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ARTICLE

Interaction between chloride and both macro- and micronutrients in annual canarygrass

William Earl May and Michael MacGregor

Abstract: Annual canarygrass (*Phalaris canariensis* L.) has a larger response to chloride (Cl^-) fertilizer than other cereal crops. This unexpected response prompted further research for unexpected interactions between Cl^- and other nutrients in annual canaryseed. The objective of this study was to compare the interaction of macronutrients and micronutrients with Cl^- on the development and grain yield of annual canarygrass. Thirteen fertilizer combinations were applied to determine the effect of macro- and micronutrients on annual canarygrass. A field study was conducted at six locations across Saskatchewan over a 4 yr period using a randomize complete block design. Grain yield had a strong chloride response at 7 of the 21 site years with a 70% increase in grain yield over the 7 site-years. A sideband application or surface application of Cl^- were both effective. At the responsive sites without the addition of Cl^-, the addition of other nutrients is not effective while at the non-responsive sites, responses to the nutrients can be achieved without the addition of Cl^-. Chloride impacted canarygrass during reproductive development. Nitrogen is the major nutrient Cl^- interacted with in this study. Canarygrass is not more responsive to phosphorus, potassium, sulfur, zinc, copper, manganese, and boron than other cereals. In conclusion, at Cl^--responsive sites the application of nutrients are ineffective in the absence of Cl^- fertilizer. In addition, the sensitivity of annual canarygrass to Cl^- indicates that it could be used to investigate the role of Cl^- in cereal crop development and grain yield.

Key words: agronomy, chloride, nitrogen, phosphorus, crop physiology.

Résumé : Le phalaris des Canaries (*Phalaris canariensis* L.) réagit plus aux engrais chlorés (Cl^-) que d'autres céréales. Cette réaction inattendue a suscité des recherches approfondies visant à établir s'il existe des liens inhabituels entre le chlore et d'autres oligoéléments, chez la plante. Les auteurs voulaient comparer l'interaction des macronutriments et des oligoéléments avec le chlore au niveau du développement du phalaris et de son rendement grainier. À cette fin, ils ont utilisé treize mélanges d'engrais et ont jaugé les effets des macronutriments et des oligoéléments sur la plante. Pendant quatre ans, ils ont poursuivi une étude sur le terrain à six endroits, en Saskatchewan, dans le cadre d'une expérience en blocs aléatoires complets. Le rendement grainier du phalaris a fortement réagi au chlore sept années-sites sur 21 en augmentant de 70 %. L'application de l'engrais Cl^- en bandes latérales s'avère aussi efficace que son épandage en surface. Ajouter d'autres éléments nutritifs aux endroits où le phalaris avait réagi sans utilisation de l'engrais chloré n'a eu aucun effet sur la plante, mais là où aucune réaction n'avait été relevée, des effets s'observent même sans qu'on ajoute l'engrais chloré. Le chlore agit sur le phalaris pendant le développement des caractères reproductifs. L'azote est le principal macronutriment à avoir interagi avec le chlore durant l'étude. Le phalaris ne réagit pas plus que les autres céréales au phosphore, au potassium, au soufre, au zinc, au cuivre, au manganèse et au bore. En résumé, aux sites où les auteurs ont noté une réaction à l'engrais chloré, l'application d'éléments nutritifs s'avère inefficace en l'absence de chlore. La sensibilité du phalaris au chlore pourrait servir à approfondir le rôle de cet élément dans le développement des céréales et leur rendement grainier. [Traduit par la Rédaction]

Mots-clés : agronomie, chlore, azote, phosphore, physiologie végétale.

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Introduction

Annual canarygrass (*Phalaris canariensis* L.) is a cereal crop whose primary market is caged birds. Recently glabrous canarygrass has been approved by Health Canada for human consumption as a gluten-free grain, creating the potential for new demand from an emerging market (Health Canada 2016). Canada has accounted for 69% to 79% of the world's annual canarygrass with over 90% of Canada's production focused in Saskatchewan (FAO 2017). Annual canarygrass was first evaluated as a hay crop in 1896 and as a grain crop in 1906 at Indian Head, SK (MacKay 1896, 1907). In Saskatchewan, annual canarygrass has become an important alternative cereal to durum wheat (*Triticum turgidum* L. ssp. Durum (Desf.) Huns.] and spring wheat (*Triticum aestivim* L.). Growing annual canarygrass allows growers to spread out their economic risks by accessing an unrelated market.

Chloride (Cl^-) has traditionally been considered a micronutrient (Broyer et al. 1954; Fixen 1993; Xu et al. 2000). Chloride is an essential micronutrient for oxygenic photosynthetic organisms (Rivalta et al. 2011); however, Cl^- can accumulate to the level of other macronutrients in plants as it is normally available in nature and actively taken up by higher plants (Wege et al. 2017). Franco-Navarro et al. (2016, 2019) found in tobacco plants, that Cl^- played specific roles in regulating leaf osmotic potential and turgor, allowing plants to improve leaf water balance parameters. In addition, Cl^- also altered water relations at the whole-plant level through reduction of plant transpiration. This was a consequence of a lower stomatal conductance, which resulted in lower water loss and greater photosynthetic and integrated water-use efficiency for biomass production. Recent research found that annual canarygrass responds to Cl^- as a fertilizer with an average yield increase of 24% when Cl^- was added in the form of KCl or $CaCl_2$ (May et al. 2012*b*). The addition of Cl^- increased panicle size and seeds per m^2 (May et al. 2012*b*). Kernel weight was also increased by Cl^- (May et al. 2013). These results indicate that Cl^- fertilizer is increasing the seed density by either increasing the success of flower initiation and seed set or reducing seed abortion during seed filling. Plant density, panicle density, test weight, and height were not affected by Cl^- (May et al. 2012*b*). Later research indicated that a wide range of cultivars of canarygrass responded to the addition of Cl^- fertilizer in the same manner (May et al. 2013). Fixen (1993) and Ruiz Diaz et al. (2012) both found a soil background level in wheat above which the addition of Cl^- no longer had significant effect. In canarygrass, the response to Cl^- has been less predictable and so far a soil residual level above which the application of Cl^- has no significant effect has not been determined.

As a cereal, annual canarygrass appears to have a greater response than other cereal crops including spring wheat, barley (*Hordeum vulgare* L.), and oat (*Avena sativa* L.) (Mohr et al. 1995*a*, 1995*b*). In Kansas, on soils with low Cl^- levels the addition of Cl^- fertilizer increased the grain yield of corn by 375 kg ha^{-1} and the grain yield of sorghum by 691 kg ha^{-1} (Lamond et al. 2000). In previous winter wheat studies the cut-off concentration for Cl^- in the residual in soil appears to be approximately 50 kg ha^{-1} in the first 60 cm, beyond that point there was no significant effect to the plant (Leikam et al. 2003). Canarygrass' strong response to Cl^- fertilizer created interest in the potential response of canarygrass to other nutrients.

Macronutrients are the largest proportions of most fertilizer blends purchased for farms today and contain molecules comprised of nitrogen (N), phosphorus (P), potassium (K), and sulfur (S). N increases grain yield in canarygrass and also affects plant height, panicle density, and test weight (Holt 1988; May et al. 2012*a*). P is one of the primary constituents of nucleic acids, energy metabolites such as ATP, and buffering molecules such as phosphate (Lambers and Plaxton 2015). P is critical to early season crop growth and development (Grant et al. 2001) and P fertilizer at seeding becomes especially important when root growth is restricted by abiotic factors such as drought (May et al. 2008). K has an important role in cell turgor pressure, and phloem transport, and a lack of K can increase the crop's susceptibility to abiotic stress and plant diseases. K is found naturally in many soils of the Canadian prairies which makes it more difficult to conduct thorough and conclusive experiments; however, there is some evidence to suggest that applications of potassium chloride (KCl) fertilizer can increase biomass and grain protein in wheat grown in lower K soils (Walsh 2020) and tiller density, grain test weight, and grain size in oats (Mohr et al. 2007). S is a constituent of some amino acids and thus proteins which contain the associated amino acids. It has been observed that the addition of S fertilizer can increase grain yield in winter wheat (Rasmussen and Allmaras 1986) and increase grain protein content in wheat (Kaiser et al. 2019).

Macronutrients are more rapidly consumed by plants, while micronutrients are absorbed at a slower rate. The micronutrients copper (Cu), zinc (Zn), manganese (Mn), and boron (B) all have specific roles in plant development. Hansch and Mendel (2009) provide an excellent review of the micronutrients under investigation in this study. Cu, Zn, and Mn protect the plant from reactive oxygen species and normalize chloroplast development and behavior (Baszyński et al. 1978; Cakmak 2008; Schmidt et al. 2013). In higher plants, deficiencies in Cu lead to lower Cu concentrations in chloroplasts, thereby lowering efficiency. Zn deficiencies affect gene expression and metabolism in cereals. Deficiencies in Mn can lower the efficiency and stability of photosystem II and lower grain yield (Schmidt et al. 2013; Ullah et al. 2017). A lack of Cl does not affect photosynthesis but does reduce the efficiency of the ATPase and the transformation of starch into sugars (Fixen 1993). B, in wheat, stimulates the structural and functional roles of the plasma membrane, sugar transport, and N fixation and

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Table 1. The fertility treatments used for the experiment.

Treatment	N $kg \cdot ha^{-1}$	P_2O_5 $kg \cdot ha^{-1}$	K_2O $kg \cdot ha^{-1}$	Cl $kg \cdot ha^{-1}$	S $kg \cdot ha^{-1}$	Cu $kg \cdot ha^{-1}$	Zn $kg \cdot ha^{-1}$	Combination of Cu, Zn, Mn, B $kg \cdot ha^{-1}$
1	0	0	0	0	0	0	0	N (0, 0, 0, 0)
2	15	0	24	18.1	0	0	0	N
3	30	0	24	18.1	0	0	0	N
4	30	30	24	18.1	0	0	0	N
5	30	30	24	18.1	15	0	0	N
6	60	30	24	18.1	15	0	0	N
7	60	30	0	0	15	0	0	N
8	60	30	24	18.1	15	3	0	N
9	60	30	24	18.1	15	0	3	N
10	60	30	24	18.1	15	0	0	Y (3, 3, 3, 1.5)
11	90	30	24	18.1	15	0	0	Y
12	60	30	24**	18.1**	15	0	0	N
13	60	30	0	18.1***	15	0	0	N

Note: **KCl broadcast on soil surface before seeding; N, P_2O_5 sideband at seeding.
***$CaCl_2$ broadcast on soil surface before seeding; N, P_2O_5 sideband at seeding.

assimilation into the plant (Seth and Aery 2017). The interaction between other nutrients and Cl^- has not been widely studied, and in his review Chen et al. (2010) concluded that plant species differ in chloride's interaction with other ions.

The objectives of this study were to determine the effect of macronutrients and micronutrients on the development and grain yield of canarygrass, if Cl^- interacts with other nutrients in annual canarygrass, the effectiveness of side banded versus surface spread Cl^- in annual canarygrass, and the level of residual Cl^- in the soil at which the grain yield will no longer respond to the addition of Cl^- fertilizer.

Materials and Methods

Site description and experimental design

For the purpose of this study the macronutrients of focus are N, P, K, and S, while Cl^-, Cu, Zn, Mn, and B are the micronutrients of focus (Saskatchewan ministry of Agriculture). Field studies were conducted in six locations across Saskatchewan (Indian Head, Swift Current, Melfort, Scott, Redvers, and Yorkton) over a 4 yr period (2014–2017) resulting in 21 site-years of data. Three site-years, Swift Current in 2015, Scott in 2016 and Redvers in 2014, were lost for various reasons.

The experimental design was a randomized complete block design with a single factor of 14 fertilizer treatments and four replications. The treatments are laid out in Table 1. The first treatment received no fertilizer and was then followed by a series of 13 treatments with additional nutrients added or removed. Treatment 2 received N, K, and Cl^- and in treatment 3 the rates of N, K, and Cl^- are increased. To test the impact of P, P is added in treatment 4 with the same rates of N, K, and Cl^-. To test the impact of S, S is added in treatment 5 and combined with all the rates of N, P, K, and Cl^- used in treatment 4. In treatment 6 the N rate is increased to 60 kg N ha^{-1} to reflect the recommended N rate while using the same rates of P, Cl^-, and S used in treatment 5. To determine the impact of Cl^-, the K and Cl^- are not applied in treatment 7 while using the same rates of N, P, and S used in treatment 6. To test the impact of Cu, Cu is added in treatment 8 and combined with the rate of N, P, K, Cl^-, and S used in treatment 6. To test the impact of Zn, Zn is added in treatment 9 and combined with the rate of N, P, K, Cl^-, and S used in treatment 6. To test the impact of Mn and B in treatment 10, Mn, B were added in combination with Cu, Zn and the rates of of N, P, K, Cl^-, and S used in treatment 6. To test the impact of a higher N rate, 90 kg N ha^{-1} was added in treatment 11 in combination with rates of P, K, Cl^-, S, Cu, Zn, Mn, and B used in treatment 10. All nutrients were side-banded during seeding except treatments 12 and 13, where only the Cl^- was applied to the soil surface before seeding. The Cl^- in treatments 12 was KCl and $CaCl_2$ in treatment 13. These two treatments can be used to separate the effects of K and Cl^-. These two treatments were added to the experiment in 2015.

The seeding date was mid-early May with an approximate seeding rate of 35 kg ha^{-1}. The cultivar used in this study was CDC Calvi. CDC Calvi is a glabrous annual canarygrass cultivar, developed for Saskatchewan by the Crop Development Centre at the University of Saskatchewan. The previous crop, seeding date, plot size, row spacing, location, elevation, and soil type are listed in Table 2. A no till cropping system was used across all sites, except Melfort in 2014, Yorkton in 2015 (both site years tilled and packed their plots before seeding) and Swift Current in 2016 (planted on Low Tillage Fallow).

Soil analysis

Soil sampling at each site consisted of sampling each plot for treatments 1 and 7 in the spring before seeding. Four soil cores were taken from each plot with sample

Table 2. Agronomic practices and physical features at each location in each year.

			Agronomic practices				Physical features			
Location	Year	Stubble	Seeding date	Plot size (m^2)	Plot dimensions (m)	Row width (cm)	Latitude	Longitude	Elevation (m)	Soil series[a]
Indian Head	2014	Canola	May 9	42.3	4.0 × 10.7	30.5	50°33′N,	103°39′W	579	Edgley Cudworth Clay Loam, Orthic Black Chernozem
	2015	Canola	May 11	42.3	4.0 × 10.7	30.5				Indian Head Heavy Clay, Rego Black Chernozem
	2016	Canola	May 9	42.3	4.0 × 10.7	30.5				
	2017	Canola	May 4	42.3	4.0 × 10.7	30.5				
Swift Current	2014	Wheat	June 2	11.7	2.1 × 5.5	22.9	50°15′N,	107°44′W	817	Swinton Silt Loam, Orthic Brown Chernozem soil
	2016	Fallow	May 14	11.7	2.1 × 5.5	22.9				
	2017	Wheat	May 18	11.7	2.1 × 5.5	22.9				
Melfort	2014	Canola	May 21	12.4	1.8 × 7	17.8	52°49′N,	104°36′W	490	Melfort Silt Clay Loam, Orthic Black Chernozem
	2015	Canola	May 19	12.4	1.8 × 7	17.8				
	2016	Canola	May 19	25.6	3.7 × 7	30.5				
	2017	Canola	May 11	25.6	3.7 × 7	30.5				
Scott	2014	Canola	May 13	15.2	1.5 × 10	25.4	52°21′N,	108°50′W	660	Scott, Orthic Dark Brown Chernozem
	2015	Barley	May 21	36.5	3.7 × 10	22.9				
	2017	Barley	May 19	36.5	3.7 × 10	22.9				
Redvers	2015	Canola	May 18	16.6	1.8 × 9.1	30.5	49°36′N,	101°43′W	595.9	Oxbow, Orthic Black Chernozem
	2016	Soybean	May 6	16.6	1.8 × 9.1	30.5				
	2017	Canola	May8	16.6	1.8 × 9.1	30.5				
Yorkton	2014	Canola	May 9	27.4	3.0 × 9.1	25.4	51°11′N,	102°29′W	500	Oxbow, Orthic Black Chernozem
	2015	Canola	May 19	35.8	3.4 × 10.7	25.4				
	2016	Canola	May 9	35.8	3.4 × 10.7	25.4				
	2017	Canola	May 19	35.8	3.4 × 10.7	25.4				

[a]Soil classification retrieved from SKSIS Working Group (2018).

depths of 0–15 cm and 15–60 cm taken. The four samples from each plot after being separated by depth were bulked together. The samples were tested for multiple nutrients including N (both depths), P (0–15 cm), K (0–15 cm), S (both depths), Cl^- (both depths), Zn (0–15 cm), Cu (0–15 cm), organic matter (0–15 cm). Analysis of Mn (0–15 cm), and B (0–15 cm) were added to the protocol at the end of 2015 growing season and the analysis was not uniformly applied to the soil from all the sites until 2017. At Yorkton in 2014 only treatment 1 was sampled and at Melfort, in 2014 and 2015 the soil samples were lost.

Soil residual P, K, and S were measured in a 0 to 15 cm depth. An $NaHCO_3$ extraction procedure (Hamm et al. 1970) was used to estimate residual soil N (NO_3), P, and K. Available Cl^- was determined by extraction of 5 g of soil with 50 mL of water followed by filtration and determination of Cl^- in the filtered extract using a Technicon™ Auto-analyzer II. (Inland Waters Directorate 1979). Available S was determined by extraction of 10 g of soil with 50 mL of 0.001 M $CaCl_2$ followed by filtration and determination of S in the filtered extract using a Technicon™ Auto-analyzer II (Hamm et al. 1973). A 12.5 g soil sample is shaken with 25.0 mL of DTPA-TEA (diethylenetriaminepentaacetic acid/triethanolamine) extractant solution for 2 h (McKeague 1978). This was filtered and analyzed for Cu, Mn, and Zn by ICP analysis on a Fisher Scientific iCAP6300 Duo.

In addition, pH, salinity, and soil texture were tested per sample at a depth of 0–15 cm. Salinity was measured by sampling for electrical conductivity in milli-Siemens. The soil physics data are missing for the Redvers site in 2016. Soil physics was only measured on a single sample bulked across the test at Yorkton in 2014.

Plant and panicle density

Plant counts were conducted 3 to 5 wk after seeding and annual canarygrass panicles were counted after panicle emergence was complete. Both plants and panicles were measured in two random 1 m sections of crop row within each plot and reported as number per square meter (m^{-2}).

Plant height, lodging, and maturity

Plant height was measured at two places in each plot and reported in centimeters (cm). Lodging was rated in each plot at physiological maturity using a 0 to 10 scale (0 = standing, 10 = completely lodged). Physiological maturity was reached when kernel moisture was approximately 30% to 35% and reported as days from seeding.

Kernel weight

Kernel weight expressed as grams per 1000 seeds, was calculated by weighing 250 seeds for all sites in 2015, weighing 200 seeds in 2016, and in 2017 a machine was used to count an approximately 8 g sample and weighing it again after the seeds were counted. The only exceptions were Melfort in 2016, which used the 2017 method and Swift Current in 2017 which counted 200 seeds.

Seeds per panicle

Seeds per panicle was calculated by converting yield to g m^{-2}, then dividing by the mass of one kernel (g), and then by the panicle density (panicles m^{-2}) to determine seeds $panicle^{-1}$.

Grain yield and test weight

Grain yield was expressed on a clean grain basis with using a 13% kernel moisture content and expressed as kilograms per hectare (kg ha^{-1}). Test weight was measured using the methods specified by the Canadian Grain Commission's Official Grain Grading Guide (2018) and expressed as grams per half litre (g 0.5 L^{-1}).

Statistical analysis

The statistical analysis from all the site years was using the PROC MIXED procedure of SAS software (Littell et al. 2006). Site-year and fertilizer treatment were fixed for all analyses to allow sites to be sorted for their response to Cl^-. The first step in the analysis was to determine which site-years had a grain yield response to Cl^-. This was done by using a contrast that compared the grain yield of treatments 6 and 7 at each site (Table 1). These treatments have the same level of applied nutrients except there is no Cl^- and K applied in treatment 7. Previous research found that canaryseed was responsive to Cl^- and not K and the assumption is that any impact observed in treatment 7 is due to Cl^-. This assumption is verifiable by comparing treatments 12 (KCl) and 13 (CaCl2). The sites that had a significant difference in grain yield for the contrast comparing treatments 6 and 7 were considered responsive sites and the sites that had a similar grain yield for treatments 6 and 7 were considered as non-responsive sites. This was done to more easily understand the effect of other nutrients and their interaction with the effect Cl^- has on the grain yield of canarygrass. A contrast was then used to examine the effect of a nutrient at just the non-responsive sites and a second contrast was used to examine the effect of a nutrient at just responsive sites. For all the variables, with the exception of N, the coefficients when two means were compared were −1 and +1 at each site year within the responsive and non-responsive sites groupings.

The N rate had a non-linear step in its growth with rates of 15, 30, 60, and 90. The values used for N were found using orthogonal matrices and rounded to four significant figures. For linear N the coefficients were: −0.5859, −0.3255, 0.1953, and 0.7160; and for quadratic N the coefficients were: 0.4960, −0.2806, −0.6787, and 0.4633.

Results and Discussion

Soil characterisation and environmental conditions

The nutrient levels, organic matter, pH, salinity, and texture of the soil before seeding are presented in Tables 3 and 4. The residual level of N in the soil from

Table 3. Soil test nutrient levels at pre-seeding over a depth of 0–15 cm and 0–60 cm at each location in each year.

Location	Year	Nitrate ($kg\ ha^{-1}$)		Sulphide ($kg\ ha^{-1}$)	Chloride ($kg\ ha^{-1}$)		Phosphate ($kg\ ha^{-1}$)	Potassium ($kg\ ha^{-1}$)	Zinc ($kg\ ha^{-1}$)	Copper ($kg\ ha^{-1}$)
		(0–15 cm)	(0–60 cm)	(0–15 cm)	(0–15 cm)	(0–60 cm)	(0–15 cm)	(0–15 cm)	(0–15 cm)	(0–15 cm)
Chloride responsive sites										
Indian Head	2014	6.5	31.0	196.3	19.1	128.4	10.6	425	5.4	3.4
Swift Current	2014	20.8	74.5	7.2	50.8	175.8	18.4	445	1.7	3.0
Yorkton	2014	20.3	43.2	28.5	62.9	73.4	36.1	297	.	.
Melfort	2015	.	.	.	.	.	.	.	.	.
Melfort	2017	8.2	21.6	11.6	57.3	95.1	61.6	393	9.8	3.1
Scott	2015	16.1	24.3	6.6	58.1	107.2	31.4	778	4.1	2.7
Scott	2017	7.3	47.8	11.2	48.5	102.3	57.2	864	6.2	2.9
Non-responsive sites										
Indian Head	2015	10.8	23.2	13.7	43.8	63.6	14.3	494	3.3	4.2
Indian Head	2016	13.3	34.0	22.2	29.4	96.1	11.7	560	4.5	5.1
Indian Head	2017	12.0	30.5	14.1	17.3	61.4	10.8	609	4.6	4.4
Swift Current	2016	17.6	45.8	572.7	77.6	222.1	11.1	494	1.2	2.4
Swift Current	2017	9.0	26.4	6.2	24.4	62.1	16.4	393	1.5	2.5
Melfort	2014	.	.	.	.	.	.	.	.	.
Melfort	2016	19.0	36.9	10.0	61.0	113.4	11.7	402	5.4	4.5
Scott	2014	7.3	20.0	15.9	47.8	120.6	25.2	455	4.0	3.3
Redvers	2015	30.7	56.6	61.2	35.5	123.0	13.5	288	1.5	1.8
Redvers	2016	35.4	92.2	302.2	45.7	177.9	32.4	536	2.4	3.2
Redvers	2017	136.6	300.8	59.0	30.4	142.5	16.6	371	1.9	0.8
Yorkton	2015	13.2	33.3	19.6	38.3	139.8	21.9	321	2.3	2.9
Yorkton	2016	19.4	37.5	22.0	49.3	153.0	20.0	429	2.8	3.2
Yorkton	2017	26.4	50.6	13.8	39.7	115.8	18.8	347	1.9	1.9

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Table 4. Soil test of pre-seeding nutrient levels, pH, salinity, and texture over a depth of 0 to 15 cm at each location in each year.

		Manganese ($kg\ ha^{-1}$)	Boron ($kg\ ha^{-1}$)	Organic matter (%)	pH	Salinity (mS)	Texture (%) Sand	Clay	Silt
Location	Year	(0–15 cm)	(0–15 cm)	(0–15 cm)	(0–15 cm)	(0–15 cm)	(0–15 cm)	(0–15 cm)	(0–15 cm)
Indian Head	2014	.	.	4.5	7.1	1.39	53	22	25
	2015	60.8	6.85	4.4	7.0	0.56	10	69	21
	2016	.	.	3.9	7.6	0.68	13	65	22
	2017	20.9	3.10	4.4	6.1	0.33	14	42	45
Swift Current	2014	.	.	3.4	6.5	0.43	33	26	42
	2016	55.5	0.95	2.4	7.0	1.65	35	26	39
	2017	59.7	0.57	2.8	6.8	0.52	16	54	30
Melfort	2014	.	.	.	.	.	.	.	.
	2015	.	.	.	.	.	.	.	.
	2016	52.9	1.36	6.6	6.4	0.52	28	41	32
	2017	39.3	1.70	5.6	6.5	0.52	16	36	48
Scott	2014	.	.	3.6	6.3	0.72	35	23	42
	2015	.	.	3.9	5.9	0.48	46	28	27
	2017	98.4	1.10	4.0	6.0	0.31	43	21	37
Redvers	2015	58.1	1.58	4.4	7.1	1.05	53	26	22
	2016	.	.	3.4	.	.	.	.	.
	2017	29.9	1.78	4.2	7.2	1.98	45	26	29
Yorkton	2014	.	.	7.2	7.3	0.67	33	30	36
	2015	.	.	4.4	6.9	0.76	36	31	33
	2016	78.7	1.79	4.6	7.2	0.58	30	34	36
	2017	34.1	1.79	4.6	7.6	0.80	45	22	32

the 0 to 15 cm depth ranged from 6.5 to 35. 4 $kg\ ha^{-1}$ and 23.2 to 92.2 $kg\ ha^{-1}$ in a 0 to 60 cm depth. The exception was the site at Redvers in 2017 which had high levels of residual N. P residual levels in the soil from a depth of 0 to 15 cm ranged from 10.6 to 61.6 $kg\ ha^{-1}$. Zn residual levels in the soil from a depth of 0 to 15 cm ranged from 1.2 to 9.8 $kg\ ha^{-1}$. Cu residual levels in the soil from a depth of 0 to 15 cm ranged from 0.8 to 5.1 $kg\ ha^{-1}$. The residual level of Cl- in the soil from the 0 to 15 cm depth ranged from 19.1 to 77.6 $kg\ ha^{-1}$ and 61.4 to 222.1 $kg\ ha^{-1}$ in a 0 to 60 cm depth.

The precipitation data is presented in Table 5 (Environment and Climate Change Canada 2020). Precipitation was within 20% of the 30 yr long-term average at 10 out of 21 site-years. Precipitation was above 120% of the 30 yr long term average at 6 out of 21 site-years and at 5 out of 21 sites precipitation was below 80% of the long term average for each site. The monthly average temperatures for each site are presented in Table 6. Average daily temperatures average across the growing season were within 10% of the 30 yr long term average at 16 out of 21 site years. At the other 10 site-years, the average daily temperate was between 110% and 120 % of the daily average temperature. Oxbow was used as a weather station for sites near Redvers as Redvers does not have 30 yr average data. Oxbow is approximately 50 km southwest of Redvers and is the closest station weather station monitored with the Environment and Climate Change Canada. The environmental conditions are important to note as Cl^-, S, and N move in the soil as moisture from precipitation moves through the soil.

Chloride response

The analysis and data presented in this paper is based on examining the effect of nutrients at the Cl^--responsive sites as one group and the non-responsive sites as a separate group to determine if a response or non-response to chloride is linked to any other nutrient effect on canarygrass. Grain yield had a strong chloride response at 7 of the 21 site years, Indian Head, Swift Current, and Yorkton in 2014, Melfort and Scott in 2015 and 2017. This is a less frequent grain yield response to Cl^- than observed in other studies (May et al. 2012*b*, 2013). The chloride level in the soil for the Cl^--responsive sites ranged from 19 to 63 $kg\ ha^{-1}$ in a 0–15 cm soil depth and this is similar to the residual level of chloride in the soil of the nonresponsive sites, and 17 to 78 $kg\ ha^{-1}$ in a 0–15 cm soil depth (Table 3). This similarity makes it difficult to develop a soil test to accurately predict a Cl^- response before the annual canarygrass is grown. This differs from winter wheat in Kansas where the

Table 5. Summary of growing season precipitation for selected experimental sites in Saskatchewan in 2014–2017.

		Precipitation (mm)							
Location	Year	April	May	June	July	August	September	6-month total (April-Sept)	% of 30-yr (1981–2010)
Indian Head	2014	60.4	36	199.2	7.8	142.2	42.3	487.9	166.7
	2015	9.5	15.6	38.3	94.6	58.8	67.8	284.6	97.3
	2016	13.9	74.7	50.2	107.9	21.9	40.5	309.1	105.6
	2017	18.5	10.4	65.6	15.4	25.2	12.4	147.5	50.4
Swift Current	2014	39.3	33.5	117	33.6	105.6	48.6	377.6	145.2
	2016	25.9	134.9	87.2	124.8	50.3	40.9	464.0	178.5
	2017	22.4	21	35.3	11	28	4.4	122.1	47.0
Melfort	2014	50.3	24.4	167.3	44.2	57.9	9.4	353.5	124.9
	2015	34.4	7.1	54.8	46.4	57.4	64.2	264.3	93.4
	2016	13.5	16.8	53.2	128.7	80.8	43.7	336.7	119.0
	2017	28.5	46.4	58	38.3	3.2	13.2	187.6	66.3
Scott	2014	41.2	23.1	60.4	80.9	30.1	23.6	259.3	94.8
	2015	16.7	4.6	65.8	48.2	69	45.4	249.7	91.3
	2017	30.9	69	37.5	29.5	59.9	20.8	247.6	90.5
Oxbow	2015	7.5	14.5	69.5	32.5	60.5	101	285.5	88.7
	2016	26.2	89	90	133.8	31	75.8	445.8	138.4
	2017	18	47.7	65.6	18.2	41.8	46.5	237.8	73.9
Yorkton	2014	59.8	45.5	235	21.5	64.3	62.3	488.4	149.4
	2015	9.9	8.1	28.2	123.1	45.6	40.7	255.6	78.2
	2016	8.9	74.7	66.4	90.5	67.8	32.6	340.9	104.3
	2017	21.6	51	80	78	62	14	306.6	93.8

Note: Environment and Climate Change Canada 2020.

Table 6. Summary of growing season average temperature for selected experimental sites in Saskatchewan in 2014–2017.

		Average temperature (°C)						6-month total	% of 30-yr
Location	Year	April	May	June	July	August	September	(April-Sept)	(1981–2010)
Indian Head	2014	0.1	10.2	14.4	17.3	17.4	12.3	11.9	92.0
	2015	4.8	10.0	16.2	18.1	17.0	12.2	13.1	100.5
	2016	3.7	12.8	16.9	17.6	16.9	12.8	13.5	103.7
	2017	4.2	11.6	15.5	18.4	16.7	11.3	13.0	99.8
Swift Current	2014	3.7	11.0	13.6	18.2	18.2	12.5	12.9	104.6
	2016	6.6	12.3	16.5	17.8	17.0	12.4	13.8	111.8
	2017	5.1	12.3	15.7	20.6	18.3	13.3	14.2	115.6
Melfort	2014	−2.8	13.5	12.8	17.1	16.8	14.3	12.0	97.7
	2015	7.4	11.2	17.0	17.7	17.3	12.9	13.9	113.8
	2016	3.2	13.6	17.2	18.1	16.3	11.9	13.4	109.4
	2017	4.3	11.6	17.7	19.1	18.2	15.0	14.3	117.0
Scott	2014	1.6	9.3	13.9	17.4	16.8	11.2	11.7	95.0
	2015	5.2	9.4	16.2	18.3	16.7	11.2	12.8	104.2
	2017	3.2	11.9	15.3	18.2	17.0	11.8	12.9	104.7
Oxbow	2015	5.9	11.3	17.0	19.5	18.9	13.8	14.4	111.9
	2016	4.4	13.0	17.2	18.6	18.6	12.7	14.1	109.5
	2017	5.4	12.1	15.6	19.9	17.4	12.7	13.9	107.6
Yorkton	2014	−0.5	10.5	14.5	18.2	17.7	12.5	12.1	94.4
	2015	5.0	10.5	16.7	19.3	17.5	12.9	13.7	106.1
	2016	2.4	13.4	17.3	18.8	16.9	12.7	13.6	105.8
	2017	4.5	11.1	15.5	19.0	17.4	13.6	13.5	105.1

Note: Environment and Climate Change Canada 2020.

Table 7. Analysis of variance for measured variables for plant development, grain yield, and qualities combined across years and locations.

Source of variance	Plant density	Panicle density	Seeds per panicle	Plant height	Plant l odging	Seed weight	Grain yield	Test weight
Treatment (trt)	0.0212	<.0001	<.0001	<.0001	<.0001	0.002	<.0001	<.0001
Site year	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
trt × Site year	<.0001	0.0233	0.007	<.0001	<.0001	0.0423	<.0001	<.0001
Contrasts								
Cl[a] (+Cl)[b]	NS[o]	NS	<.0001	0.0146	NS	0.0262	<.0001	<.0001
Cl (-Cl)[c]	NS	NS	NS	NS	NS	NS	NS	<.0001
Surface vs. sideband[d] (+Cl)	NS	NS	NS	NS	NS	NS	NS	NS
Surface vs. sideband (-Cl)	NS	NS	NS	NS	NS	NS	NS	NS
Surface vs. no chloride[e] (+Cl)	NS	NS	0.0005	0.0101	NS	NS	<.0001	<.0001
Surface vs. no chloride (-Cl)	NS	NS	NS	NS	NS	NS	NS	0.0096
KCl v $CaCl_2$[f] (+Cl)	NS	NS	NS	NS	NS	NS	NS	NS
KCl vs. $CaCl_2$ (-Cl)	NS	NS	NS	NS	NS	NS	NS	NS
Non-Chloride Nutrient[g] (+Cl)	NS	0.0005	NS	<.0001	NS	NS	NS	<.0001
Non-chloride nutrient (-Cl)	NS	<.0001	0.027	<.0001	<.0001	NS	<.0001	0.0082
Cu[h] (+Cl)	NS	NS	NS	NS	NS	NS	NS	NS
Cu (-Cl)	NS	NS	NS	NS	NS	NS	NS	NS
Zn[i] (+Cl)	NS	NS	NS	NS	NS	NS	NS	NS
Zn (-Cl)	NS	0.0179	NS	NS	NS	NS	NS	NS
Micro blend[j] (+Cl)	NS	NS	NS	NS	NS	NS	NS	NS
Micro blend (-Cl)	NS	NS	NS	NS	NS	NS	NS	NS
P[k] (+Cl)	NS	NS	NS	NS	NS	NS	NS	0.0183
P (-Cl)	NS	NS	NS	0.028	NS	NS	NS	NS
S[l] (+Cl)	NS	NS	NS	NS	NS	NS	NS	NS
S (-Cl)	NS	NS	NS	NS	NS	NS	NS	NS
N[m] (Linear) (+Cl)	0.0008	0.0073	NS	<.0001	<.0001	NS	0.0003	<.0001
N (Linear) (-Cl)	NS	<.0001	0.0091	<.0001	<.0001	NS	<.0001	0.0003
N[n] (Quad.) (+Cl)	NS	NS	NS	0.0102	NS	NS	NS	NS
N (Quad.) (-Cl)	NS	NS	NS	<.0001	NS	NS	NS	NS

[a]Contrast was −1(Treatment 7), +1(Treatment 6).
[b](+Cl) = combined site-years that were responsive to Chloride.
[c](-Cl) = combined site-years that were not responsive to Chloride.
[d]Contrast was −1(Treatment 6), +1(Treatment 12).
[e]Contrast was −1(Treatment 7), +1(Treatment 12).
[f]Contrast was −1(Treatment 12), +1(Treatment 13).
[g]Contrast was −1(Treatment 1), +1 (Treatment 7).
[h]Contrast was −1(Treatment 6), +1(Treatment 8).
[I]Contrast was −1(Treatment 6),+1(Treatment 9).
[j]Contrast was −1(Treatment 6), +1(Treatment 10).
[k]Contrast was −1(Treatment 3), +1(Treatment 4).
[l]Contrast was −1(Treatment 4), +1(Treatment 5).
[m]Contrast was −0.5859 (Treatment 2), −0.3255 (Treatment 3), 0.1953 (Treatment 6), +0.7160 (Treatment 11).
[n]Contrast was 0.4960 (Treatment 2), −0.2806 (Treatment 3), −0.6787 (Treatment 6), +0.4633 (Treatment 11).
[o]NS, not significant.

relationship between Cl^- levels in the soil and yield was consistent enough to allow the development of a soil test to predict the grain yield response to Cl^- levels in the soil (Leikam, et al. 2003). Previous research investigating the effect of Cl^- on annual canarygrass found a similar range found a similar range 15 to 91 kg ha^{-1} in a 0–15 cm soil depth (May et al. 2012b).

Contrasts were used to look at the effect of nutrients at responsive, Cl^- (+Cl^-), and non-responsive Cl^- (-Cl^-) sites and the results are presented in Table 7. The first contrast examines the effect of Cl^- at the responsive sites and the second contrast examines the effect of Cl^- at the non-responsive sites. As would be expected Cl^- had a large impact on grain yield at the responsive sites and not the non-responsive sites. The effect of the nutrient treatments on canarygrass grain yield is presented in Figs. 1 and 2. At the responsive sites without the addition of Cl^-, the addition of other nutrients

Fig. 1. The effect of nutrients on the grain yield of canarygrass at sites responsive to chloride fertilizer. Yes, these treatments contain the micronutrient blend.

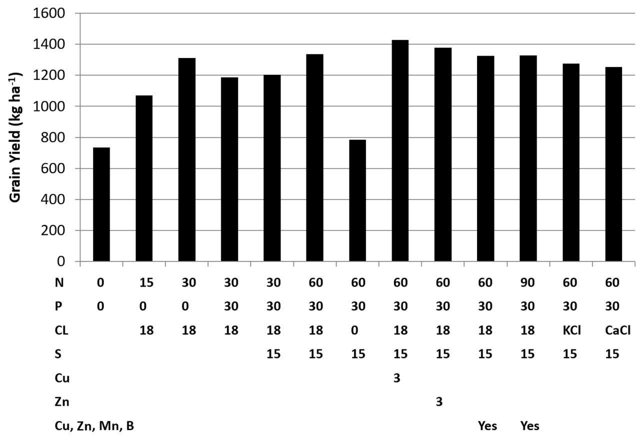
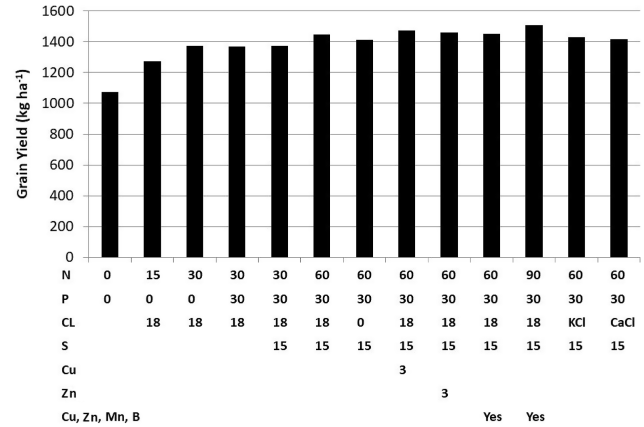


Fig. 2. The effect of nutrient on the grain yield of canarygrass at sites that were non-responsive to chloride fertilizer. Yes, these treatments contain the micronutrient blend.



including N is not effective, while at the non-responsive sites responses to the nutrients can be achieve without the addition of Cl^-. The grain yield increase ($P < 0.0001$) at the responsive sites was over 550 kg ha^{-1} or 70% (Fig. 1). Previous studies reported an increase of approximately 300 kg ha^{-1} or 25%; however, this was calculated across all the sites, both responsive and non-responsive (May et al. 2012*b*, 2013). In Kansas an 8% grain yield increase has been observed in winter wheat when averaged across all site-years (Ruiz Diaz et al. 2012). This highlights the greater sensitivity annual canaryseed has to a Cl^- deficiency compared with winter wheat. At the chloride responsive sites the addition of Cl^- increased seeds per panicle from 20.2 to 32.0 ($P < 0.0001$), seed weight from 7.63 to 7.90 g 1000 kernels^{-1} ($P = 0.0262$), height 87.8 to 91.7 cm ($P = 0.0146$), and test weight from 338.4 to 351.5 g 0.5 L^{-1} ($P < 0.0001$), but not plant or panicle density indicating that the chloride response occurred at or after aanthesis (Tables 7 and 8). At the non-responsive sites, only test weight was affected by Cl^- with a small increase from 354.7 to 358.8 g 0.5 L^{-1} ($P < 0.0001$) with the addition of chloride (Tables 7 and 9). When surfaced applied Cl^- in treatment 12 was compared with sided banded Cl^- in treatment 6 the effect of the chloride did not differ (Table 7; contrast surface vs. sideband). At the chloride responsive sites, when surface applied chloride was compared with the no chloride treatment (contrast surface vs. no chloride (+Cl^-) in Table 7) the surface applied chloride increased seeds per panicle from 20.2 to 33.7 ($P < 0.0001$), plant height from 87.8 to 91.6 cm ($P = 0.0146$), grain yield from 785 to 1276 kg ha^{-1} ($P < 0.0001$) and test weight from 338.4 to 349.4 g 0.5 L^{-1} ($P < 0.0001$) (Tables 7 and 8). The response of the annual canarygrass to surface applied Cl^- was similar to the response observed from side banded chloride. This means that for producers that cannot or do not wish to side band or mid-row band Cl^- at seeding, they can use a surface application of chloride in the spring to ensure that the canarygrass is not deficient in Cl^-. At the non-responsive sites, the surface applied chloride had a similar effect as the side banded chloride only increasing the test weight from 354.7 to 358.8 ($P = 0.01$) (Tables 7 and 9). There was no difference between the two forms of surface applied chloride fertilizer KCl and $CaCl_2$ at both the chloride responsive and non-responsive sites (contrasts KCl vs. $CaCl_2$, Table 7). This indicates that any form of soluble Cl^- fertilizer should work as a surface application and that K was not contributing to the observed grain yield response.

Micronutrient responses

The impact of the micronutrients placed in a fertilizer band on the development and yield of canarygrass were not large. Comparing treatment 6 and 8, contrasts Cu (+Cl^-) and Cu (-Cl^-) in Table 7, the addition of Cu in the fertilizer band had no effect on the development and yield of canarygrass at both the chloride responsive and non-responsive sites (Table 7). Comparing treatment 6 and 9, the addition of Zn in the fertilizer band only increased panicle density from 390.6 to 409.7 panicles m^{-2} at the non-responsive sites ($P = 0.0179$) (Tables 7 and 9). Combining all four micronutrients, Cu, Zn, Mn, and B, and adding them to the fertilizer band did not impact canarygrass development or grain yield at the responsive and non-responsive sites. These results indicate that canarygrass is not particularly sensitive to these four micronutrients and they do not appear to impact Cl^- deficiency in annual canarygrass.

N, P, and S responses

The effect of the combination of N, P, and S fertilizer in the absence of Cl^- fertilizer on canarygrass development and grain yield was examined by comparing treatment 1 to treatment 7 (Tables 1 and 7, contrast nonchloride nutrient). At the Cl^--responsive sites the addition of this fertilizer combination increased panicle

Table 8. The means for the variable average across the chloride responsive sites.

Treatment	Plant density	Panicle density	Seeds per panicle	Plant height	Plant lodging	Seed weight	Grain yield	Test weight
1	212.4	**469.9**	20.6	**80.63**	0.333	7.621	735.7	**340.86**
2	239.2	468.7	29.4	85.36	0.333	7.858	1070.0	355.92
3	226.0	501.4	33.7	89.29	0.333	7.955	1313.2	**356.51**
4	228.6	511.9	29.4	88.77	0.333	7.918	1188.5	**352.41**
5	228.3	527.6	30.8	89.41	0.333	7.943	1203.9	352.55
6	219.4	534.1	**32.0**	**91.67**	0.417	**7.896**	**1336.0**	**351.52**
7	226.4	**548.2**	**20.2**	**87.82**	0.333	**7.630**	**785.1**	**338.37**
8	225.6	538.3	35.6	90.56	0.333	7.943	1427.9	353.08
9	230.4	538.4	32.8	90.94	0.333	7.978	1378.4	352.87
10	234.5	573.7	30.1	92.25	0.417	7.802	1326.0	349.66
11	219.0	554.0	30.7	91.45	0.583	7.835	1330.2	347.26
12	211.1	524.0	**33.7**	**91.63**	0.417	**7.797**	**1275.7**	**349.39**
13	221.5	523.7	31.8	91.56	0.417	7.786	1253.0	347.17

Note: Means that are bolded are significantly different from at least one other mean using contrasts except for the linear and quadratic contrasts.

Table 9. The means for the variable average across the chloride non-responsive sites.

Treatment (trt)	Plant density	Panicle density	Seeds per panicle	Plant height	Plant lodging	Seed weight	Grain yield	Test weight
1	210.1	**328.6**	**46.7**	**88.0**	**1.02**	7.778	**1071.8**	**358.0**
2	206.2	355.9	48.4	88.5	1.08	7.883	1270.9	359.6
3	209.2	371.5	49.7	**90.9**	1.35	7.896	1374.5	360.0
4	210.6	368.4	52.0	**92.9**	1.58	7.826	1367.9	359.6
5	215.2	387.2	50.7	94.5	1.50	7.780	1372.4	359.8
6	212.8	**390.6**	53.6	94.2	2.39	7.796	1447.6	**358.8**
7	214.1	**402.2**	**50.3**	**94.2**	**2.32**	7.712	**1410.6**	**354.7**
8	199.1	408.7	50.0	95.2	2.34	7.811	1471.2	356.9
9	201.1	**409.7**	50.2	93.9	2.29	7.766	1460.3	357.8
10	208.1	382.0	52.3	93.0	2.27	7.915	1451.8	357.5
11	202.2	400.5	53.2	94.2	2.75	7.895	1508.6	356.8
12	220.1	382.0	52.4	93.8	2.07	7.770	1428.3	**357.1**
13	219.4	395.7	51.7	94.7	1.98	7.848	1417.5	357.8

Note: Means that are bolded are significantly different from at least one other mean using contrasts except for the linear and quadratic contrasts.

density from 469.9 to 548.2 panicles m^{-2} ($P = 0.0005$), and plant height from 80.6 to 87.8 cm ($P < 0.0001$) and decreased test weight from 340.9 to 338.4 g 0.5 L^{-1} ($P < 0.0001$), while it had no effect on seeds per panicle, seed weight, and grain yield (Tables 7 and 8). At the non-responsive sites, the application of fertilizer except Cl^- increased panicle density from 328.6 to 402.2 panicles m^{-2} ($P < 0.0001$), seeds per panicle from 46.7 to 50.3 ($P = 0.027$), grain yield from 1071.8 to 1410.6 kg ha^{-2} ($P < 0.0001$) and plant height from 88.0 to 94.2 cm ($P < 0.0001$) while test weight decreased from 358.0 to 354.7 g 0.5 L^{-1} ($P = 0.0082$) (Tables 7 and 9). Therefore, at sites responsive to chloride the addition of other fertilizers had very little effect on grain yield and the yield components formed after anthesis in the absence of Cl^- fertilizer. In addition, lodging was increased from 1.02 to 2.32 ($P < 0.0001$) at the non-chloride responsive sites by the addition of N, P, and S; however, lodging was low and the small increase is due to the increased yield potential and lodging was not high enough to reduce grain yield (Tables 7 and 9).

The addition of P and S fertilizer did not have a large impact on the development and grain yield of canary-grass (Table 7). Comparing treatments 3 and 4, the addition of P affected test weight at the responsive sites and plant height at the non-responsive sites (contrasts P (+Cl^-) and P (-Cl^-) in Table 7). There was a small decrease in test weight that is probably not of biological importance when P fertilizer was added. It is interesting to note that treatment 3, which only received N and Cl^-

fertilizer, had numerically the highest test weight for both the responsive and non-responsive sites.

The effect of N fertilizer in the presence of Cl^- was examined at both Cl^--responsive and non-responsive sites. With the small impact of the micronutrients P and S on canarygrass development and grain yield, we were comfortable using a contrast that ignored the level of these nutrients. Using treatments 2, 4, 6, and 11, nearly all the variables had a linear N response at both the Cl^--responsive and in the Cl^- non-responsive sites. The only exceptions were plant density and seed weight at Cl^- non-responsive sites, and seeds per panicle and seed weight at the responsive sites. The linear decrease in plant density as the N rate increased may not be biologically significant as the plant density of the zero fertilizer treatment was lower or similar to the treatment with the highest fertilizer rate. The biggest effect of on the yield components with increasing the N rate was panicle density. In both the non-responsive ($P < 0.0001$) and responsive sites ($P = 0.0073$) as the N rate increased the panicle density increased (Tables 7–9). A similar increase in panicle density as the N rate increased was observed in previous research (May et al. 2012*a*). In the non-responsive sites, increasing the N rate increased the seeds per panicle ($P = 0.0091$, Table 7) but not at the responsive sites. It is interesting to note that the biggest impact of the N appeared to occur before anthesis, and the greatest impact of the chloride occurred after anthesis. As expected, increasing the N rate increased plant height, lodging, and grain yield. At the responsive sites grain yield increased 25% from 1070 to 1330 kg ha^{-1} and at the non-responsive sites grain yield increased 19% from 1271 to 1509 kg ha^{-1} (Tables 7–9). This small increase in grain yield as the N rate increases has been observed in other research studies (Holt 1988; May et al. 2012a). Test weight decreased as the N rate increased at the responsive (356 to 347 g 0.5 L^{-1}) and non-responsive sites (360 to 357 g 0.5 L^{-1}). This small decrease in test weight as the N rate increased was observed in a previous study on canarygrass (May et al. 2012a) and in oat (May et al. 2004).

Conclusions

Cl^- fertilizer increase the grain yield of annual canarygrass by 70% at sites that responded to Cl^- fertilizer. No clear relationship between the level of Cl^- in the soil with the responsiveness of the canaryseed to Cl^- fertilizer could be ascertained; therefore, Cl^- should be applied to all canaryseed grown on the Great Plains of North America. The large range in residual Cl^- levels at which a response occurred indicates that we are missing the knowledge needed to develop a response curve. Not only does Cl^- increase grain yield and test weight on its own, it amplifies the effect of other nutrients especially N in Cl^--responsive fields. When Cl^- is required by the annual canarygrass, a sideband application or surface application are both effective application methods. The effect of P, K, S, Zn, Cu, Mn, and B indicate that canarygrass is not more responsive to these nutrients than other cereals. N is the major nutrient Cl^- interacts with in annual canarygrass. In conclusion, at Cl^- responsive sites the application of nutrients are ineffective in the absence of Cl^- fertilizer. In addition, the sensitivity of annual canarygrass to Cl^- indicates that it could be used to investigate the role of Cl^- in cereal crop development and grain yield.

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