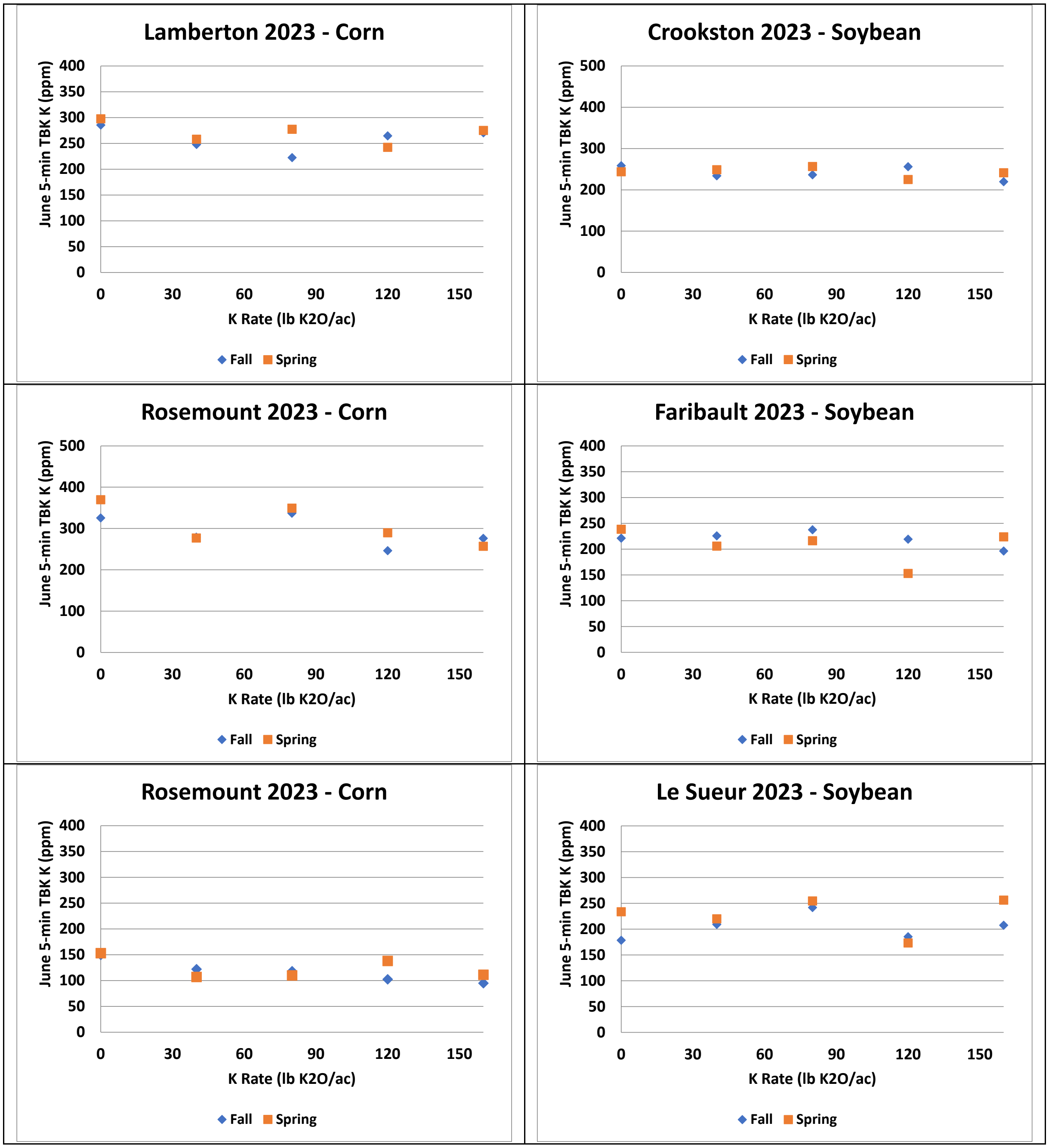

Figure 8. Summary of the amount of K extracted by incubating soil for 5 minutes with tetraphenylboron minus the amount of K extracted by the moist soil ammonium acetate test for samples collected in June of 2023.

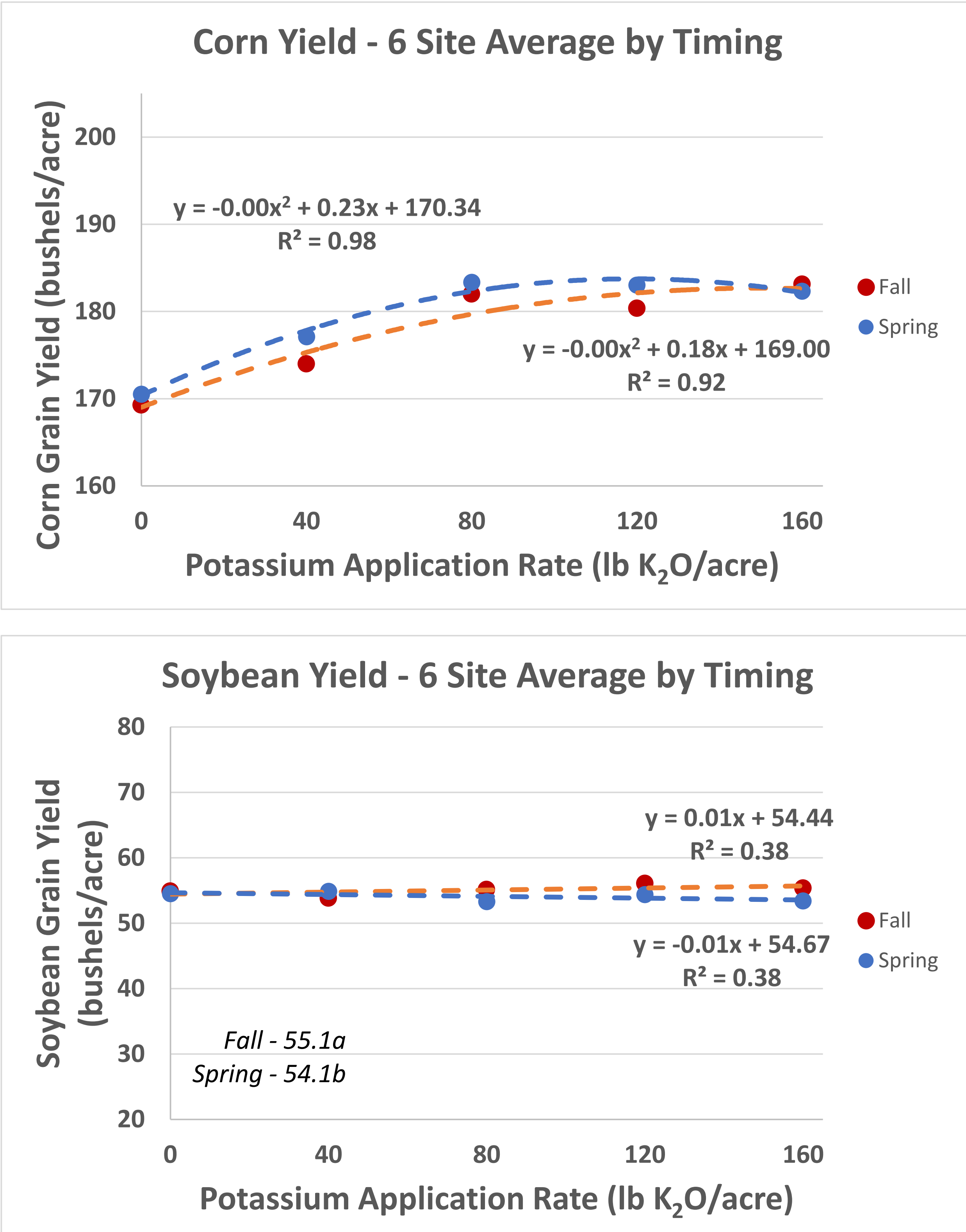

Figure 9. Summary of corn and soybean grain yield response to K as KCl applied in the fall versus in the spring. Data are summarized across six total site years from 2022-2023.

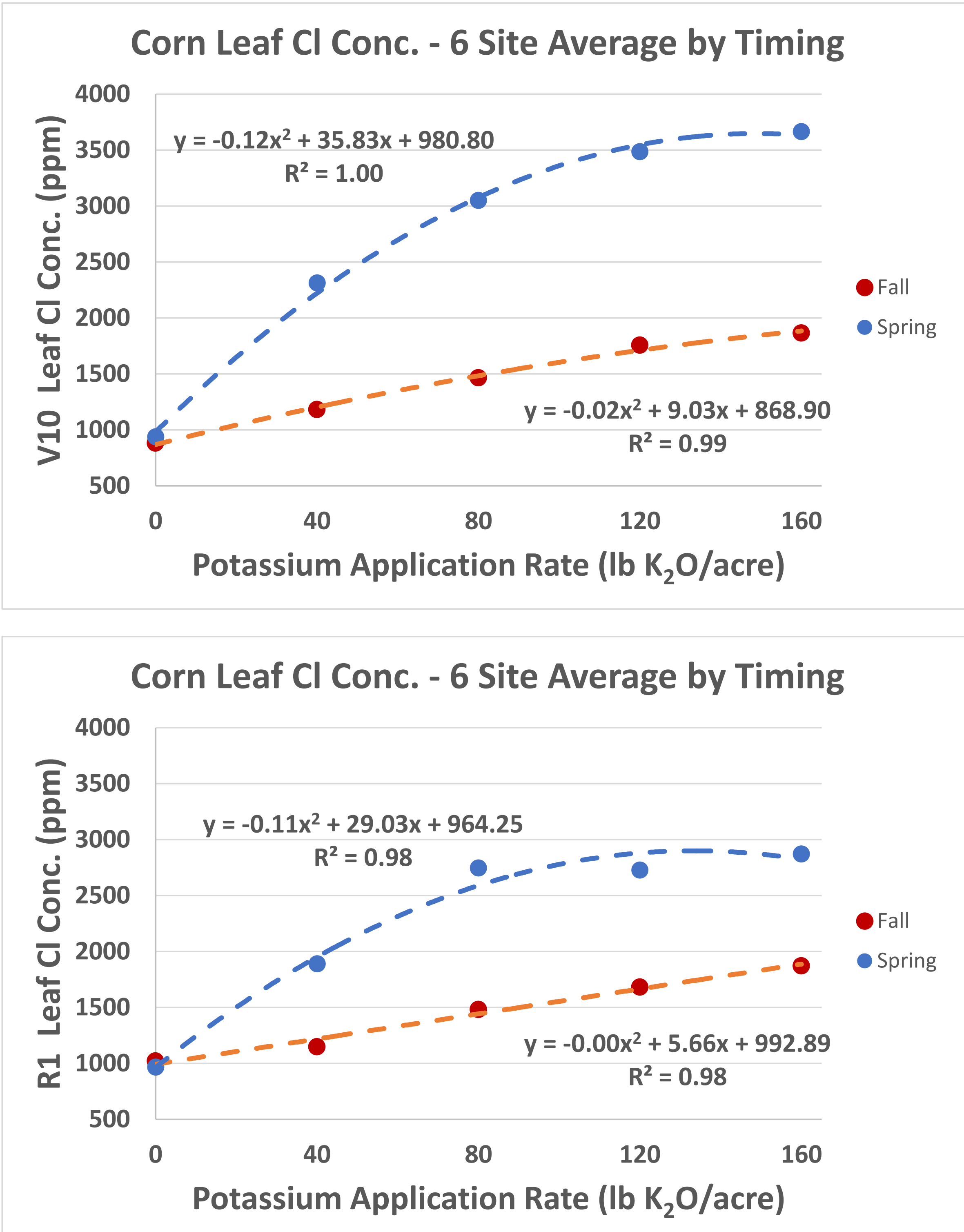

Figure 10. Summary of the effect of K application rate as KCl on the concentration of Cl in the uppermost fully developed corn leaf at V10 and the leaf opposite and below the ear at R1. Data are summarized across six total site years from 2022-2023.

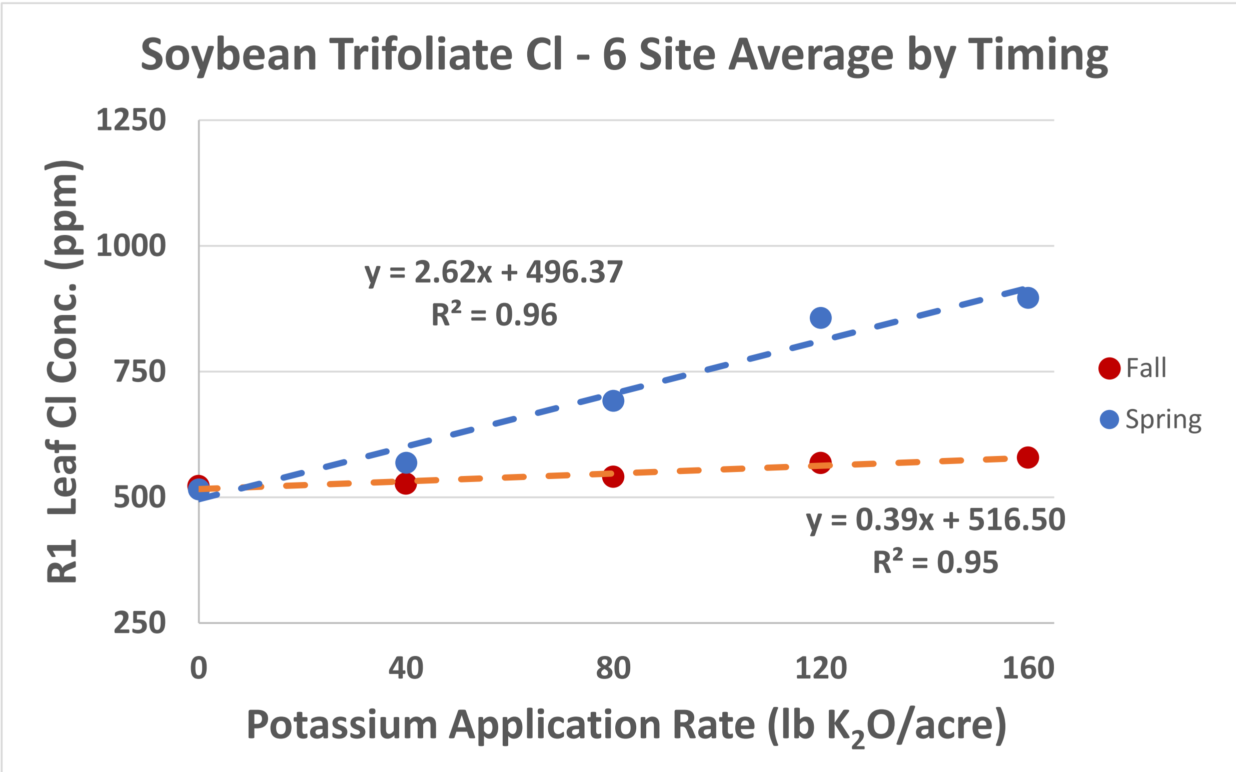

Figure 11. Summary of the effect of K application rate as KCl on the concentration of Cl in the uppermost fully developed soybean trifoliate at R1. Data are summarized across six total site years from 2022-2023.

Analysis across years (2022-2023)

Potassium rate and timing effects on average corn and soybean yield across site-years is summarized in Figure 9. For corn there was no effect of K timing on corn grain yield. However, yield was increased by the application of K up to 80 lbs K_2O applied per acre. There was no further increase or a decrease in corn grain yield when rates above 80 lbs K_2O per acre were applied. Soybean grain yield did not significantly differ among the different K application rates. However, soybean grain yield averaged 1 bushel per acre less across all site years when K fertilizer was applied in the spring. While the K rate by timing interaction was not significant at the $P \leq 0.10$ probability level, the general trend was a larger decrease in yield between fall and spring K application as K application rate increased. This effect will be evaluated over time and is important as it will allow for the assessment of the maximum rate of K_2O that could be applied directly ahead of soybean to no risk losing yield.

The effect of K application rate and time on corn leaf and soybean trifoliate K concentration across six site-years is summarized in Figures 10 and 11, respectively. Increasing rate of K application as KCl increased the concentration of Cl in leaf tissue as expected. The increase though was less for fall application compared to spring. In most cases the concentration of Cl was double when KCl was applied in the spring versus the fall for both crops. It is not known if the decrease in Cl concentration is directly a result of Cl leaching out of the root zone from fall application or Cl being tied up in the soil over time. If Cl uptake is of concern than the data indicates fall application of K would be best to reduce the amount of Cl taken up by a crop.