Copper fertilizer management for optimum seed yield and quality of crops in the Canadian Great Plains

S. S. Malhi[1] and R. Karamanos[2]

[1]Agriculture and Agri-Food Canada, P.O. Box 1240, Melfort, Saskatchewan S0E 1A0 (Phone: 306-752-2776 Ext. 230; Fax: 306-752-4911; E-mail: malhis@agr.gc.ca);
[2]Western Co-operative Fertilizers Limited, Calgary, Alberta

BACKGROUND

- Management practices have long-term effects on In the Prairie Provinces, deficiency of Cu is not wide spread but when it occurs it can cause a serious reduction in seed yield (up to 50% or more) and quality of wheat.
- Copper deficiency has been observed on coarse textured soils, and it usually occurs in irregular patches within fields.
- Copper deficiency in cereals produces characteristic symptoms of yellowing and curling of young leaves, pigtailing of leaf tips, limpness or wilting, delay in heading, aborted heads and spikelets, head and stem bending, etc.
- Crop species vary in their sensitivity to Cu deficiency, but cereals are more sensitive to Cu deficiency than other crops.
- Lack of Cu in soil also has been associated with some cereal diseases and wheat is often cited as the most severely affected cereal and most sensitive to Cu deficiency.

OBJECTIVE

- The objective of this report is to summarize research information from various experiments conducted in the Prairie Provinces of Canada on various crops related to Cu fertilizer rate, time of application (one-time initial, annual, at sowing in spring and during the growing season), source, placement method (surface-broadcast, broadcast-incorporation, sideband, seedrow-placement and in-crop foliar spray) and formulation (liquid, fine crystals/powder and granular), crop species/cultivar, balanced fertilization (interaction with other nutrients and herbicides), Cu deficiency and crop diseases, residual Cu in soil and yield response and soil/plant test issues in relation to crop yield and seed quality.
- The indicators considered are seed yield, straw yield, seed quality (protein, hectolitre weight, thousand kernel weight, concentration of Cu in seed), Cu- and N-use efficiency (seed yield per unit of applied Cu or N), Cu uptake, recovery of applied Cu, residual DTPA-extractable Cu in soil.

SUMMARY AND CONCLUSIONS

- Prevention and/or correction of Cu deficiency on Cu-deficient soils have a dramatic effect on seed yield and quality of cereals.

- Surface broadcast followed by incorporation of granular Cu fertilizers into the soil at 3-5.6 kg Cu ha^{-1} was usually sufficient in preventing Cu deficiency in wheat on Cu-deficient soils and improving seed yield and quality.
- Soil incorporation of granular Cu fertilizers up to 2.0 kg Cu ha^{-1} was not generally effective in increasing seed yield of wheat in the year of application, but it became effective after multiyear 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 on Cu-deficient soils.
- Compared to granular Cu fertilizers, surface spray broadcast application followed by incorporation of solution Cu fertilizers into the soil was found very effective in preventing Cu deficiency and increasing wheat seed yield in the year of application under certain soil-climatic conditions.
- Seedrow-placed or sidebanded granular Cu fertilizers (when applied at lower rates) were usually less effective in increasing seed yield of wheat than foliar or soil incorporated Cu applications.
- The results suggest that soil application of granular Cu fertilizers at relatively low rates may not be reliable to prevent Cu deficiency in order to produce optimum seed yield of wheat on Cu-deficient soils, particularly under dry soil conditions in the initial year or with seedrow-placement and sideband application.
- For immediate correction of Cu deficiency in wheat, foliar application at low rates (0.20-0.28 kg Cu ha^{-1}) of some Cu fertilizers at tillering to flag-leaf growth stage can be used. 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.
- In some cases on extremely Cu-deficient soils, 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 produced maximum seed yield of wheat.
- Some Cu fertilizers were less effective than others in preventing/correcting Cu deficiency and increasing seed yield of wheat in the year of application, and even after multiyear annual applications. This was associated with the amount of available/soluble Cu in the fertilizer.
- Application of Cu fertilizers to wheat on Cu-deficient soils improved seed quality (kernel plumpness, hectoliter weight, thousand kernel weight and concentration of Cu in seed), but there was no effect of Cu fertilization on protein concentration in seed.
- The sensitivity of crops to Cu deficiency was in the order of (wheat, flax, canary seed) > (barley, alfalfa) > (timothy seed, oats, corn) > (peas, clovers) > (canola, rye, forage grasses).
- For cereals the order of sensitivity to Cu deficiency was winter wheat > spring wheat > barley > oats > triticale > rye. Some cultivars of wheat were more sensitive to Cu deficiency than others.
- High levels of available P in soil were observed to induce/increase severity of Cu deficiency in wheat.

- Spring wheat was most sensitive to stem melanosis, but 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 the application of Cu fertilizers.
- 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 this soil test for Cu may not provide reliable prediction for Cu fertilizer recommendations on marginally Cu-deficient soils.
- Plant tissue testing usually had a poor relationship between total Cu concentration in shoots, but youngest leaves gave higher correlation than whole plants.
- There was some increase in residual DTPA-extractable Cu in the 0-15 cm soil in some treatments where Cu was applied at high rates.
- The findings suggest the need 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, Zn 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.

LITERATURE CITED

- **Flaten, P. L. 2002.** Copper Fertilization of Wheat. M.Sc. thesis, University of Saskatchewan, Saskatoon, SK.
- **Flaten, P. L., Karamanos, R. E. and Walley, F. L. 2003.** Effectiveness of copper fertilization strategies in the year of application. Can. J. Plant Sci. In Press.
- **Karamanos, R. E. 2000.** Micronutrients – update 2000. Pages 334-352 *in* Proc. Soils and Crops Workshop, February 2000, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.
- **Karamanos, R. E., Kruger, G. A. and Stewart, J. W. B. 1986.** Copper deficiency in cereals and oilseed crops in Northern Canadian Prairie soils. Agron. J. **78**: 317-323.
- **Karamanos, R. E., Goh, T. B. and Harapiak, J. T. 2003.** Determining wheat responses to copper in prairie soils. **83**: 213-221.
- **Karamanos, R. E., Pomarenski, Q., Goh, T.B. and Flore, N.A. 2004.** The effect of foliar copper application on grain yield and quality of wheat. Can. J. Plant Sci. **84:** 47-56.
- **Karamanos, R. E.,Walley F. L. and Flaten, P. L. 2005.** Effectiveness of seedrow placement of granular copper products for wheat, Can. J. Soil Sci. (*in press*).
- **Malhi, S. S. 2000.** Unpublished results.

- **Malhi, S. S., Piening, L. J. and MacPherson, D. J. 1989.** Effect of copper on stem melanosis and yield of wheat: Sources, rates and methods of application. Plant Soil.**119**:199-204.
- **Malhi, S. S., Cowell, L. and Kutcher, H. R. 2005.** Relative effectiveness of various sources, methods, times and rates of copper fertilizers in improving grain yield of wheat on a Cu-deficient soil. Can. J. Plant Sci. **85**: 59-65.
- **Piening, L. J., MacPherson, D. J. and Malhi, S. S. 1989.** Stem melanosis of some wheat, barley and oat cultivars on a copper deficient soil. Can. J. Plant Pathol. **11**: 65-67.
- **Solberg, E., Evans, L., Penny, D. C. and Maurice, D. 1995.** Copper deficiency in cereal crops. Agri-Fax, Alberta Agriculture, Food and Rural Development, Edmonton, Alberta, Canada. 5 pp.
- **Solberg, E., DeMulder, J. and Hoar, B. 1996.** Copper deficiency, diagnosis, crops, symptoms, diseases, fertilizers, AARI - M260; and Copper deficiency, crop variety response, disease and herbicide interactions, FFF - 92032, Final Report, Alberta Agriculture, Food and Rural Development, Edmonton, Alberta, Canada. 130 pp.

ACKNOWLEDGEMENTS

- The authors thank Darwin Leach for technical help in preparing the tables and figures.

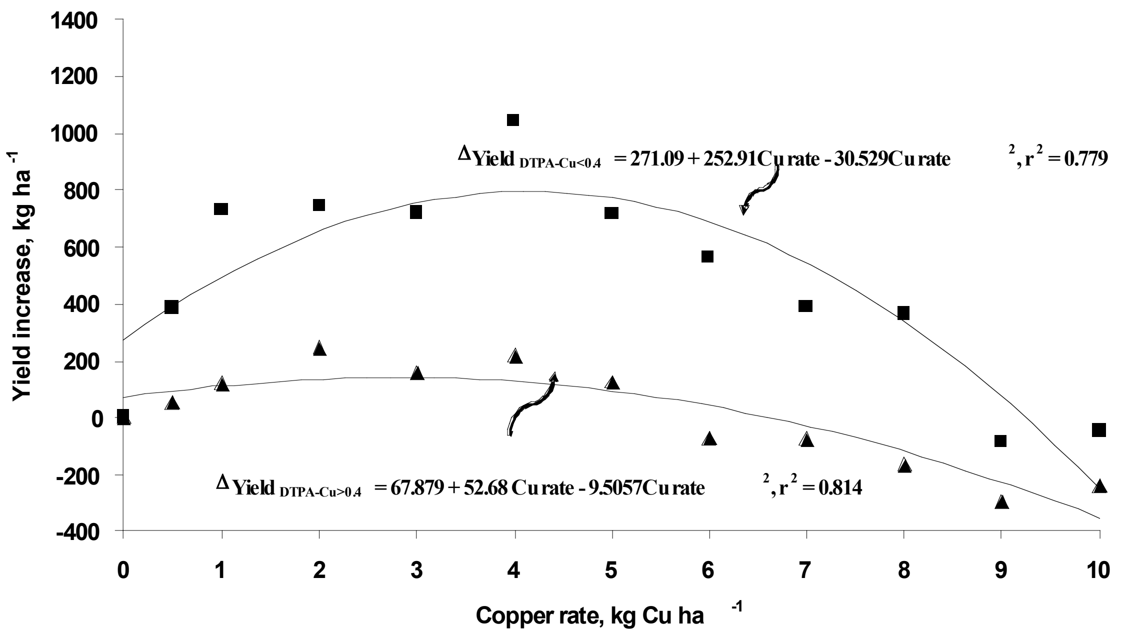

Figure 1. Seed yield increases of wheat from broadcast and incorporated Cu fertilizers for deficient (■, DTPA-Cu <0.4 mg kg^{-1}) and sufficient (▲, DTPA-Cu >0.4 mg kg^{-1}) soils (Karamanos and Goh 2004).

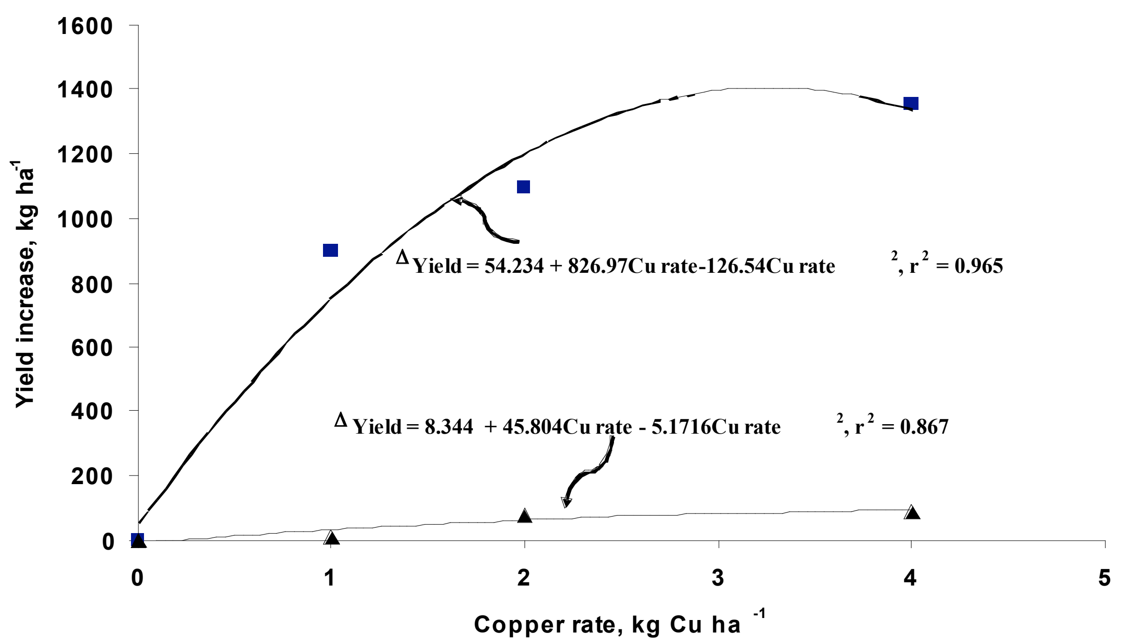

Figure 2. Seed yield increases of wheat from broadcast and incorporated Cu fertilizers for deficient (■, DTPA-Cu <0.4 mg kg^{-1}) and sufficient (▲, DTPA-Cu >0.4 mg kg^{-1}) soils (Karamanos and Goh 2004).

Table 1. Characteristics of Cu fertilizer products used in the field experiment

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	$CuSO_4 5H_20$	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^{-1}	Tiger Industries, Calgary, AB, Canada
Cu sequestered I (liquid)	Tiger foliar	Cu complexed with lignin sulphonate	61.1 g L^{-1}	Tiger Industries, Calgary, Alberta, 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)	Phosyn Coptrel 500	Cu oxychloride	500 g L^{-1}	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.

Table 2. Effect of time of foliar application of Cu fertilizers (0.20-0.28 kg Cu ha^{-1}) on seed yield of wheat on Cu-deficient soils (prepared from Malhi et al. 2005; Solberg et al. 1996; Karamanos et al. 2004)

Reference	Cu source		Seed yield (kg ha^{-1}) with foliar-applied Cu at different growth stages				
Malhi et al. 2005			Control		4-leaf		Flag leaf
	Cu chelate Yr-1		1566		1844		2709
	Cu chelate Yr-2		1620		2440		2675
	Cu chelate Yr-3		1262		3016		2641
Solberg et al. 1996 [z]			Control		Late-boot		Heading
	Cu chelate		638		2695		806
	Cu sulphate		638		2204		538
Karamanos et al. 2004 [y]			Control		Fekes 6		Fekes 6 & 10
	Cu citric acid	Expt 1	2291		3205		3454
		Expt 2	1310		2164		2054
		Expt 3	1230		1579		2177
Karamanos et al. 2004 [y]			Control	Fekes 2	Fekes 6	Fekes 10	Fekes 2 & Fekes 6
	Cu citric acid		230	355	1417	772	1109
			1162	1438	1642	1506	1616

[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]Fekes 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 3. Effect of Cu sources on seed yield of wheat on Cu-deficient soils (prepared from Malhi et al. 2005; Flaten et al. 2003; Karamanos et al. 2004)

Reference	Method of application	Rate of Cu (kg Cu ha^{-1})	Seed yield (kg ha^{-1}) from different Cu sources				
Karamanos et al. 2004			Oxysulphate		Ammonium sulphate + Cu		Cu chelate
			Cumulative after 4 annual applications				
		0	600				
	Seedrow-placed	1.0	997		1560		1256
		2.0	1437		2089		1465
		4.0	1256		2430		2105
	Broadcast-incorporated	4.0			278 3		
Flaten et al. 2003			Control		Cu sulphate		Cu oxide
	Broadcast-incorporated	5.6	207		813		277
		11.2	207		957		235
	Broadcast	5.6	188		558		293
		11.2	188		559		443
Malhi et al. 2005			Control	Cu lignin sulphonate	Cu sulphate	Cu oxysulphate I	Cu oxysulphate II
	Broadcast-incorporated	2.0 Yr-3	1262	2724	2823	2049	2299
	Seedrow-placed	1.0 Yr-3	1262	2162	2324	1380	1641
Malhi et al. 2005			Control	Cu lignin sulphonate	Cu sulphate	Cu sequestered I	Cu sequestered II
	Foliar flag-leaf	0.25 Yr-1	1566	2709	2571	2555	1341
		0.25 Yr-2	1620	2675	2813	2697	2574
		0.25 Yr-3	1262	2641	2492	2165	2417

Table 4. Effect of method of application on seed yield of wheat on Cu-deficient soils (prepared from Malhi et al. 1989, 2005; Flaten 2002; Flaten et al. 2003; Karamanos et al. 2004, 2005)

Reference	Cu source	Rate of Cu (kg Cu ha^{-1})	Seed yield (kg ha^{-1}) with different placement methods					
Malhi et al. 2005			**Control**	**Broadcast-incorporated (2.0 kg Cu ha^{-1})**		**Seedrow-placed (1.0 kg Cu ha^{-1})**		**Foliar Flag-leaf (0.25 kg Cu ha^{-1})**
	Cu lignosulphonate	**Yr-1**	**1566**	**1821**		**1588**		**2709**
		Yr-2	**1620**	**2236**		**1801**		**2675**
		Yr-3	**1262**	**2724**		**2162**		**2641**
Karamanos et al. 2004			**Control**	**Broadcast-incorporated (4.0 kg Cu ha^{-1})**	**Foliar Fekes 6 (0.25 kg Cu ha^{-1})**	**Fekes 6 + Fekes 10**	**Fekes 6 + Soil**	**Fekes 6 + Fekes 10 + Soil**
	Cu sulphate		**2291**	**3971**	**3205**	**3454**	**3561**	**3810**
			1310	**2829**	**2164**	**2644**	**2520**	**2513**
			1297	**2654**	**2311**	**2090**	**2392**	**2614**
			961	**1666**	**1344**	**1357**	**1673**	**1828**
			1230	**2002**	**1579**	**2177**	**1996**	**2352**
Karamanos et al. 2005			**Control**	**Seedrow-placed (1.0 kg Cu ha^{-1})**		**Seedrow-placed (2.0 kg Cu ha^{-1})**		**Foliar (0.22 kg Cu ha^{-1})**
	Cu sulphate		**897**	**1421**		**1696**		**2436**
Malhi et al. 1989			**Control**	**Solution broadcast-incorporated**		**Granular sidebanded**		**Foliar**
	Cu chelate	**2**	**294**	**1529**		**746**		**2505**
		4	**294**	**1680**		**1515**		**2076**
	Cu sulphate	**10**	**294**	**2016**		**511**		**2112**
		20	**294**	**2658**		**963**		**1996**
Flaten 2002			**Control**	**Broadcast-incorporated (5.6 kg Cu ha^{-1})**	**Seedrow-placed (1.1 kg Cu ha^{-1})**		**Foliar Fekes 6 (0.28 kg Cu ha^{-1})**	**Foliar Fekes 10 (0.28 kg Cu ha^{-1})**
	Cu sulphate		**207**	**813**	**357**		**527**	**1053**
			Control	**Broadcast (5.6 kg Cu ha^{-1})**	**Broadcast 11.2 kg Cu ha^{-1})**		**Seedrow-placed (1.1 kg Cu ha^{-1})**	**Foliar Febes 10 (0.28 kg Cu ha^{-1})**
Flatan et al. 2003	**Cu sulphate**		**188**	**558**	**559**		**357**	**1053**

Table 5. Effect of formulation of Cu fertilizer on seed yield of wheat (prepared from Malhi et al. 1989, 2000; Karamanos et al. 1986)

Reference	Cu source	Rate of Cu (kg Cu ha $^{-1}$)	Seed yield (kg ha $^{-1}$) with Cu formulations: Control	Granular broadcast - incorporated	Solution broadcast - incorporated
Karamanos et al. 1986	Cu sulphate	5.6	1078	2248	2343
Malhi et al. 1989	Cu sulphate	20	764	1544	1579
S.S. Malhi 2000 (unpublished results)	Cu lignin sulphonate	0.5	999 (2.5) [z]	959 (2.5)	1151 (3.7)
		1.0		981 (2.3)	1414 (4.0)
		2.0		934 (2.9)	1442 (5.7)
		4.0		939 (2.1)	1471 (5.5)

[z]The values in brackets refer to uptake of Cu in seed (kg Cu ha $^{-1}$).

Table 6. Comparison of cultivars of cereals for stem melanosis severity and grain 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).

Crop	Cultivar	Disease severity % Without Cu	Disease severity % With Cu	Yield (kg/ha $^{-1}$) Without Cu	Yield (kg/ha $^{-1}$) With Cu
Wheat	Park	100	96	9	1522
	Neepawa	15	8	16	1967
Barley	Leduc	0	0	3956	4244
	Galt	0	0	3421	3447
	Klages	0	0	2487	5484
	Bonanza	0	0	3991	4517
Oats	Dumont	0	0	1792	4459
	Cascade	0	0	2575	4061
	Athabasca	0	0	3344	4431
	Calibre	0	0	2532	4843

Table 7. Residual effect of copper chelate applied at 3 kg Cu ha -1 in 1984, on stem melanosis incidence and grain 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)

Treatment	Percent disease 1984	Percent disease 1985	Percent disease 1986	Grain yield (kg ha $^{-1}$) 1984	Grain yield 1985	Grain yield 1986	Grain yield 1987
Control	78	93	100	288	431	214	315
NPK	70	97	100	220	245	226	216
Cu + NPK	8	36	63	1502	1631	2092	1297

Table 8. Effect of DTPA-extractable Cu in soil (0-15 cm) 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).

Parameter	Seed yield (kg ha^{-1})		Return $ invested on Cu fertilizer at wheat price ($ Mg^{-1})		
	- Cu	+ Cu	100	150	200
Soil Cu level (mg Cu kg^{-1})					
<0.4	1857	2725	1.35	2.03	2.70
0.4 -0.8	2860	3144	0.73	1.09	1.45
>0.8	3577	3557	0.00	0.00	0.00
Soil texture					
Loamy sand	2450	3640	5.55	8.33	11.10
Sandy loam	1210	2360	*0.70?*	*1.05?*	*1.39?*
Fine sandy loam	1950	2610	1.44	2.16	2.88
Loam	3470	3610	0.27	0.40	0.54