2022 Annual Report

for the

Agriculture Demonstration of Practices and Technologies (ADOPT) Program

Project Identification

Project Title: Evaluating the 4R Principles (Rate, Placement and Timing) For Copper Application on Wheat Yield and Seed Quality

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Producer Group Sponsoring the Project: Western Applied Research Corporation (WARC)

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Northeast Agriculture Research Foundation (NARF), Melfort, SK (R.M #428)
Conservation Learning Center (CLC), Prince Albert, SK (R.M #461)

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Objectives and Rationale

Project Objectives:

To demonstrate the effects of copper (Cu) products and application timings on maturity, yield and quality of wheat grain. Additionally, to assess whether or not certain foliar copper products can correct deficiencies at different application rates.

Project Rationale:

Copper (Cu) is a micronutrient that is essential to crop production with roles in protein formation, as an enzyme co-factor (Winfield United 2023), and in pollen tube formation (Yara Canada 2023). While the soil in many areas of the Canadian Prairies have adequate levels of Cu to grow a successful wheat crop (McKenzie 2016), Cu deficiency can be difficult to diagnose as it usually occurs in irregular patches throughout fields. Visual symptoms typically show up as the leaf tips “pig tailing”, along with excessive tillering, aborted heads, delayed maturity, prolonged flowering and poor grain filling. Increased incidence of root rot, stem and head melanosis and the increased incidence of ergot can also be associated with Cu deficiency. For wheat production Cu is an important constituent of many enzymes, as it acts as a catalyst in photosynthesis and a key component of lignin formation. Sufficient Cu levels in wheat enable proper flowering and pollination, and is important for standability to reduce lodging.

Copper sulfate is a relatively common source of Cu fertilizer that can be broadcast at a rate of 3-8 lbs Cu/ac and then incorporated into the soil to correct Cu deficiency for several years (McKenzie 2016). Chelated Cu products can be used to correct a deficiency using a lower rate than Cu sulfate (Solberg et al. 1999). MicroWrap ™ is a chelated Cu product marketed by ATP (ATP Nutrition Ltd., Oak Bluff, MB) that can be applied to monoammonium phosphate (MAP) or as a liquid in the seed furrow. Ruffin Tuff Cu ™ is another chelated Cu (5 Cu-6S) product that is formulated as a granule to be applied in the seed row and is also marketed by ATP. Microbolt ® Cu is a chelated liquid Cu product marketed by Alpine (Nachurs Alpine Solutions, New Hamburg, ON) that can be applied in furrow or as a foliar spray.

Methodology and Results

Methodology:

The trial was established at Scott (WARC), Melfort (NARF) and Prince Albert (CLC) in Saskatchewan in 2022. An HRSW variety in each location was used, Scott and Prince Albert used AAC Viewfield and Melfort seeded AAC Brandon. Scott used a 6-row Fabro knife opener with 10-inch row spacing, Melfort used a 6-row Fabro plot seeder on 12-inch row spacing and Prince Albert used a Fabro double disc opener on 10-inch spacing. Seeding depths ranged between each location based on available moisture, Scott seeded at a depth of 1.5 inches and rolled afterwards, Melfort aimed for 1 to 1.5 inches depth and Prince Albert had a depth of 2 inches. Melfort applied nitrogen (urea;46-0-0) to meet the recommended rate of 136 kg N/ha, phosphorus (MAP;11-52-0) at 49 kg P_2O_5/ha, potassium (KCl;0-0-60) at 11 kg K_2O/ha, and sulphur (AMS;21-0-0-24) at 6 kg S/ha. Nitrogen was applied in the mid-row, phosphorus was placed in the seed-row, K and S were applied in the side band. Scott balanced urea across all treatments and midrow banded at seeding at a rate of 104 kg/ha, MAP at 65 kg/ha and no potassium or sulphur were applied based on soil test recommendations. Prince Albert applied nitrogen at 82 kg/ha, phosphorus at 95 kg/ha and no potassium or sulphur were applied. Chelated Cu products were chosen due to the medium-ranged Cu levels at all three locations. Cu products that were applied at seeding consisted of ATP MicroWrap and Ruffin-Tuff Copper. The ATP MicroWrap was applied as a coating of the mono-ammonium phosphate (MAP) at a rate of 3L per tonne of MAP. The Ruffin-Tuff Copper product was in a granule form that was applied in the seed-row at a rate of 5 lbs/ac in Scott and Melfort and 8 lbs/ac in Prince Albert.

The foliar application of Alpine MicroBolt was applied at a rate of 2.5 L product/ha. Scott applied the Alpine MicroBolt treatments using a Roger push sprayer, Melfort used a flat-fan type nozzle, with 77 L spray solution/ha at 50 PSI with a target speed of 10 km/h. Prince Albert applied the Alpine MicroBolt using a CO_2 back pack sprayer with flat-fan nozzles. The first node application (Zadoks 31) of Alpine MicroBolt was applied on June 16th for Scott, June 20th for Melfort and July 8th for Prince Albert. While the booting application (Zadoks 45) occurred on July 4th at Scott, July 12th at Melfort and July 18th at Prince Albert.

The trial at all sites received the necessary crop protection products as required. Post-emergent herbicide applications at Scott consisted of applying the herbicides pinoxaden (Axial, 0.5L/ac) along with pyrasulfotole and bromoxynil (Infinity, 0.33L/ac) on June 16th. An additional in-crop herbicide of bromoxynil and MCPA (Buctril M, 0.4L/ac) was applied on June 22nd. Melfort applied pinoxaden (Axial, 0.5 L/ac) on June 22nd for the control of grassy weeds. A mixture of fluroxypyr, clopyralid, and MCPA (Prestige XL, 0.947 L/ac) was applied at Melfort for the control of broadleaf weeds on June 28th. Prince Albert applied pyrasulfotole and bromoxynil (Infinity, 0.83L/ac) along with fenoxaprop-p-ethyl (Puma Advance, 1.02 L/ha) on June 28th. The foliar fungicide metconazole (Caramba, 400mL/ac) was applied at Scott on July 14th and Melfort on July 18th, while Prince Albert did not apply a fungicide.

On August 30th, Scott harvested six rows from each plot with a plot combine for a total harvested area of 12.192 m^2/plot. Melfort harvested five plot rows for each plot on September 15th with a plot combine for a total harvested area of 10.66 m^2/plot. Prince Albert used a plot combine to harvest 6 rows on September 16th for a total harvested area of 10.78m^2/plot (Appendix 1).

Table 1: Treatments used in Evaluating the 4R Principals (Rate, Placement, Timing) for Copper Application on Wheat Yield and Quality at Scott, Melfort and Prince Albert, SK in 2022.

Treatment #	Product(s)	Placement	Timing	Rates (g Cu/ha)
1	Control-No added Cu	N/A	N/A	N/A
2	ATP MicroWrap[x]	Seed-placed	Seeding	26
3	Ruffin-Tuff Copper[y]	Seed-placed	Seeding	281
4	Alpine MicroBolt Cu[z]	Foliar	1st node	189
5	Alpine MicroBolt Cu	Foliar	Boot stage	189
6	Alpine MicroBolt Cu	Foliar	1st node & Boot stage	378
7	ATP MicroWrap Alpine MicroBolt Cu	Seed-placed & Foliar	Seeding 1st node	215
8	ATP MicroWrap Alpine MicroBolt Cu	Seed-placed & Foliar	Seeding Boot stage	215
9	Ruffin-Tuff Copper Alpine MicroBolt Cu	Seed-placed Foliar	Seeding 1st node	470
10	Ruffin-Tuff Copper Alpine MicroBolt Cu	Seed-placed Foliar	Seeding Boot stage	470
11	ATP MicroWrap Alpine MicroBolt Cu	Seed-placed Foliar	Seeding 1st node Boot stage	404
12	Ruffin-Tuff Copper Alpine MicroBolt Cu	Seed-placed Foliar	Seeding 1st Node Boot stage	559

[x] ATP MicroWrap ™: Chelated product applied onto monoammonium phosphate granules at 3L product/tonne MAP, 5-0-0-6 Zn-2 B-1Cu
[y] Ruffin-Tuff ™, Copper lignosulfate, granular product added to fertilizer blend at 5.6 kg/ha, 5 Cu-6 S
[z] Alpine MicroBolt® Cu: Applied at 2.47 L product/ha as a foliar spray

Data Collection

Soil samples in the spring of 2022 were collected at three depth increments (0-15 cm, 15-30 cm, and 30-60 cm) in order to determine fertilizer rate recommendations. Plant density at Melfort was assessed by counting the number of emerged plants along 2-1m sections of crop row per plot (1 in the front and 1 in the back). At Scott and Prince Albert, plant density was assessed by counting emerged plants on 4-1m sections of crop row per plot (2 in the front and 2 in the back). Plant density counts were conducted once emergence was completed, approximately 4 weeks after emergence. The averages of these two sections were used to calculate plant density in all locations. Plant nutrient analysis was determined for each treatment based on 13 flag leaves sampled from each plot following the booting application of Alpine MicroBolt. The samples were then bulked by treatment so that 12 samples were analyzed for plant nutrient analysis by AgVise Laboratories (AgVise Laboratories, Northwood, ND). Fusarium head blight (FHB) ratings were visually assessed between late milk (Zadok 77) and soft dough (Zadok 85), where 10 heads were rated from each plot using a scale that expressed the area of the head bleached by FHB (Figure 1). If other diseases were present, they were also noted and evaluated. Scott had leaf disease, so ratings were assessed between tiller and heading growth stages by rating 10 leaves per plot using a rating scale (Figure 2). Prince Albert also noted ergot in their plots. Maturity ratings were recorded at physiological maturity (hard dough) when kernel moisture from the lower third of the spike is less than 40% and the seed is no longer easily severed when pinched between thumbnail and fingernail. Days to maturity (DTM) was assessed for every plot by counting the number of days between seeding and maturity. Yields were determined from cleaned harvested grain samples and corrected to 14% moisture content. Grain protein were collected as indicators of seed quality.

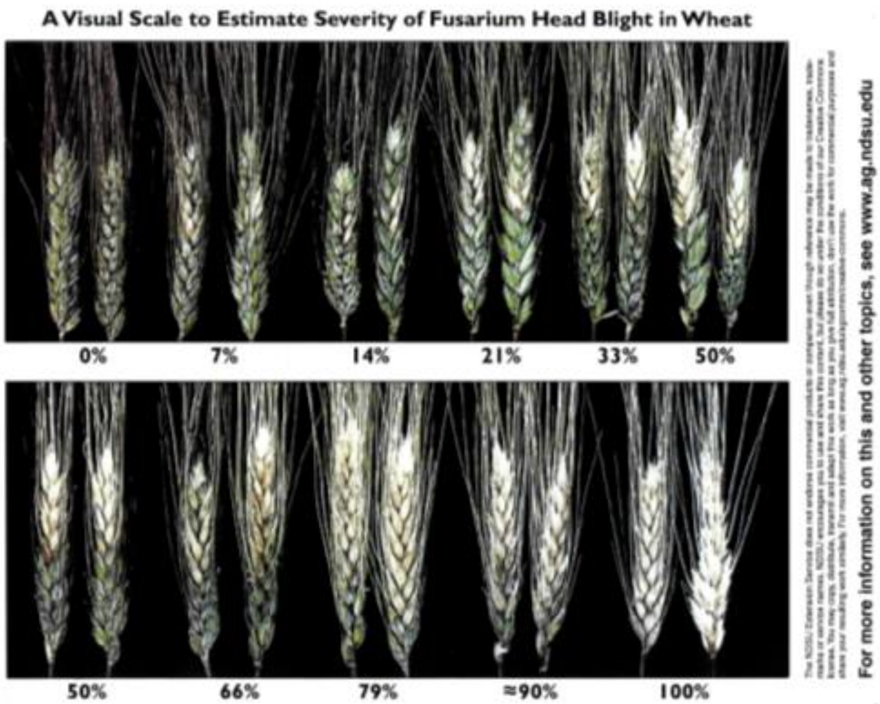

Figure 1. Visual scale to estimate severity of Fusarium Head Blight (FHB) for Evaluating the 4R Principles (Rate, Placement and Timing) For Copper Application on Wheat Yield and Seed Quality study at Scott, Melfort and Prince Albert, SK 2022.

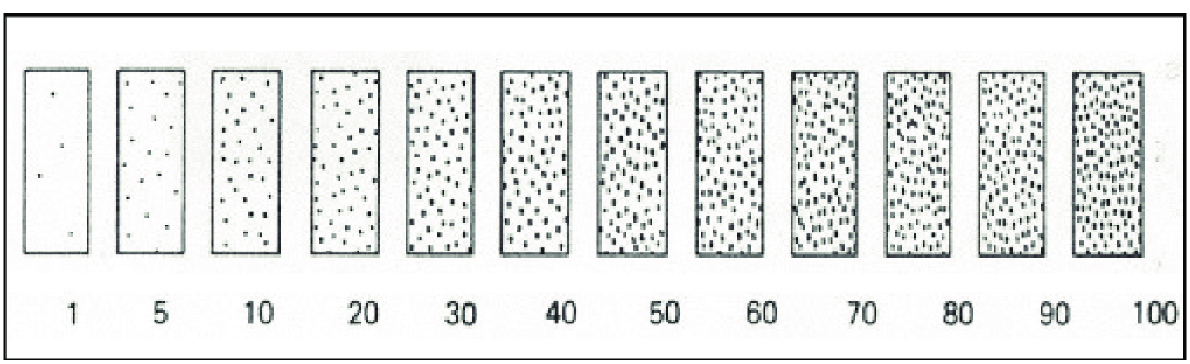

Figure 2. Rating scale used to assess amount of leaf disease on wheat between the tiller and heading growth stages for Evaluating the 4R Principles (Rate, Placement and Timing) for Copper Application on Wheat Yield and Seed Quality study at Scott, Melfort, and Prince Albert, SK 2022.

Data Analysis

Treatments were grouped into 3 different groups for factorial analysis. First, comparing rates and timing of foliar Cu (treatments 1,4,5,6), then comparing placement, rate, and timing with MicroWrap as the seeding time source of Cu (treatments 1,2,7,8,11). Lastly, comparing placement, rate, and timing with Ruffin-Tuff as the seeding time source of Cu (treatments 1,3,9,10,12). The presence of significant differences between treatments was tested using an ANOVA. A Dunnett's test was used to differentiate treatments from the control treatment which was treatment 1 (No Cu) at Melfort.

Results:

Growing Conditions

At Scott, the spring of 2022 was very dry and cool for the first two months of the growing season. There was very little residual soil moisture from the previous year, as drought conditions persisted throughout 2021. The temperature was relatively average in June compared to the long-term average with below average precipitation. The majority of the precipitation in June occurred in a single day, June 13th, with 21.2 mm of rainfall. The month of July was unusually warm, with 12 days above 27^{o}C, with the highest temperature recorded at 34.4^{o}C on July 29th. The overall precipitation in July was 25% higher than the long-term average; however, the majority of rainfall occurred on a single weekend of July 30th and July 31st, with a total of 53.2 mm. In general, the month of July had poor growing conditions as the daily temperatures were above average with very little available soil moisture. Similar conditions persisted into the month of August, with very warm conditions throughout the entire month. There were 14 days above 27^{o}C, with the extreme temperature of 34.9^{o}C recorded on August 31st. There was below average precipitation in August compared to the long-term average, with most rainfall occurring in a single event. There was 22.5 mm out of 32.2 mm of rainfall on August 2nd. September was considered dry with only 12.6 mm of rainfall and relatively warm temperatures compared to the long-term average (Table 2).

Overall, temperature and precipitation at Melfort in 2022 were similar to the long-term average. Between the months of May to September, Melfort had an average temperature of 15.1 ^{o}C compared to the long-term average of 14.3 ^{o}C and received 269.9 mm of precipitation compared to the long-term average of 265.0 mm. In examining the months of May-September individually, there were deviations from the long-term average for temperature and precipitation. In May, Melfort received 90.8mm of precipitation, which is significantly more than the long-term average of 42.9 mm, while having slightly cooler temperatures (9.9 ^{o}C) than the average (10.7 ^{o}C). The average temperature in June was similar to May and there was 78.1 mm of precipitation which was greater than the long-term average (54.3 mm). In July, temperatures started to rise while precipitation fell. This month experienced a 0.7 ^{o}C increase in temperature (18.2 ^{o}C) compared to the long-term average (17.5 ^{o}C), and 34.9 mm of rainfall compared to 76.7 mm. This trend continued through August and September. August had an average temperature of 18.7 °C; 1.9 °C higher than the long-term (16.8 °C), while receiving only 36.5 mm of rainfall, whereas the long-term average is 52.4 mm. The average temperature in September (13.7 °C) was once again greater than the long-term average (10.8 °C), with precipitation being 29.6 mm, which is more consistent to the long-term average (38.7mm) (Table 2).

In Prince Albert, following snowmelt, spring conditions were relatively dry until June 15. This was followed by precipitation in late June and July. May consistently had lower temperatures (10.5 °C) than the long-term average (11.3 °C), with significantly lower precipitation of 17.9 mm versus 39.4 mm. Precipitation was more relative to the long-term average, but as stated previously, it did not occur until the middle of June. Therefore, Prince Albert received the majority of 75.7 mm of precipitation in the latter half of June, a significant amount compared to the long-term average of 79.7 mm for the entire month. The temperature was slightly lower in June and consistent in July compared to the long-term average. July had slightly less rainfall, which continued until October, while temperatures in these months were higher. On average, throughout the entire summer, from May until October, the temperature for 2022 in Prince Albert was only 0.7 °C higher than the long-term average (13.0 °C), and precipitation was 232.9 mm (2022) versus 289.7 mm (long-term) (Table 2).

Table 2. Mean monthly temperature and precipitation accumulated from May to September 2022 at Scott, Melfort and Prince Albert, SK.

Year	**May**	**June**	**July**	**August**	**September**	**Average/ Sum**
Scott						
--*Temperature (°C)* ---						
2022	10.0	15.0	18.3	18.9	13.8	15.2
Long-term[x]	10.8	14.8	17.3	16.3	11.2	14.1
--*Precipitation (mm)*---						
2022	11.0	57.1	86.5	32.1	12.6	199.3
Long-term[x]	38.9	69.7	69.4	48.7	26.5	253.2
Melfort						
--*Temperature (°C)* ---						
2022	9.9	15.2	18.2	18.7	13.7	15.14
Long-term[y]	10.7	15.9	17.5	16.8	10.8	14.3
--*Precipitation (mm)*---						
2022	90.8	78.1	34.9	36.5	29.6	269.9
Long-term[y]	42.9	54.3	76.7	52.4	38.7	265
Prince Albert						
--*Temperature (°C)* ---						
2022	10.5	15.5	18.3	18.5	13.3	15.2
Long-term[z]	11.3	16.2	18.7	17.1	11.6	15.0

--*Precipitation (mm)*--						
2022	17.9	75.7	63.7	37.8	26.3	221.4
Long-term[z]	39.4	79.7	77	44.6	29	269.7

[x]Long-term average (1985-2014)
[y]Long-term average (1981-2010)
[z]Long-term average (2012-2021)
https://www.src.sk.ca/download-weather-summaries?token=U1Hl-f_hq2Ta8GbJVxNq38zrt33iKNn1hBbpSDl8Mps

Soil Sample Results

Spring soil test results indicated that nitrogen levels at Scott were 20 lb/ac at the 0-6" depth and 31 lb/ac at the 6-12" depth. At Melfort, nitrogen was found to be 20 lb/ac at the 0-6" depth and 25 lb/ac at the 6-12" depth. Prince Albert soil tests indicated that nitrogen levels were 38 lbs at the 0-6" depth and 42 lbs at the 6-12" depth. Phosphorous was measured using an Olsen extraction at all locations and showed high levels of available phosphorous (20 ppm) at Scott, medium levels (10 ppm) at Melfort, and low levels (5 ppm) at Prince Albert. The soil pH was 6.0 at the 0-6" depth at Scott and Melfort and 5.7 in Prince Albert. Organic matter was 4.6% in Scott, 9.5% in Melfort, and 2.9% in Prince Albert. Melfort had the highest Cu levels at 0.85 ppm, followed by Scott (0.65 ppm), and Prince Albert (0.41 ppm).

Table 3. Residual soil nutrient levels in the spring of 2022 found in Evaluating the 4R Principals (Rate, Placement, Timing) for Copper Application on Wheat Yield and Quality at Scott, Melfort, and Prince Albert, SK in 2022.

	Residual Soil Levels				
	Nitrogen (lb/ac)[a]	**Phosphorus (ppm)**	**Potassium (ppm)**	**Sulphur (lb/ac)**	**Copper (ppm)**
Scott	51	20	474	36	0.65
Melfort	68	10	362	32	0.84
Prince Albert	90	5	194	26	0.41

[a] Soil residual nitrogen a measurement of availability from 0-60cm, phosphorus and potassium 0-15cm, and sulphur a 0-30 cm depth in the soil

Group 1: Foliar Placement

Treatments 1, 4, 5 and 6 were grouped to understand the effects of changes in Cu timing (No Cu, 1st node stage, boot stage,1st node + boot stage) and rate (0, 189, 189, 378 g Cu/ha) when Cu is delivered through foliar placement only (Alpine MicroBolt Cu).

When looking at timing of foliar Cu, no significant interactions were observed. Thus, indicating that with foliar Cu, timing at 1st node, boot stage, and 1st node + boot stage had no significant effects on plant density, FHB, DTM, yield or protein. When observing significance of foliar Cu rates, plant density (p=0.0314) was significantly different from the absolute check at Melfort, while foliar Cu had not been applied at time of plant density counts, these differences could be environmental (Table 4).

Looking at each site individually, DTM for all timings and rates in Scott and Prince Albert resulted in a significant difference from the absolute check (Melfort). This could be due to the additional precipitation Melfort received throughout the growing season. As foliar timings at each site went from the check to 1st node, to boot then finally, to the dual application at the 1st node + boot stages, a trend of increasing yield was seen at Scott and to a lesser effect, Melfort. Whereas, in Melfort the dual application of foliar Cu also resulted in the highest yield (Table 5). Also, the higher rate of foliar Cu resulted in the highest yield at Scott and Melfort, with yields of 3718 kg/ha and 5008 kg/ha, respectively (Table 6).

Table 4. The effect of timing when Cu is applied by foliar placement only (trt 1, 4, 5, 6) in Evaluating the 4R Principals (Rate, Placement, Timing) for Copper Application on Wheat Yield and Quality at Scott, Melfort, and Prince Albert, SK in 2022.

	p-values	
	Cu Timing	Cu Rate
Plants/m^2	0.07	0.0314*
FHB (%)	1.00	0.9742
DTM	0.43	0.6519
Yield (kg/ha)	0.77	0.5472
Protein	0.98	0.9273

*indicates a treatment that was significantly different from the absolute check (Melfort 0 g Cu/ha)

Table 5. The effect of timing when Cu is applied by foliar placement only (trt 1, 4, 5, 6) by individual site in Evaluating the 4R Principals (Rate, Placement, Timing) for Copper Application on Wheat Yield and Quality at Scott, Melfort, and Prince Albert, SK in 2022.

		Plants/m^2	**FHB**	**Maturity**	**Yield**		**Protein**
Site	**Cu Timing**		(%)	(Days) [b]	(kg/ha)	(bu/ac)	(%)
Scott	No Cu Check[a]	205	0.0	96 *	3,396	51	16.2
	1st Node	210	0.2	96*	3,423	51	16.4
	Boot	186	0.4	98 *	3,441	51	16.3
	1st Node + Boot	205	0.0	98*	3,718	55	16.4
Melfort	No Cu Check [a]	205	0.3	106	4,407	65	14.7
	1st Node	239	1.0	105	4,916	72	14.5
	Boot	273	0.3	105	4,811	71	14.6
	1st Node + Boot	255	0.4	105	5,008	74	14.5
Prince Albert	No Cu Check	187	9.4	83*	4,961	74	14.2
	1st Node	212	8.9	83*	4,464	66	14.1
	Boot	213	9.9	83*	4,614	69	14.3
	1st Node + Boot	230	9.4	83*	4,486	67	14.0

[a]No Cu at Melfort was used as the absolute check for comparison
[b] *indicates a treatment that was significantly different from the absolute check

Table 6. The effect when Cu is applied at different rates with foliar Cu only (trt 1, 4, 5, 6) by individual site in Evaluating the 4R Principals (Rate, Placement, Timing) for Copper Application on Wheat Yield and Quality at Scott, Melfort, and Prince Albert, SK in 2022.

		Plants/m^2	FHB	Maturity	Yield		Protein
Site	**Cu Rate (g Cu/ha)**		(%)	(Days) [b]	(kg/ha)	(bu/ac)	(%)
Scott	0[a]	205	0.0	96*	3,396	51	16.2
	189	198	0.3	97*	3,432	51	16.3
	378	205	0.0	98*	3,718	55	16.4
Melfort	No Cu Check[a]	205	0.3	106	4,407	65	14.7
	189	259	0.6	105	4,856	71	14.5
	378	255	0.4	105	5,008	74	14.5
Prince Albert	0	187	9.4	83*	4,961	74	14.2
	189	213	9.4	83*	4,539	67	14.2
	378	230	9.4	83*	4,486	67	14.0

[a]No Cu at Melfort was used as the absolute check for comparison
[b] *indicates a treatment that was significantly different from the absolute check

Group 2: MicroWrap Seed Placement and Foliar

Treatments 1, 2, 7, 8 and 11 were grouped to understand the effects of changes in Cu placement (No Cu, seed, seed + foliar), timing (No Cu, seed, seed + 1st node, seed + boot, seed + 1st node + boot) and rate (0, 26, 215, 215, and 404 g Cu/ha) when the Cu source at seeding was MicroWrap.

Cu placement, timing and rates resulted in no significant interactions, as results for plant density, FHB, DTM, yield and protein were generally the same. There were significant ($p<0.05$) differences in yield based on placement ($p=0.0083$) and rate ($p=0.03$) (Table 7). These results showcased different trends that occurred for placement and rates at individual locations. Regarding placement, Melfort and Scott had similar trends, while Prince Albert had a different trend. Melfort had a strong trend of increasing yield from the dual application of Cu at seeding + foliar, resulting in the highest yield (4936 kg/ha), followed by seed placement (4700 kg/ha) and lastly, the check (4407 kg/ha). Scott had a similar trend, such that the dual application resulted in the highest yield (3598 kg/ha), but the check (3396 kg/ha) out yielded the seed placement (3252 kg/ha) treatment. Prince Albert's trend was different, such that the check had the highest yield of 4961 kg/ha and the dual application had the lowest (4538 kg/ha) (Table 8).

Timing of Cu had no significant trends, but it can be noted that in Scott and Melfort, higher yields tended to occur from seed + 1st node and seed + boot treatments. The seed + 1st node + boot treatment had a lower yield than the seed + 1st node and seed + boot treatments, which may be a result of higher Cu rates being applied. Cu applied at seeding and the check had the lowest yields at the two locations. Prince Albert saw a different trend with the check having the highest yield, and relatively decreasing to the lowest yield at the seed + 1st node + boot treatments (Table 9).

Cu rate had similar trends observed at Scott and Melfort with a rate of 215 g Cu/ha resulting in the highest yield at both locations (3663 and 4989 kg/ha). A slight yield reduction was caused by 404 g Cu/ha, which could be an effect of high Cu rates. The check and 26 g Cu/ha resulted in the two lowest yields at both locations. Prince Albert, again, had a different trend, such that the check had the highest yield (4961 kg/ha), followed by 26 g Cu/ha, 404 g Cu/ha and lastly, 215 g Cu/ha (Table 10).

Table 7. The effect of Cu placement when the Cu source at seeding is MicroWrap (trt 1, 2, 7, 8, 11) in Evaluating the 4R Principals (Rate, Placement, Timing) for Copper Application on Wheat Yield and Quality at Scott, Melfort, and Prince Albert, SK in 2022.

	p-values					
	Cu Placement	Site*Cu Placement	Cu Timing	Site*Cu Timing	Cu Rate	Site*Cu Rate
Plants/m^2	0.09	0.41	0.30	0.83	0.16	0.67
FHB (%)	0.50	0.60	0.83	0.93	0.72	0.85
DTM	0.30	0.13	0.24	0.35	0.45	0.32
Yield (kg/ha)	0.51	0.0083*	0.62	0.060	0.44	0.03*
Protein	0.83	0.94	0.96	1.0	0.88	0.99

*indicates a treatment that was significantly different from the absolute check (Melfort 0 g Cu/ha)

Table 8. The effect of Cu placement when the Cu source at seeding is MicroWrap (trt 1, 2, 7, 8, 11) by individual site in Evaluating the 4R Principals (Rate, Placement, Timing) for Copper Application on Wheat Yield and Quality at Scott, Melfort, and Prince Albert, SK in 2022.

		Plants/m^2	**FHB**	**Maturity**	**Yield**		**Protein**
Site	**Cu Placement**		(%)	(Days)	(kg/ha) [b]	(bu/ac)	(%)
Scott	No Cu Check[a]	205	0.0	96	3396*	51	16.2
	Seed	197	0.0	96	3252*	48	16.5
	Seed + Foliar	206	0.0	97	3598*	54	16.3
Melfort	No Cu Check	205	0.3	106	4407	65	14.7
	Seed	231	0.4	105	4700	69	14.7
	Seed + Foliar	252	0.3	105	4936*	72	14.8
Prince Albert	No Cu Check	187	9.4	83	4961	74	14.2
	Seed	205	12.3	83	4808	71	14.4
	Seed + Foliar	205	7.0	83	4535	67	14.4

[a]No Cu at Melfort was used as the absolute check for comparison
[b] *indicates a treatment that was significantly different from the absolute check

Table 9. The effect of Cu timing when the Cu source at seeding is MicroWrap (trt 1, 2, 7, 8, 11) by individual site in Evaluating the 4R Principals (Rate, Placement, Timing) for Copper Application on Wheat Yield and Quality at Scott, Melfort, and Prince Albert, SK in 2022.

		Plants/m^2	**FHB**	**Maturity**	**Yield**		**Protein**
Site	**Cu Timing**		(%)	(Days)	(kg/ha)	(bu/ac)	(%)
Scott	No Cu Check[a]	205	0.0	96	3396	51	16.2
	Seed	197	0.0	96	3252	48	16.5
	Seed + 1st Node	203	0.0	97	3799	57	16.2
	Seed + Boot	205	0.0	98	3526	53	16.3
	Seed + 1st Node + Boot	210	0.0	97	3470	52	16.3

Melfort	No Cu Check	205	0.3	106	4407	65	14.7
	Seed	231	0.4	105	4700	69	14.7
	Seed + 1st Node	253	0.2	105	4910	72	14.8
	Seed + Boot	241	0.5	106	5068	74	14.7
	Seed + 1st Node + Boot	261	0.3	105	4832	71	14.9
Prince Albert	No Cu Check	187	9.4	83	4961	74	14.2
	Seed	205	12.3	83	4808	71	14.4
	Seed + 1st Node	201	8.5	83	4520	67	14.4
	Seed + Boot	208	5.5	83	4610	69	14.4
	Seed + 1st Node + Boot	207	6.9	83	4483	67	14.5

[a]No Cu at Melfort was used as the absolute check for comparison
[b] *indicates a treatment that was significantly different from the absolute check

Table 10. The effect of Cu rate when the Cu source at seeding is MicroWrap (trt 1, 2, 7, 8, 11) by individual site in Evaluating the 4R Principals (Rate, Placement, Timing) for Copper Application on Wheat Yield and Quality at Scott, Melfort, and Prince Albert, SK in 2022.

		Plants/m^2	**FHB**	**Maturity**	**Yield**		**Protein**
Site	**Cu Rate (g Cu/ha)**		(%)	(Days)	(kg/ha)[b]	(bu/ac)	(%)
Scott	No Cu Check[a] (0)	205	0.0	96	3396*	51	16.2
	26	197	0.0	96	3252*	48	16.5
	215	204	0.0	97	3663*	55	16.2
	404	210	0.0	97	3470*	52	16.3
Melfort	0	205	0.3	106	4407	65	14.7
	11	231	0.4	105	4700	69	14.7
	87	247	0.4	106	4989	73	14.8
	164	261	0.3	105	4832	71	14.9
Prince Albert	0	187	9.4	83	4961	74	14.2
	11	205	12.3	83	4808	71	14.4
	87	204	7.0	83	4565	68	14.4
	164	207	6.9	83	4483	67	14.5

[a]No Cu at Melfort was used as the absolute check for comparison
[b] *indicates a treatment that was significantly different from the absolute check

Group 3: Ruffin-Tuff Seed placement and Foliar

Treatments 1, 3, 9, 10 and 12 were grouped to understand the effects of changes in Cu placement (No Cu, seed, seed + foliar), timing (No Cu, seed, seed + 1st node, seed + boot, seed + 1st node + boot) and rate (0, 281, 470, 470, and 559 g Cu/ha) when the Cu source at seeding was Ruffin - Tuff. Within these treatments no significance difference to the check at Melfort was found for placement, timing or rate (Table 11).

When looking at yield at the three locations in regards to placement, no trends were observed. Each location had a different treatment yield the highest and the lowest (Table 12). Similar results occurred for Cu timing as no trends were observed (Table 13). At Scott and Prince Albert, a trend for timing (seed + 1st node + boot) and rate (559 g Cu/ha) resulted in the lowest yields (3123 and 4384 kg/ha), respectively. These trends could again suggest that yields were negatively affected by the increased amount of Cu applied. No trends were observed regarding rate at either of the three locations (Table 14).

Table 11. The effect of Cu placement when the Cu source at seeding is Ruffin-Tuff (trt 1, 3, 9, 10, 12) in Evaluating the 4R Principals (Rate, Placement, Timing) for Copper Application on Wheat Yield and Quality at Scott, Melfort, and Prince Albert, SK in 2022.

	p-values		
	Cu Placement	Cu Timing	Cu Rate
Plants/m^2	0.2849	0.4867	0.3533
FHB (%)	0.3802	0.4445	0.5714
DTM	0.8493	0.2616	0.283
Yield (kg/ha)	0.7112	0.6447	0.5387
Protein	0.8323	0.474	0.4894

*indicates a treatment that was significantly different from the absolute check (Melfort 0 g Cu/ha)

Table 12. The effect of Cu placement when the Cu source at seeding is Ruffin-Tuff (trt 1, 3, 9, 10, 12) by individual site in Evaluating the 4R Principals (Rate, Placement, Timing) for Copper Application on Wheat Yield and Quality at Scott, Melfort, and Prince Albert, SK in 2022.

		Plants/m^2	**FHB**	**Maturity**	**Yield**		**Protein**
Site	**Cu Placement**		(%)	(Days)	(kg/ha) [b]	(bu/ac)	(%)
Scott	No Cu Check[a]	205	0.0	96	3396	51	16.2
	Seed	195	0.2	97	3210	48	16.5
	Seed + Foliar	199	0.0	97	3439	51	16.3
Melfort	No Cu Check	205	0.3	106	4407	65	14.7
	Seed	261	0.3	105	4988	73	14.9
	Seed + Foliar	234	0.4	105	4701	69	14.8
Prince Albert	No Cu Check	187	9.4	83	4961	74	14.2
	Seed	203	10.8	83	4769	71	14.1
	Seed + Foliar	199	5.5	83	4471	66	14.5

[a]No Cu at Melfort was used as the absolute check for comparison
[b] *indicates a treatment that was significantly different from the absolute check

Table 13. The effect of Cu timing when the Cu source at seeding is Ruffin-Tuff (trt 1, 3, 9, 10, 12) by individual site in Evaluating the 4R Principals (Rate, Placement, Timing) for Copper Application on Wheat Yield and Quality at Scott, Melfort, and Prince Albert, SK in 2022.

		Plants/m^2	**FHB**	**Maturity**	**Yield**		**Protein**
Site	**Cu Timing**		(%)	(Days)	(kg/ha)	(bu/ac)	(%)
Scott	No Cu Check[a]	205	0.0	96	3396	51	16.2
	Seed	195	0.2	97	3210	48	16.5
	Seed + 1st Node	200	0.0	98	3768	56	16.0
	Seed + Boot	198	0.0	97	3425	51	16.4
	Seed + 1st Node + Boot	199	0.0	96	3123	47	16.4
Melfort	No Cu Check	205	0.3	106	4407	65	14.7
	Seed	261	0.3	105	4988	73	14.9
	Seed + 1st Node	222	0.2	106	4423	65	14.8

	Seed + Boot	225	0.1	105	4875	72	14.5
	Seed + 1st Node + Boot	253	0.7	105	4736	70	14.9
Prince Albert	No Cu Check	187	9.4	83	4961	74	14.2
	Seed	203	10.8	83	4769	71	14.1
	Seed + 1st Node	209	2.6	83	4411	66	14.0
	Seed + Boot	188	9.8	83	4619	69	14.7
	Seed + 1st Node + Boot	201	4.0	83	4384	65	14.7

[a]No Cu at Melfort was used as the absolute check for comparison
[b] *indicates a treatment that was significantly different from the absolute check

Table 14. The effect of Cu rate when the Cu source at seeding is Ruffin-Tuff (trt 1, 3, 9, 10, 12) by individual site in Evaluating the 4R Principals (Rate, Placement, Timing) for Copper Application on Wheat Yield and Quality at Scott, Melfort, and Prince Albert, SK in 2022.

		Plants/m^2	**FHB**	**Maturity**	**Yield**		**Protein**
Site	**Cu Rate (g Cu/ha)**		(%)	(Days)	(kg/ha)[b]	(bu/ac)	(%)
Scott	No Cu Check[a] (0)	205	0.0	96	3396	51	16.2
	114	195	0.2	97	3210	48	16.5
	190	199	0.0	98	3596	54	16.2
	227	199	0.0	96	3123	47	16.6
Melfort	0	205	0.3	106	4407	65	14.7
	114	261	0.3	105	4988	73	14.9
	190	223	0.2	105	4681	69	14.7
	227	253	0.7	105	4736	70	14.9
Prince Albert	0	187	9.4	83	4961	74	14.2
	114	203	10.8	83	4769	71	14.1
	190	198	6.2	83	4514	67	14.3
	227	201	4.0	83	4384	65	14.7

[a]No Cu at Melfort was used as the absolute check for comparison
[b] *indicates a treatment that was significantly different from the absolute check

Conclusion and Recommendations:

The risk of Cu deficiency increases in soils with coarse texture, high organic matter, and high soil pH (Solberg et al. 1999). Although, this contradicts the results from Prince Albert, who had an unusually low OM (2.9%), the lowest pH (5.7), and the lowest soil Cu (0.41 ppm) out of the three sites. Also, Melfort had the highest OM (9.5%), but the highest soil Cu (0.84 ppm). Overall, no site had Cu deficient soil which could explain the lack of significant results occurring from the study, but some interesting trends did occur. A tissue test sampled between tillering (Solberg et al. 1999) and early stem elongation (Winfield United 2023) with a value of 5-25 ppm of Cu is thought to be sufficient for the production of wheat (Heard Manitoba Agriculture). Tissue test samples were taken at all three locations after the boot application of foliar Cu but before heading occurred (Zadoks 50). All treatments resulted in Cu ppm higher than 5 in Melfort and Prince Albert, therefore having adequate Cu for wheat production. In Scott, six treatments had Cu ppm lower than 5, but no yield effect were observed.

FHB severity was low at Scott and Melfort and highest at Prince Albert. Prince Albert's high FHB could be due to precipitation and environmental conditions, along with not applying a fungicide, allowing for a better observation if Cu applications could reduce disease pressure. Prince Albert also noted ergot disease in their plots. Ergot was noted but not rated per plot in Prince Albert. Therefore, it is unclear if the Cu application decreased overall ergot infection. Two studies in Alberta found Cu applications in deficient soils resulted in lower ergot infections, with the early application having improved yield and controlled ergot compared to the late application (Evans et al. 1993). Scott rated leaf disease, but overall ratings were low. Therefore, no significant effects or observable trends were seen. Melfort had greater DTM than Scott and Prince Albert, resulting in a significant difference at Scott and Prince Albert from the absolute check (Melfort 0 g Cu/ha). This could be due to the additional precipitation Melfort received throughout the growing season along with a later seeding date, and less due to Cu applications. Overall, yield was greater at Melfort and Prince Albert than at Scott, this could be due to Scott having multiple years of decreased precipitation and higher temperatures.

Throughout the three sites, yield significance was seen at Scott, but not at Melfort or Prince Albert, even when there is a large yield gain when compared to the check in Melfort. This could be due to multiple factors, consisting of but not limited to, Scott having a larger CV than Melfort and Prince Albert, resulting in a higher distribution of data around the mean which could be the result of environmental factors. Scott also had a larger range from the highest to lowest value for yield (kg/ha) among plots when compared to Melfort and Prince Albert.

Results from this trial are similar to a project conducted in 2004, where over a period of 8 years, it was concluded that a foliar application at Feekes 2 (tillering) was ineffective. A single foliar application at Feekes 10 (swollen boot) was the most effective, followed by a single foliar application at Feekes 6 (1^{st} node). In conclusion, application at later stages appeared to be more effective; however, in some cases a combination of two foliar Cu applications resulted in maximum yield (Karamanos, R.E. et al., 2004).

When foliar applications alone were considered (treatment 1, 4, 5, and 6), yield increases from the dual application at 1^{st} node + boot stages were seen at Scott and Melfort. Also, the higher rate of foliar Cu resulted in the highest yield at Scott and Melfort. Thus, showing that foliar Cu could benefit yield. Also, having the lowest overall Cu rates out of the three Cu products, lessened the over-application of Cu, which caused yield decreases in the other groupings.

At Melfort, when MicroWrap was seed placed and used in combinations of foliar treatments (treatment 1, 2, 7, 8 and 11), Cu that was placed with the seed and applied foliar had a significantly greater yield than the absolute check (0 g Cu/ha-Melfort). Although this trend did not occur at Scott and Prince Albert. Melfort and Scott had trends of high yields occurring from the dual application of Cu at seeding + foliar. Similarly, in Scott and Melfort, higher yields tended to occur from seed + 1^{st} node and seed + boot treatments. Whereas, a decline in yields occurred at the seed + 1^{st} node + boot treatment. This could in turn be a result from higher total Cu rates being applied.

Ruffin-Tuff seed placement with foliar applications (treatment 1, 3, 9, 10 and 12) saw no significant or observable trends occur. Overall, the three groups measured resulted in little to no difference in the data parameters from the copper variables, regardless of placement, timing, or rates.

Extension Activities

A fact sheet will be created and distributed on the WARC website as well as all Agri-ARM and WARC events to ensure the information will be transferred to producers. Kade Kettenbach (WARC) will discuss the 2022 results from this trial at the AgriARM Research Update on March 2, 2023. Once complete, this report will be available on the NARF website. This trial was featured at the CLC Field Day July 28, 2022 with approximately 60 attendees.

Supporting Information

Acknowledgements

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Appendices:

Appendix A

Table A1. Agronomic information for the study of Evaluating the 4R Principles (Rate, Placement and Timing) For Copper Application on Wheat Yield and Seed Quality study at Scott, Melfort and Prince Albert, SK 2022.

Scott, SK			
Agronomic Information	Product	Rate	Date
Fertilizer	Urea (46-0-0) & MAP (11-52-0)	104 kg/ha & 65 kg/ha	May 9, 2022
Seed	AAC Viewfield	112 lb/ac	May 9, 2022
Cu Applications	As per protocol	As per protocol	As per protocol
Herbicide: Pre-plant	-	-	-

In-Crop 2nd In-Crop	Axial & Infinity Buctril M	0.5 L/ac & 0.33 L/ac 0.4 L/ac	June 16, 2022 June 22, 2022
Fungicide	Caramba	400 ml/ac	July 14, 2022
Insecticide	-	-	-
Desiccation	Glyphosate 540, Heat LQ & Merge	1 L/ac, 59ml/ac & 200 ml/ac	August 18, 2022
Harvest	-	-	August 30, 2022

Melfort, SK			
Agronomic Information	Product	Rate	Date
Fertilizer	Urea (46-0-0), MAP (11-52-0), KCl (0-0-60) & AMS (21-0-0-24)	136 kg/ha, 49 kg/ha, 11 kg/ha & 6 kg/ha	May 24, 2022
Seed	AAC Brandon	93 lb/ac	May 24, 2022
Cu Applications	As per protocol	As per protocol	As per protocol
Herbicide: Pre-plant 2nd Pre-plant In-Crop 2nd In-Crop	 Avadex Roundup Transorb HC 640 Axial Prestige XL	 1.2 L/ac 0.67 L/ac 0.5 L/ac 0.947 L/ac	 May 12, 2022 May 21, 2022 June 22, 2022 June 28, 2022
Fungicide	Caramba	400 mL/ac	July 18, 2022
Insecticide	-	-	-
Desiccation	-	-	-
Harvest	-	-	September 15, 2022

Prince Albert, SK			
Agronomic Information	Product	Rate	Date
Fertilizer	Urea (46-0-0) & MAP (11-52-0)	82 kg/ha & 95 kg/ha	June 8, 2022
Seed	AAC Viewfield	95 lb/ac	June 8, 2022
Cu Applications	As per protocol	As per protocol	As per protocol
Herbicide: Pre-plant In-Crop	 Prepass A & B Infinity & Puma Advance	 40 mL/ac & 0.38 L/ac 0.34 L/ac & 0.41 L/ac	 May 26, 2022 June 28, 2022
Fungicide	-	-	-
Insecticide	-	-	-
Desiccation	-	-	-
Harvest	-	-	September 16, 2022

Abstract

Abstract/Summary

Copper (Cu) is an essential micronutrient and can be deficient in soils with coarse texture, high organic matter, frequent applications of manure, or high soil pH. There are many Cu products available to correct soil deficiencies at various times in the growing season. A small plot demonstration was undertaken during 2022 in Scott, Melfort and Prince Albert, SK to assess the effects of copper placement, timing, and rates on wheat. To do so, two chelated Cu products (MicroWrap Cu ™ and Ruffin Tuff Cu ™) were tested at seeding alone or in combination with a foliar Cu product (MicroBolt Cu ®) applied at either the first node (Zadoks 31), booting (Zadoks 45), or both of those stages.

Treatments were grouped into 3 different groups for factorial analysis. First, comparing rates and timing of foliar Cu, then comparing placement, rate, and timing with MicroWrap as the seeding time source of Cu. Lastly, comparing placement, rate, and timing with Ruffin-Tuff as the seeding time source of Cu.

In group 1, as foliar timings at each site went from the check to the dual application at the 1st node + boot stages, a trend of increasing yield was seen at Scott and to a lesser effect, Melfort, whereas the dual application of foliar Cu resulted in the highest yield. Also, the higher rate of foliar Cu resulted in the highest yield at Scott and Melfort, with yields of 3718 kg/ha and 5008 kg/ha, respectively.

In group 2, Cu placement in Melfort had a strong trend of increasing yields from the check to the dual application of Cu at seeding + foliar. Therefore, the dual application resulted in the highest yield (4936 kg/ha), followed by seed placement and lastly, the check. Scott had a similar trend such that the dual application resulted in the highest yield (3598 kg/ha), but the check out-yielded the seed placement treatment. Timing of Cu had no significant trends, but it can be noted that in Scott and Melfort, higher yields tended to occur from seed + 1st node and seed + boot treatments. Whereas, a decline in yields then occurred at the seed + 1st node + boot treatment, possibly resulting from higher Cu rates being applied. Cu rate had similar trends at Scott and Melfort with a rate of 215 g Cu/ha resulting in the highest yield at both locations (3663 and 4989 kg/ha). A slight yield reduction was caused by 404 g Cu/ha, another possible effect of high Cu rates.

When looking at yield at the three locations in regards to placement and rate, no trends were observed in the 3rd grouping. At Scott and Prince Albert, a trend for timing (seed + 1st node + boot) and rate (559 g Cu/ha) resulted in the lowest yields (3123 and 4384 kg/ha). These trends could again suggest that yields were negatively affected by the increased amount of Cu applied.

When flag leaves were sampled prior to heading, the treatments that received a foliar application of Cu at the booting stage in Melfort and Prince Albert had tissue Cu levels >5ppm, which is adequate for wheat production. Scott had multiple treatments below 5 ppm, but no yield effects were seen. The background soil Cu content of the trial area was measured at 0.65 ppm at Scott, 0.84 ppm at Melfort and

0.41 ppm at Prince Albert. Soils in Scott, Melfort and Prince Albert would not be classified as Cu deficient, which could account for the lack of significant results. Overall, foliar Cu resulted in greater yields, but higher rates may have been responsible for yield decreases.

Finances

Expenditure Statement

Provided in attached spreadsheet.

References

Evans, I., Maurice, D., Penny D., and Solberg E. 1993. Wheat Diseases and Copper Nutrition. Better Crops/Winter 1993/94. Albert Agriculture Food and Rural Development, Soil and Crop Management Branch. [Online]. Available. http://www.ipni.net/publication/bettercrops.nsf/0/CE79FBD85104C75985257D320053E15D/$FILE/BC-1993-4%20p6.pdf [February 22, 2023].

Heard, J. Copper Deficiency in Wheat. Manitoba Agriculture. [Online]. Available: https://www.gov.mb.ca/agriculture/crops/seasonal-reports/pubs/copper-deficiency-in-wheat.pdf [January 26 2023].

Karamanos, R.E., Q. Pomarenski, T.B. Goh and N. Flore. 2004. The effect of foliar copper application on grain yield and quality of wheat. Can. J. Plant sci. 84:47-56. [Online]. Available: https://cdnsciencepub.com/doi/pdf/10.4141/P03-090 [February 22, 2023].

McKenzie, R. 2016. Managing copper deficiency in cereal crops. Top Crop Manager. [Online]. Available: https://www.topcropmanager.com/managing-copper-deficiency-in-cereal-crops-19699/ [January 26 2023].

R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

R Studio Team. 2020. RStudio: Integrated development for R. RStudio, PBC, Boston, MA.
Saskatchewan Ministry of Agriculture. 2023. Fusarium Head Blight. [Online]. Available: https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/disease/fusarium-head-blight [February 8, 2023].

Solberg, E., Evans, I., Penny, D. 1999. Copper Deficiency: Diagnosis and Correction Agronomy Unit, Plant Industry Division, Alberta Agriculture. [Online]. Available: https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex3476/$file/532-3.pdf?OpenElement [January 26 2023].

Winfield United. 2023. Copper is Golden for Wheat Yields. [Online]. Available: https://www.winfieldunited.com/news-and-insights/copper-is-golden-for-wheat-yields#:~:text=Copper%20is%20essential%20for%20pollination,system%20and%20improves%20plant%20health [January 26 2023].

Yara Canada. 2023. Copper Requirements for Cereal Crops. [Online]. Available: https://www.yaracanada.ca/crop-nutrition/why-micronutrients/copper-requirements-for-cereal-crops/ [January 26 2022].