Feasibility of copper fertilization for optimum crop yield in the Canadian Prairies

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Background

In the Canadian prairie soils, deficiency of Cu is not widespread but whenever it occurs it can cause a drastic reduction in seed yield and quality of most cereals, especially wheat. In wheat, Cu deficiency symptoms include yellowing and curling of young leaves, pigtailing of leaf tips, limpness or wilting, delay in heading, aborted heads and spikelets, head and stem bending, as well as stem melanosis disease in certain wheat cultivars.

In organic (peat) soils, Cu deficiency is a major limitation to small grain production and often these soils respond dramatically to Cu fertilization. In mineral soils, Cu deficiency usually occurs in coarse textured soils, in irregular patches within fields. In Saskatchewan, approximately 1 million acres are estimated to be potentially deficient in Cu for optimum yield. For economic reasons, a reliable prediction of plant-available Cu in soil during the crop growing period is needed in order apply Cu fertilizers at appropriate rates, using proper Cu sources (Table 1). In western Canada, DTPA-extractable Cu is a good measure of available Cu in soil. Seed yield response of wheat to Cu fertilizer is expected in soils containing < 0.4 ppm Cu (Figure 1). However, soil tests for Cu do not always provide an accurate indication of available Cu in soil, especially on soils mildly deficient in Cu or soils with heavy texture. For example, Cu deficiency symptoms and seed yield response of wheat to Cu fertilizer has been also observed on soils containing 0.8 mg Cu kg^{-1}; on the other hand, clay soils with Cu levels below the critical level did not respond to Cu additions. In-crop assessment of Cu deficiency also has potential to improve crop yield. Visual symptoms usually occur when the crop is moderately to severely lacking in Cu. In addition, visual symptoms can be confused with those caused by herbicide injury or frost. Nevertheless, visual diagnostic can be an effective tool when combined with soil and tissue testing (Table 2). Plant tissue testing can also be used to determine Cu deficiency in plants, but information provided by this method may be too late to correct the Cu deficiency problem and restore seed yield to the optimum level for the current crop.

Crop species vary in their sensitivity to Cu deficiency, cereals being more sensitive than other crops (Tables 3 and 4). Furthermore, cultivars within the various cereal crops species differ in their sensitivity to Cu deficiency. Increasing supply of P, N and Zn can increase severity of Cu deficiency in crops. High levels of P, Zn, Fe, Mn and Al in soil can restrict Cu absorption by plant roots and induce Cu deficiency in crop plants, and high level of N in soil can delay the translocation of Cu in crop plants. Application of N alone to a situation of mild Cu deficiency (absence of visual Cu deficiency symptoms) can result in severe Cu deficiency symptoms and loss of seed yield. This is most likely due to delay in translocation of Cu from older leaves to new leaves, thus enhancing the severity of Cu deficiency.

Table 1. Characteristics of Cu fertilizer products used in field experiments

Cu fertilizer product	Trade name[z]	Chemical formulation	Cu content or concentration	Product producer or distributor
Cu lignosulphonate (granular)	Micro Tech	Cu lignin sulphonate	5%	RSA Micro Tech, Seattle, WA, USA
Cu sulphate (granular)	Copper sulphate	Cu $SO_4 5H_2 0$	25%	Pestell Minerals and Ingredients, New Hamburg, ON, Canada
Cu oxysulphate I (granular)	Cu 15% Micro Mix	Cu treated with H_2SO_4	15%	Cameron Chemicals, Inc., Portsmouth, VA, USA
Cu oxysulphate II	Frits-220G	Cu treated with H_2SO_4	20%	Frit Industries, Ozark, AL, USA
Cu chelate-EDTA liquid	Tiger EDTA	Cu EDTA[2]	93.5 g/L	Tiger Industries, Calgary, AB, Canada
Cu sequestered I (liquid)	Tiger foliar	Cu complexed with lignin sulphonate	61.1 g//L	Tiger Industries, Calgary, AB, Canada
Cu sulphate/chelate (granular dissolvable)	Pro-Sol Cu CAC	Copper sulphate citric acid EDTA	20%	Frit Industries, Ozark, AL, USA
Cu sequestered II (liquid)	PhosynCoptrel 500	Cu oxychloride	500 g/L	Phosyn Canada, Grand Falls, NB, Canada

[Z]The use of trade names, proprietary produce or vendor does not imply endorsement by authors or Agriculture and Agri-Food Canada.

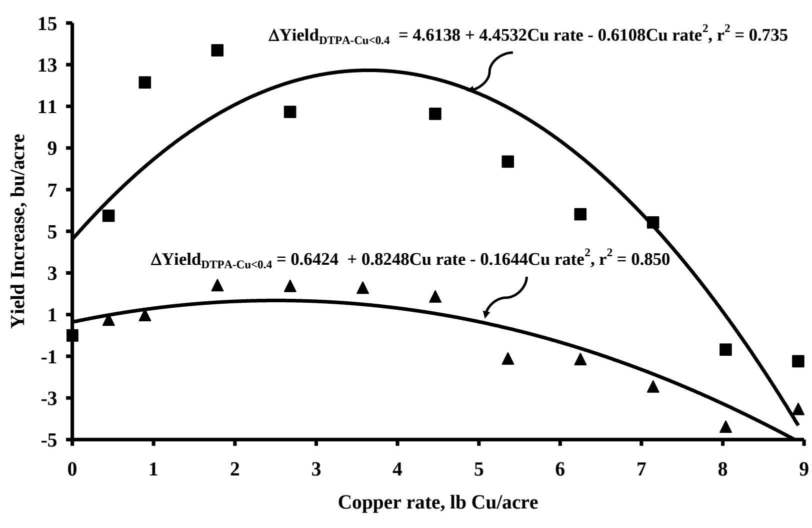

Figure 1. Yield increase of wheat for deficient (■, DTPA-Cu <0.4 ppm) and sufficient (▲, DTPA-Cu >0.4 ppm) soils (adapted from: Karamanos, R. E. and Goh, T. B. 2004. Effect of rate of copper application on the yield of hard red spring wheat. Comm. Soil Sci. Plant Anal. 35: 2037-2047).

Deficiency of Cu is also associated with crop diseases. In the Canadian prairies, spring wheat (cv. Park) grown on Cu-deficient soils was found highly susceptible to stem melanosis, which was effectively controlled by the application of Cu (Tables 3 and 4). Incidences of other diseases of wheat, such as take-all, powdery mildew and ergot, have been reduced when Cu was added to Cu-deficient soils: however, Cu deficiency in itself is not the cause of these diseases. Wilting of leaves in alfalfa has also been induced by Cu deficiency in soil. This report summarizes results of Cu fertilizer management experiments conducted in the Canadian Prairies to prevent and/or control Cu deficiency in crops for optimum yield.

Table 2. Copper concentration (ppm Cu) in whole plant (WP) and youngest fully emerged leaf (YFEL) of barley at mid-tiller (GS 25) to stem elongation (GS 39) from Cu-responsive and non-responsive sites (prepared from Solberg et al. 1996)

Site	DTPA-extractable Cu in soil (ppm Cu)	Cu-responsive sites				DTPA-extractable Cu in soil (ppm Cu)	Non-responsive sites			
		YFEL		WP			YFEL		WP	
		Cu-	Cu+	Cu-	Cu+		Cu-	Cu+	Cu-	Cu+
1	0.5	3.2	3.2	2.9	2.9	0.5	5.3	5.2	2.8	2.8
2	0.5	3.4	4.0	3.0	2.9	0.6	6.7	6.5	3.6	3.7
3	0.7	3.7	5.5	3.1	2.8	1.8	5.0	5.6	3.5	3.2
4	0.5	4.9	4.8	3.0	3.1	0.3	6.5	6.4	3.5	3.5
Mean	0.55	3.8	4.4	3.0	2.9	0.80	5.9	5.9	3.3	3.3

Table 3. Comparisons of six wheat cultivars for stem melanosis severity and seed yield with and without added copper in a field experiment on a Black Chernozemic sandy loam soil at Lacombe, Alberta in 1985 (prepared from Piening et al. 1989)

	Disease severity (%)		Seed yield (bu/acre)	
	Without Cu	With Cu	Without Cu	With Cu
Park	100	39	1.1	24.4
Neepawa	18	2	5.9	31.6
Sinton	6	0	2.8	22.2
Thatcher	5	0	2.9	25.6
Columbus	10	2	3.8	23.6
Katepawa	19	1	3.5	31.9

Table 4. Comparison of cultivars of cereals for stem melanosis severity and seed yield with and without added copper in a field experiment on a Cu deficient Black Chernozemic sandy loam soil at Lacombe, Alberta in 1986 (prepared from Piening et al. 1989)

		Disease severity %		Seed yield (bu/acre)	
Crop	Cultivar	Without Cu	With Cu	Without Cu	With Cu
Wheat	Park	100	96	0.1	22.7
	Neepawa	15	8	0.2	29.3
Barley	Leduc	0	0	58.9	63.2
	Galt	0	0	50.9	51.3
	Klages	0	0	37.0	81.6
	Bonanza	0	0	59.4	67.2
Oats	Dumont	0	0	26.7	66.4
	Cascade	0	0	38.3	60.4
	Athabasca	0	0	49.8	65.9
	Calibre	0	0	37.7	72.1

Summary of Findings

Prevention and/or correction of Cu deficiency in crops on Cu-deficient soils has a dramatic effect on seed yield and quality of cereals, especially wheat, and occasionally yield increases up to 400% are observed with Cu fertilization. Source, rate, formulation, time and method of Cu application, and proper balancing of Cu with P, Mn, N or other nutrients in soil all affect seed yield of wheat on Cu-deficient soils. Where Cu deficiency in soil is expected in advance, seed yields are usually optimized with broadcast/incorporation application of granular Cu fertilizers at 2.7-5.06 lb Cu/acre at seeding on most soils (Table 5). Soil incorporation of granular Cu fertilizers up to 1.8 lb Cu/acre was not generally effective in increasing seed yield of wheat in the year of application, but it became effective after three annual applications. Surface-broadcast application of granular Cu fertilizers without incorporation was much less effective in preventing Cu deficiency and improving seed yield of wheat than incorporated Cu fertilizers. The requirement of Cu for optimum seed yield and quality on Cu-deficient soils tended to increase with increasing amount of P in soil and rate of applied P.

Table 5. Seed yield response of wheat to broadcast and incorporation of different rates of granular Cu fertilizers on Cu-deficient soils (prepared from Solberg et al. 1996; Flaten 2002; Karamanos et al. 2005; Malhi et al. 2005)

Reference	Cu source	Seed yield (bu/acre) at Cu rates (lb Cu/acre)				
Karamanos et al. 2005		0.0	1.8	3.6		
	Cu sulphate	49.8	59.1	59.4		
Flaten 2002		0.0	5.0	10.0		
	Cu sulphate	2.8	8.3	8.3		
	Cu sulphate	3.1	12.1	14.2		
Malhi et al. 2005		0.0	0.4	1.8		
	Cu lignin sulphonate	23.3	23.5	27.1		
Solberg et al. 1996		0.0	5.0	10.0		
	Cu sulphate	20.5	43.5	49.8		
		0.0	2.5	5.0	7.5	10.0
	Cu sulphate	16.5	22.6	29.3	30.2	29.8
		11.3	32.4	28.5	33.9	32.3

Compared to granular Cu fertilizers, surface spray broadcast application followed by incorporation of solution Cu fertilizers into the soil at 0.45 to 1.8 lb Cu/acre was found much more effective in preventing Cu deficiency and increasing wheat seed yield in the year of application (Table 6). Seedrow-placed granular Cu affords neither agronomically nor does economically acceptable yield increase; however, chelated product can provide maximum yields, albeit at a greater cost compared to broadcast and incorporation. The findings also suggest that seed dressing or banding is not a desirable method of application for Cu fertilizers, because it reduces availability of Cu to plant roots due to poor distribution of granules with low rates of Cu fertilizer. Some Cu fertilizers (e.g., Cu oxide) were not effective in increasing seed yield in the year of application, and were still generally less effective than other fertilizers even after a series of annual applications (Table 7). Application of Cu fertilizers at high initial rates can maintain or build-up Cu levels in soils and give residual benefits for a number of years (Table 8).

If Cu deficiency in wheat appears during the growing season, foliar application of Cu fertilizer at low rates (about 0.18-0.25 lb Cu/acre) between first node visible (Feekes 6) and flag-leaf can be used to correct Cu deficiency and restore seed yield considerably (Table 9). But foliar applications at very early or very late growth stages were not effective or much less effective. In some cases on soils with extreme Cu deficiency, two foliar applications (one at late tillering or first node formation and the other at flag-leaf or boot stage) of Cu fertilizer or a combination of both soil and foliar applications were found to produce maximum seed yield.

The sensitivity of crops to Cu deficiency is usually in the order of (wheat, flax, canary seed) > (barley, alfalfa) > (timothy seed, oat, corn) > (peas, clovers) > (canola, rye, forage grasses) (Solberg et al. 1996). Spring wheat was most sensitive to stem melanosis, while other cereals were not affected by this disease. Stem melanosis in wheat was associated with deficiency of Cu in soil and the disease was reduced substantially with application of Cu fertilizer (Tables 3 and 4).

Soil analysis for DTPA-extractable Cu in soil can be used as a good diagnostic tool to predict Cu deficiency on Cu-deficient soils, but the soil test may not provide reliable prediction of Cu fertilizer recommendation for optimum yield and economic returns on $ invested on Cu fertilizer on soils with soil tests above the critical level of 0.4 ppm Cu (Table 10). Plant tissue testing usually had a poor relationship between total Cu concentration in shoots and degree of Cu deficiency, but youngest leaves gave higher correlation than whole plants.

Conclusions

For immediate correction of Cu deficiency in wheat, foliar application of low rates of some Cu fertilizers at late tillering to flag-leaf growth stage can be used, but soil incorporation of Cu fertilizers prior to seeding is suggested for optimum seed yield. Since Cu deficiency in crops often occurs in irregular patches within fields, foliar application may be the most practical way to correct Cu deficiency in wheat during the growing season.

Table 6. Effect of method of application on seed yield of wheat on Cu-deficient soils (prepared from Flaten 2002; Karamanos et al. 2004, 2005; Malhi et al. 1989, 2005)

Reference	Cu source	Rate (lb Cu/acre)	Seed yield (bu/acre) with different placement methods					
Karamanos et al. 2005			Control	Broadcast-incorporated	Sidebanded			Seedrow-placed
	Cu sulphate	3.6 Yr-1	48.9[z]	59.4	56.6			55.2
		3.6 Yr-2	23.7	35.4	29.5			31.9
		3.6 Yr-3	21.5	28.5	22.1			21.4
		3.6 Yr-4	19.8	27.9	24.9			23.4
		Yr-5[y]	23.1	35.2	29.9			28.5
Malhi et al. 2005			Control	Broadcast-incorporated (1.8 lb Cu/acre)	Seedrow-placed (0.9 lb Cu/acre)			Foliar flag-leaf (0.2 lb Cu/acre)
	Cu lignosulphonate	Yr-1	23.3	27.1	23.6			40.3
		Yr-2	24.1	33.3	26.8			39.8
		Yr-3	18.8	40.5	32.2			39.3
Karamanos et al. 2004			Control	Broadcast-incorporated (3.6 lb Cu/acre)	Foliar Feekes 6[x] (0.2 lb Cu[/acre])	Feekes 6 + Feekes 10[w]	Feekes 6 + soil	Feekes 6 + Feekes 10 + soil
	Cu sulphate		34.1	59.1	47.7	51.4	53.0	56.7
			19.5	42.1	32.2	39.3	37.5	37.4
			19.3	39.5	34.4	31.1	35.6	38.9
			14.3	24.8	20.0	20.2	24.9	27.2
			18.3	29.8	23.5	32.4	29.7	35.0
Karamanos et al. 2005				Seedrow-placed[x]				
				0	0.9 lb Cu/acre		1.8 lb Cu/acre	
	Cu sulphate			13.3	21.1		25.2	
	Cu lignosulphonate	Plus Foliar	0.2 lb/acre	34.9	34.1		38.8	
Malhi et al. 1989			Control	Solution broadcast-incorporated	Granular sidebanded			Foliar
	Cu chelate	1.8	4.4	22.8	11.1			37.3
		3.6	4.4	25.0	22.5			30.9
	Cu sulphate	8.9	4.4	300.0	7.6			31.4
		18	4.4	39.6	14.3			29.7
Flaten 2002			Control	Broadcast-incorporated (5.0 lb Cu /acre)	Seedrow-placed (1.0 lb Cu/acre)		Foliar Feekes 6 (0.2 lb Cu/acre)	Foliar Feekes 10 (0.2 lb Cu/acre)
	Cu sulphate		3.1	12.1	5.3		7.8	15.7
Karamanos et al. 2005			Control	Broadcast (5.0 lb Cu /acre)	Broadcast (10.0 lb Cu/acre)		Seedrow-placed (1.0 lb Cu/acre)	Foliar Feekes 10 (0.2 lb Cu/acre)
	Cu sulphate		2.8	8.3	8.3		5.3	15.7

[z]Average of control for three placement treatments.
[y]Residual effect only in year 5. [x]Third year of a 3-year experiment with annual seedrow application of Cu.
[x]Feekes 6 = first node visible.
[w]Feekes 10 = sheath of last leaf completely out.

Table 7. Effect of Cu sources on seed yield of wheat on Cu-deficient soils (prepared from Flaten 2003b; Karamanos et al. 2004; Malhi et al. 2005)

Reference	Method of application	Rate of Cu (lb Cu/acre)	Seed yield (bu/acre) from different Cu sources				
Karamanos et al. 2004			Oxysulphate		Ammonium sulphate + Cu		Cu chelate
			First year				
	Seedrow-placed	0	40.6				
		0.9	34.1		40.8		49.0
		1.8	39.6		41.4		46.9
		3.6	34.1		41.8		48.3
	Broadcast-incorporated Cu sulphate	3.6			57.0		
			Cumulative after four annual applications				
	Seedrow-placed	0	8.9				
		0.9	14.8		23.2		18.7
		1.8	21.4		31.1		21.8
		3.6	18.7		36.2		31.3
	Broadcast-incorporated Cu sulphate	3.6			41.4		
Flaten et al. 2003					Cu sulphate		Cu oxide
	Broadcast-incorporated	0			3.1		
		5.0	0.0		12.1		4.1
		10.0	0.0		14.2		3.5
	Broadcast	0.0			2.8		
		5.0	0.0		8.3		4.4
		10.0	0.0		8.3		6.6
Malhi et al. 2005			Control	Cu lignin sulphonate	Cu sulphate	Cu oxysulphate A	Cu oxysulphate B
	Broadcast-incorporated	1.8 Yr-1	23.3	27.1	23.7	24.6	21.6
		1.8 Yr-2	24.1	33.3	29.1	24.6	26.1
		1.8 Yr-3	18.8	40.5	42.0	30.5	34.2
	Seedrow-placed	0.9 Yr-1	23.3	23.6	27.2	21.4	20.1
		0.9 Yr-2	24.1	26.8	28.2	18.6	21.2
		0.9 Yr-3	18.8	32.2	34.6	20.5	24.4
	Foliar flag-leaf	0.22 Yr-1	23.3	40.3	38.3	38.0	20.0
		0.22 Yr-2	24.1	39.8	41.9	40.1	38.3
		0.22 Yr-3	18.8	39.3	37.1	32.2	36.0

Table 8. Residual effect of copper chelate applied at 2.7 lb Cu/acre in 1984, on stem melanosis incidence and seed yield of Park wheat grown in 1985 to 1987 on a Cu-deficient Black Chernozemic sandy loam soil at Lacombe, Alberta soil (prepared from Malhi et al. 1989)

	Percent disease			Seed yield (bu/acre)			
Treatment	1984	1985	1986	1984	1985	1986	1987
Cu	3	45	76	26.6	22.9	25.5	18.6
Cu + Zn	4	40	70	24.1	24.6	24.4	17.5
Cu + NPK	8	36	63	22.4	24.3	31.1	19.3
Cu + Zn + NPK	1	28	66	26.7	23.6	25.0	16.0
Zn	76	97	100	3.6	6.4	2.7	3.8
Zn + NPK	76	100	100	4.6	5.9	2.8	3.5
NPK	70	97	100	3.3	3.6	3.4	3.2
Control	78	93	100	4.3	6.4	3.2	4.7
$LSD_{0.05}$	26	25	19	7.1	5.6	6.2	6.2

Table 9. Effect of time of foliar application of Cu fertilizers (0.18-0.25 lb Cu/acre) on seed yield of wheat on Cu-deficient soils (prepared from Solberg et al. 1996; Karamanos et al. 2004; Malhi et al. 2005)

Reference	Cu source	Seed yield (bu/acre) with foliar-applied Cu at different growth stages				
Malhi et al. 2005		Control	Cu at 4-leaf	Cu at flag leaf		
	Cu chelate Yr-1	23.3	27.4	40.3		
	Cu chelate Yr-2	24.1	36.3	39.8		
	Cu chelate Yr-3	18.8	44.9	39.3		
Solberg et al.		Control	Late-boot	Heading		
1996[z]	Cu chelate	9.5	40.1	12.0		
	Cu sulphate	9.5	32.8	8.0		
Karamanos et al.		Control	Feekes 6	Feekes 6 and 10		
2004[y]		34.1	47.7	51.4		
		19.5	32.2	30.6		
		18.3	23.5	32.4		
			Feekes			
		Control	2	6	10	2 + 6
	Cu citric acid	3.4	5.3	21.1	11.5	16.5
		17.3	21.4	24.4	22.4	24.0

[z]Late boot refers to growth stage when one-fourth of the heads were out and heading refers to when all heads were out.

[y]Feekes 2, Fekes 6 and Fekes 10 growth stages refer to beginning of tillering, beginning of stem elongation and sheath of last leaf completely out, respectively.

Table 10. Effect of DTPA-extractable Cu in soil (0-6 in) and soil texture on seed yield of wheat and its response to applied Cu fertilizer (based on 115 experiments conducted in the three Prairie Provinces. (prepared from Karamanos et al. 2003)

	Seed yield (bu/acre)		Return $ invested on Cu fertilizer at wheat price ($/bu)		
Parameter	- Cu	+ Cu	2.72	4.08	5.44
Soil Cu level (ppm Cu)					
<0.4	27.6	40.6	1.35	2.03	2.70
0.4-0.8	42.6	46.8	0.73	1.09	1.45
>0.8	53.2	52.9	0.00	0.00	0.00
Soil texture					
Loamy sand	36.5	54.2	5.55	8.33	11.10
Sandy loam	18.0	35.1	5.36	8.05	10.73
Fine sandy loam	29.0	38.8	1.44	2.16	2.88
Loam	51.6	53.7	0.27	0.40	0.54

Future Research Needs

The findings suggest the need for future research to consider ways of increasing dispersion/dissolution of Cu ions from granules and their uniform distribution into the soil, and to develop Cu fertilizer products/formulations that can be used on a commercial scale to prevent and/or correct Cu deficiency in the growing season and optimize seed yield and quality. Management decisions for use of Cu fertilizers should consider both immediate and long-term effects of Cu fertilizer on crop yield, seed quality and economics. Research is also required to determine the long-term effects of balanced application of Cu with P, Mn or N and other nutrients on accumulation and distribution of nitrate-N and other nutrients in the soil profile, along with nutrient, water and energy use efficiency. More research should be conducted in relation to soil/plant tissue testing issues. Copper deficiency in plants affects the amount of live pollen produced, which can result in partially filled or even empty heads on plants which are apparently healthy. This issue needs to be verified to find if Cu indeed is involved in pollination/fertilization, especially in grass species.

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