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EFFECT OF APPLICATION OF COAL POWDER AND LIME ON ALFALFA GROWTH ON COPPER POLLUTED ACIDIC SOIL

T. Raichev[1], *A. Arsova*[1], *S. Popandova*[1], *G. Józefaciuk*[2]

[1]N. Poushkarov Institute of Soil Science and Agroecology, 7 Shosse Bankya, Sofia 1080, Bulgaria
[2] Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, P.O. Box 201, 20-290 Lublin 27, Poland

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A b s t r a c t. The aim of this study was to test the hypothesis that a combined treatment of copper contaminated acid soil with lime and a coal powder decreases copper toxicity due to a synergetic effect of pH increase and association of Cu^{2+} ions in organo-mineral complexes. A two-year-long pot experiment with alfalfa was carried out on a pseudopodzolic soil contaminated with four Cu levels in the range 0-900 mg kg^{-1} soil. The amendments applied were lime, coal powder and a precomposted mixture of lime and coal powder. The compost and lime application increased yield and decreased copper content in plants at all levels of copper pollution. Coal powder alone depressed plant growth. The combined application of lime and coal powder maintained soil pH in the optimum range (5.1-5.6) during the whole experiment and had a pronounced effect on yield of the second and next crops, depending on the level of liming.

K e y w o r d s: organo-mineral melioration, copper pollution, acid soil, alfalfa

INTRODUCTION

In acid soils heavy metals are readily taken up by plants [1,2,6]. The quality of acidic soils has been improved mainly by liming, which leads to aluminum and heavy metals detoxication [3]. The effectiveness of liming depends on soil properties [5]. It is commonly known, that heavy metals form stable complexes with soil organic matter, decrease their activity in soil solution. Thus, an addition of organic compounds should has a positive chemical melioration effect on polluted soils.

The aim of the present study is to test the possibility of coal powder application for chemical melioration of copper polluted acid soil. The coal material can be treated as a semi-permanent source of organic material similar to a strongly humified soil organic matter [7]. The effect of melioration was characterised by plant yield and copper content in plants.

MATERIAL AND METHODS

A two-year-long pot experiment with alfalfa was carried out on a pseudopodzolic soil (Distric Planosol). The physicochemical characteristic of this soil is the following: pH=4.9; exch. Al = 3.0 cmol kg^{-1}; $CEC_{pH\,8.2}$ = 23.2 cmol kg^{-1}; exch. Ca^{2+}+Mg^{2+} = 13.6 cmol kg^{-1}; humus content = 2%.

The soil was contaminated with copper at four levels: Cu_0=0; Cu_1=100; Cu_2=300; Cu_3= 600; Cu_4=900 mg kg^{-1} soil.

The soil samples, contaminated as above were amended with the melioration agents in the following variants:

- $CaCO_3$ addition - Ca_0= 0.0 and $Ca_{opt.}$= 3.2 g kg^{-1} soil. The latter value is an optimum liming rate calculated for the soil used [5].
- precomposted mixture of $CaCO_3$ and the coal powder addition (1:4 lime:coal ratio): K_1= 8.0; K_2= 16.0; K_3= 24.0 g kg^{-1} soil. ($CaCO_3$ content in K_2 corresponds to the optimum lime dose, Ca_{opt}).

- coal powder: B_1=12.8; B_2= 1.5B_1=19.2 g kg^{-1} soil.

Mineral nutrients (1N:1 P:0.5 Ca:0.5 K:0.2 S:0.2 Mg; total amount of 1 g kg^{-1}soil) were applied in all the melioration variants. Soil moisture was kept approximately constant at 60% of field capacity. For all the melioration variants, alfalfa was used as a test plant because of its sensitivity to soil acidity and heavy metals toxicity. Alfalfa is characterized by a low degree of heavy metal accumulation [8]. The effect of melioration was evaluated by the yield of six subsequent cuts (dry mass) of the alfalfa crop and a copper content in plant (AAS determination). Soil pH(H_2O) was measured in all pots.

RESULTS AND DISCUSSION

Results are shown in Tables 1 and 2 and in Figs 1-3. In Table 1 the alfalfa yield depending on the applied meliorants is presented. A positive effect on the yield is observed

Table 1. Yield of alfalfa (dry mass) at different melioration variants

Treatment	I cut	II cut	III cut	IV cut	V cut	VI cut
	(g / 10 plants)					
Cu_0Ca_0	0.88	0.87	0.49	0.17	0.26	0.24
Cu_0Ca_{opt}	1.99	2.30	2.09	1.98	3.79	3.28
Cu_0K_1	1.37	1.33	1.60	0.82	1.33	1.50
Cu_0K_2	2.09	3.34	2.47	2.36	5.17	5.10
Cu_0B_2	1.20	1.54	2.27	2.14	4.78	4.45
Cu_0B_1	1.28	0.79	1.56	0.74	1.45	1.90
Cu_0B_2	0.85	0.47	1.02	0.64	1.66	1.04
Cu_1Ca_0	0.72	0.72	0.42	0.15	0.24	0.12
Cu_1Ca_{opt}	1.78	2.10	1.93	1.80	3.76	2.82
Cu_1K_1	0.89	1.10	1.08	0.81	2.20	0.95
Cu_1K_2	1.82	2.89	2.15	2.14	5.15	4.26
Cu_1K_3	0.79	1.25	1.31	2.04	3.97	3.42
Cu_1B_1	0.69	0.62	0.49	0.26	0.24	0.33
Cu_1B_2	0.40	0.41	0.38	0.25	0.43	0.44
Cu_2Ca_0	0.15	0.10	0.21	0.13	0.20	0.05
Cu_2Ca_{opt}	1.39	1.81	1.54	1.70	3.44	2.32
Cu_2K_1	0.63	1.09	0.90	0.74	2.02	0.50
Cu_2K_2	1.45	2.17	1.82	1.96	3.26	3.32
Cu_2K_3	0.71	1.10	1.20	1.91	3.79	1.96
Cu_2B_1	0.33	0.32	0.23	0.20	0.19	0.24
Cu_2B_2	0.25	0.33	0.16	0.17	0.31	0.11
Cu_3Ca_0	0.12	0.00	0.00	0.00	0.00	0.00
Cu_3Ca_{opt}	0.98	1.45	1.14	1.58	2.86	1.19
Cu_3K_1	0.61	0.95	0.83	0.64	1.98	0.71
Cu_3K_2	1.37	1.55	1.62	1.82	2.62	2.49
Cu_3K_3	0.68	1.06	0.98	1.78	3.30	2.11
Cu_3B_1	0.00	0.00	0.00	0.00	0.00	0.00
Cu_3B_2	0.00	0.00	0.00	0.00	0.00	0.00
Cu_4Ca_0	0.00	0.00	0.00	0.00	0.00	0.00
Cu_4Ca_{opt}	0.93	1.19	1.00	1.40	2.95	0.00
Cu_4K_1	0.57	0.83	0.67	0.49	0.67	0.38
Cu_4K_2	1.04	1.39	1.48	1.69	2.82	2.50
Cu_4K_3	0.49	1.05	0.88	1.62	3.00	2.01
Cu_4B_1	0.00	0.00	0.00	0.00	0.00	0.00
Cu_4B_2	0.00	0.00	0.00	0.00	0.00	0.00

Table 2. Copper content in alfalfa and final soil pH at different melioration variants

Treatment	pH (H_2O)	Cu (mg kg^{-1}) I+II cut	Cu (mg kg^{-1}) III cut	Cu (mg kg^{-1}) IV cut
Cu_0Ca_0	4.7	11.0	11.0	14.1
Cu_0Ca_{opt}	5.2	9.5	10.0	13.0
Cu_0K_1	4.9	11.0	15.0	10.0
Cu_0K_2	5.6	13.0	9.0	12.0
Cu_0K_3	5.8	11.5	11.0	12.0
Cu_0B_1	4.5	13.5	9.0	15.0
Cu_0B_2	4.6	13.0	12.0	9.0
Cu_1Ca_0	4.4	27.0	24.0	19.1
Cu_1Ca_{opt}	5.0	12.0	13.0	16.0
Cu_1K_1	4.7	19.0	22.0	18.0
Cu_1K_2	5.3	15.0	14.0	17.0
Cu_1K_3	5.6	12.5	15.0	13.0
Cu_1B_1	4.3	27.0	22.0	32.0
Cu_1B_2	4.5	28.0	25.0	34.0
Cu_2Ca_0	4.2	33.0	25.0	31.0
Cu_2Ca_{opt}	4.8	13.5	16.0	20.5
Cu_2K_1	4.6	26.0	23.0	20.0
Cu_2K_2	5.3	15.0	17.0	13.0
Cu_2K_3	5.6	11.5	15.0	13.5
Cu_2B_1	4.2	40.0	39.0	34.3
Cu_2B_2	4.6	35.0	30.0	19.0
Cu_3Ca_0	-	-	-	-
Cu_3Ca_{opt}	4.7	19.5	19.0	22.0
Cu_3K_1	4.5	31.0	26.0	26.0
Cu_3K_2	5.2	17.0	15.0	18.0
Cu_3K_3	5.5	18.0	15.0	16.5
Cu_3B_1	-	-	-	-
Cu_3B_2	-	-	-	-
Cu_4Ca_0	-	-	-	-
Cu_4Ca_{opt}	4.6	21.5	23.0	28.0
Cu_4K_1	4.4	36.0	30.0	35.0
Cu_4K_2	5.1	20.0	20.0	24.0
Cu_4K_3	5.5	16.5	17.0	19.5
Cu_4B_1	-	-	-	-
Cu_4B_2	-	-	-	-

for the melioration variants with the two highest amounts of lime-coal compost (K_2 and K_3). In the control variants (Cu_0) the yield from I, II and III cut is maximum at the middle dose of the K_2 compost, followed the optimum liming Ca_{opt} dose. Coal powder (B_1 and B_2) addition did not have a favorable effect on yield. For the first three cuts, at all pollution levels, the effectiveness of the meliorants increased in the following sequence:

$$K_2 > Ca_{opt} > K_3 > K_1 > B_1 > B_2 .$$

The effect of the applied compost (K_2 and K_3) is better shown by the yields of the next cuts, which are higher than these at optimum liming observed at all copper levels. The following sequence of melioration effectiveness on the IV cut is observed:

$$K_2 > K_3 > Ca_{opt} > K_1$$

At higher copper levels (Cu_2 to Cu_4), the V cut gives maximum yield in the variant with maximum compost dose (K_3). The yield for other meliorants is:

$$K_3 > K_2 \approx Ca_{opt} > K_1.$$

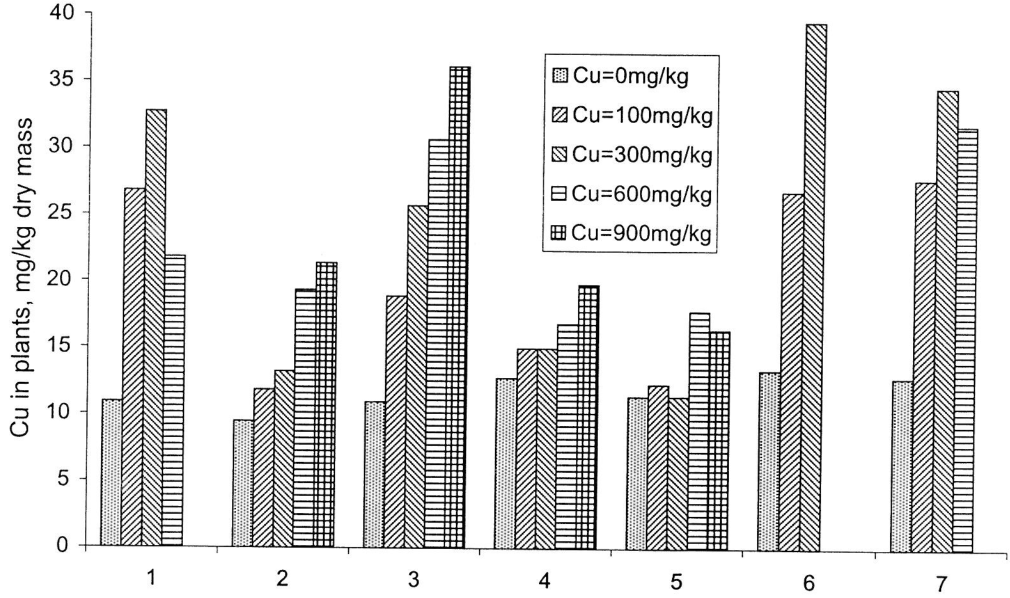

Fig. 1. Copper alfalfa (I and II cut) related to soil pollution at different melioration treatments. 1 - Ca_0, 2 - $Ca_{opt.}$, 3 - K_1, 4 - K_2, 5 - K_3, 6 - B_1, 7 - B_2.

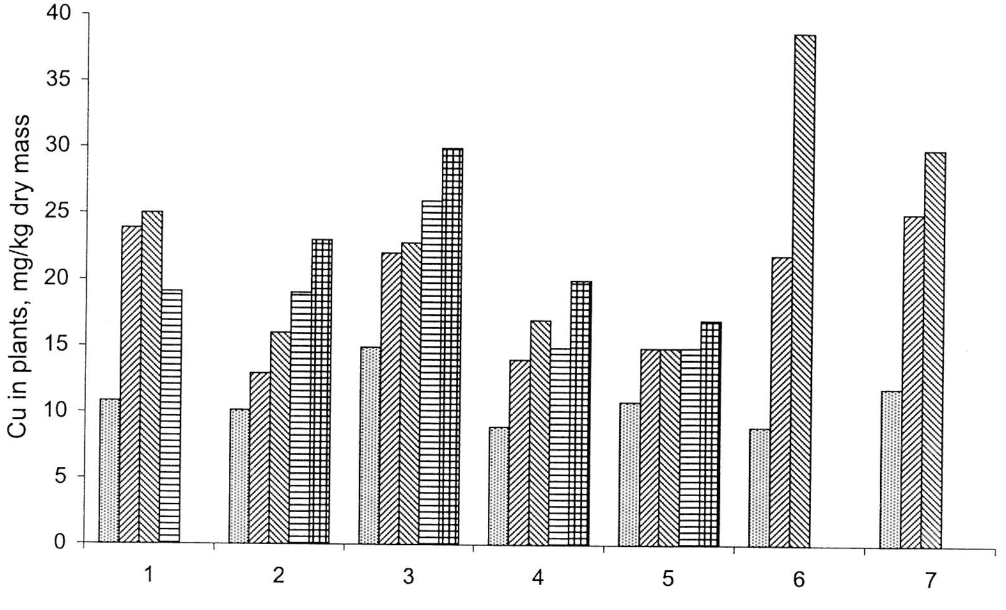

Fig. 2. Copper alfalfa (III cut) related to soil pollution at different melioration treatments. Explanations as in Fig. 1.

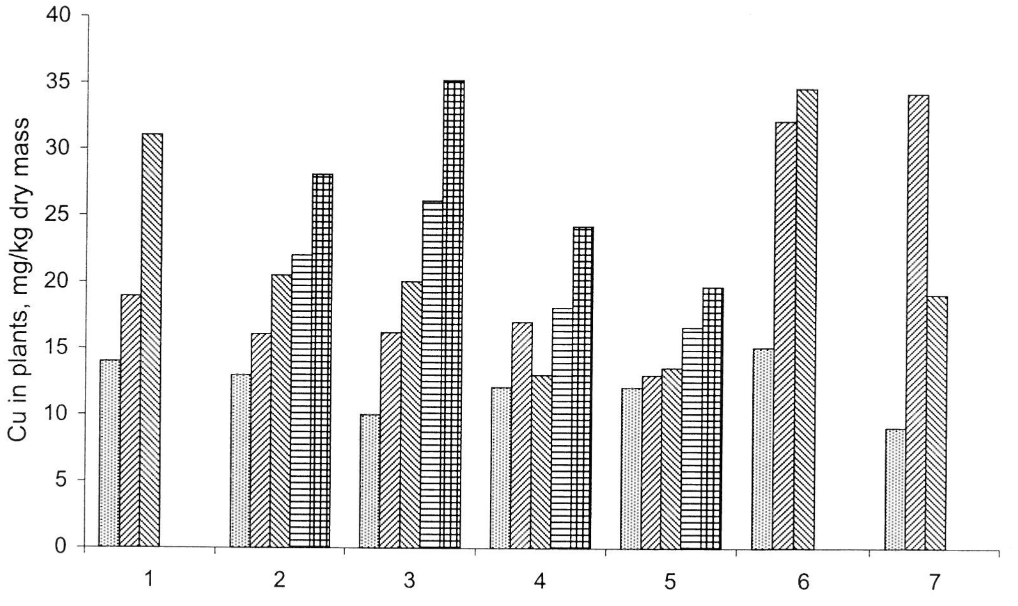

Fig. 3. Copper alfalfa (IV cut) related to soil pollution at different melioration treatments. Explanations as in Fig. 1.

At Cu_3 and Cu_4 copper levels, the effect of the maximum dose of compost (K_3) on yield (V cut) is well pronounced. For example, the yield from the IV cut is roughly equal in the variants with the second and third dose of compost (K_2 and K_3). The yield from the V cut, however, is higher when the maximum dose of compost (K_3) is applied. The effect of liming on yield (VI cut) is reduced at the copper level Cu_3=600 mg kg^{-1} soil and plants die at the next level Cu_4=900 mg kg^{-1} soil. Plants die also in the control pots (Ca_0) at high pollution levels (Cu_3 and Cu_4) and also in the variants with only coal powder treatment (B_1 and B_2). At maximum copper level (Cu_4=900 mg kg^{-1}) plants at the VI cut grow only in the variants with the two highest doses of compost (K_2 and K_3). The above data can indicate the time dependent effect of the simultaneous coal and lime application on the detoxication of soil.

Increasing pollution reduced yield and increased the copper uptake by plants. In Table 2 copper content in plants as well as soil pH relative to the applied meliorants are presented. Copper in plants (I and II cuts) decreased in variants with the combined melioration (lime and coal powder) and liming (Ca_{opt}). The effect was observed at all pollution levels. At Cu_3= 600 and Cu_4=900 mg kg^{-1} copper levels, however, the compost in the two highest doses (K_2 and K_3) caused a stronger decrease of Cu in plants (III and IV cuts) than liming. At maximum copper pollution (Cu_4) the time-effect of the highest dose of compost (K_3) is well expressed and results in a low copper content in plants (III and IV cuts). Maximum copper content in plants was observed in the variants with coal powder (B_1 and B_2) at levels Cu_1 and Cu_2. At higher copper levels (Cu_3 and Cu_4) the plants died.

From Figs 1-3 the effect of applied meliorants on copper content in plants at different cuts can be evaluated. The lower copper content in plants at compost treatments compared to these at optimum liming, especially at high pollution levels is seen.

Simultaneous lime and coal powder treatment stabilised soil pH in the optimum range.

The two highest doses (K_2 and K_3) maintained relatively stable pH during the whole period of the experiment (Table 2). At the end of the experiment pH varied in the range 5.6-5.1 for Cu_0K_2 and Cu_4K_2 variants and in 5.8-5.5 range for Cu_0K_3 and Cu_4K_3 variants. The soil pH decreased at liming ($Ca_{opt.}$) from 5.2 in the control variants without pollution (Cu_0) to 4.6 at the highest pollution level (Cu_4).

CONCLUSION

Melioration of copper contaminated acid soil with the compost of lime and coal powder appeared to increase alfalfa yield and decrease copper in plants. When compared to liming compost buffered soil pH better during two years pot experiment and had a better time -effect on yield and the decrease of copper content in plants.

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