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COPPER CONCENTRATION IN THE TOP PLANT TISSUE AS AN INDICATOR OF CU TOXICITY

Jolanta Korzeniowska, Ewa Stanislawska-Glubiak
Institute of Soil Science and Plant Cultivation,
Department of Soil Tillage System and Fertilization in Wroclaw, Poland

ABSTRACT

The objective of this research was to determine if copper concentration in the top plant tissue can be a reliable indicator of Cu toxicity. A four-year microplots experiment was carried out with 4 copper treatments: 0, 30, 60, and 90 kg ha $^{-1}$. Spring wheat, red clover, and maize were grown on the microplots filled with sandy acid soil. In the first and second year, after application of the highest Cu rate, wheat and clover yields dramatically decreased. In spite of the fact that the yield decreases were very deep, the Cu tissue concentrations didn't reflect them; there never was an excessive Cu accumulation in top plants. This study and inspection of the published researches reveal that the Cu concentration in plant top tissue or in grain is not a sensitive or reliable indicator of Cu phytotoxicity, and it carries a possibility of misleading assessment.

Key words: copper, phytotoxicity, indicators, top tissue, wheat, red clover, maize

INTRODUCTION

Copper is a required element for plant growth, as it serves an important role in plant structure and function [6, 8]. However, increased concentrations of Cu in soils can lead to toxic effects in plants. Sometimes, plant test is used to recognize incipient Cu toxicity in soils. For that reason, some authors established an upper critical level value for Cu toxicity in plant tissue. For example, USEPE [21] reported that 40 mg kg^{-1} Cu in maize shoots did not decrease top growth, and identified this tissue concentration as the No Observable Adverse Effect Level (NOAEL). According to MacNicol and Backett [13], and Mocquot et al. [16] Cu critical level in maize shoots was 21 mg kg^{-1}. Borkert et al. [3] confirmed that the critical Cu toxicity level for maize leaves and also for rice was 20 mg kg^{-1}. The critical Cu concentration in the seedling citrus leaves varied from 60-68 mg kg^{-1} according to Alva et al. [1].

In contrast, other authors [10, 14, 15] concluded that the Cu concentration in the shoots, is not a suitable indicator of Cu toxicity because of the strong barrier to Cu transfer from roots to shoots.

The objective of this research was to evaluate if copper concentration in the top plant tissue can be a reliable indicator of Cu toxicity.

MATERIALS AND METHODS

In Baborowko, near Poznan (West Poland) a four-year microplots experiment was carried out with four copper treatments: 0, 30, 60, and 90 kg ha^{-1}. The copper as $CuSO_4$ was added only in the first year. The residual effect was investigated for the next three years. Copper sulphate was applied as a water solution. The 1x1x 0.6 m microplots were sunk into the ground in the open field and filled with sandy acid soil. Its characteristics are given in table 1. Spring wheat, red clover (in two following years), and maize for silage, were the plants used in the experiment. The NPK fertilizers were applied according to each plant requirement. There were 4 replications in completely randomized design. The microplots were watered as needed. Soil samples and plant tissue samples were gathered in each year of the experiment. The following samples were collected: for wheat - grain and shoots at the beginning of shooting stage, for clover - shoots at the beginning of flowering, and for maize - ear leaves during initial silk and ears in the milk-ripe stage. Wheat was harvested at full maturity, clover - at the beginning of flowering, and maize - at milk-ripe stage. Copper in plant tissue after wet digestion, and in soil after 1 mol HCl·dm^{-3} extraction was analyzed by atomic absorption spectrometry (AAS).

Table 1. Properties of soil used in the experiment

PH in KCl	Fraction < 0.02 mm %	Organic Matter %	Cu extr. in HCl mg kg^{-1}
3.8	15	0.62	1.4

RESULTS AND DISCUSSION

In the first and second year, after highest Cu rate application, wheat and clover yields dramatically decreased (tab. 2). In the third and fourth year some clover and maize yield decreases were observed at the 90 Cu rate, but smaller than in the two previous years (tab. 3). Copper toxicity during the experiment depended on several overlapping factors such as: Cu fixation throughout the duration of the experiment, differences between plant species, and pH changes. Other authors confirm different tolerance of various plant species to Cu toxicity, and strong influence of pH level on toxicity of copper [7, 10].

Table 2. Yields and Cu concentrations in I and II year of experiment

Cu rate	Wheat – year I			Red clover – year II			
	Grain yield	Cu in shoots	Cu in grain	1^{st} cut		2^{ed} cut	
				Yield	Cu	Yield	Cu
kg ha^{-1}	%	mg kg^{-1}		%	mg kg^{-1}	%	mg kg^{-1}
0	100 b	3.8	3.7	100 b	3.8	100 b	5.1
30	112 b	5.2	3.8	96 b	4.6	123 c	6.4
60	102 b	6.9	4.0	100 b	6.0	100 b	7.3
90	39 a	8.2	4.2	45 a	7.6	53 a	10.2

Different letters in a column indicate significant differences at the 5% level according to Tukey's Test.

Table 3. Yields and Cu concentrations in III and IV year of experiment

Cu rate	Red clover – year III				Maize – year IV		
	1st cut		2ed cut		Yield	Cu in leaves	Cu in ears
	Yield	Cu	Yield	Cu			
kg ha^{-1}	%	mg kg^{-1}	%	mg kg^{-1}	%	mg kg^{-1}	
0	100 a	5.0	100 a	3.4	100 b	10.2	2.6
30	104 a	5.4	105 a	4.4	109 bc	10.0	3.2
60	108 a	6.5	108 a	4.8	117 c	10.5	3.2
90	107 a	7.7	94 a	6.2	83 a	10.2	3.6

Different letters in a column indicate significant differences at the 5% level according to Tukey's Test.

In spite of the fact that the yield decreases were very deep, the Cu tissue concentrations didn't reflect them; there never was an excessive Cu accumulation in top plants. Even when plant yields were 39% or 45-53% in relation to control treatment, the plant tissue was still in the optimum range (or average level) of Cu concentration (tab. 4). Although the Cu tissue concentrations systematically increased with the increment of Cu rates and Cu soil concentrations (tab. 5), they never did exceed optimum level, even at the highest rate of Cu, which caused strong yield decrease.

Table 4. Concentration Cu in wheat, clover and maize (mg kg^{-1})

Cu concentration	Wheat grain	Wheat shoots	Clover shoots	Clover hay	Maize leaves
Optimum[1]	-	7-15	7-15	-	6-12
Average for Poland[2]	4.2	-		7.8	-

[1] according to Bergman [2], [2] according to Kaminska et al. [9]

Table 5. Cu concentration and soil pH during the experiment

Cu rate kg ha^{-1}	Cu in soil mg kg^{-1}		
	year I	year III*	year IV
0	1.4	1.4	3.3
30	6.7	6.3	6.0
60	19.0	13.0	16.0
90	35.0	24.0	33.0
pH	3.9	4.2	3.5

*year II – lack of data

Numerous other studies also showed no significant relationship between yield decrease caused by toxic Cu rates and Cu concentration in plants top tissue. Usually the high Cu rates caused the yield decrease, but only a slight increase of Cu concentration in plants, which was contained in, or lightly exceeded, the optimum level according to Bergmann [2]. For example, Piotrowska et al [17] reported that in spite of the 20% yield decrease, Cu concentration in maize shoots was in the optimum range, and didn't exceed 12.5 mg kg^{-1}. Similar results were presented for pea and horse bean, by Rogoz [18]. Karon showed [10] that even a huge yield depression (nearly 90%) was associated with only a relatively small Cu increase in oat shoots (did not exceed 17 mg kg^{-1}). The data presented by Chang also confirmed the lack of relation between the yield decrease and Cu concentration in top tissue [4]. He reported that on one hand, the significant yield reduction was not associated with excessive Cu accumulation in maize shoots, and on the other hand, sometimes there was no yield reduction, even though the Cu concentration in tissue was very high. According to McBride [14], shoot Cu in maize increased to the greatest extent with the first 200 mg kg^{-1}, with smaller increases at higher additions. Moreover, Straczynski reported [19, 20] that Cu concentration in grain and straw of wheat, barley, rye, and oat didn't exceed their normal level, despite the high soil contamination level due to nearby of copper plant.

However, some other studies have shown results that contradict the research presented above. Jurkowska et al. showed [7] that yield decrease caused by Cu rates was associated with high increase of Cu concentration in oat shoots (up to 291 mg kg^{-1}). Very high Cu accumulation by grass, herb, and red clover tops that grown in the nearby of copper plant Legnica was also found by Maciejewska [12].

In fact, the problem of low Cu accumulation in top tissue, despite a very high Cu concentration in soil and corresponding yield decrease, lies in the Cu uptake and distribution by plant roots. In the Cu excess situation, copper ions are strongly absorbed and accumulated by plant roots, but not by top tissue [7, 8, 14, 17, 18]. McBride [14] and Lexmond and Vorm [11] found that excessive amounts of copper lead to the root stunting and damage. Stunted roots, with low surface area, can retard significantly Cu uptake to shoots. According to McBride [14,15], these results are an indication that plant shoots or leaf analyses for Cu are a potentially misleading indicator of Cu phytotoxicity. Chang considered [4] that the leaves are not an appropriate indicator for Cu phytotoxicity as well.

The above conclusions concern only the Cu excess in soil. In Cu deficiency situation, top tissue can be a good indicator of Cu deficiency in soil.

It is also interesting to note that hemp appears to be some exception between crops. Their top tissue can accumulate much more copper than any other agricultural plants [5, 19].

CONCLUSIONS

This study and inspection of the published researches reveal that the Cu concentration in plant top tissue or in grain is not a sensitive or reliable indicator of Cu phytotoxicity. Top tissue of wheat, barley, oat, rye, maize, red clover, pea, and horse bean usually don't accumulate Cu amounts corresponding with Cu soil contamination, despite the occurrence of yield decrease. Moreover shoot or leaf Cu is the least reliable indicator for Cu phytotoxicity in plant because of the possibility of misleading assessment. Root tissue could be a much better indicator of Cu phytotoxicity, but it is less usefull because of technical difficulties. Assessment of copper phytotoxicity should only be based on the analysis of Cu concentration in soil.

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Jolanta Korzeniowska
Institute of Soil Science and Plant Cultivation
Department of Soil Tillage System and Fertilization in Wroclaw
pl. Sw. Macieja 5, 50-244 Wroclaw, Poland
e-mail: j.korzeniowska@iungwr.edu.pl