Forage and Livestock Research

Copper enrichment in fodder wheat, barley and oats – An option to improve cattle productivity

Background:

Many cattle consuming locally produced forages are susceptible to copper (Cu) deficiency in Alberta. A significant challenge for livestock producers in several parts of the province, including the Lakeland region, is that Cu concentrations in both soils and locally produced forages (e.g., hay and silage) are too low to meet animal health and performance targets. Cows experiencing insufficient Cu supply have low conception rates and often suffer weight loss unless Cu supplementation is provided.

Under average conditions, beef cattle require a daily intake of approximately 10 mg kg^{-1} Cu in ration dry matter. However, if cattle are exposed to high levels of sulfates in drinking water, this requirement increases to 20–25 ppm (BCRC, 2017). Cu supplementation via injections or free-choice mineral kits can help correct deficiencies in cattle but may not be sufficient when animals are fed Cu-deficient forages grown on soils with low Cu levels.

Therefore, it is important to note that the Cu content of forage crops grown in the Lakeland region of Alberta is generally below the established levels required for cattle production, although molybdenum (Mo) levels are very low (data retrieved from feed analysis reports of MD of Bonnyville, County of St. Paul, and Smoky Lake County). In this context, there is a critical need to increase the Cu content of locally grown forages, particularly wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and oats (*Avena sativa* L.), which are the most susceptible to Cu deficiency.

Enhancing the Cu content of forage crops through foliar-applied Cu amendments presents a promising and cost-effective approach to improving cattle health and productivity. However, this technique has not been widely adopted in the region due to limited technical information on foliar Cu fertilization of forage crops. Consequently, a field investigation was conducted at the LARA Research Farm during the 2025 growing season to assess the response of fodder wheat, barley, and oats grown on grey-wooded soil to varying levels of foliar Cu fertilizer, with the following principal objectives:

Objectives:

i. To provide regional and unbiased information regarding the effect of different rates of copper sulfate (CuSO4) foliar application on forage dry matter yield of wheat, barley and oats.
ii. To investigate the effect of different rates of CuSO4 foliar application on forage nutritive value of wheat, barley and oats.
iii. To increase Cu content of forage wheat, barley and oats to improve animal performance and productivity.
iv. To determine any antagonism between Cu, zinc (Zn) and iron (Fe) concentration.
v. To determine the adequate concentration of Cu foliar spray to correct Cu deficiency without leaf bronzing in forage wheat, barley and oats when grown in a grey-wooded soil.

Materials and Methods:

The trial was conducted at the LARA Research Farm (54°18′N, 110°37′W; NE 25-61-5-W4) in Fort Kent, Alberta, during the 2025 growing season. Prior to seeding, soil samples were collected from depths of 0–6 and 6–12 inches to determine nutrient levels at Element Lab, Edmonton. Seeding rate (g/plot) was calculated using the formula: 1000 kernel weight*(desired plants/m2/1000) *plot area m2*(100/germination%) *1.05.

The factor 1.05 was used during calculations to take care of seedling mortality. The desired plant density was set at 300 plants/m^2 for barley and oats, and 350 plants/m^2 for wheat.

The experiment comprised 3 cereal species (wheat, cv. Alotta; barley, cv. AB Maximizer; and oats cv. CDC Endure) and 4 Cu spray concentrations, representing a total of (3x4) 12 treatments. The Cu was applied in the sulfate form ($CuSO4.5H_2O$; 25% Cu).

The Cu treatments (T) are as follows:

Treatment	Product ($CuSO4.5H_2O$)	Water Volume
Control	0	0
0.1 lb Cu/acre	0.4 lb/acre	10 gallons per acre
0.3 lb Cu/acre	1.2 lb/acre	10 gallons per acre.
0.5 lb Cu/acre	2.0 lb/acre	10 gallons per acre.

The experiment was planted in a randomized complete block design (RCBD) with four replications of 12 treatments. Seeding was carried out using a LARA Fabro five-row seeder with 9" row spacing. Plots were seeded to a depth of 1-1.5" depending on soil conditions and available moisture. Based on soil test results, the recommended rate of fertilizers was side banded during seeding. All Cu treatments were mixed with water and applied at a rate of 10 gallons (37.85 liters) of water per acre. Spraying was carried out when each crop reached the booting stage, using a backpack sprayer under windless conditions. Hand weeding occurred throughout the growing season to maintain the experimental area weed free. The net plot size was 6.9 m^2 (1.15 m by 6 m). Harvesting was carried out when barley grains reached the soft dough stage, and wheat and oats reached the late milk stage. Individual plots were harvested with LARA Alfalfa-Omega self-propelled forage harvester. For each treatment plot, approximately 400 g of chopped forage (subsample) was dried to a constant weight and submitted to A & L Canada Laboratories Inc. for quality analysis.

A second subsample of approximately 250 g of freshly harvested material was collected from each plot and dried to a constant weight for dry matter calculations. The data for forage DM yield and each of the quality parameters were subjected to analysis of variance (ANOVA) and means were subsequently compared by the least significant difference (LSD) test at ≤ 0.05 probability level using the agricolae (version 1.3-7) package of the R (4.3.2) software.

Oats

Foliar Cu applications significantly increased the Cu content of silage oats by up to approximately 174% relative to the control. As expected, silage Cu concentrations increased linearly with increasing foliar Cu rates. The highest Cu application rate (0.5 lb Cu ac^{-1}) resulted in a Cu concentration of 8.04 mg kg^{-1}, whereas the control plots (no Cu application) contained 2.93 mg kg^{-1}. Intermediate application rates of 0.1 and 0.3 lb Cu ac^{-1} produced Cu concentrations of approximately 3.61 and 6.51 mg kg^{-1}, respectively (Fig 3e-1).

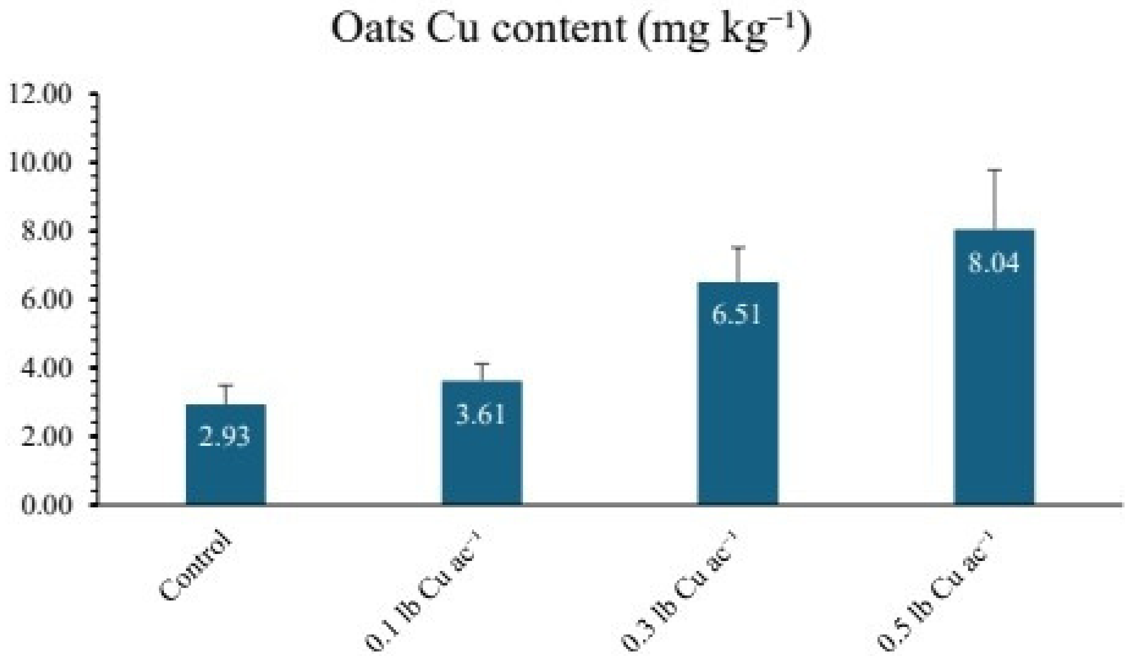

Figure 3e-1. Oats Cu content as influenced by different foliar Cu application rates.

Except for Cu, most silage quality attributes were not significantly influenced by the different Cu treatments applied; however, the values obtained remained within adequate ranges to meet the nutritional requirements of the various beef cattle categories. In Cu-treated plots, crude protein (CP) ranged from 12.4% to 12.7%, while total digestible nutrients (TDN) ranged from 65.71% to 66.19%, both of which are sufficient to meet the requirements of lactating beef cattle. Compared with the control, Cu-treated plots showed slightly higher ADF and NDF values; however, these differences were not statistically significant. On average, the control plots contained 28.81% ADF and 51.53% NDF, whereas in Cu-treated plots, ADF and NDF ranged from 29.16% to 29.76% and 51.82% to 52.72%, respectively (Table 3e-1).

It is well established that antagonistic interactions can occur among Zn, Cu, Fe, and Mn. In this study, Zn levels were below the range considered adequate (~30 mg kg^{-1}) for beef cattle; however, this was not due to Cu application, as the untreated control plots also showed low Zn (21.3 mg kg^{-1}). Cu treatments did not cause statistically significant changes in the Fe, Mn, or Zn content of the silage (Table 3e-3). Untreated control plots contained, on average, 21.3 mg kg^{-1} Zn, 127.85 mg kg^{-1} Fe, and 66.28 mg kg^{-1} Mn, whereas Cu-treated plots had Zn, Fe, and Mn concentrations ranging from 19.8 to 22.35 mg kg^{-1}, 130.01 to 153.27 mg kg^{-1}, and 58.46 to 68.75 mg kg^{-1}, respectively, indicating that foliar Cu applications.

In terms of forage DM yield, no significant differences were observed between the Cu-treated plots and the untreated control plots, indicating that foliar Cu fertilization @ 0.1-0.5 lb Cu ac^{-1} can enhance the Cu concentration of silage oats (by up to 174%) without adversely affecting forage productivity. The control plots produced an average forage DM yield of 1.96 t ac^{-1}, whereas yields in the Cu-treated plots ranged from 1.81 to 1.85 t ac^{-1}.

Among the Cu-treated plots, the 0.5 lb Cu ac^{-1} treatment resulted in the numerically highest yield, while the 0.3 lb Cu ac^{-1} treatment produced the lowest (Table 3e-1).

Table 3e-1. Forage dry matter (DM) yield, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and total digestible nutrients (TDN) of fodder oat under different Cu treatments.

Treatment	DM Yield (t/ac)		CP (% DM)		NDF (% DM)		ADF (% DM)		TDN (% DM)	
Control	1.96	a	12.14	a	51.53	a	28.81	a	66.46	a
0.1 lb Cu/acre	1.82	a	12.70	a	52.72	a	29.26	a	66.11	a
0.3 lb Cu/acre	1.81	a	12.40	a	52.57	a	29.16	a	66.19	a
0.5 lb Cu/acre	1.85	a	12.63	a	51.82	a	29.76	a	65.71	a
Pr (>F)	0.7634		0.65		0.907		0.885		0.884	

Note : Significance Codes : 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'.

Table 3e-2. Forage calcium (Ca), phosphorous (P), potassium (K), magnesium (Mg), and sodium (Na) content of fodder oat under different Cu treatments.

Treatment	Ca (% DM)		P (% DM)		K (% DM)		Mg (% DM)		Na (% DM)	
Control	0.39	a	0.14	a	1.15	a	0.29	a	0.57	a
0.1 lb Cu/acre	0.37	a	0.15	a	1.18	a	0.27	a	0.54	a
0.3 lb Cu/acre	0.37	a	0.15	a	1.25	a	0.28	a	0.51	a
0.5 lb Cu/acre	0.33	a	0.15	a	1.09	a	0.24	a	0.51	a
Pr (>F)	0.387		0.964		0.388		0.21		0.84	

Note : Significance Codes : 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'.

Table 3e-3. Forage copper (Cu), zinc (Zn), iron (Fe), and manganese (Mn) content of fodder oat under different Cu treatments.

Treatment	Cu (mg kg^{-1})		Zn (mg kg^{-1})		Fe (mg kg^{-1})		Mn (mg kg^{-1})	
Control	2.93	b	21.23	a	127.85	a	66.28	a
0.1 lb Cu/acre	3.61	b	21.24	a	153.27	a	60.43	a
0.3 lb Cu/acre	6.51	a	22.35	a	144.80	a	68.75	a
0.5 lb Cu/acre	8.04	a	19.80	a	130.01	a	58.46	a
Pr (>F)	5.24e-05***		0.67		0.544		0.352	

Note: Significance Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'; mg kg^{-1}: milligram per kilogram.

Wheat

The experiment demonstrated a significant increase in Cu content (71% higher than the control) in plots that received foliar Cu fertilization. The highest average Cu concentration (7.08 mg kg^{-1}) was recorded with $CuSO_4$ applied @ 0.5 lb Cu ac^{-1}, while the lowest value (4.15 mg kg^{-1}) was observed in the untreated control plots. Foliar applications of 0.3 and 0.1 lb Cu ac^{-1} resulted in intermediate Cu concentrations of 6.70 and 5.37 mg kg^{-1}, respectively (Fig 3e-2).

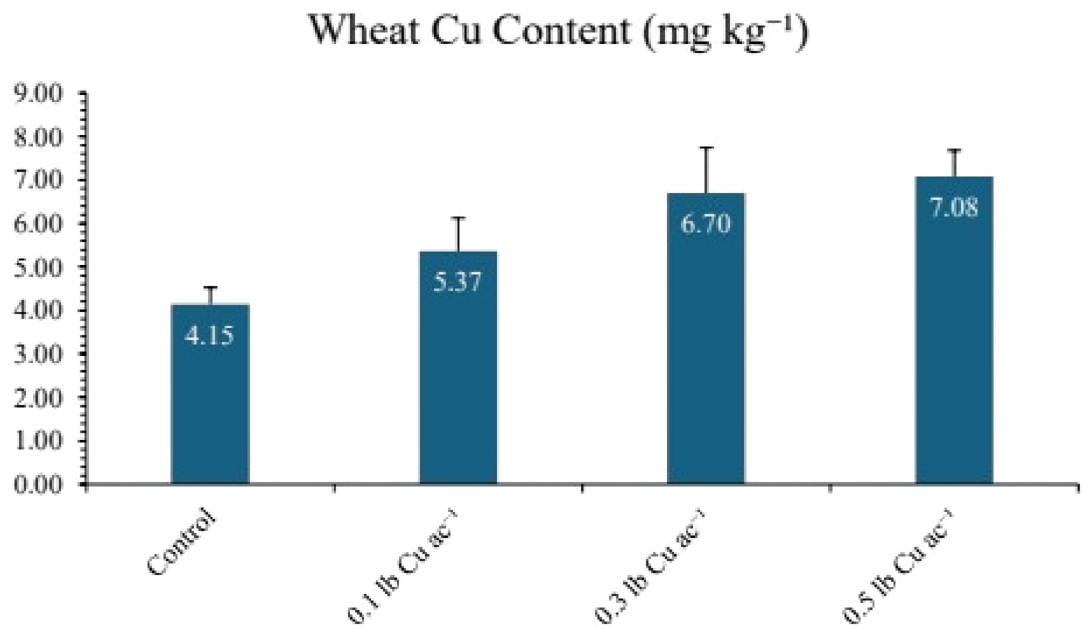

Figure 3e-2. Wheat Cu content as influenced by different foliar Cu application rates.

With regard to wheat silage quality, apart from Cu, none of the other attributes examined were significantly affected by foliar Cu fertilization (Table 3e-4, 5 & 6); similar trends were observed in silage oats. In the plots sprayed with $CuSO_4$, CP and TDN levels ranged from 10.81% to 11.10% and 67.15% to 68.82%, respectively, both of which are sufficient to meet the nutritional requirements of lactating beef cattle. Notably, the highest Cu application rate resulted in numerically lower ADF and NDF values; however, these differences were not statistically significant.

Concerning Zn, Fe, and Mn contents, although Cu applications can potentially negatively affect these micronutrients, the concentrations measured in the Cu-treated plots did not decline drastically. In these plots, Zn, Fe, and Mn concentrations ranged from 18.15-20.24, 120.04-129.58, and 50.69-55.78 mg kg^{-1}, respectively. In the control plots, Zn, Fe, and Mn concentrations averaged 21.04, 126.56, and 53.73 mg kg^{-1}, respectively (Table 3e-6).

Regarding dry matter yields, foliar application of $CuSO_4$ did not result in significant differences compared to the control. Across treatments, DM yield ranged from 3.49 to 3.60 t ac^{-1}, with the highest yield observed at 0.3 lb Cu ac^{-1} and the lowest at 0.5 lb Cu ac^{-1} (3e-4).

Table 3e-4. Forage dry matter (DM) yield, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and total digestible nutrients (TDN) of fodder wheat under different Cu treatments.

Treatment	DM Yield (t/ac)		CP (% DM)		NDF (% DM)		ADF (% DM)		TDN (% DM)	
Control	3.50	a	11.30	a	50.75	ab	26.37	a	68.36	a
0.1 lb Cu/acre	3.50	a	10.81	a	51.30	a	27.93	a	67.15	a
0.3 lb Cu/acre	3.60	a	11.10	a	50.30	ab	26.83	a	68.00	a
0.5 lb Cu/acre	3.49	a	11.10	a	47.87	b	25.79	a	68.82	a
Pr (>F)	0.2473		0.885		0.182		0.363		0.362	

Note : Significance Codes : 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'.

Table 3e-5. Forage calcium (Ca), phosphorous (P), potassium (K), magnesium (Mg), and sodium (Na) content of fodder wheat under different Cu treatments.

Treatment	Ca (% DM)		P (% DM)		K (% DM)		Mg (% DM)		Na (% DM)	
Control	0.18	a	0.14	a	0.85	a	0.23	a	0.01	a
0.1 lb Cu/acre	0.19	a	0.15	a	0.90	a	0.23	a	0.01	a
0.3 lb Cu/acre	0.20	a	0.15	a	0.90	a	0.23	a	0.01	a
0.5 lb Cu/acre	0.17	a	0.15	a	0.86	a	0.22	a	0.01	a
Pr (>F)	0.216		0.913		0.214		0.746		0.325	

Note : Significance Codes : 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'

Table 3e-6. Forage copper (Cu), zinc (Zn), iron (Fe), and manganese (Mn) content of fodder wheat under different Cu treatments.

Treatment	Cu ($mg\ kg^{-1}$)		Zn ($mg\ kg^{-1}$)		Fe ($mg\ kg^{-1}$)		Mn ($mg\ kg^{-1}$)	
Control	4.15	c	21.04	a	126.56	a	53.73	a
0.1 lb Cu/acre	5.37	b	18.15	a	129.58	a	50.87	a
0.3 lb Cu/acre	6.70	a	19.90	a	126.61	a	55.78	a
0.5 lb Cu/acre	7.08	a	20.24	a	120.04	a	50.69	a
Pr (>F)	0.000401***		0.614		0.83		0.709	

Note: Significance Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'; $mg\ kg^{-1}$: milligram per kilogram.

Barley

Despite the absence of a statistically significant overall treatment effect, foliar CuSO4 application resulted in a nearly twofold (approximately 93%) numerical increase in silage barley Cu concentration compared with the untreated control. The highest mean Cu concentration (6.65 mg kg^{-1}) was recorded with CuSO4 applied @ 0.3 lb Cu ac^{-1}. In contrast, the control plots, which did not receive any Cu application, had the lowest mean Cu content (3.45 mg kg^{-1}), highlighting the effect of foliar Cu fertilization on increasing Cu levels in the forage. Foliar applications of 0.5 and 0.1 lb Cu ac^{-1} resulted in mid-range Cu concentrations of 6.56 and 4.75 mg kg^{-1}, respectively (Table 3e-3).

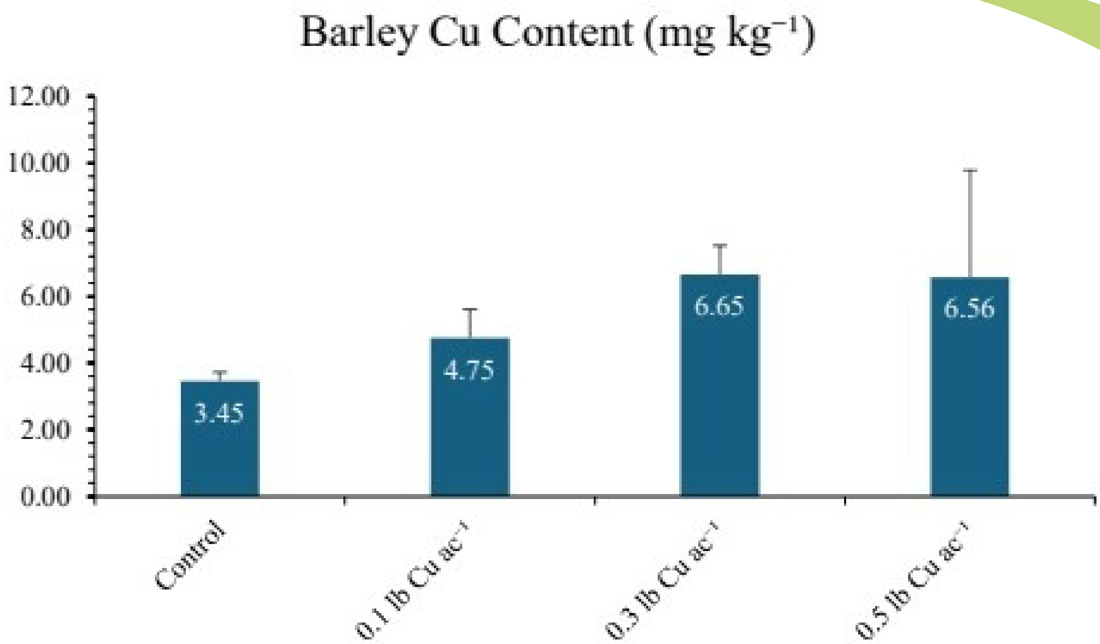

Figure 3e-3. Barley Cu content as influenced by different foliar Cu application rates.

In contrast to silage wheat and oats, the TDN level of silage barley was significantly influenced by foliar Cu treatments. The highest mean TDN (70.92%) was observed in the control plots, while Cu-treated plots showed slightly lower values ranging from 69.06% to 70.84%; these levels remain sufficient to meet the energy requirements of lactating beef cattle. Foliar Cu applications also significantly influenced fibre content, as reflected in ADF and NDF values. Control plots recorded the lowest ADF (23.08%) and NDF (45.65%), whereas Cu-treated plots showed slightly higher values (ADF 23.18–25.47% and NDF 46.65–49.57%), indicating that foliar Cu treatments increase the fiber fractions in forage barley (Table 3e-7).

As mentioned earlier, there was a possibility of observing antagonistic interactions among Cu, Zn, Fe, and Mn. However, none of the Cu application rates significantly reduced Zn, Fe, or Mn levels. On average, the control plots contained 17.8 mg kg^{-1} Zn, 95.81 mg kg^{-1} Fe, and 35.13 mg kg^{-1} Mn. In Cu-treated plots, Zn, Fe, and Mn concentrations ranged from 17.00 to 17.72 mg kg^{-1}, 86.23 to 95.98 mg kg^{-1}, and 30.75 to 32.89 mg kg^{-1}, respectively, indicating that foliar Cu applications did not adversely affect the levels of these micronutrients (Table 3e-9).

Similar to silage oats and wheat, foliar applications of Cu did not significantly affect the DM yield of silage barley. The highest forage biomass (2.96 t ac^{-1}) was observed with CuSO4 applied @ 0.1 lb Cu per acre, while the lowest DM yield (2.84 t ac^{-1}) occurred with 0.5 lb Cu ac^{-1}. The 0.3 lb Cu ac^{-1} treatment produced the second highest yield (2.89 t ac^{-1}), and the untreated control plots produced the second-lowest yield (2.86 t ac^{-1}). Overall, these results indicate that foliar Cu applications had only minor effects on forage DM yield (Table 3e-7).

Table 3e-7. Forage dry matter (DM) yield, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and total digestible nutrients (TDN) of fodder barley under different Cu treatments.

Treatment	DM Yield (t/ac)		CP (% DM)		NDF (% DM)		ADF (% DM)		TDN (% DM)	
Control	2.86	a	12.74	a	45.65	b	23.08	b	70.92	a
0.1 lb Cu/acre	2.96	a	12.20	b	46.65	b	23.18	b	70.84	a
0.3 lb Cu/acre	2.89	a	12.29	ab	49.57	a	25.45	a	69.08	b
0.5 lb Cu/acre	2.84	a	12.17	b	49.53	a	25.47	a	69.06	b
Pr (>F)	0.8977		0.109		0.0213*		0.0173*		0.0175*	

Note : Significance Codes : 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'.

Table 3e-8. Forage calcium (Ca), phosphorous (P), potassium (K), magnesium (Mg), and sodium (Na) content of fodder barley under different Cu treatments.

Treatment	Ca (% DM)		P (% DM)		K (% DM)		Mg (% DM)		Na (% DM)	
Control	0.28	a	0.12	a	0.89	a	0.26	a	0.32	a
0.1 lb Cu/acre	0.28	a	0.12	a	0.88	a	0.26	a	0.33	a
0.3 lb Cu/acre	0.31	a	0.12	a	0.87	a	0.27	a	0.34	a
0.5 lb Cu/acre	0.30	a	0.12	a	0.85	a	0.28	a	0.35	a
Pr (>F)	0.837		0.899		0.953		0.746		0.976	

Note : Significance Codes : 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'.

Table 3e-9. Forage copper (Cu), zinc (Zn), iron (Fe), and manganese (Mn) content of fodder barley under different Cu treatments.

Treatment	Cu (mg kg^{-1})		Zn (mg kg^{-1})		Fe (mg kg^{-1})		Mn (mg kg^{-1})	
Control	3.45	b	17.80	a	95.81	a	35.13	a
0.1 lb Cu/acre	4.75	ab	17.39	a	86.23	a	31.16	a
0.3 lb Cu/acre	6.65	a	17.72	a	95.98	a	32.89	a
0.5 lb Cu/acre	6.56	a	17.00	a	89.89	a	30.75	a
Pr (>F)	0.111		0.959		0.842		0.178	

Note: Significance Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'; mg kg^{-1}: milligram per kilogram.

Conclusions

Overall, the findings demonstrate that foliar application of CuSO4 at rates of 0.3 to 0.5 lb Cu per acre successfully increased the Cu concentration of silage wheat, barley, and oats by approximately two- to threefold compared with the control where no Cu was applied.

Although dry matter yield was 20-30% lower than expected due to extremely dry growing conditions in Northeastern Alberta, foliar Cu fertilization itself did not cause any additional reductions in yield or other quality characteristics.

It is well established that growing and finishing cattle require a minimum of 10 mg Cu kg^{-1} in their diet to maintain adequate mineral status. In this study, foliar application of $CuSO_4$ increased Cu concentrations from 2.93 to 8.04 mg kg^{-1} in oats, from 4.15 to 7.08 mg kg^{-1} in wheat, and from 3.45 to 6.65 mg kg^{-1} in barley; however, these levels remain below the threshold needed to fully satisfy the animals' Cu requirements. These results indicate that although foliar Cu application at the rates used can substantially enhance silage Cu content, additional Cu supplementation is still necessary to ensure cattle receive adequate dietary Cu to support optimal growth, health, and productivity. Although it is possible that foliar Cu rates higher than 0.5 lb Cu ac^{-1} could increase silage Cu concentrations to 10 mg kg^{-1} or more, such increases may markedly reduce other essential micronutrients (Zn, Fe, and Mn) and negatively impact dry matter yield. Therefore, foliar $CuSO_4$ applications within the 0.3-0.5 lb Cu ac^{-1} range appear both effective and agronomically safe.

Because this study was conducted during a single growing season that was unfortunately extremely dry, further experimentation over at least two additional years is needed to validate these findings and strengthen the recommendations.

Proudly funded by:

RDAR Results Driven Agriculture Research

MUNICIPAL DISTRICT BONNYVILLE NO. 87

Alberta

COUNTY 19 ST. PAUL

Sustainable Canadian Agricultural Partnership
Competitive. Innovative. Resilient.

Canada