Copper Fertilization of Wheat on Soils with Marginal Copper Levels

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Abstract

Copper (Cu) is the micronutrient most often deficient in Saskatchewan. Fertilizer placement is an important consideration, particularly in minimum tillage systems, because Cu is generally thought of as immobile in soil. Several new products and methods of application have become available since the last local research was completed in the mid-eighties. This study was conducted to identify relative effectiveness, as indicated by response of hard red spring wheat (*Triticum aestivum* L. cv. AC Barrie) to a variety of Cu fertilization strategies on mineral soils having low levels of available Cu. Field experiments at five Saskatchewan sites over three years compared the effect of Cu treatment on wheat yield, tissue and grain Cu concentration, thousand kernel weight and grain Cu accumulation. The ranking of Cu fertilization method from most to least effective, was: foliar Cu (sulphonate) at Feekes 6 or 10 > broadcast and incorporated Cu sulphate at 5.5 kg ha^{-1} or 11 kg ha^{-1} > broadcast Cu sulphate with no incorporation. Broadcast Cu oxysulphate was ineffective, particularly without incorporation. Seed placed Cu sulphate or oxysulphate were also ineffective. Where Cu deficiencies are confirmed, foliar application of Cu products are recommended for response of wheat within the year of application.

Introduction

In western Canada, Cu fertilizers are applied either as soil or foliar treatments. Soil applied products need to be distributed in the soil in a way that enhances efficient Cu uptake because Cu moves very little in the soil and compounding this, only very small amounts are applied due to low requirements of plants.

Copper sulphate (bluestone, $CuSO_4 \cdot 5H_2O$) (CS) has been the most common Cu fertilizer used to correct field deficiencies, owing to its high water solubility, relatively low cost and wide availability (Mortvedt 1991). It is normally broadcast and incorporated at rates of 3.5 to 15 kg Cu ha^{-1} for maximum effectiveness. Historically, Cu sulphate (CS) applications have been found to provide residual benefits for 5, 12 or even 100 yr (Gartrell, 1981). The benefit of this method is sometimes increased in the year following application, then sustained for many years (Gartrell 1981).

Copper oxysulphates (CO) are oxides of relatively low solubility that are partially acidulated with H_2SO_4. These products have been developed to be more compatible with application equipment than CS, which is corrosive to metal. Their degree of solubility, usually related to availability, is directly related to their degree of acidulation, which varies according to the manufacturer (Mortvedt 1991).

Foliar treatments to date have been considered an emergency method for in-crop use where the deficiency is not recognized until after seeding. Foliar products can be applied to the growing crop as a sulphate, oxide or chelate in water solution. Pre-seeding broadcast CS has generally been considered more cost efficient because of its residual value and one-time application cost.

A significant shift towards less tillage has taken place in Saskatchewan over the past 10-yr with 29% of the area seeded under a zero-till system in 2000 compared to 9% in 1990 (Nagy 2001). Unique fertilizer placement issues relating to zero-tillage generally have not been studied in previous micronutrient research. The objective of this field experiment was to identify relative effectiveness, as indicated by response of wheat, of several Cu placement strategies on soils with low levels of available Cu.

Materials and Methods

In 2000 - 2002, field trials were conducted at five sites in Saskatchewan, as described in Table 1. Data was collected in the year of application for all five sites and effects of residual Cu were monitored at the Smeaton and Choiceland sites for one and two years respectively following application.

The field experiment consisted of applying Cu as copper sulphate (CS) or copper oxysulphate (CO) to the soil either by broadcasting and incorporating with a pre-seeding tillage or broadcasting without tillage before seeding, or by placing it in the seed row at seeding. These treatments were compared to foliar applications at first node stage (Feekes 6) or boot stage (Feekes 10) of wheat. Broadcast Cu was applied at traditional and doubled rates of 5.6 and 11.2 kg Cu ha^{-1}; seed placed Cu (as CS or CO) was applied at 1.1 kg Cu ha^{-1}; and foliar Cu was applied at 0.28 kg Cu ha^{-1}. Two no-Cu control treatments included tillage or no tillage prior to seeding. The treatments were arranged in a randomized complete block design with six replicates.

Hard red spring wheat (*Triticum aestivum* L. cv. AC Barrie) was seeded at a rate of 320-340 seeds m^{-2} between May 2 and 16 of any year. All experiments were seeded into standing stubble, except for the Whitefox site, which had been summerfallow. Each plot measured 13.7 m long with six spring wheat rows at 23 cm spacing and two guard rows of winter wheat. Front and back ends of plots were subsequently trimmed to leave 7.6 m final plot length for harvest purposes.

All plots received a blanket treatment of macronutrient fertilizers as follows: N side-banded as 46-0-0 at 72-80 kg N ha^{-1}, the rate depending on the site; P seed placed as 12-51-0 at 26 kg P_2O_5 ha^{-1} (also including 7 kg N ha^{-1}); K broadcast and incorporated via the seeding operation, as K_2SO_4 at 67-100 kg K_2O ha^{-1}, the rate depending on the site; S provided with the K_2SO_4 at 22-36 S kg ha^{-1}, the rate depending on the site. Each plot was seeded using a small plot air seeder equipped with paired row openers and on-row packing (Harmon International Industries Inc., Saskatoon SK).

The broadcast CS (Pestell Minerals and Ingredients, New Hamburg, ON, Canada) and CO (Tiger Tech Copper 15/12, Tiger Industries, Calgary, AB, Canada) treatments were applied prior to seeding. The oxysulphate product consisted of 11.5% water-soluble Cu in a sulphate form. Foliar application of Cu (RSA MicroTech Liquid Cu 5%, complexed with lignin sulphonate, Seattle, WA, USA) was done with a CO_2 hand sprayer, applying the product with 225 L H_2O ha^{-1}, at 0.28 kg Cu ha^{-1}, the highest rate recommended by the manufacturer. First and second dates of application (representing Feekes 6 and 10 growth stages, respectively) were sprayed between June 22 and July 5 in any year.

Results

Germination at all sites was acceptable. Growing conditions in 2000 were normal at Bradwell, and Star City, whereas Choiceland was relatively wet (Table 2). Smeaton was particularly dry in 2001 and 2002, as was Choiceland in 2002, receiving about half of normal precipitation.

Year 1: According to the LSD analysis, in the year of application, wheat grain yields responded significantly to fertilizer Cu at only three of five sites (Choiceland, Smeaton, and Whitefox) (Table 3). At Choiceland, the seed placed CS outyielded the no-till control, as did the early foliar treatment. At Smeaton, the broadcast and incorporated CS treatment at normal and doubled rates produced significant increases in yields, as did the broadcast and incorporated CO at the doubled rate. At Whitefox, all Cu treatments other than the seed placed and CO treatments produced significant yield increases. The later foliar treatment was more effective than the earlier treatment at Whitefox.

The contrast analysis showed foliar Cu to increase yields significantly as compared to all other placements (Table 3). Incorporation produced significant responses to broadcast CS, whereas there were mixed results for the same placements of CO. At Smeaton and Whitefox, where contrasts showed broadcast and incorporated CS to increase yields significantly over the control, tillage appeared to be the key factor to providing significant benefit to broadcast CS. Only the Whitefox site produced a positive yield response to broadcast Cu without incorporation. The CO treatments (all placements) and the seed placed treatments (both products) were generally not significantly different than the control treatments, as seen in both the LSD and contrast analyses.

Years 2 and 3 (Residual Responses): There were no positive responses to Cu applications seen in the data according to the LSD analysis. However, the contrast analysis showed there to be a positive response to broadcast and incorporated CS and CO over other placements. This response, as seen at Choiceland in Year 2, may be a response to tillage generally, rather than to the success of the effective mixing the product.

Discussion

Although other parameters were measured, such as thousand-kernel weight, grain and tissue Cu concentrations, grain yield was overall the best and clearest indicator of effectiveness of Cu application. This is as one might expect, given that Cu is directly involved in the process of pollen grain formation.

Where there were Cu responses, foliar treatments tended to be the most effective for increasing wheat grain yield. In other research, timing has been considered critical to the success of foliar application, yet there were no consistent differences between the two times of application used in this study. Manufacturer recommendations include a range of Feekes 6 to 10 for the foliar product used in this experiment, therefore, the two timings used may have been expected to perform similarly.

Some research has shown response to foliar applications to be erratic and less effective than soil applications (Karamanos et al. 1986, Penney et al. 1993). One reason to justify foliar applications over soil applications is the adsorptive behavior of Cu to soil constituents, rendering soil applied Cu unavailable to plants (Graham et al. 1981). This may provide a reason for success of foliar applications in this study. It could also be assumed that, due to the wide variety of foliar products available and used in the various studies, some would be more effective than others.

It has been suggested that foliar Cu applications may be acting as a fungicide, directly influencing yield in that manner. Although Cu has been used as a constituent of some fungicides, the rates at which it would normally be applied as a fungicide are 10 to 100 times that of Cu rates used to correct deficiencies (Graham and Webb 1991). Past research indicates that foliar Cu applied at a typical fertilizer rate is more likely to increase disease resistance rather than to act directly as a fungicide (Graham and Nambiar 1981). Disease ratings were not done in this study, but there were no noticeable outbreaks of diseases such as ergot.

Broadcast and incorporated CS has been long known as a successful treatment for correction of Cu deficiency (Martens and Westermann 1991). In this study of responses in the year of fertilizer application, broadcast and incorporated CS performed only second to the foliar treatments. No evidence indicated an advantage to using a higher Cu rate.

There were only two sites where the LSD’s showed a significant yield increase due to broadcast or broadcast and incorporated CS compared with the control (i.e., Whitefox and Smeaton). Perhaps this was due to lower levels of available Cu at these two sites, separating the results to a greater degree than at the other three sites. Other work has shown broadcast treatments to perform better in the year following application (Gartrell 1981). However, in these experiments, no conclusions could be drawn regarding the effectiveness of residual Cu. The general lack of response to applied Cu was likely due to drought conditions in the years of monitoring residual responses, as yields were 50-60% of normal, at best.

Copper treatments in the form of CO (all placement methods and rates) and seed placements (either CO or CS) were not generally effective. It could be expected that CO would not be as effective as CS due to relatively poor solubility and therefore, poor root to Cu contact. Seed placed granular Cu products have not performed well historically (Loewen-Rudgers et al. 1978, Varvel 1983). This may be due to widely spaced placement of relatively large granules within a seed row as a consequence of large granule size and low application rates, both of which may vary between products, and are dependent on manufacturer’s specifications. Gilkes and Sadleir (1979) have suggested that the ability of a root to take up Cu is limited to distances of less than 2 cm when using Cu superphosphate in a very Cu-deficient sandy soil (0.4 mg total Cu kg^{-1}). Placement is therefore critical to success of Cu fertilizer applications.

Although the question of soil Cu critical levels was not included in the objectives of this study, the critical level for wheat of 0.4 mg DTPA-extractable (available) Cu kg^{-1} soil was observed to be a reasonable estimate. The five sites used for the field experiment had levels of 0.2 to 0.8 mg available Cu kg^{-1} soil. Those four sites with levels over 0.4 mg Cu kg^{-1} were less responsive, whereas the two fields with less than 0.4 mg Cu kg^{-1} were very responsive to Cu. Since there were fewer and smaller significant positive responses of wheat at sites with higher levels of available Cu, it is reasonable to classify soils with 0.4 – 0.8 mg Cu kg^{-1} soil as 'marginal', reflecting the uncertainty of economic response, while at the same time suggesting the potential for response. Alerting landowners of a potential but uncertain response is useful, considering the patchy nature of Cu deficiencies within fields, combined with typical composite soil sampling methods from large fields.

Conclusions

In general, responses of wheat to the various Cu fertilizer application methods can be described in order of effectiveness, from highest to lowest, as foliar Cu (sulphonate) at Feekes 6 or 10 > broadcast and incorporated CS at 5.5 kg ha^{-1} or 11 kg ha^{-1} > broadcast CS. Field test strips of foliar Cu may be used to confirm responsiveness to Cu fertilizer before proceeding with large-scale applications.

Broadcast and incorporated CS and CO do not constitute effective strategies for alleviating Cu deficiency in the year of application. Doubling the recommended 5 kg Cu ha^{-1} rate of broadcast CS or CO does not improve responses of wheat in the first year. Copper oxysulphate and seed placed treatments were ineffective and should not be recommended for expected yield enhancement in the year of application. Strategies designed to improve continuity of Cu within the seed row could improve the potential for seed placed Cu. The choices for correcting Cu deficiencies in minimum tillage operations appear to be limited to foliar applications in years of wheat. However, it may be reasonable to consider a one-time use of tillage to achieve the long-term benefits of incorporated CS cited in other literature.

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References

Gartrell, J. W. 1981. Distribution and correction of copper deficiency in crops and pastures. Pages 313-354 *in* J. F. Loneragan et al., eds. Copper in soils and plants: Proceedings of the Golden Jubilee International Symposium, Perth, Western Australia, May 7-9, 1981. Academic Press Australia.

Gilkes, R. J. and Sadleir, S. B. 1979. The influence of placement geometry on the effectiveness of copper superphosphate. Aust. J. Soil Res. **17:** 121-128.

Graham, R. D. and Nambiar, E. K. S. 1981. Advances in research on copper deficiency in cereals. Aust. J. Agric. Res. **32:** 1009-1037.

Graham, R. D. and Webb, M. J. 1991. Micronutrients and disease resistance and tolerance in plants. Pages 329-370 *in* J. J. Mortvedt et al., eds. Micronutrients in Agriculture. Soil Science Society of America, Inc., Madison, Wisconsin, USA.

Karamanos, R. E., Kruger, G. A. and Stewart, J. W. B. 1986. Copper deficiency in cereal and oilseed crops in northern Canadian prairie soils. Agron. J. **78:** 317-323.

Loewen-Rudgers, L., McAndrew, D. and McKenzie, D. 1978. Micronutrient deficiencies in Manitoba crops. Pages 114-126 *in* eds. 22nd Annual Manitoba Soil Science Meeting Proceedings. University of Manitoba, Winnipeg, Manitoba.

Martens, D. C. and Westermann, D. T. 1991. Fertilizer applications for correcting micronutrient deficiencies. Pages 549-592 *in* J. J. Mortvedt et al., eds. Micronutrients in Agriculture. Soil Science Society of America, Inc., Madison, Wisconsin, USA.

Mortvedt, J. J. 1991. Micronutrient fertilizer technology. Pages 523-548 *in* J. J. Mortvedt et al., eds. Micronutrients in Agriculture. Soil Science Society of America, Inc., Madison, WI, USA.

Nagy, C. N. 2001 An economic and agronomic analysis of reduced tillage. Centre for Studies in Agriculture, Law and Environment, University of Saskatchewan, SK.

Penney, D. C., Solberg, E. D., Evans, I. R. and Maurice, D. 1993. The copper deficiency syndrome. Pages 66-80 *in* eds. 30th Annual Alberta Soil Science Workshop Proceedings. Edmonton, Alberta.

Varvel, G. E. 1983. Effect of banded and broadcast placement of Cu fertilizers on correction of Cu deficiency. Agron. J. **75:** 99-101.

Table 1. Physico-chemical Properties of Soils at Sites used for Copper Form and Placement Field Experiments in 2000 to 2002.

Soil Property/Nutrient[†]	Bradwell 2000	Choiceland 2000	Choiceland 2001	Choiceland 2002	Smeaton 2001	Smeaton 2002	Star City 2000	Whitefox 2001
Soil pH (1:2 soil:water)	5.6	5.9	5.9	6.4	5.3	Not	5.9	4.5
Electrical Conductivity (mS cm^{-1})	0.1	0.2	0.1	0.2	0.1	available	0.2	0.1
Textural Class (by hand feel)	Loam	Clay Loam	Clay Loam	Clay Loam	Sandy Loam		Clay Loam	Loamy Sand
NO_3-N (mg kg^{-1})	10.3	12.7	8.4	20.5	7.0		21.8	12.4
P (mg kg^{-1})	32.6	12.6	5.1	14.0	53.7		14.8	97.6
K (mg kg^{-1})	422	161	117	>300	122		188	124
SO_4-S (mg kg^{-1})	16	18	7	>24	7		22	5
Cu (DTPA extraction)								
0-15 cm (mg kg^{-1})	0.6	0.6	0.8	0.8	0.2		0.7	0.3
15-30 cm (mg kg^{-1})	0.5	0.9	0.8	0.9	0.2		0.8	0.1
Fe (mg kg^{-1})	69	98	105	122	102		74	131
Zn (mg kg^{-1})	40.1	16.1	0.8	1.9	0.4		27.5	1.8
Mn (mg kg^{-1})	1.7	1.2	7.8	16.5	12.6		1.7	18.8
B (mg kg^{-1})	1.2	0.8	0.5	0.6	0.3		0.8	0.2
Organic Matter (%)	2.0	3.3	3.3	3.3	1.4		2.9	1.5

[†] 0-15 cm depth, unless otherwise noted.

Table 2. Precipitation Data for the Sites used for Copper Placement Experiments in 2000 to 2002.

	Precipitation (mm)			
Month	**2000**	**2001**	**2002**	**Normal**[†]
		Bradwell		
May	10.7	--[§]	--	44.2
June	77.8	--	--	63.4
July	80.5	--	--	58.0
August	21.8	--	--	36.8
Total	190.8	--	--	202.4
		Choiceland		
May	49.5	7.6	11.1	43.7
June	74.9	47.0	49.8	72.4
July	132.1	110.5	6.1	77.8
August	85.8	13.2	58.7	59.5
Total	342.3	178.3	125.7	253.4
		Smeaton		
May	--	2.6	0.0	43.7
June	--	42.9	50.8	72.4
July	--	59.7	15.2	77.8
August	--	17.8	93.0	59.5
Total	--	123.0	159.0	253.4
		Star City		
May	53.3	--	--	41.4
June	73.9	--	--	61.9
July	110.0	--	--	66.6
August	32.0	--	--	53.1
Total	269.2	--	--	223.0
		Whitefox		
May	--	34.3	--	43.7
June	--	25.4	--	72.4
July	--	148.6	--	77.8
August	--	19.1	--	59.5
Total	--	227.4	--	253.4

[†] Source: Environment Canada, Saskatoon, SK.

Table 3. Wheat Grain Yields for a Variety of Copper Placements, Forms and Rates at Five Locations.

Treatment	Treatment Number	Bradwell Year 1 2000	Choiceland Year 1 2000	Star City Year 1 2000	Smeaton Year 1 2001	Whitefox Year 1 2001	Choiceland Year 2 2001	Smeaton Year 2 2002	Choiceland Year 3 2002
		Grain Yield (kg ha^{-1})							
0 kg Cu ha^{-1}, No Till Control	1	3101	2885	2934	1333	188	1656	759	1295
0 kg Cu ha^{-1}, Till Control	2	3438	2902	2951	1106	207	1805	553	1310
5.6 kg Cu ha^{-1} as CS[z], Broadcast	3	3021	2926	2879	1467	558	1637	636	1278
5.6 kg Cu ha^{-1}as CS, Broadcast with tillage	4	2899	2870	2928	1586	813	1742	549	1303
11.2 kg Cu ha^{-1} as CS, Broadcast	5	3062	2985	2924	1296	559	1720	584	1409
11.2 kg Cu ha^{-1} as CS, Broadcast with tillage	6	2945	2946	2985	1637	957	1875	655	1398
5.6 kg Cu ha^{-1} as CO[y], Broadcast	7	3098	2940	2905	1243	293	1601	698	1099
5.6 kg Cu ha^{-1} as CO, Broadcast with tillage	8	2953	2796	2760	1476	277	1952	679	1460
11.2 kg Cu ha^{-1} as CO, Broadcast	9	3070	3020	2913	1059	443	1616	557	1317
11.2 kg Cu ha^{-1} as CO, Broadcast with tillage	10	2982	2951	2948	1568	235	1829	731	1361
1.1 kg Cu ha^{-1} as CS, Seed placed	11	2846	3054	2922	1410	357	1697	746	1291
1.1 kg Cu ha^{-1} as CO, Seed placed	12	3339	2931	2840	1054	174	1780	486	1403
0.28 kg Cu ha^{-1} as Copper complex, Foliar, Feekes 6	13	3450	3072	3026	1575	527	1791	642	1415
0.28 kg Cu ha^{-1} as Copper complex, Foliar, Feekes 10	14	3288	2953	3152	1311	1053	1627	715	1159
LSD (0.05)		422	145	227	389	337	167	292	217
Contrasts	*Treatments Compared*	*Differences between Means*							
Broadcast with tillage – Till Control	4,6,8,10 – 2	-493 **	-11	-46	461 **	364 **	44	101	71
Broadcast – No Till Control	3,5,7,9 – 1	-38	83	-29	-67	275 *	-12	-140	-19
Seed placed – No Till Control	11,12 – 1	-9	108 ‡	-53	-101	77	83	-143	52
Foliar – No Till Control	13,14 – 1	268	128 *	155	110	601 **	53	-81	-8
Broadcast with tillage CS – Broadcast CS	4,6 – 3,5	-119	-48	55	230 ‡	326 **	130 *	-8	7
Broadcast with tillage CO – Broadcast CO	8,10 – 7,9	-116	-107 *	-55	372 **	-112	282 **	78	203 *
Broadcast with tillage – Seed placed	4,6,8,10 – 11,12	-147	-102 *	25	335 **	305 **	111 *	38	34
Broadcast with tillage – Foliar	4,6,8,10 – 13,14	-424 **	-122 **	-183 *	124	-219 *	141 **	-25	94
Broadcast – Seed placed	3,5,7,9 – 11,12	-30	-25	24	34	198 ‡	-95 ‡	3	-71
Broadcast – Foliar	3,5,7,9 – 13,14	-306 *	-45	-184 *	-177	-326 **	-65	-60	-11
Seed placed – Foliar	11,12 – 13,14	-277‡	-20	-208 *	-211	-524 **	30	-63	60
Broadcast with tillage CS – Broadcast with tillage CO	4,6 – 8,10	-46	34	103	89	629 **	-81	-103	-60
Broadcast CS – Broadcast CO	3,5 – 7,9	-42	-24	-7	231 ‡	191	70	-18	136 ‡

[z] Copper sulphate

[y] Copper oxysulphate

‡,*,** represent differences at significance levels of $P \leq 0.10$, 0.05 and 0.01, respectively.