Part 2 - Yield loss upon liming caused by low Mn and Cu contents in cereals

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Abstract

Lime addition to soils caused average yield losses of 7%. Concentrations of Mn and Cu but not of boron and zinc in grains declined in limed plots. Decline in concentrations of Mn and Cu were significantly correlated with increasing soil pH values. Crop data indicated that concentrations of Mn and Cu in grains reached low, critical levels. Yields declined at threshold values amounting to 15 mg Mn kg^{-1} for wheat and barley, 25 mg Mn kg^{-1} for rye, 40 mg Mn kg^{-1} for oat and 3 mg Cu kg^{-1} for the four cereals.

Key words Base saturation, field trials, grain concentration, lime, micronutrients, soil pH

Introduction

Liming of agricultural soils is necessary to counteract acidification and Al^{3+} dissolution and can increase yields by up to 70% (e.g. Farhoodi and Coventry, 2008). However, negative yield responses to lime additions have also been reported. The mechanisms reported behind yield losses include (a) calcium magnesium imbalance (Carran, 1991), (b) iron deficiency due to high bicarbonate levels blocking Fe(III) reduction in the root (Mengel and Kirkby, 2001), and (c) zinc deficiency caused by lime added with phosphorus fertilizer (Verma and Minhas, 1987; Hylander, 1995).
As plant availability of micronutrients with the exception of Mo is decreasing at higher soil pH values (Lindsay, 1974), one can assume that liming can decrease micronutrient availability and thereby cause yield reduction. Cereals grains from field trials were studied to find out if shortage of micronutrients could explain yield losses upon liming measured over several years.

Material and methods

In field trials described by Mattson and Kihlstrand (2003) started in 1999, the effect of different types and treatment of lime - geological origin, particle size, and application rate - was tested. At five out of fifteen sites, crop yields declined after lime addition as compared to control treatments. Crop samples from these sites were analyzed on boron, zinc, copper and manganese to find out if low uptake of these micronutrients may explain yield reductions. Samples were analyzed upon digested in concentrated nitric acid and the micronutrients were determined on an inductively coupled plasma-mass spectrometer (Elan 6100 ICP-MS, Perkin Elmer SCIEX instruments). Metal concentrations are expressed in mg per kg grain dry weight. In addition, soil pH values (measured in water) were determined. Data were analyzed with the statistics provided with Microsoft Excel (Microsoft Corp., Redmond, WA). Curve fits and correlations were made using Sigma Plot (SPSS Inc., Chicago, IL).

Results and discussion

Lime additions to soil resulted in yield reductions lasting at least four years (2000-2003) including cereals, potatoes, peas and oil seed rape (Table 1). In most cases, yield declines were statistically significant but also non-significant losses are included in this paper. Large yield declines of up to 25% were rare and losses of less than 10% were most frequent. Liming soils to 85% of their base saturation resulted in an average yield loss of 6% and liming up to or above 100% base saturation to an average reduction of 8% but deviations were measured.

In order to find if lime additions reduced micronutrient availability, mean concentrations in crops were compared (Table 2). In most cases, mean concentrations in treated and untreated crops were not significantly different although standard deviations indicate a wider range in crops from limed soils. Concentrations of manganese were ca 3 times higher in oats (ca 46 mg kg^{-1} dm) than in barley (ca 14 mg kg^{-1} dm) but similar between wheat and rye (ca 24 mg kg^{-1} dm). Copper concentrations of different cereal grains were similar (ca 3.3 mg kg^{-1} dm). However, a comparison of mean Mn concentration in wheat grain upon liming, 23 mg kg^{-1} dm (Table 2), was much lower than the level reported for wheat grain in a Swedish survey, 30 mg kg^{-1} dm (Eriksson et al, 2000).

Mean concentrations in grains gave no indications about the effect of liming on micronutrient uptake and crop data were further analyzed taking into account soil pH values. Such analysis showed that lime additions did not affect boron and zinc concentrations in grains (data not shown) as no significant change was found. Boron concentrations in grains remained around 5 mg kg^{-1} dm independent of soil pH, which are actually higher than normal values reported for cereals from different parts of the world (Kabata-Pendias, 2001). Also zinc concentrations in grains showed no significant decline with higher soil pH values and mean values (ca 30 mg kg^{-1} dm) were in accordance with normal values measured in grains (Eriksson et al., 2000). Shortage of boron or zinc for crops was excluded.

In contrast, plotting Mn and Cu concentrations in grains versus soil pH values showed significant relationships. Metal concentrations in grains declined with increasing pH values (Figure 1). For example, liming soils to pH values of 6.5 and above resulted in a decline of Mn in wheat grain to around 10 mg kg^{-1} dry weight, which is very low representing less than 5% of wheat samples in a Swedish survey (Eriksson et al., 2000). Similarly, Mn concentrations in oat grain declined at pH values between 6 and 7 to approximately 30 mg kg^{-1} dry weight, which far below the average of 47 mg Mn kg^{-1} dry weight reported by Eriksson et al. (2000). The same trend was found for Mn in barley grain reaching 10 mg kg^{-1} dry matter at soil pH values of 6.5 as compared to the average value of 17 mg Mn kg^{-1} dm for Swedish barley grain (Eriksson et al., 2000). Liming also decreased copper concentrations in grains declining from ca 4.5 mg kg^{-1} dm at a soil pH of 6 to a minimum between 2.5 and 3 mg Cu kg^{-1} dm at a pH of 7 (Figure 1). For comparison, mean Cu concentrations reported for Swedish grain are 3.9 for wheat, 3.7 for oat, and 4.7 mg kg^{-1} dm for barley (Eriksson et al., 2000).

Similar declines in metal concentrations in crops with increasing soil pH were also reported by Öborn et al. (1995). The question arises whether declines of Cu and Mn in grains correlate with yield losses and reached critically low levels? Alloway (2005) pointed out that moderate yield losses of up to 10% could be due low level of micronutrients.

A sigmoidal function, Hill-equation with 3 parameters (Hunt, 1982), was used to fit Mn and Cu concentrations in grains to yields (Figure 2). Plotting metal concentrations in grains against relative yields (whereby the maximum yield from each site was set to 100) showed yields declining with decreasing concentration at certain levels (Figure 2). For barley, oat and rye, yields declined significantly ($P < 0.05$) with decreasing Mn concentration in grain. The same was found for copper and crop yield. We ascribed both low Mn and Cu concentrations being responsible for the yield decline.

Data in Figure 2 were also used for an arbitrary definition of critical concentrations in grains below which yield declines can be expected. For manganese, concentrations in barley and wheat of less than 15 mg kg^{-1}, in rye concentrations of less than 25 mg kg^{-1} and in oat of less less than 40 mg kg^{-1} were identified as threshold values. Concerning copper, concentrations less than 3 mg kg^{-1} were identified for the four types of cereals. Further investigations are required to corroborate our observations.

Conclusions

- Lime addition induced yield declines. Concentrations of Mn and Cu in grains declined with increasing pH in soil.
- Copper and manganese reached low, critical concentrations in grains upon liming but not zinc or boron.
- Low concentrations of both Mn and Cu in grains were assumed to be responsible for yield declines observed.

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Table 1. Data on negative yield response upon liming at 5 field trials during the years 2000-2003. Figures in brackets indicate relative yields as compared to the control

Site and crop	**Yield** (kg ha^{-1}; water content 15%)

	Control No lime	Lime addition 70-85% base sat.	Lime addition ≥ 100% base sat.
Märsta			
Barley	3800	3800 (100)	3730 (98)
Oat	3680	3600 (98)	3440 (94)
Spring wheat	5300	5200 (98)	5080 (96)
Oat	4400	4400 (100)	4000 (90)
Kivik			
Barley	5660	5170 (91)	5280 (93)
Winter wheat	8960	8450 (94)	8150 (91)
Barley	5220	4890 (94)	4940 (95)
Fjälkinge			
Rye	5090	5410 (106)	4810 (94)
Potato	8440*	9431 (111)	7875 (93)
Rye	6210	5650 (91)	4510 (73)
Tågarp			
Winter wheat	8020	7660 (95)	7370 (92)
Halmstad			
Oat	5840	5670 (97)	5810 (99)
Peas	3220	3050 (95)	3970 (123)
Winter wheat	8840	8560 (97)	8640 (98)
Oilseed rape	1470	1300 (88)	1110 (75)
Mean relative yield decline		***- 6 %***	***- 8 %***

Table 2. Mean concentrations of Mn, Zn, B, and Cu in cereals from limed-amended as compared to un-limed control sites (± standard deviation). Different letters indicate significant difference (P=0.05) between treatments for the particular crop and micronutrient

Crop and treatment	Concentration in cereal grain (mg kg^{-1} dry matter)			
	Mn	Zn	B	Cu
Barley				
Control	15.1 ± 0.7a	31.2 ± 2.4a	4.4 ± 3.3a	3.8 ± 1.2a
Limed	13.4 ± 1.5a	28.4 ± 4.6a	6.2 ± 2.1a	3.7 ± 1.1a
Oat				
Control	48.3 ± 8.1a	38.4 ± 1.3a	4.4 ± 3.7a	4.5 ± 1.2a
Limed	44.3 ± 9.5a	38.4 ± 3.0a	11.0 ± 11.2a	3.8 ± 1.1a
Wheat				
Control	27.1 ± 11.1a	30.4 ± 8.1a	5.6 ± 2.9a	3.1 ± 0.7a
Limed	22.1 ± 9.9a	28.9 ± 6.7a	5.7 ± 3.5a	3.0 ± 0.7a
Rye				
Control	28.1 ± 1.7a	28.5 ± 2.7a	6.0 ± 3.4a	2.3 ± 0.2a
Limed	20.0 ± 2.0b	22.9 ± 2.9a	5.8 ± 2.4a	2.2 ± 0.2a

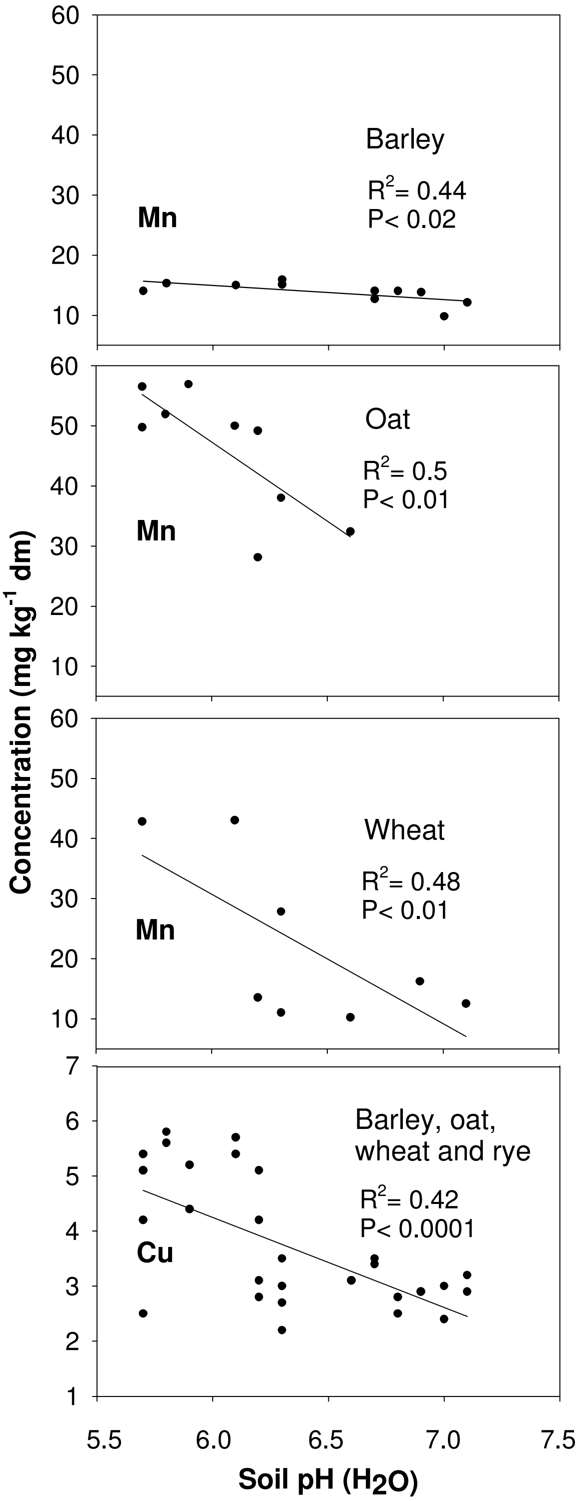

Figure 1. Concentrations of manganese and copper in grain in relation to soil pH values.

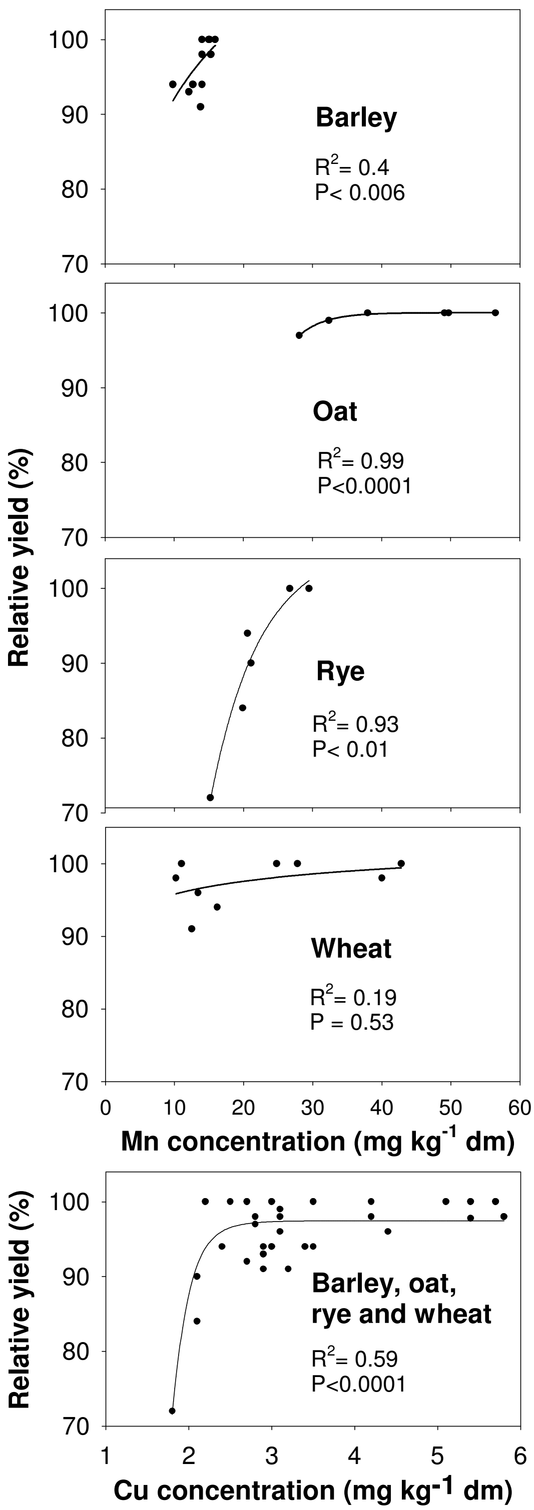

Figure 2. Dry matter concentrations of Mn and Cu in grain related to crop yield.