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Chloride Fertilization's Impacts on Kansas Winter Wheat Grain Yield During 2021-2022

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L.O. Pradella, J.R. Soler, and R.P. Lollato

Summary
Previous work suggests that wheat can respond to chloride fertility in Kansas and other regions, but this response depends on Cl availability and the wheat variety. In this study, we aimed to identify and quantify the effects of chloride fertilizer application in different areas and winter wheat varieties across Kansas. Sixteen field experiments were conducted during the 2021–2022 growing season. All experiments were conducted in a split-plot design with Cl fertility levels as whole plot (0 or 20 lb Cl/a) and wheat variety as subplots, with either three or four replicates. One protocol evaluated 24 winter wheat varieties in three locations, while the second protocol evaluated two winter wheat varieties in 13 locations. Chloride fertilization occurred using ammonium chloride and the remaining N rate was applied as urea so that it was not limiting for grain yield. Fertilizer applications occurred in the spring, at the end of the tillering stage (Feekes 4). At all experiments, two fungicide applications (Feekes 7 and 10.5) ensured that diseases were not a confounding factor. Across experiments and treatments, total available Cl ranged from 13 to 63 lb/a, and grain yield ranged from 35 to 92 bushels per acre. The results of these 16 experiments predominantly suggested that the wheat variety × location interaction determined wheat yield, only with trends of Cl fertilization effect ($P < 0.08$). Chloride available between soil supply and fertilizer applied was associated positively with chloride concentration in the wheat biomass tissue at anthesis, and had an exponential rise to maximum relationship with relative grain yield. These results are constrained to a single growing season, but showed a limited potential benefit of Cl fertilization under the studied soil and weather conditions. Expanding the study to locations with less available Cl at sowing, or greater precipitation amounts, could likely increase the chances of finding positive results for Cl fertilization.

Introduction
Kansas wheat production is often exposed to environmental stresses (Lollato et al., 2020a) which leads producers to a conservative management of the crop (Jaenisch et al., 2021). Consequently, there are large yield gaps between the potential and actual yield of winter wheat in the state (Jaenisch et al., 2021). Previous research has demonstrated that improved management practices, including that of fertilizer, could help reduce the yield gaps (de Oliveira Silva et al., 2020, Jaenisch et al., 2022; Lollato et al., 2019a, b).

Topdressing chloride (Cl) fertilizer can increase winter wheat yields, especially when the soil has a low Cl concentration (Ruiz Diaz et al., 2019). This response may be cultivar-specific (Ruiz Diaz et al., 2012). Wheat response to Cl is generally expressed in improved color, suppression of fungal disease, and increased yield (Ruiz Diaz, 2019). The symptoms of Cl deficiency can be confounded with pathogenic diseases; thus, it is important to control diseases in studies evaluating Cl response (Engel et al., 1997). The objectives of this study were to quantify the effects of Cl application on wheat yield and its dependency on varieties across the state of Kansas.

Procedures

Treatments, Experimental Design, and Management

Two different field studies were conducted during the 2021-2022 winter wheat growing season. The first study compared 24 winter wheat varieties as affected by the presence or absence of chloride fertilization via ammonium chloride at a rate of 31 lb/a (~ 20 lb/a of chloride) in three locations (Ashland Bottoms, Hays, and Hutchinson). The second study had a more quantitative approach and was established across 13 locations in Kansas (Table 1), but only explored two varieties with contrasting Cl response based on previous data (WB4303, highly symptomatic; RockStar, highly asymptomatic) as exposed to the same two Cl fertilization regimes. The experimental design was a split-plot with three to four replicates and Cl fertilizer as the whole plot and variety as the subplot. Fertilizer applications occurred at spring greenup (Feekes 4) at the same time as the urea application. The urea rates were adjusted to the fertilization treatment, aiming to apply the same amount of nitrogen per area (approximately 190 lb N/a so that N was not a limiting factor). At all experiments, fungal diseases were controlled with two applications of 13 fluid ounces per acre of Nexicor foliar fungicide. Measurements included initial soil fertility at the study sites (one composite sample consisting of 15 individual cores from 0 to 6 and 6 to 18 inches of depth per site), biomass sampled from 3.28 linear feet at anthesis (Feekes 10.5) that was sent to the lab for chloride concentration analysis, and grain yield at harvest maturity (corrected for zero moisture content). Weather data were retrieved from the Kansas Mesonet (https://mesonet.k-state.edu/) using the nearest weather station to each field experiment.

Statistical Analyses

A three-way ANOVA was performed where variety, fertilization treatment, location, and their interactions were considered fixed effects, and fertilization nested within replication and location was a random effect. Least square means were grouped using Tukey's test ($p < 0.05$). Non-linear regressions were used to detect relationships between total Cl availability and Cl concentration at anthesis, as well as Cl availability and wheat relative grain yield.

Results

Weather and Soil Conditions

Seasonal precipitation ranged from 5.6 to 26 inches (data not shown). Soil Cl concentration ranged from 2.4 to 11.4 ppm depending on location and evaluated depth (Table 1).

Grain Yield

In the trial evaluating the Cl presence in 24 winter wheat varieties at three locations, a significant variety × location occurred for grain yield, suggesting that the different variety performances depended on location—which is typical in agronomic trials (Munaro et al., 2020; Lollato et al., 2020b). In Ashland Bottoms, the varieties WB4401, AG Golden, KS Ahearn, and KS Hatchett were in the highest yielding group; while in Hutchinson this group was composed of SY Wolverine, WB4699, and Joe. In Hays, there were no statistical differences among the varieties evaluated. While there was a tendency of location × chloride interaction, it was only at $P = 0.12$ (Table 2).

In the quantitative trial evaluating the response of only two varieties to Cl fertilization at 13 locations, there were significant interactions between variety × location and a tendency for a chloride × location interaction ($P = 0.08$; Table 3). These interactions suggested that WB4303 out-yielded RockStar in two locations; RockStar out-yielded WB4303 in eight locations, and there were no significant differences between varieties in three locations. The presence of Cl only impacted yields significantly in two locations, increasing or decreasing yields (Table 3).

Relationships Among Available Chloride, Biomass Chloride Concentration, and Grain Yield

Across the entire database of 16 trials, the total amount of Cl available accounting for soil available Cl in the 0- to 18-in. depth plus the fertilizer applied, ranged from 13 to 63 lb Cl/a (Figure 1). Available Cl related linearly and positively to Cl concentration in the biomass at anthesis (Figure 1A), and had an exponential rise to the maximum relationship with relative grain yield (Figure 1B).

Preliminary Conclusions

As varieties were the main effects interacting with the environment to drive winter wheat yields in this research, results show that Cl fertilization provided a limited benefit at these locations. These preliminary conclusions are constrained by the environments studied, which were predominantly dry and with relatively high soil available Cl. This research will continue to explore more environmental conditions and soil types potentially driving wheat response to Cl fertilizer.

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Table 1. Results from the soil fertility analyses for the 0 to 6 and for the 6 to 18-inch depth layers from each location study location during the 2021-2022 growing season

Location	Depth	OM	pH	NO_3-N	P-M	K	CEC	Cl	Sand	Silt	Clay
	in.	%		-------------	ppm	-------------	meq/100 g	ppm	---------------	%	---------------
Ashland Bottoms	0 to 6	1.7	5.8	26.7	54.6	256	8.07	11.4	38	54	8
Ashland Bottoms	6 to 18	0.8	7.2	5.6	31.2	156	9.22	2.5	35	53	12
Belleville	0 to 6	2.7	5.1	17.5	75.5	571.9	25.32	4.5	20	56	24
Belleville	6 to 18	2.8	6	8.6	57.1	730	28.19	5.1	10	54	36
Great Bend	0 to 6	1.9	5.7	21.9	164.1	618.9	23.87	7.2	20	54	26
Great Bend	6 to 18	1.3	7.2	12.9	57	557.9	27.7	8.4	20	40	40
Hays	0 to 6	1.8	6	26.4	76.4	709.3	25.1	4.1	18	52	30
Hays	6 to 18	2	6.4	18.7	45.5	614.2	28.02	3.3	22	42	36
Hutchinson (early)*	0 to 6	2.5	5.4	47	61.2	324.5	22.23	4.9	28	48	24
Hutchinson (early)*	6 to 18	2.7	7	43.5	36.1	295.9	25.49	5.3	34	39	27
Hutchinson (late)	0 to 6	3.3	5.6	34.5	84.6	434.7	25.11	4	34	38	28
Hutchinson (late)	6 to 18	2.3	5.9	21.2	51.6	386	26.73	3.2	26	44	30
Hutchinson (optimum 1)	0 to 6	1.6	6.7	37.7	46.9	214	15.19	2.4	38	42	20
Hutchinson (optimum 1)	6 to 18	1.7	7.5	34.4	24.4	216.6	26	2.5	36	40	24
Leoti	0 to 6	1.7	6.8	28.8	74.7	692.3	19.01	5.8	26	46	28
Leoti	6 to 18	1.8	7.4	20.9	32.7	677.3	26.31	5	26	43	31
Manhattan	0 to 6	2.3	6.6	10.4	23.1	243.2	26.31	4.1	22	50	28
Manhattan	6 to 18	3	7.2	7.5	13.4	260.3	28.09	3.2	22	46	32
Solomon (soybeans)	0 to 6	4.5	7.1	22.3	62.2	263	21.16	6.3	40	36	24
Solomon (cover crops)	0 to 6	2.9	7.4	11.8	42.8	349.8	22.67	6.1	20	44	36
Solomon (cover crops)	6 to 18	2.5	7.2	9.8	18.5	325.5	23.35	7.4	20	41	39
Solomon (wheat)	0 to 6	2.4	7	23.7	25.9	337.5	21.73	7.8	10	54	36
Solomon (wheat)	6 to 18	3	7.6	10	10.2	348.6	28.63	4.7	6	52	42

OM = organic matter. CECS = cation exchange capacity.

* The study was replicated in the field here labeled Hutchinson (early) also during the optimum sowing time; thus, these soil values also refer to the study Hutchinson (optimum 2).

Table 2. Least square means of grain yield of 24 winter wheat varieties exposed to two chloride fertilization practices at three locations during the 2021-2022 growing season

	Ashland Bottoms			Hays			Hutchinson		
Variety	No	Yes	Mean	No	Yes	Mean	No	Yes	Mean
	bu/a								
AG Golden	**61.0**	**67.4**	**64.2a**	67.2	68.4	67.8	65.0	61.6	63.3
Bob Dole	56.7	59.7	58.2	58.7	69.2	64.0	59.7	57.8	58.8
DoubleStop CL Plus	56.5	48.6	52.5	52.2	52.4	52.3	54.7	54.3	54.5
Gallagher	61.8	61.4	61.6	56.8	57.5	57.1	57.5	54.9	56.2
Green Hammer	55.7	53.8	54.8	53.7	64.4	59.0	56.5	55.8	56.2
Joe	61.8	57.1	59.4	62.3	60.1	61.2	**66.2**	**64.3**	**65.3a**
KS Ahearn	62.1	63.8	62.9	56.5	56.1	56.3	62.7	63.6	63.1
KS Dallas	55.5	58.6	57.0	72.8	63.5	68.2	61.2	61.9	61.6
KS Hatchett	61.9	63.3	62.6	59.5	63.0	61.3	61.9	59.8	60.9
LCS Link	57.0	61.5	59.3	57.1	63.6	60.3	59.0	59.5	59.3
LCS Valiant	55.3	61.1	58.2	55.7	56.7	56.2	60.5	62.8	61.6
Larry	62.6	58.8	60.7	64.7	59.4	62.0	62.5	59.3	60.9
RockStar	60.7	60.7	60.7	59.0	54.5	56.8	65.3	61.0	63.2
SY Monument	57.7	65.9	61.8	57.1	65.0	61.1	63.5	62.2	62.8
SY Rugged	51.0	50.1	50.6	67.0	69.3	68.1	55.3	53.8	54.5
SY Wolverine	**62.5**	**65.3**	**63.9a**	62.9	62.1	62.5	**70.7**	**67.4**	**69.1a**
Showdown	57.0	62.1	59.6	57.8	63.4	60.6	62.1	61.6	61.8
Smith's Gold	56.3	56.7	56.5	56.7	60.5	58.6	57.0	57.9	57.5
WB4269	59.3	59.1	59.2	62.5	59.9	61.2	63.0	60.3	61.6
WB4303	59.3	59.7	59.5	55.2	60.4	57.8	60.5	57.8	59.1
WB4401	**67.7**	**69.3**	**68.5a**	68.8	64.7	66.8	56.5	55.6	56.1
WB4595	60.6	57.9	59.3	68.9	60.1	64.5	65.4	63.1	64.3
WB4699	60.9	62.2	61.6	63.5	63.6	63.6	**65.1**	**72.5**	**68.8a**
Zenda	55.2	55.5	55.4	59.9	64.3	62.1	52.7	52.8	52.8
Mean	59.0	60.0	59.5	60.7	61.8	61.2	61.0	60.1	60.5
Source of variation									
Variety	0.2			0.5			0.2		
Chloride	<0.0001			0.2			<0.0001		
V × Cl	0.31			0.93			0.95		

Varieties in the highest yielding group for Ashland Bottoms and Hutchinson are shown in bold.

Table 3. Least square means of grain yield of two winter wheat varieties exposed to two chloride fertilization practices at thirteen locations during the 2021-2022 growing season

		Variety		Source of variation		
Location	**Chloride**	**RockStar**	**WB4303**	**Chloride**	**Variety**	**Cl × V**
Ashland Bottoms	No	58.4	56.8	0.94	0.35	0.08
	Yes	55.0	60.0			
Belleville	No	79.3	74.1	0.67	0.44	0.36
	Yes	77.8	78.2			
Great Bend	No	28.4	**33.1**	0.93	0.05	0.45
	Yes	29.8	**32.1**			
Hays	No	**69.4**	56.1	0.40	<.0001	0.62
	Yes	**72.0**	56.8			
Hutchinson (early)	No	**70.0**	58.4	0.27	<.0001	0.80
	Yes	**68.4**	57.3			
Hutchinson (late)	No	**41.6**	37.7	0.86	0.00	0.92
	Yes	**41.9**	37.7			
Hutchinson (optimum 1)	No	54.8	51.1	0.17	0.08	0.78
	Yes	52.1	47.2			
Hutchinson (optimum 2)	No	**77.4**	66.7	0.13	0.00	0.15
	Yes	**71.5**	66.5			
Leoti	No	**55.1**	42.0	0.84	<.0001	0.48
	Yes	**56.5**	41.2			
Manhattan	No	**58.5**	49.5	0.01	<.0001	0.65
	Yes	**55.3**	45.1			
Solomon (CC)	No	**44.1**	36.0	0.23	0.02	0.23
	Yes	**44.1**	41.2			
Solomon (soybeans)	No	32.8	**36.9**	0.06	0.02	0.11
	Yes	36.2	**37.2**			
Solomon (wheat)	No	**66.4**	61.3	0.79	0.00	0.97
	Yes	**66.7**	61.6			

Varieties in the highest yielding group are shown in bold.

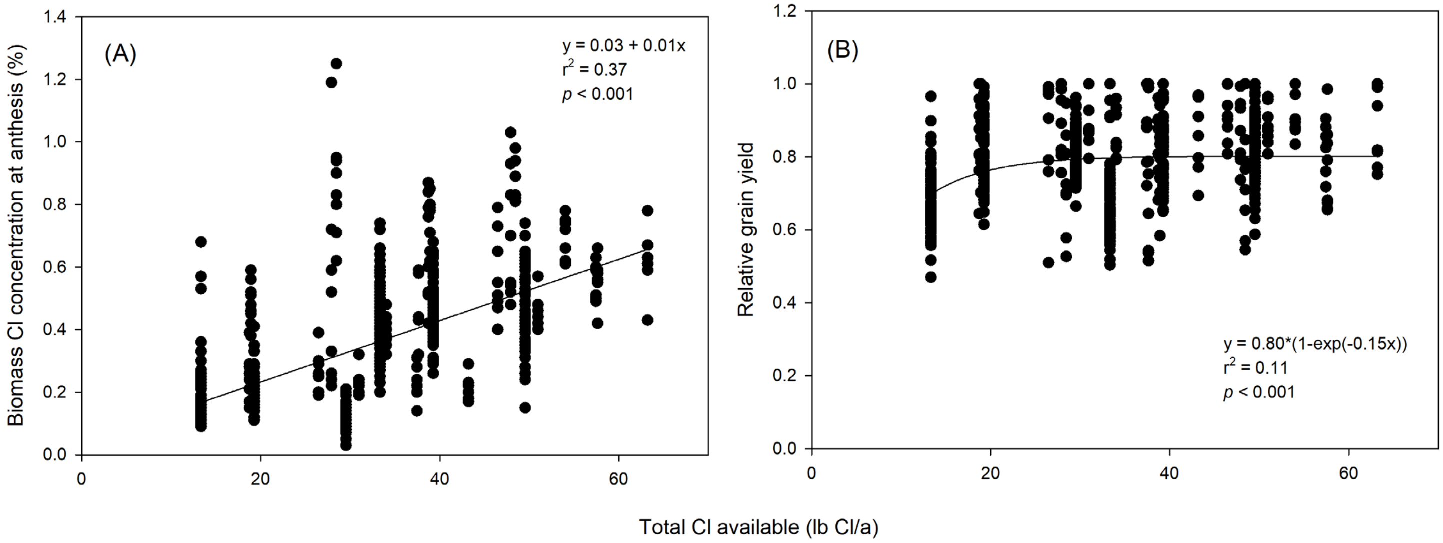

Figure 1. Relationship between total chloride available (account for soil Cl in the 18-inch profile plus Cl fertilizer applied) (A) biomass chloride concentration at anthesis and (B) relative grain yield across the entire database of 16 experiments across Kansas during the 2021-2022 growing season.