Phytoremediation of copper-contaminated soil by *Artemisia absinthium*: comparative effect of chelating agents (2021)

Table 1: Some physicochemical characteristics of background and contaminated soils (mean ± SD)

Soil characteristics	Background soil	Contaminated soil
pH	7.8 ± 0.1	7.9 ± 0.3
Organic matter, g/kg	64.8 ± 3.8	36.1 ± 4.0
Sand, g/kg	310 ± 40	400 ± 40
Silt, g/kg	390 ± 40	390 ± 30
Clay, g/kg	300 ± 30	210 ± 10
Cu_{total}, mg/kg	71.6 ± 11.0	3480.3 ± 209.8
$Cu_{bioavailable}$, mg/kg	3.2 ± 0.5	494.4 ± 24.1

Table 2: Description of experimental schemes implemented under ex-situ conditions.

Experimental scheme number	Description of the experimental scheme
1	Background (uncontaminated) soil
2	Contaminated soil
3	Contaminated soil + NH_4NO_3 (0.1 g/kg soil)
4	Contaminated soil + NH_4NO_3 (0.1 g/kg soil) + citric acid (5 mM/kg soil)
5	Contaminated soil + NH_4NO_3 (0.1 g/kg soil) + malic acid (5 mM/kg soil)
6	Contaminated soil + NH_4NO_3 (0.1 g/kg soil) + EDTA (0.5 mM/kg soil)
7	Contaminated soil + NH_4NO_3 (0.1 g/kg soil) + EDTA (1 mM/kg soil)
8	Contaminated soil + NH_4NO_3 (0.1 g/kg soil) + EDTA (2 mM/kg soil)
9	Contaminated soil + NH_4NO_3 (0.1 g/kg soil) + EDTA (0.5 mM/kg soil) + citric acid (5 mM/kg soil)
10	Contaminated soil + NH_4NO_3 (0.1 g/kg soil) + EDTA (0.5 mM/kg soil) + malic acid (5 mM/kg soil)
11	Contaminated soil + NH_4NO_3 (0.1 g/kg soil) + citric acid (2.5 mM/kg soil) + malic acid (2.5 mM/kg soil)

Table 3: Copper content in roots and above-ground parts (dry mass) of *A. absinthium* grown by different experimental schemes.

Scheme number	**Root (mg/kg)**	**Above-ground part (mg/kg)**	**Increase in root copper content compared with control (by a factor of)**	**Increase in above-ground part copper content compared with control (by a factor of)**
1	68.30 ± 2.38	33.80 ± 1.97	–	–
2	360.00 ± 14.91	60.96 ± 3.44	5.27	1.80
3	363.96 ± 13.10	57.96 ± 3.76	5.33	1.71
4	367.92 ± 17.32	109.44 ± 6.08	5.39	3.24
5	309.96 ± 11.59	142.32 ± 7.59	4.54	4.21
6	285.60 ± 12.02	162.60 ± 7.13	4.18	4.81
7	337.08 ± 16.73	264.36 ± 10.97	4.94	7.82
8	361.92 ± 14.25	386.40 ± 18.41	5.30	11.43
9	342.84 ± 14.16	179.13 ± 8.09	5.02	5.30
10	356.88 ± 18.07	185.50 ± 7.86	5.23	5.49
11	271.56 ± 9.98	187.00 ± 8.87	3.98	5.53

Table 4: Correlation analysis of some studied criteria.

	Mass of above-ground part	**Mass of root**	**$Cu_{above\text{-}ground}$**	**Cu_{root}**	**EDTA**
Mass of above-ground part	1				
Mass of root	0.778	1			
$Cu_{above\text{-}ground}$	-0.714	-0.750	1		
Cu_{root}	-0.771	-0.619	0.367	1	
EDTA	-0.598	-0.645	0.910	0.279	1

Source: https://link.springer.com/article/10.1007/s10653-021-01151-2

Table 1: Chemical attributes of the investigated Inceptisol and Entisol of the vineyards.

Soil Attributes[a]	Inceptisol	Entisol
Clay (g kg^{-1})	210	270
Organic matter (g kg^{-1})	46	23
pH_{H2O}	5.9	5.7
Al^{3+} (cmol$_c$ kg^{-1})	0.0	0.0
Available Cu (mg kg^{-1})	198.6	91.3
Available K (mg kg^{-1})	60	100
Available P (mg kg^{-1})	50.7	19.5
Exchangeable Ca (mmol$_c$ kg^{-1})	95.4	76.9
Exchangeable Mg (mmol$_c$ kg^{-1})	29.2	22.9
CEC mmol$_c$ kg^{-1}	154	127

Samples were taken from 0 to 20 cm in depth.
[a]P, K, Cu: extractor Mehlich-1; Ca2+, Mg2+, Al3+: extractor KCl 1 mol L^{-1}; CEC: cation exchange capacity in pH 7.0; Organic matter, by oxidation with $Na_2Cr_2O_7$ 2 mol L^{-1} + H_2SO_4 5 mol L-1; Clay: Pipette method

Table 2: Absolute frequency (AF) and relative (RF) of each specie, shoots dry mass of each species (SDM) and total dry mass production of the plants per area (ADM), root dry mass (RDM), SDM/RDM ratio and contribution of each species to the total dry mass production (CSTDM) of the plant species collected in summer and winter, in a Inceptisol and Entisol planted with vines.

	Inceptsol						**Entisols**					
Species	AF (plants m^{-2})	RF (%)	SDM (g)	RDM (g plant^{-1})	ADM (kg ha^{-1})	SDM/RDM	AF (plants m^{-2})	RF (%)	SDM (g)	RDM (g plant^{-1})	ADM (kg ha^{-1})	SDM/RDM
Summer Collect												
S. nodiflora	11.0 b	7.1	2.4 b	0.3 b	98.6 a	9.7 b	6.0 c	2.8	0.4 b	0.1 b	19.2 b	8.3 a
Setaria sp.	11.2 b	7.2	2.7 b	0.3 b	110.3 a	13.5 b	–		–	–	–	–
D. carota	–		–	–	–	–	5.6 c	2.6	0.8 b	0.2 b	34.9 b	4.7 b
I. cairica	4.0 c	2.6	0.7 b	0.3 b	30.5 b	4.3 b	9.6 c	4.4	1.8 b	0.2 b	72.9 a	9.6 a
S. rhombifolia	10.0 b	6.5	1.3 b	0.1 b	54.9 b	33.3 a	25.6 b	11.8	3.1 a	1.1 b	124.2 a	5.0 a
C. compressus	76.8 a	49.5	4.3 b	0.9a	173.1 a	4.2 b	100.8 a	46.6	7.2 a	2.5 b	290.3 a	2.8 b
E. heterophylla	4.0 c	2.6	0.6 c	0.08 c	24.1 b	7.6 b	4.0 c	1.8	0.1 c	0.1 b	3.2 c	3.2 b
R. obtusifolius	–		–	–	–	–	5.3 c	2.5	4.2 a	3.1a	169.4 a	1.3 b
C. leucanthemu	16.0 b	10.0	6.8 a	1.0 a	275.8 a	6.6 b	19.0 c	8.8	12.6 a	3.2 a	504.4 a	5.4 a

m												
P. tomentosa	6.0 c	3.9	0.9 b	0.1 b	36.2 b	6.7 b	10.0 c	4.6	3.0 a	0.8 b	118.2 a	3.5 b
T. pratense	16.0 b	10.3	5.4 a	1.1 a	217.4 a	6.1 b	30.4 b	14.1	3.9 a	0.9 b	150.4 a	4.4 b
Total	155.0	100			1020.9		216.3	100			1483.9	
Sorensen's similarity coefficient	0.86											
Winter Collect												
O. dillenii	7.2 c	2.5	1.8 c	0.1 b	74.1 b	11.6 ns	28.0 a	8.2	1.4 c	0.4 b	59.7 c	3.5 b
L. multiflorum	23.2 b	8.2	46.1 a	3.0 a	1847.7 a	15.5	25.6 a	7.5	81.6 a	7.9 a	3265.4 a	10.4 a
D. carota	4.0 c	1.4	7.5 b	1.3 a	303.0 b	24.8	7.2 b	2.1	6.3 b	1.1 b	255.6 b	12.3 a
V. sativa	10.4 c	3.6	5.3 c	0.2 b	215.6 b	39.9	–	–	–	–	–	–
S. rhombifolia	–		–	–	–	–	60.0 a	17.6	0.6 c	0.5 b	24.1 c	1.0 c
C. compressus	149.6 a	52.1	0.6 c	0.1 b	24.8 c	3.6	60.0a	17.6	0.2 c	0.1 c	8.6 c	2.5 b
R. obtusifolius	16.0 c	5.6	1.8 c	0.1 b	74.6 c	41.6	–		–	–	–	–
C. leucanthemum	24.0 b	8.2	2.0 c	0.4 b	80.8 c	5.8	127.2 a	37.3	6.3	2.6 a	254.0	2.7 b
S. oleraceus	5.6 c	1.9	12.8 b	1.8 a	512.2	7.3	–		–	–	–	–
P. tomentosa	40.0 b	13.9	6.6 b	0.8 b	264.4 b	22.1	24.8 a	7.3	4.3 b	0.9 b	172.7 b	7.6 a
T. campestre	–		–	–	–	–	4.0 b	1.2	1.3 c	0.2 c	53.6 c	6.3 a
T. pratense	7.2 c	2.5	11.0 b	1.2 a	440.6 b	10.3	4.0 b	1.2	6.3 b	0.9 b	152.5 b	3.9 b
Total	287.2	100			3397.2		340.8	100			4246.2	
Sorensen's similarity coefficient	0.74											

Same letters in the column do not differ statistically by the randomization test ($p > 0.05$); ns – not significant diferences.

Table 3: Cu content in the shoots (CuS), Cu accumulated in the shoots (ACuS) and Cu exported in the shoots of each species (CuESp), in plants collected in summer and winter, under a Inceptisol and Entisol, planted with vines.

Species	CuS (mg kg^{-1})	ACuS (ug plant^{-1})	CuESp (g ha^{-1})	CuS (mg kg^{-1})	ACuS (ug plant^{-1})	CuESp (g ha^{-1})
	Summer collect					
S. nodiflora	46.7 a	46.3 a	5.1 b	24.5 b	10.9 b	1.4 c
Setaria sp.	17.6 c	13.1 b	1.9 b	–	–	–
D. carota	–	–	–	12.3 c	8.1 b	0.7 c
I. cairica	18.6 c	14.2 b	0.7 b	22.6 b	13.8 b	2.1 c
S. rhombifolia	20.3 c	17.7 b	2.1 b	17.0 c	9.9 b	4.2 b
C. compressus	37.9 b	9.1 b	29.3 a	36.0 a	11.3 b	36.5 a
E. heterophylla	12.3 c	7.4 b	0.4 c	9.4 c	0.7 c	0.3 c
R. obtusifolius	–	–	–	15.4 c	49.5 a	0.8 c
C. leucanthemum	33.5b	69.5 a	5.3 b	25.7 b	171.3 a	4.9 b
P. tomentosa	57.7 a	32.7 a	3.3 b	28.7 b	45.2 a	2.9 b
T. pratense	32.5 b	46.5 a	5.1 b	30.8 b	26.4 a	9.1 b
Total			53.2			62.9
	Winter collect					
O. dillenii	42.2 a	27.5 b	3.0 b	43.4 b	9.2 c	12.1 b
L. multiflorum	11.1 b	92.4 a	2.3 c	14.8 c	251.2 a	3.8 c
D. carota	13.2 b	100.6 a	0.5 d	43.7 b	155.7 a	3.2 c
V. sativa	15.9 b	31.8 b	1.6 c	–	–	–
S. rhombifolia	–	–	–	34.3 b	1.5 c	21.1 a
C. compressus	46.5 a	0.7 c	67.5 a	69.0 a	0.9 c	42.4 a
R. obtusifolius	34.3 a	17.7 b	5.6 b	–	–	–
C. leucanthemum	26.2 b	14.5 b	6.3 b	52.8 a	8.1 c	69.2 a
S. oleraceus	18.8 b	177.8 a	1.0 c	–	–	–
P. tomentosa	28.4 b	17.2 b	11.3 b	28.6 c	21.3 c	7.1 c
T. campestre	–	–	–	10.6 c	14.1 c	0.4 d
T. pratense	16.2 b	95.7 a	1.1 c	20.4 c	82.3 b	0.8 d
Total			100.2			160.1

Same letters in the column do not differ statistically by the randomization test ($p > 0.05$).

Table 4: Cu content in the roots (CuCR), Cu accumulated in the roots (ACuR), translocation factor (TFCu), bioconcentration factor in the shoots (BCFCuS), bioconcentration factor in the roots (BCFCuR), in different species of plants collected in summer and winter, in a Inceptisol and Entisol planted with vines.

Inceptsol					**Entisols**					
Species	CuCR (mg kg^{-1})	ACuR (ug planta^{-1})	TF_{Cu}	BCFCuS	BCFCuR	CuCR (mg kg^{-1})	ACuR (ug planta^{-1})	TF_{Cu}	BCFCuS	BCFCuR
						Summer collect				
S. nodiflora	70.6 b	46.3 a	0.7 a	0.23 a	0.35 b	59.1 b	10.9 b	0.4 c	0.26 b	0.65 b
Setaria sp.	65.4 b	13.1 b	0.2 b	0.08 c	0.32 b	–	–	–	–	–
D. carota	–	–	–	–	–	19.0 c	8.1 b	0.6 a	0.13 c	0.21 c
I. cairica	26.6 c	14.2 b	0.7 a	0.09 c	0.13 c	41. b	13.8 b	0.5 b	0.24 b	0.46 b
S. rhombifolia	20.4 c	17.7 b	0.9 a	0.10 c	0.10 c	16.1 c	9.9 b	1.0 a	0.18 c	0.18 c
C. compressus	126.0 a	9.1 b	0.3 b	0.19 b	0.63 a	129.1 a	11.3 b	0.3 c	0.39 a	1.41 a

E. heterophylla	48.3 b	7.4 b	0.2 b	0.06 c	0.24 b	56.5 b	0.7 c	0.2 c	0.10 c	0.62 b
R. obtusifolius	–	–	–	–	–	10.6 c	49.5 a	1.4 a	0.16 c	0.12 c
C. leucanthemum	76.8 b	69.5 a	0.4 b	0.16 b	0.38 b	87.8 a	171.3 a	0.3 c	0.28 b	0.96 a
P. tomentosa	97.8 b	32.7 a	0.5 a	0.29 a	0.49 b	58.3 b	45.2 a	0.4 c	0.31 b	0.64 b
T. pratense	44.5 b	46.5 a	0.7 a	0.16 b	0.22 b	55.0 b	26.4 a	0.5 b	0.33 b	0.60 b
						Winter collect				
O. dillenii	49.9 b	27.5 b	0.87 b	0.21 a	0.25 b	41.7 c	9.2 c	1.0 b	0.47 b	0.45 c
L. multiflorum	187.5 a	92.4 a	0.05 e	0.05 b	0.94 a	274.3 a	251.2 a	0.05 d	0.16 c	3.0 a
D. carota	14.7 c	100.6 a	0.91 b	0.06 b	0.07 c	13.4 d	155.7 a	3.2 a	0.47 b	0.14 d
V. sativa	99.6 b	31.8 b	0.16 d	0.08 b	0.50 b	–	–	–	–	–
S. rhombifolia	–	–	–	–	–	31.3 c	1.5 c	1.1 b	0.37 b	0.34 c
C. compressus	229.5 a	0.7 c	0.20 d	0.23 a	1.15 a	69.0 c	0.9 c	1.0 b	0.75 a	0.75 c
R. obtusifolius	21.6 c	17.7 b	1.59 a	0.17 a	0.10 c	–	–	–	–	–
C. leucanthemum	134.1 a	14.5 b	0.22 d	0.13 b	0.67 a	266.3 a	8.1 c	0.1 c	0.57 a	2.91 a
S. oleraceus	59.5 b	177.8 a	0.32 c	0.09 b	0.30 b	–	–	–	–	–
P. tomentosa	117.9 a	17.2 b	0.24 c	0.14 b	0.59 a	95.8 b	21.3 c	0.3 c	0.31 c	1.04 b
T. campestre	–	–	–	–	–	49.2 c	14.1 c	0.2 c	0.11 c	0.53 c
T. pratense	47.4 b	95.7 a	0.35 c	0.08 b	0.23 b	52.0 c	82.3 b	0.3 c	0.22 c	0.56 c

Same letters in the column do not differ statistically by the randomization test ($p > 0.05$).

Source: https://www.tandfonline.com/doi/epub/10.1080/15226514.2021.1940835?needAccess=true

Tolerance and phytoremediation potential of grass species native to South American grasslands to copper-contaminated soils (2021)

Table 1: Soil physical and chemical features at layer 0.0–0.20 m in Typic Hapludalf soil in South American grassland.

	Natural grassland
Clay (g kg^{-1})	54
Sand (g kg^{-1})	894
Silt (g kg^{-1})	52
Organic matter (g kg^{-1})	9.0
pH_{H2O} (1:1)	5.2
Exchangeable Al (mg kg^{-1})	0.4
Total Cu (mg kg^{-1})	3.68
Available Cu by EDTA (mg kg^{-1})	0.7
Total Zn (mg kg^{-1})	6.26
Available Zn by EDTA (mg kg^{-1})	0.9
Available K by Mehlich-1 (mg kg^{-1})	66.4
Available P by Mehlich-1 (mg kg^{-1})	3.6
Available Fe by EDTA (mg kg^{-1})	5.9
Available Mn by EDTA (mg kg^{-1})	15.4
Exchangeable Ca (mg kg^{-1})	0.5
Exchangeable Mg (mg kg^{-1})	0.2
CEC_{ef}*, $cmol_c$ kg^{-1}	1.4
$CEC_{pH\ 7.0}$, $cmol_c$ kg^{-1}**	3.2

*CECef: ability to effectively exchange cations; **CECph 7.0: cation exchange capacity at pH 7.0.

Table 2: Chemical features of soil solution withdrawn during the grown of three native cover crop species in soils with increased Cu levels.

Chemical parameters of the solution	Cu doses	Plant species		
		A. affinis	*P. notatum*	*P. plicatulum*
		1st Sampling		
pH	0	5.41 aA*	5.42 aA	5.74 aA
	40	5.29 aA	5.28 aA	5.18 bA
	80	5.24 aA	5.29 aA	5.32 bA
Dissolved organic carbon (mg L^{-1})	0	28.33 aA	29.33 aA	25.67 aA
	40	25.33 bA	25.33 aA	26.33 aA
	80	31.00 aA	28.67 aA	29.00 aA
Soluble Cu (mg L^{-1})	0	0.021 cA	0.019 cA	0.017 cA
	40	0.357 bA	0.386 bA	0.331 bA
	80	0.984 aA	1.016 aA	0.943 aA
		2nd Sampling		
pH	0	5.43 bC	5.88 aB	7.56 aA
	40	5.67 aB	5.65 aB	6.78 bA
	80	5.29 bB	5.91 aA	6.03 cA
Dissolved organic carbon (mg L^{-1})	0	16.67 bB	25.00 aA	25.67 aA
	40	19.33 bB	26.33 aA	23.00 aA
	80	22.67 aB	27.00 aA	27.67 aA
Soluble Cu (mg L^{-1})	0	0.014 cA	0.014 cA	0.016 cA

	40	0.427 bA	0.479 bA	0.366 bA
	80	1.296 aB	1.520 aA	1.137 aB
		3rd Sampling		
pH	0	5.74 aB	7.21 aA	7.12 aA
	40	5.61 aC	6.14 bB	6.68 bA
	80	5.19 bB	5.34 cB	6.70 bA
Dissolved organic carbon (mg L^{-1})	0	19.7 aC	43.0 aA	32.7 aB
	40	18.5 aB	27.9 bA	18.2 bB
	80	18.2 aB	23.3 cA	21.8 bA
Soluble Cu (mg L^{-1})	0	0.018 cA	0.030 cA	0.014 cA
	40	0.360 bA	0.331 bA	0.276 bA
	80	1.214 aA	1.189 aA	0.774 aB

*Means followed by the same lowercase letter did not differ between Cu doses within the same species (column) and means followed by the same uppercase letter did not differ between species within the same Cu dose (row) in the Scott–Knott test ($p < 0.05$).

Table 3: Macro and micronutrient levels in Axonopus affinis, Paspalum notatum, and Paspalum plicatulum plants grown in soils with increased Cu levels.

	Plant species						
		A. affinis	***P. notatum***	***P.plicatulum***	***A. affinis***	***P. notatum***	***P. plicatulum***
Nutrient	**Cu doses**	**Shoot**			**Root**		
P(gkg^{-1})	0	1.44 aB*	1.76 bA	0.71 bC	1.57 aA	0.69 bB	0.42 cC
	40	1.52 aB	2.12 aA	0.70 bC	1.54 aA	1.12 aB	0.57 bC
	80	1.09 bA	0.91 cB	1.09 aA	0.82 bB	0.64 bC	1.14 aA
K (g kg^{-1})	0	17.34 aA	16.54 bA	8.14 bB	13.29 aA	7.39 cB	4.27 bC
	40	14.96 aB	21.69 aA	8.54 bC	11.48 aB	13.99 bA	5.32 bC
	80	17.60 aA	15.53 bA	15.40 aA	6.56 bC	18.13 aA	9.59 aB
Ca (g kg^{-1})	0	7.15 bA	5.52 bB	4.48 bB	4.73 bA	2.32 cB	4.62 bA
	40	7.87 bA	4.99 bB	4.57 bB	5.22 bA	3.94 bB	5.18 bA
	80	18.26 aA	7.16 aB	6.59 aB	8.28 aA	5.22 aC	6.97 aB
Mg (gkg^{-1})	0	8.79 bA	8.89 aA	7.80 aA	10.96 aA	4.51 bB	5.03 aB
	40	9.92 bA	7.67 aB	8.17 aB	12.27 aA	6.52 aB	6.40 aB
	80	16.81aA	7.25 aC	9.32 aB	7.72 bA	7.59 aA	7.63 aA
Cu (mg kg^{-1})	0	12.88 cA	17.88 cA	15.64 cA	68.84 cA	41.92 cA	41.68 cA
	40	30.44 bA	32.08 bA	25.72 bA	429.32 bA	182.76 bB	240.64 bB
	80	72.88 aA	44.48 aB	36.44 aC	599.64 aA	385.40 aB	594.56 aA
Zn (mg kg^{-1})	0	44.32 aA	26.12 bB	19.24 bB	41.84 aA	23.72 cA	21.80 bA
	40	56.80 aA	59.76 aA	28.56 bB	61.04 aB	98.12 aA	49.16 aB
	80	50.64 aB	58.52 aA	43.44 aB	65.24 aA	75.12 bA	66.24 aA
Fe (mg kg^{-1})	0	348.64 cA	143.04 bB	90.72 aB	886.6 bB	1996.6 aA	971.4 aB
	40	565.44 bA	175.16 bB	153.88 aB	1323.4 bB	2268.2 aA	1472.9 aB
	80	905.28 aA	315.48 aB	143.32 aC	1927.7 aA	1308.2 bA	1281.8 aA
Mn (mg kg^{-1})	0	144.48 cA	56.36 bB	123.00 aA	175.48 cA	108.36 bA	117.80 aA
	40	219.24 bA	173.28 aB	137.88 aB	402.24 bA	199.35 bB	132.44 aB
	80	818.68 aA	203.68 aB	138.88 aC	1657.4 aA	327.68 aB	138.76 aC

*Means followed by the same lowercase letter did not differ between Cu doses within the same species (column) and means followed by the same uppercase letter did not differ between species within the same Cu dose (row) in the Scott–Knott test ($p < 0.05$).

Source: https://www.tandfonline.com/doi/full/10.1080/15226514.2020.1852528

Effects of *Herbaspirillum sp.* p5-19 assisted with alien soil improvement on the phytoremediation of copper tailings by *Vetiveria zizanioides L.* (2021)

Table 1: Experiment design.

Treatment	CK[a]	B[b]	M10[c]	M10B[d]	M20[e]	M20B[f]	C5[g]	C5B[h]	C10[i]	C10B[j]
Soil weight (kg)	0	0	1.2	1.2	2.4	2.4	2.0	2.0	5.0	5.0
Tailings weight (kg)	12.0	12.0	10.8	10.8	9.6	9.6	10.0	10.0	7.0	7.0
Total weight (kg)	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Bacterial suspension (ml)	0	40.0	0	40.0	0	40.0	0	40.0	0	40.0
Deionized water (ml)	40.0	0	40.0	0	40.0	0	40.0	0	40.0	0

[a]Tailings (the unimproved control)
[b]Tailings with bacterial suspension (Herbaspirillum sp. p5-19)
[c]10% soil and 90% tailings (w/w)
[d]10% soil and 90% tailings (with bacterial suspension)
[e]20% soil and 80% tailings
[f]20% soil and 80% tailings (with bacterial suspension)
[g]The surface of tailings is covered with 5 cm of soil
[h]The surface of tailings is covered with 5 cm of soil (with bacterial suspension)
[i]The surface of tailings is covered with 10 cm of soil
[j]The surface of tailings is covered with 10 cm of soil (with bacterial suspension)

Table 2: Basic physical and chemical properties and heavy metal concentrations of substrate.

Substrate	pH value	Electric conductivity (μS cm^{-1})	Total nitrogen concentration (mg kg^{-1})	Total phosphorus concentration (mg kg^{-1})	Total potassium concentration (mg kg^{-1})	Heavy metal concentrations (mg kg^{-1})			
						Mn	**Cu**	**Zn**	**Cd**
Tailings	7.18 ± 0.01b	711.66 ± 3.24b	262.01 ± 4.72c	170.15 ± 3.15b	925.76 ± 5.82d	2462.57 ± 96.25a	447.08 ± 27.17a	670.12 ± 32.16a	2.47 ± 0.23a
Soil	7.71 ± 0.02a	1822.71 ± 8.78a	765.12 ± 6.28a	1331.47 ± 9.97a	1773.95 ± 11.13a	314.24 ± 12.12c	21.49 ± 1.12c	483.38 ± 21.31c	0.24 ± 0.02b
M10	7.14 ± 0.01b	724.10 ± 2.46b	272.88 ± 3.80bc	176.29 ± 4.77b	952.94 ± 17.57c	2378.48 ± 105.31ab	447.08 ± 20.08a	625.11 ± 33.53b	2.27 ± 0.30a
M20	7.14 ± 0.01b	729.51 ± 2.03b	284.46 ± 5.87b	185.91 ± 3.36b	980.54 ± 6.37b	2299.82 ± 72.45b	407.27 ± 22.32b	612.14 ± 107.65b	2.03 ± 0.18a

Lowercase letters indicate significant differences among treatments, $p < 0.05$ (total samples N = 16; replication n = 4)
M_{10} 10% soil and 90% tailings, M_{20} 20% soil and 80% tailings

Table 3: Traits of p5-19.

Strain	IAA synthesis/μg ml^{-1}	Siderophore production/μmol l^{-1}	Phosphate solubilization/mg l^{-1}	Nitrogen fixation
P5-19	55.36 ± 1.78	8.39 ± 0.02	45.17 ± 1.60	+

Values are means ± standard deviations of four samples. + means the p5-19 had the ability to fix nitrogen

Table 4: Influence of p5-19 and alien soil improvement on heavy metal translocation by *V. zizanioides*.

Treatments	TF			
	Mn	Cu	Zn	Cd
CK	0.55 ± 0.04c	0.08 ± 0.01ab	0.43 ± 0.04bc	0.42 ± 0.06ab
B	0.66 ± 0.07bc	0.08 ± 0.01ab	0.50 ± 0.05a	0.50 ± 0.05ab
M10	0.55 ± 0.15c	0.09 ± 0.01a	0.39 ± 0.06bc	0.42 ± 0.13ab
M10B	0.64 ± 0.04bc	0.09 ± 0.01a	0.52 ± 0.04a	0.52 ± 0.08ab
M20	0.55 ± 0.08c	0.07 ± 0.01ab	0.36 ± 0.08 cd	0.46 ± 0.08ab
M20B	0.66 ± 0.01bc	0.08 ± 0.00ab	0.50 ± 0.03ab	0.61 ± 0.08a
C5	0.63 ± 0.01bc	0.08 ± 0.01ab	0.25 ± 0.07d	0.38 ± 0.05b
C5B	0.77 ± 0.03ab	0.08 ± 0.01ab	0.31 ± 0.01 cd	0.44 ± 0.08ab
C10	0.88 ± 0.07a	0.06 ± 0.00b	0.43 ± 0.06bc	0.48 ± 0.15ab
C10B	0.86 ± 0.01a	0.07 ± 0.01ab	0.52 ± 0.02a	0.58 ± 0.05ab

Lowercase letters indicate significant differences among treatments, $p < 0.05$ (total samples N = 40; replication n = 4). Notes: CK, tailings (the unimproved control); B, tailings with bacterial suspension (*Herbaspirillum sp.* p5-19); M10, 10% soil and 90% tailings; M10B, 10% soil and 90% tailings (with bacterial suspension); M20, 20% soil and 80% tailings; M20B, 20% soil and 80% tailings (with bacterial suspension); C5, the surface of tailings is covered with 5 cm of soil; C5B, the surface of tailings is covered with 5 cm of soil (with bacterial suspension); C10, the surface of tailings is covered with 10 cm of soil; C10B, the surface of tailings is covered with 10 cm of soil (with bacterial suspension)

Source: https://link.springer.com/article/10.1007/s11356-021-15091-y

Efficacy of copper foliar spray in preventing copper deficiency of rainfed wheat (*Triticum aestivum L.*) grown in a calcareous soil (2020)

Table 1: Characteristics of studied soils (0-30 cm).

Soil properties	Soil "1" (2016-17 season)	Soil "2" (2017-18 season)
Clay (%)	46.5	58.8
Silt (%)	36.8	28
Sand (%)	16.3	12.7
pH[a]	8.7	8.8
Free carbonates (%)[b]	16.9	14.9
Total carbonates (%)[c]	47.6	21.9
Organic matter (%)[d]	2.81	2.59
P_2O_5 (mg kg^{-1})[e]	44	35
K_2O (mg kg^{-1})[f]	313	527
MgO (mg kg^{-1})[f]	448	814
CaO (mg kg^{-1})[f]	7280	8548
Zn (mg kg^{-1})[g]	0.35	0.25
Fe (mg kg^{-1})[g]	4.66	4.31
Mn (mg kg^{-1})[g]	3.76	3.59
Cu (mg kg^{-1})[g]	0.35	0.61

a Determined in a soil: water ratio of 1:5.
b Extracted by ammonium oxalate.
c Determined by volumetric method.
d Determined using the Walkley and Black method.
e Determined by Olsen method.
f Extracted by the ammonium acetate.
g Determined using the DTPA extraction.

Table 2: Chlorophyll content index of wheat flag leaf under different copper foliar spray concentrations measured in soil "2" (2017-18 season).

Cu rate (%)	Chlorophyll content index
Control	52.2 ± 13.2 a
0.01 %	53.9 ± 15.3 a
0.03 %	51.6 ± 14.3 a
0.05 %	36.7 ± 16.4 b
0.10 %	34.1 ± 17.9 b
0.20 %	27.9 ± 18.7 c

Data are means ± standard deviation (n = 125).
Means followed by the same letters are not significantly different.

Table 3: Flag leaf area (cm²) of wheat under different copper foliar spray concentrations in the studied soils.

	Cu rate (%)	Flag leaf area (cm²)
Soil 1[a] (2016-17 season)	Control	7.50 ± 2.39 a
	0.20 %	6.81 ± 2.94 a
	0.40 %	8.07 ± 3.13 a
	0.60 %	6.67 ± 2.10 a
	0.80 %	7.76 ± 2.66 a
	1.00 %	7.25 ± 3.34 a
Soil 2[a] (2017-18 season)	Control	33.3 ± 8.6 a
	0.01 %	33.2 ± 11 a
	0.03 %	29.6 ± 13.9 a
	0.05 %	27.1 ± 13.3 a
	0.10 %	28.1 ± 7.7 a
	0.20 %	22.3 ± 8.4 a

Data are means ± standard deviation (n = 125).
Means followed by the same letters are not significantly different.
a Cu content is around 0.35 mg kg^{-1} in soil “1” and 0.61 mg kg^{-1} in soil “2”.

Table 4: Grain yield and harvest index of wheat under different copper foliar spray concentrations in the studied soils.

Cu rate (%)	Grain yield (qx ha^{-1})	Harvest index
	Soil 1[a] (2016-17 season)	
Control	14.31 ± 3.83 a	0.23 ± 0.03 a
0.20 %	14.84 ± 4.65 a	0.22 ± 0.03 a
0.40 %	12.93 ± 3.42 a	0.21 ± 0.02 a
0.60 %	14.78 ± 4.46 a	0.22 ± 0.04 a
0.80 %	11.76 ± 4.82 a	0.20 ± 0.03 a
1 %	13.13 ± 3.56 a	0.21 ± 0.04 a
	Soil 2[a] (2017-18 season)	
Control	56.21 ± 9.85 b	0.38 ± 0.04 a
0.01 %	62.78 ± 4.99 a	0.41 ± 0.07 a
0.03 %	57.28 ± 6.81 b	0.41 ± 0.06 a
0.05 %	51.85 ± 8.16 b	0.41 ± 0.06 a
0.10 %	54.62 ± 5.43 b	0.40 ± 0.04 a
0.20 %	53.66 ± 5.52 b	0.40 ± 0.05 a

Data are means ± standard deviation (n = 25).
Means followed by the same letters are not significantly different.
a Cu content is around 0.35 mg kg^{-1} in soil “1” and 0.61 mg kg^{-1} in soil “2”.

Table 5: Number of kernels, pollination rate and 1000-kernel weight of wheat under different copper foliar spray concentrations in the studied soils.

Cu rate (%)	Number of kernels ear^{-1}	Pollination rate (%)	1000-kernel weight (g)
	Soil 1[a] (2016-17 season)		
Control	25.7 ± 4.0 a	67.8 ± 9.7 bc	22.8 ± 2.3 a
0.20 %	25.9 ± 3.2 a	70.1 ± 10.1 bc	23.5 ± 2.2 a
0.40 %	24.6 ± 4.2 a	66.8 ± 8.9 c	21.8 ± 1.9 a
0.60 %	26.3 ± 5.4 a	75.5 ± 11.0 a	23.9 ± 3.0 a
0.80 %	24.1 ± 5.0 a	67.7 ± 10.6 bc	22.3 ± 2.2 a
1 %	23.8 ± 5.1 a	66.3 ± 11.1 c	21.8 ± 1.9 a
	Soil 2[a] (2017-18 season)		
Control	50.8 ± 10.6 a	87.7 ± 8.3 a	35.9 ± 3.3 bc
0.01 %	47.4 ± 11.6 a	87.5 ± 7.9 a	38.9 ± 3.1 a
0.03 %	46.5 ± 10.1 a	85.0 ± 11.9 a	37.2 ± 2.5 b
0.05 %	48.1 ± 9.5 a	87.2 ± 7.3 a	36.5 ± 2.9 bc
0.10 %	48.3 ± 9.5 a	86.6 ± 11.2 a	36.3 ± 3.1 bc
0.20 %	45.7 ± 10.4 a	85.6 ± 7.9 a	34.6 ± 2.2 c

Data are means ± standard deviation (n = 250 for number of kernels per ear and for pollination rate and n = 25 for 1000-kernel weight).
Means followed by the same letters are not significantly different.
a Cu content is around 0.35 mg kg^{-1} in soil "1" and 0.61 mg kg^{-1} in soil "2".

Table 6: Copper contents of flag leaf and kernels under different copper foliar spray concentrations in the studied soils.

Cu rate (%)	Flag leaf Cu content (mg kg^{-1})	Kernel Cu content (mg kg^{-1})
	Soil 1[a] (2016-17 season)	
Control	5.4 ± 0.5 c	5.9 ± 0.7 c
0.20 %	16.3 ± 3.6 bc	7.4 ± 0.4 b
0.40 %	19.4 ± 6.3 bc	7.6 ± 0.6 b
0.60 %	30.9 ± 10.3 b	7.4 ± 0.7 b
0.80 %	36.3 ± 18.3 b	8.6 ± 0.8 a
1 %	55.7 ± 18.9 a	9.2 ± 0.7 a
Regression model	y = 46.1x + 4.2 (R^2=0.95)	y = 2.8x + 6.2 (R^2=0.88)
	Soil 2[a] (2017-18 season)	
Control	5.5 ± 1.2 d	8.1 ± 0.5 b
0.01 %	14.6 ± 4.3 cd	8.6 ± 0.4 b
0.03 %	29.7 ± 7.0 cd	8.9 ± 1.1 b
0.05 %	43.0 ± 12.6 c	9.6 ± 0.9 ab
0.10 %	105.2 ± 33.8 b	10.9 ± 1.6 a
0.20 %	144.2 ± 41.1 a	11.1 ± 1.7 a
Regression model	y = 721.4 x + 10.1 (R^2=0.96)	y = 14.9x + 8.5 (R^2=0.83)

Data are means ± standard deviation (n = 5).
Means followed by the same letters are not significantly different.
a Cu content is around 0.35 mg kg^{-1} in soil "1" and 0.61 mg kg^{-1} in soil "2".

Table 7: Flag leaf mineral contents under different copper foliar spray concentrations in the studied soils.

	Cu rate (%)	Control	0.20%	0.40%	0.60%	0.80%	1%
Soil 1[a] (2016-17 season)	N (%)	2.4 ± 0.41a	2.41 ± 0.38a	2.49 ± 0.41a	2.44 ± 0.56a	2.26 ± 0.38a	2.23 ± 0.43a
	P (%)	0.15 ± 0.03a	0.14 ± 0.02a	0.15 ± 0.02a	0.15 ± 0.03a	0.15 ± 0.01a	0.15 ± 0.02a
	K (%)	0.80 ± 0.11a	0.73 ± 0.07a	0.72 ± 0.03a	0.72 ± 0.09a	0.74 ± 0.04a	0.81 ± 0.10a
	Mg (%)	0.47 ± 0.05a	0.48 ± 0.04a	0.47 ± 0.02a	0.46 ± 0.05a	0.48 ± 0.02a	0.49 ± 0.03a
	Zn (mg kg^{-1})	30.0 ± 6.6a	27.7 ± 6.5a	31.6 ± 5.0a	27.0 ± 5.6a	23.7 ± 2.6a	27.2 ± 4.0a
	Fe (mg kg^{-1})	131.9 ± 10.7a	139.6 ± 19.7a	133.9 ± 14.2a	134.7 ± 27.3 a	132.8 ± 15.4a	136.2 ± 20.5a
	Mn (mg kg^{-1})	58.8 ± 5.0a	58.4 ± 8.4a	60.2 ± 7.9a	56.4 ± 12.2a	55.4 ± 10.5a	56.7 ± 5.1a
Soil 2[a] (2017-18 season)	Cu rate (%)	Control	0.01 %	0.03 %	0.05 %	0.10 %	0.20 %
	N (%)	3.03 ± 0.41a	2.86 ± 0.56a	2.77 ± 0.57a	2.7 ± 0.38a	2.70 ± 0.18a	3.07 ± 0.38a
	P (%)	0.23 ± 0.02a	0.23 ± 0.02a	0.24 ± 0.03a	0.24 ± 0.03a	0.23 ± 0.02a	0.23 ± 0.03a
	K (%)	1.76 ± 0.15a	1.72 ± 0.12a	1.87 ± 0.19a	1.86 ± 0.19a	1.82 ± 0.21a	1.72 ± 0.29a
	Mg (%)	0.32 ± 0.02a	0.31 ± 0.08a	0.27 ± 0.04a	0.28 ± 0.03a	0.27 ± 0.03a	0.27 ± 0.03a
	Zn (mg kg^{-1})	25.1 ± 0.7bc	27.6 ± 2.7ab	26.7 ± 3.2ab	28.4 ± 1.0a	23.4 ± 1.2c	23.4 ± 1.4c
	Fe (mg kg^{-1})	115.2 ± 8.3b	130.4 ± 9.6a	121.3 ± 5.4ab	117.1 ± 7.9a b	116.8 ± 5.5ab	113.0 ± 11.1b
	Mn (mg kg^{-1})	203.8 ± 24.3a	211.4 ± 65.6a	174.2 ± 27.5a	173.3 ± 21.8 a	176.2 ± 21.3a	175.2 ± 36.0a

Data are means ± standard deviation (n = 5).
Means followed by the same letters are not significantly different.
a Cu content is around 0.35 mg kg^{-1} in soil "1" and 0.61 mg kg^{-1} in soil "2".

Source: https://www.tandfonline.com/doi/full/10.1080/01904167.2020.1739294

Foliar application of gibberellic acid endorsed phytoextraction of copper and alleviates oxidative stress in jute (*Corchorus capsularis L.*) plant grown in highly copper-contaminated soil of China (2020)

Table 1: Physiochemical properties of Cu-contaminated soil used in pot experiment

Characteristics	Units	Cu-contaminated soil
pH	–	7.4
EC	µS/cm	284
CEC	cmol/kg	18.2
Organic matter	g/kg	30.96
Exchangeable K	mg/kg	120.25
Exchangeable N	g/kg	16
Exchangeable P	g/kg	0.17
Total Cu	mg/kg	2221

Table 2: Effect of different concentration of GA_3 on plant height (cm), plant fresh weight (g), plant dry weight (g), and chlorophyll contents (mg^{-1} FW) on *C. capsularis* seedlings grown on Cu-contaminated soil.

Treatments	Plant height	Plant fresh weight	Plant dry weight	Chlorophyll contents
Cu	86 ± 2 c	88 ± 2 c	53 ± 2 c	1.5 ± 0.01 d
Cu + GA_{3-10}	101 ± 3 b	101 ± 2 b	63 ± 2 b	1.8 ± 0.01 c
Cu + GA_{3-50}	109 ± 3 a	111 ± 2 a	68 ± 2 a	1.9 ± 0.01 b
Cu + GA_{3-100}	113 ± 2 a	115 ± 2 a	72 ± 2 a	2.1 ± 0.01 a

Means sharing similar letter(s) within a column for each parameter do not differ significantly at P < 0.05. Data in the table are means of three repeats (n = 3) of just one harvest of *C. capsularis* seedlings ± standard deviation (SD). Relative radiance of plastic filter used: Cu (Cu contamination soil without the application of GA_3), Cu + GA_{3-10} (Cu contamination soil with the application of 10 mg/L GA_3), Cu + GA_{3-50} (Cu contamination soil with the application of 50 mg/L GA_3), and Cu + GA_{3-100} (Cu contamination soil with the application of 100 mg/L GA_3)

Table 3: Effect of different concentration of GA3 on Cu (mg/kg) uptake and accumulation in different parts (roots, leaves, and stems) of *C. capsularis* seedlings

Treatments	Roots	Leaves	Stems
Cu	63 ± 2 c	131 ± 8 c	110 ± 4 c
Cu + GA_{3-10}	79 ± 5 b	178 ± 5 b	148 ± 5 b
Cu + GA_{3-50}	86 ± 4 b	199 ± 5 a	175 ± 5 a
Cu + GA_{3-100}	90 ± 1 a	200 ± 8 a	185 ± 5 4 a

Means sharing similar letter(s) within a column for each parameter do not differ significantly at $P < 0.05$. Data in the table are means of three repeats ($n = 3$) of just one harvest of *C. capsularis* seedlings ± standard deviation (SD). Relative radiance of plastic filter used: Cu (Cu contamination soil without the application of GA_3), Cu + GA_{3-10} (Cu contamination soil with the application of 10 mg/L GA_3), Cu + GA_{3-50} (Cu contamination soil with the application of 50 mg/L GA_3), and Cu + GA_{3-100} (Cu contamination soil with the application of 100 mg/L GA_3)

Investigating the potential of different jute varieties for phytoremediation of copper-contaminated soil (2020)

Table 1: Effect of high concentration of Cu on plant height (cm), plant diameter (mm), plant fresh weight (g), stem core fresh weight (g), plant dry weight (g), and germination percentage (%) of different varieties of jute

Varieties	Plant height	Plant diameter	Plant fresh weight	Stem core fresh weight	Plant dry weight	Germination percentage
HongTieGuXuan	237 ± 4 a	8 ± 0.2 d	130 ± 4 b	92 ± 4 b	47 ± 2 b	83 ± 6 b
C-3	242 ± 5 a	8 ± 0.3 c	144 ± 4 a	100 ± 5 a	56 ± 3 a	93 ± 6 a
GuBaChangJia	216 ± 4 b	10 ± 0.4 b	104 ± 3 c	82 ± 3 c	37 ± 1 c	73 ± 6 c
ShangHuoMa	204 ± 4 c	11 ± 0.3 a	102 ± 3c	71 ± 3 d	35 ± 2 d	53 ± 6 d

Means sharing similar letter(s) within a column for each parameter do not differ significantly at P < 0.05. Data in the tables are means of three repeats (n = 3) of just one harvest of jute varieties ± standard deviation (SD)

Table 2: Effect of high concentration of Cu on chlorophyll a (mg g^{-1} FW), chlorophyll b (mg g^{-1} FW), total chlorophyll (mg g^{-1} FW), and carotenoid (mg g^{-1} FW) contents of different varieties of jute

Varieties	Chlorophyll a	Chlorophyll b	Total chlorophyll	Carotenoid
HongTieGuXuan	1.64 ± 0.02 a	0.71 ± 0.03 a	2.36 ± 0.04 b	0.70 ± 0.01 b
C-3	1.72 ± 0.08 a	0.80 ± 0.02 a	2.53 ± 0.07 a	0.75 ± 0.01 a
GuBaChangJia	1.26 ± 0.04 b	0.35 ± 0.09 b	1.62 ± 0.05 c	0.41 ± 0.04 c
ShangHuoMa	1.15 ± 0.06 c	0.22 ± 0.1 c	1.31 ± 0.06 d	0.30 ± 0.02 d

Means sharing similar letter(s) within a column for each parameter do not differ significantly at $P < 0.05$. Data in the tables are means of three repeats ($n = 3$) of just one harvest of jute varieties ± standard deviation (SD)

Table 3: Cu accumulation by roots (mg kg^{-1}), leaves (mg kg^{-1}), stem core (mg kg^{-1}), and bast (mg kg^{-1}) in different varieties of jute

Varieties	Roots	Leaves	Stem core	Bast
HongTieGuXuan	83 ± 5 b	188 ± 5 b	165 ± 4 b	105 ± 4 b
C-3	100 ± 4 a	215 ± 5 a	185 ± 4 a	120 ± 4 a
GuBaChangJia	63 ± 3 c	148 ± 4 c	130 ± 5 c	83 ± 4 c
ShangHuoMa	48 ± 3 d	128 ± 5 d	120 ± 5 d	60 ± 3 d

Means sharing similar letter(s) within a column for each parameter do not differ significantly at $P < 0.05$. Data in the tables are means of three repeats ($n = 3$) of just one harvest of jute varieties ± standard deviation (SD)

Table 4: The efficiency of different varieties of jute in extracting Cu concentration (mg kg^{-1}) from contaminated soil at post-harvesting stage

Varieties	Initial concentration	(Final conc.) after uptake	Total Cu uptake	Removal (%)
HongTieGuXuan	2221	1880 ± 13 c	341	15
C-3	2221	1763 ± 22 d	458	20
GuBaChangJia	2221	1938 ± 21 b	283	12
ShangHuoMa	2221	2050 ± 16 a	171	9

Means sharing similar letter(s) within a column for each parameter do not differ significantly at $P < 0.05$. Data in the tables are means of three repeats ($n = 3$) of just one harvest of jute varieties ± standard deviation (SD)

Source: https://link.springer.com/article/10.1007%2Fs11356-020-09232-y

Effect of copper oxide nanoparticles on two varieties of sweetpotato plants (2020)

Table 1: Copper concentration in root tissues, stems, and leaves of Beauregard-14 and Covington varieties exposed for 150 days to nCuO, bCuO, and $CuCl_2$ at 0, 25, 75, and 125 mg/kg ($p \leq 0.05$, n = 3).

Varieties	**B-14 Cu (mg/kg)**	**Covington Cu (mg/kg)**	**B-14 Cu (mg/kg)**	**Covington Cu (mg/kg)**
Treatments	**Periderm**		**Perimedulla**	
Control	18.5 ± 1.3	43.4 ± 9.1	6.2 ± 2.4	1 ± 0.2
nCuO25	52.6 ± 8.3	45.2 ± 10	2.6 ± 0.1	2 ± 0.2
nCuO75	100.6 ± 20	74.8 ± 15.2	4 ± 1.9	3.6 ± 0.2
nCuO125	54.4 ± 14.3	42.3 ± 16.3	6.4 ± 0.7	4.3 ± 0.5
bCuO25	193.5 ± 22.5	91.5 ± 25.9	4.2 ± 0.2	2.2 ± 0.4
bCuO75	70.2 ± 12	65.2 ± 14.9	5 ± 0.3	2.4 ± 0.4
bCuO125	27 ± 4.6	136.8 ± 35.8	6.1 ± 0.6	11.9 ± 9.4
$CuCl_2$ 25	53.3 ± 17.6	22.5 ± 4.3	2.1 ± 0.5	2 ± 1.1
$CuCl_2$ 75	66.6 ± 41.3	73.8 ± 45.2	3.8 ± 1.2	5 ± 1.4
$CuCl_2$ 125	18.5 ± 2.2	60.6 ± 15	5.4 ± 0.5	7.2 ± 0.4
	Cortex		**Medulla**	
Control	5.1 ± 0.2	1 ± 0.1	1.8 ± 0.5b	2 ± 0.4
nCuO25	3.6 ± 0.7	2.5 ± 0.47	2.3 ± 0.6 ab	2.6 ± 0.58
nCuO75	4.2 ± 1.5	4.5 ± 0.9	5.5 ± 3.2 ab	3.5 ± 0.3
nCuO125	30.9 ± 3.5	4.5 ± 0.2	10.1 ± 3.6 ab	3.9 ± 1.3
bCuO25	4 ± 0.2	2.4 ± 0.1	3.7 ± 0.7 ab	2.9 ± 1.2
bCuO75	6 ± 1.4	3.3 ± 0.6	3.4 ± 0.7 ab	3.5 ± 0.7
bCuO125	6.2 ± 0.5	6.9 ± 2	3.5 ± 0.5 ab	5.3 ± 1.6
$CuCl_2$ 25	2.8 ± 0.5	1.4 ± 0.1	1.4 ± 0.3b	1.4 ± 0.1
$CuCl_2$ 75	2.8 ± 0.5	3.7 ± 1.4	9.1 ± 0.6 ab	6 ± 2.2
$CuCl_2$ 125	6.4 ± 0.6	3.8 ± 0.3	13.0 ± 4.5a	5.9 ± 0.3
	Stem		**Leaves**	
Control	1.6 ± 0.3b	2.3 ± 0.6	7.8 ± 1	5.6 ± 2.9b
nCuO25	3.5 ± 0.2 ab	3.1 ± 0.1	13.8 ± 5.1	22.9 ± 11.3 ab
nCuO75	5.9±1a	12.9 ± 9.1	16.9 ± 6.5	9.5 ± 1.3b
nCuO125	4.2 ± 1.7 ab	4 ± 1	7.1 ± 0.3	10.2 ± 2.5 ab
bCuO25	4.3 ± 0.3 ab	3.1 ± 0.7	9.2 ± 2.6	6.7 ± 1.3b
bCuO75	4.4 ± 0.4 ab	4.6 ± 0.2	8.3 ± 0.6	25.6 ± 6.9 ab
bCuO125	6.3 ± 0.3a	4.6 ± 0.9	14.8 ± 0.4	23 ± 6.5 ab
$CuCl_2$ 25	2.8 ± 0.2 ab	1.7 ± 0.3	18.6 ± 5.2	12.1 ± 7.6 ab
$CuCl_2$ 75	3.7 ± 0.4 ab	4.2 ± 2	10 ± 2.8	70.9 ± 24.7 ab
$CuCl_2$ 125	4.8 ± 0.6 ab	5.3 ± 0.2	11.1 ± 2.1	93 ± 26a

Table 2: Root production in sweetpotato plants exposed for 140 days to nCuO, bCuO, and CuCl2 at 0, 25, 75, and 125 mg/kg, $p \leq 0.05$ (n = 3).

Treatment (mg/kg)	**Beauregard-14**							
	Root fresh weight (g)		**Total weight (g)**	**No. Storage roots**	**No. Pencil roots**	**Length of storage roots (cm)**	**Diameter of storage roots (cm)**	**Ratio no.pencil/no.storage**
	Storage Roots	**Pencil Roots**						
Control	457.3 ± 16.4abc	28 ± 3.1	485.3	9.7 ± 1.8	7 ± 1.2	14.7 ± 1.3	4.6 ± 0.7	0.72
nCuO25	414.5 ± 11.5abc	29 ± 12.1	443.5	9.5 ± 4.5	13.5 ± 1.5	12 ± 0.8	4.3 ± 0.4	1.42
nCuO75	514 ± 23.4abc	36.7 ± 10.1	550.7	7.7 ± 2	8 ± 2.1	13.4 ± 1.3	3.6 ± 0.3	1.04
nCuO125	265±8c	50.3 ± 6.7	315.3	4.5 ± 0.5	11.3 ± 1.8	7.4 ± 0.9	2.8 ± 0.3	2.51
bCuO25	269 ± 64.3bc	27.5 ± 2.9	333.3	8.7 ± 1.2	6.3 ± 2	10 ± 0.8	6.6 ± 2.3	0.72
bCuO75	637.3 ± 30.5a[a]	24.6 ± 8.4	661.9	6.3 ± 0.3	7.3 ± 1.2	15 ± 1.3	4.9 ± 0.2	1.16
bCuO125	619 ± 78.5 ab[a]	37.2 ± 2.4	656.2	11.7 ± 5.6	7.7 ± 0.3	14.6 ± 1.2	5.3 ± 0.4	0.66
$CuCl_2$ 25	280.6 ± 5.3bc	26.3 ± 8.7	306.9	8.3 ± 0.8	6.7 ± 1.2	12.8 ± 1.2	3.3 ± 0.3	8.1
$CuCl_2$ 75	407.3 ± 76.3abc	46.2 ± 3.8	453.5	4.3 ± 1	8.3 ± 0.9	13.5 ± 2.2	4.3 ± 0.2	1.93
$CuCl_2$ 125	507 ± 49.7abc	30 ± 9.6	537	6.6 ± 1.4	8.3 ± 1.5	12.3 ± 0.8	3.9 ± 0.3	1.26
				Covington				
Control	436 ± 41.9	42.5 ± 8.1	478.7	5.3 ± 0.3	7.5 ± 2.3	14.6 ± 0.8b	4.4 ± 0.5	1.42
nCuO25	464.7 ± 54	61.5 ± 31	526.2	2.5 ± 0.5	10.5 ± 1.5	20.7±2a	4.6 ± 0.2	4.2
nCuO75	472.1 ± 75	33 ± 9.1	505.1	5.7 ± 1.3	8 ± 3.5	16 ± 2.5b	4.6 ± 0.3	1.4
nCuO125	428 ± 69.5	15.7 ± 0.9	497.5	5 ± 0.5	6.3 ± 1.3	15 ± 1.8b	4.1 ± 0.2	1.26
bCuO25	424.3 ± 77.6	26 ± 7.9	450.3	4 ± 1.1	6 ± 2.1	17.7 ± 2.8b	4.7 ± 0.3	1.5
bCuO75	563.5 ± 60.3[a]	66.3 ± 12.1	629.8	4.7 ± 1.2	9.3 ± 3	15.2 ± 1.3b	4.6 ± 0.2	1.98
bCuO125	565.5 ± 47.3[a]	54 ± 15.3	619.5	2.3 ± 0.6	11.3 ± 1.5	15.1 ± 2.5b	5.4 ± 0.8	4.91
$CuCl_2$ 25	289.8 ± 53.3	43.6 ± 14.2	333.4	6.3 ± 4.3	7 ± 4	12±1b	3.8 ± 0.3	1.11
$CuCl_2$ 75	366.8 ± 47.6	66 ± 11.3	465.8	3 ± 1.5	10 ± 4	15.3 ± 2.1b	3.9 ± 0.4	3.33
$CuCl_2$ 125	429.5 ± 44.7	61 ± 13.4	490.5	2.6 ± 0.6	6 ± 1	13.4 ± 1.7b	3.8 ± 0.4	2.31

Table 3: Distribution of the macronutrients and micronutrients into the storage root tissues of Beauregard-14 and Covington sweetpotato varieties. Plants were cultivated for 150 days in soil amended nCuO, bCuO, and CuCl2 at 0, 25, 75, and 125 mg/kg ($p \leq 0.05$; n = 3).

			Treatments (mg/kg)									
Tissue	**Macronutrient**	**Variety**	**Control**	**nCuO25**	**nCuO75**	**nCuO125**	**bCuO25**	**bCuO75**	**bCuO125**	**$CuCl_2$ 25**	**$CuCl_2$ 75**	**$CuCl_2$ 125**
Periderm	**P**	B-14	7101.4±314.9a	5551.1±568.6a	6429.6±325.5a	7063.9±867.6a	4443.7±391.3 ab	5471.8±293a	6812.2±147.3a	6077.1±791.3a	5552.6±982a	1393.15±201b
		COV	1398.9±297	1100.2±664.9	2853±20.25.8	1787.5±571.8	1713.3±426.2	344.7±165.4	3268.5±1252.7	907.5±214.5	1230.7±689.8	2240.5±806.5
	Mg	B-14	54 ± 3.6b	52.2 ± 9.3b	69.5 ± 4.4b	77.3 ± 12.7a	56.1 ± 2.6	61.9 ± 3.3b	61.5 ± 0.4b	68.9 ± 8.8b	60.1 ± 7.3b	73.9 ± 5.6b
		COV	61.3 ± 5	53.6 ± 9.9	57.3 ± 3.7	49.2 ± 4.6	68.9 ± 6.4	57.2 ± 1.2	46.1 ± 7	50 ± 3.5	65.3 ± 0.3	52.4 ± 3.2
Cortex	**P**	B-14	5732±739.6bc	4373.1±592.1c	11006.2±2070.4 ab	11810.2±641.8a	9329.7±1365.4abc	10586.4±1092.4 ab	11041.8±1120.4 ab	12395.3±732.3a	11583±1162.2 ab	9649±1508.1abc
		COV	7220.6±845.8	9390.4±2069.3	9794±935.6	10707.6±744.5	10298.9±1741.2	9695.8±707.2	12284.2±1953.8	8098.7±639.4	10690.9±225.1	11475±983.7
	Mg	B-14	15.2 ± 1.3bc	9.2 ± 0.8c	43 ± 6.2a	46.8±8a	37.9 ± 4.3 ab	50.7 ± 4.1a	53.6 ± 2.5a	48.5 ± 2.8a	41.7 ± 3.2a	47.8 ± 6.7a
		COV	36.5 ± 4.4	28.6 ± 2.5	36.4 ± 2.3	39.7 ± 1.1	32.2 ± 3.2	34.9 ± 2.2	57.1 ± 3.3	35.2 ± 1.5	36 ± 3.6	36.9 ± 1.9
Medulla	**P**	B-14	7328±2180.7	7567.1±1570.7	8218.9±2884	12455.4±1809.2	8659.9±1165.8	6269.2±499	5226.7±849.4	6316.3±1772.3	6579.6±183	9870.7±1217.5
		COV	7001.2±516.6b	8351.1±1020.8 ab	11050.6±759.7 ab	8067.1±4216 ab	6747.5±1694b	7852±630.1 ab	8376±468.4 ab	6750.3±509.4b	13283.4±1440.5a	10837.6±2632.7 ab
	Mg	B-14	45 ± 4.4	47.1 ± 5.2	44.1 ± 10	44.4 ± 8	39.1 ± 5.4	37.6 ± 1.3	31.2 ± 2.4	34.9 ± 8.5	45 ± 42	63.7 ± 14.7
		COV	34.8 ± 2.6	44.3 ± 3.5	54.3 ± 12	48.1 ± 6.6	36.7 ± 10	47.2 ± 9.5	43.8 ± 9	31 ± 3.3	63 ± 12.16	57.8 ± 18.3
Tissue	**Micronutrient**	**Variety**	**Control**	**nCuO25**	**nCuO75**	**nCuO125**	**bCuO25**	**bCuO75**	**bCuO125**	**$CuCl_2$ 25**	**$CuCl_2$ 75**	**$CuCl_2$ 125**
Periderm	**Zn**	B-14	0.18±0.01b	0.22±0.04 ab	0.3±0.05 ab	0.25±0.04 ab	0.19±0.02 ab	0.23±0.02 ab	0.16±0.01b	0.27±0.06 ab	0.24±0.03 ab	0.31±0.03a
		COV	0.2±0.02b	0.26±0.01 ab	0.22±0.03 ab	0.22±0.03 ab	0.25±0.01 ab	0.23±0.02 ab	0.26±0.02 ab	0.19±0.01b	0.337±0.04a	0.22±0.05 ab
Cortex	**Zn**	B-14	0.2±0.01 ab	0.14±0.01b	0.25±0.05 ab	0.35±0.08a	0.19±0.03 ab	0.28±0.03 ab	0.26±0.03 ab	0.23±0.02 ab	0.26±0.04 ab	0.33±0.07 ab
		COV	0.24±0.02	0.25±0.02	0.35±0.02	0.28±0.04	0.28±0.03	0.23±0.01	0.4±0.03	0.29±0.01	0.3±0.02	0.22±0.06
Medulla	Mn	B-14	0.18 ± 0.04	0.06 ± 0.02	0.75 ± 0.04	0.41 ± 0.05	0.36 ± 0.03	0.3 ± 0.04	0.33 ± 0.04	0.55 ± 0.1	0.31 ± 0.02	0.38 ± 0.07
		COV	0.29 ± 0.08b	1.24 ± 0.7b	2.5 ± 0.7 ab	2.5 ± 0.4 ab	1.7 ± 0.4b	1.7 ± 0.5b	3.5 ± 0.7a	1 ± 0.4b	0.6 ± 0.4b	3.8 ± 0.3a
	Zn	B-14	4.56 ± 0.27	0.26 ± 0.05	0.24 ± 0.09	0.32 ± 0.06	0.23 ± 0.03	0.18 ± 0.02	0.17 ± 0.03	3 ± 0.06	0.3 ± 0.03	0.42 ± 0.08
		COV	0.2±0.02b	0.27±0.03 ab	0.29±0.04 ab	0.2±0.01 ab	0.19±0.04b	0.2±0.01 ab	0.22±0.01 ab	0.14±0.01b	0.35±0.04a	0.24±0.09 ab
	Ni	B-14	28.4 ± 8.2abc	11 ± 5.8c	29.7 ± 8.7abc	36.3 ± 7.4abc	28 ± 5.3 ab	24.8 ± 4.5abc	24 ± 9.1bc	16.8±7c	68.3 ± 7.5a	61.6 ± 3.7 ab
		COV	89.8 ± 8	30.1 ± 7.7	15.2 ± 1.9	36.1 ± 8.8	93.7 ± 9.6	29.1 ± 6.9	51.8 ± 18.5	25.8 ± 1.9	52.9 ± 11.6	103.2 ± 7.3

Source: https://www.sciencedirect.com/science/article/pii/S0981942820302904

Evaluating the potential use of Cu-contaminated soils for giant reed (*Arundo donax, L.*) cultivation as a biomass crop (2020)

Table 1: Chemical and physical characterization of the soil used as substrate for the growth of the plants

Parameter	U.M	Valore
Sand	%	24.4
Silt	%	47.6
Clay	%	28.0
pH		7.6
Organic matter	%	1.79
Nitrogen	%	0.12
P Olsen	mg kg^{-1}	25.20
P2O5	mg kg^{-1}	58.40
K2O	mg kg^{-1}	598.14
Cation-exchange capacity (CEC)	meq 100 g^{-1}	29.51
Field capacity	wt%	
Ca	meq 100 g^{-1}	24.33
Mg	meq 100 g^{-1}	3.21
K	meq 100 g^{-1}	1.27
Na	meq 100 g^{-1}	0.70

Table 2: Main morphological traits of the plants after 30, 90, and 180 days after the treatment. When present, different letters represent significant differences between the treatments ($P < 0.01$) within each column

Treatment (ppm)	Days after contamination (n)		
	30	**90**	**180**
Height of the main stem (cm)			
Control	73.3	101.7	93.0
200	76.5	102.5	97.2
400	76.3	105.7	98.5
800	76.0	111.2	105.3
Number of stems (*n*)			
Control	9.7	9.7	9.2
200	8.7	9.3	8.8
400	8.2	8.2	7.5
800	7.8	8.5	7.5
Chlorophyll content (SPAD units)[1]			
Control	39.7 a	32.4	33.4
200	40.4 a	31.4	27.1
400	38.2 a	31.7	30.0
800	28.4 b	30.0	31.0

[1]Measured at 30, 90, and 150 days from contamination

Source: https://link.springer.com/article/10.1007/s11356-019-07503-x

Predicting copper contamination in wheat canopy during the full growth period using hyperspectral data (2020)

Table 1: Characteristics of soil in field experiment plot

Organic matter	pH	N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	TCC (mg kg^{-1})	ACC (mg kg^{-1})
2.36%	7.20	157.75	96.20	122.55	31.16	5.42

TCC means total copper content and ACC means available copper content

Table 2: Green vegetation spectral indices used in this paper

Index	Wavebands (nm)	Formula	Reference
Rg	520–680	Maximum value of spectral reflectance in 520–680 nm	Yang et al. (2009)
Rr	650–690	Minimum value of spectral reflectance in 650–690 nm	Wang et al. (2017a, b)
Dr	680–760	Maximum value of the first derivative of spectral reflectance in 680–760 nm	Li et al. (2017)
MCARI	550, 670, 700	$MCARI = [R_{700} - R_{670} - 0.2(R_{700} - R_{550})](R_{700}/R_{670})$	Daughtry et al. (2000)
SIPI	445, 680, 800	$\mathrm{SIPI}=\frac{R_{800}-{R}_{445}}{R_{800}-{R}_{680}}$	Penuelas et al. (1995)
RVI	671, 864	$\mathrm{RVI}=\frac{R_{864}}{R_{671}}$	Li et al. (2007)
NDVI	680, 800	$\mathrm{NDVI}=\frac{R_{800}-{R}_{680}}{R_{800}+{R}_{680}}$	Tillack et al. (2014)
MTVI	550, 670, 712	$MTVI = 1.5[1.2(R_{712} - R_{550}) - 2.1(R_{670} - R_{550})]$	Guang and Liu (2009)
MTVI/RVI	550, 670, 671, 712, 864	$\mathrm{MTVI}/\mathrm{RVI}=\frac{1.5\left[1.2\left({R}_{712}-{R}_{550}\right)-2.1\left({R}_{670}-{R}_{550}\right)\right]}{R_{864}/{R}_{671}}$	This study
MTVI/SIPI	445, 550, 670, 680, 712, 800	$\mathrm{MTVI}/\mathrm{SIPI}=\frac{1.5\left[1.2\left({R}_{712}-{R}_{550}\right)-2.1\left({R}_{670}-{R}_{550}\right)\right]}{\left({R}_{800}-{R}_{445}\right)/\left({R}_{800}-{R}_{680}\right)}$	This study
NDVI/SIPI	445, 680,800	$\mathrm{NDVI}/\mathrm{SIPI}=\frac{{\left({R}_{800}-{R}_{680}\right)}^2}{\left({R}_{800}+{R}_{680}\right)\left({R}_{800}-{R}_{445}\right)}$	This study

Table 3: Correlation analysis of wheat leaf copper content (A) and wheatear copper content (B) with vegetation indices

Spectral index	Correlation coefficients (*R*)		
	Tillering stage (20)	**Jointing stage (20)**	**Heading stage(20)**
Rg	0.7778**	0.7400**	0.5162*
Rr	0.7212**	0.7170**	0.6583**
Dr	− 0.8086**	− 0.6669**	− 0.5384*
MCARI	− 0.5888**	− 0.3371	0.2291
SIPI	0.7535**	0.7350**	0.6185**
RVI	− 0.6998**	− 0.6075**	− 0.3625
NDVI	− 0.7949**	− 0.7527**	− 0.6428**
MTVI	− 0.6004**	− 0.2776	0.2419
NDVI/SIPI	− 0.8180**	− 0.7486**	− 0.6597**
MTVI/RVI	0.0680	0.7790**	0.5956**
MTVI/SIPI	− 0.6711**	− 0.4635*	0.1140

*Means that the significance has reached the level of 0.05

**Means that the significance has reached the level of 0.01

Table 4: Predicting models built based on sensitive spectral indices and validation results

Growth period	Spectrum parameter	Training (n = 20)			Validation (n = 10)		
		Regression equation	R^2	P	R^2	RMSE	MAE
Tillering stage	Rg	y = 0.2581x + 0.3356	0.605**	5.410E-5	0.655**	0.5616	0.4957
	Rr	y = 0.1836x + 1.2612	0.520**	3.328E-4	0.605**	0.5941	0.5348
	Dr	y = − 3.4686x + 3.8645	0.654**	1.599E-5	0.663**	0.5486	0.4293
	SIPI	y = 1.7151x + 0.1638	0.568**	1.252E-4	0.509*	0.6739	0.5315
	RVI	y = − 0.1123x + 3.1417	0.490**	5.934E-4	0.670**	0.6058	0.558
	NDVI	y = − 2.8824x + 4.0991	0.632**	2.819E-5	0.683**	0.534	0.4608
	NDVI/SIPI	y = − 2.6559x + 3.8139	0.669**	1.0514 E-5	0.709**	0.5111	0.4464
Jointing stage	Rg	y = 0.5718x − 1.6388	0.548**	1.914 E-4	0.661**	0.8312	0.6167
	Rr	y = 0.4879x + 0.556	0.514**	3.740 E-4	0.527*	0.9669	0.7724
	SIPI	y = 8.5544x − 6.7168	0.540**	2.231 E-4	0.437*	1.0572	0.8522
	RVI	y = − 0.2523x + 4.528	0.369**	0.004	0.426*	1.056	0.8807
	NDVI	y = − 7.0119x + 7.5721	0.567**	1.283 E-4	0.573*	0.8913	0.7152
	NDVI/SIPI	y = − 5.7518x + 6.4197	0.560**	1.466 E-4	0.569*	1.3676	1.111
Heading stage	Rr	y = 0.1309x + 1.2675	0.433	0.671	0.073	0.5506	0.4546
	NDVI	y = − 2.5053x + 3.7945	0.413	0.513	0.255	0.4954	0.4146
	NDVI/SIPI	y = − 2.1726x + 3.492	0.435	0.505	0.306	0.4857	0.4064

* Means that the significance has reached the level of 0.05

** Means that the significance has reached the level of 0.01

Table 5: Predicting models built based on sensitive spectral bands and validation results

Growth period	Spectrum band	Training (n = 20)				Validation (n = 10)		
		Regression equation	R^2	P	AIC	R^2	RMSE	MAE
Tillering stage	W_{488}	$y = 1.774 + 44.696W_{488}$	0.765**	4.589E-7	− 30.610	0.050	1.956	1.439
	W_{728}	$y = 3.828 - 4.746W_{728}$	0.818**	4.382E-8	− 35.763	0.720**	0.752	0.654
	W_{730}	$y = 3.745 - 3.766W_{730}$	0.748**	8.520E-7	− 29.257	0.552*	1.009	0.879
	W_{731}	$y = 3.648 - 3.725W_{731}$	0.740**	1.136E-6	− 28.623	0.639**	0.880	0.750
Jointing stage	W_{543}	$y = -0.546 + 14.819W_{543}$	0.774**	3.237E-7	− 51.677	0.613**	2.033	1.761
	W_{738}	$y = 2.206 - 3.088W_{738}$	0.741**	1.129E-6	− 48.944	0.585**	1.999	1.716
	W_{741}	$y = 2.183 - 3.235W_{741}$	0.830**	2.443E-8	− 57.345	0.684**	1.986	1.707
	W_{743}	$y = 2.337 - 3.788W_{743}$	0.782**	2.338E-7	− 52.385	0.599**	2.017	1.737
Heading stage	W_{399}	$y = 2.168 + 40.695W_{399}$	0.660**	1.338E-5	− 44.529	0.357	0.550	0.488
	W_{480}	$y = 1.15 + 64.748W_{480}$	0.625**	3.313E-5	− 42.558	0.650**	0.434	0.364
	W_{754}	$y = 3.13 - 6.054W_{754}$	0.627**	3.144E-5	− 42.671	0.406*	0.831	0.687
	W_{913}	$y = 2.032 - 6.497W_{913}$	0.598**	6.446E-5	− 41.124	5E-05	0.728	0.565

* Means that the significance has reached the level of 0.05

** Means that the significance has reached the level of 0.01

Table 6: Multiple regression models in different growth periods of wheat

Growth period	Training (n = 20)				Validation (n = 10)		
	Equation of multiple regression model	R^2	P	AIC	R^2	RMSE	MAE
Tillering stage	$y = 2.644 + 33.557W_{488} - 3.506W_{728} - 2.707W_{730} + 3.941W_{731}$	0.934**	1.179E-8	− 49.875	0.168	1.443	1.081
Jointing stage	$y = 1.167 + 6.09W_{543} - 0.052W_{738} - 1.758W_{741} - 0.421W_{743}$	0.868**	1.892E-6	− 56.485	0.672**	1.992	1.725
Heading stage	$y = 2.453 + 1.527W_{399} + 10.429W_{480} - 3.484W_{754} - 4.17W_{913}$	0.870**	1.688E-6	− 57.746	0.526*	0.578	0.471

* Means that the significance has reached the level of 0.05

** Means that the significance has reached the level of 0.01

Source: https://link.springer.com/article/10.1007/s11356-020-09973-w

Phytoremediation potential of castor (*Ricinus communis L.*) in the soils of the abandoned copper mine in Northern Oman: implications for arid regions (2020)

Table 1: Physicochemical characteristics of the studied soils: Cu-mine soils (A, B, C, D, and E), slag, and native soils

Soil	A	B	C	D	E	Slag	Native
Texture pH	Sandy clay loam 5.9^{ab}	Sand 7.1^{b}	Loamy sandy clay 6.3^{ab}	Sandy loam 6.4^{ab}	Sandy loam 5.9^{ab}	Coarse 4.5^{a}	Sand 7.6^{b}
EC (μS cm^{-1})	1470 ± 576^{ab}	1510 ± 423^{ab}	1653 ± 676^{b}	942 ± 345^{ab}	955 ± 296^{ab}	655 ± 235^{a}	670 ± 120^{a}
OM (%)	0.46 ± 0.2^{ab}	0.30 ± 0.1^{ab}	0.89 ± 0.6^{b}	0.67 ± 0.3^{ab}	0.52 ± 0.3^{ab}	0.10 ± 0.02^{a}	0.2 ± 0.03^{ab}
N (%)	0.15 ± 0.01^{c}	0.11 ± 0.06^{b}	0.06 ± 0.01^{ab}	0.11 ± 0.01^{b}	0.08 ± 0.01^{ab}	0.03 ± 0.01^{a}	0.0 ± 0.01^{b}
P (mg kg^{-1})	998 ± 116.2^{d}	419 ± 15.8^{bc}	391 ± 37.5^{bc}	356 ± 17.9^{abc}	558 ± 169.0^{c}	264 ± 38.5^{ab}	139 ± 15.8^{a}
K (mg kg^{-1})	924 ± 37.3^{d}	442 ± 17.0^{b}	666 ± 52.3^{c}	1091 ± 34.1^{e}	1159 ± 15.8^{e}	610 ± 67.3^{c}	312 ± 42.3^{a}
As (mg kg^{-1})	21 ± 2.3^{ab}	18 ± 3.6^{ab}	16 ± 1.5^{a}	22 ± 2.1^{ab}	20 ± 2.2 ^{b}	20 ± 1.8^{ab}	10 ± 3.1^{a}
B (mg kg^{-1})	218 ± 12.8^{bc}	188 ± 4.3^{abc}	189 ± 5.9^{abc}	186 ± 0.5^{c}	185 ± 4.1^{ab}	198 ± 8.8^{d}	51 ± 6.6^{a}
Cu (mg kg^{-1})	8196 ± 481.1^{d}	3156 ± 306.0^{c}	1746 ± 124.5^{b}	3178 ± 355.8^{c}	3397 ± 265.3^{c}	19,627 ± 561.9^{e}	14 ± 3.5^{a}
Fe (mg kg^{-1})	60,164 ± 2332.4^{f}	53,152 ± 1046.3^{d}	56,532 ± 4415.6^{e}	45,009 ± 2796.9^{c}	38,694 ± 347.9^{b}	59,141 ± 1274.9^{h}	17,446 ± 1016.3^{a}
Mn (mg kg^{-1})	756 ± 98.7^{a}	768 ± 44.5^{a}	752 ± 49.0^{a}	372 ± 17.3^{a}	298 ± 8.8^{a}	275 ± 16.7^{a}	257 ± 11.8^{a}
Zn (mg kg^{-1})	896 ± 104.4^{c}	361 ± 41.9^{b}	333 ± 117.7^{b}	69 ± 6.0^{a}	102 ± 13.1^{a}	203 ± 5.4^{a}	378 ± 4.8^{a}

Means ± standard errors (n = 3). Values followed by the same letter(s) within a column are not significantly different at $P \leq 0.05$

Table 2: Tolerance indices (%) of the plant height, fresh mass, and dry mass of the shoots and roots of castor after 90 days of growth in Cu-mine soils (A, B, C, D, and E) and slag

Soil	**Height**	**Fresh mass**		**Dry mass**	
		Roots	**Shoots**	**Roots**	**Shoots**
A	126.21	225.58	232.29	169.30	172.35
B	82.49	85.21	119.01	89.60	102.49
C	127.46	263.97	278.63	226.81	229.47
D	126.55	357.89	319.83	359.85	314.51
E	132.77	255.74	405.99	236.72	327.73
Slag	48.14	50.71	31.91	24.77	18.14

Table 3: Translocation factor (TF) and bioconcentration factor (BCF) for Cu, Cu extraction ratio (MER), plant effective number of shoots (PENs), and plant effective number of total plant (PENt) of castor in Cu-mine soils (A, B, C, D, and E), slag, and native soils

Soil type	TF	BCF	MER (%)	PENs*	PENt**
A	0.02	0.15	0.17	19,101	296
B	0.03	0.22	0.37	34,418	809
C	0.03	0.36	1.96	24,077	534
D	0.03	0.11	0.34	20,442	404
E	0.02	0.26	0.76	16,625	253
Slag	0.02	0.13	0.02	132,687	1970
Native	0.16	0.84	5.58	386,518	42,459

*Number of castor shoots needed to remove 1 g of Cu after 90 days of growth

**Number of total plant (castor) needed to remove 1 g of Cu after 90 days of growth

Table 4: Translocation factor (TF), bioconcentration factor (BCF), metal extraction ratio (MER), plant effective number of shoots (PENs), and plant effective number of total plant (PENt) of castor in Cu-mine soils (A, B, C, D, and E), slag, and native soils for As, B, Fe, Mn, and Zn

Soil	Elements	TF	BCF	MER (%)	PENs*	PENt**
A	As	0.61	0.32	6.92	168,715	50,522
	B	4.47	0.91	42.91	2630	1693
	Fe	0.03	0.06	0.11	3202	82
	Mn	1.29	1.03	33.57	947	420
	Zn	0.33	0.31	4.49	5608	1099
B	As	0.72	0.25	5.92	266,752	89,772
	B	4.62	0.93	43.75	4540	3005
	Fe	0.03	0.07	0.12	5408	130
	Mn	1.27	0.68	21.64	1902	856
	Zn	0.46	0.42	7.52	12,017	3035
C	As	0.81	0.36	31.31	105,668	37,214
	B	4.25	0.73	113.20	2579	1640
	Fe	0.02	0.10	0.45	1951	35
	Mn	1.39	0.61	67.54	949	434
	Zn	0.34	0.32	15.32	9124	1801
D	As	0.68	0.36	17.31	73,267	22,482
	B	5.17	1.18	112.04	1028	654
	Fe	0.04	0.05	0.22	2228	60
	Mn	2.31	0.15	12.93	2363	1252
	Zn	0.43	0.47	16.93	19,539	4451
E	As	0.45	0.54	27.39	47,292	12,243
	B	3.64	1.21	155.99	1194	781
	Fe	0.14	0.06	1.20	673	69
	Mn	2.87	0.54	65.38	1535	948
	Zn	0.34	0.67	27.66	11,711	2455
Slag	As	0.41	0.38	0.91	1,413,228	297,619

	B	7.30	0.84	6.11	19,470	12,434
	Fe	0.02	0.05	0.01	59,710	813
	Mn	2.12	0.24	1.36	145,525	71,780
	Zn	0.38	0.20	0.45	583,397	116,031
Native	As	0.79	0.29	6.09	306,824	106,196
	B	9.15	0.70	29.80	6148	4341
	Fe	0.11	0.01	0.06	28,994	2175
	Mn	1.61	0.12	3.59	49,686	23,994
	Zn	0.49	0.41	6.33	221,278	56,784

*Number of castor shoots needed to remove 1 g of metal after 90 days of growth
**Number of total plant (castor) needed to remove 1 g of metal after 90 days of growth

Table 5: Mean heavy metal concentrations (As, B, Fe, Mn, and Zn) in dry mass of the shoots and roots of castor after growing in Cu-mine soils (A, B, C, D, and E), slag, and native soils (mg kg^{-1})

Soil type	**As**		**B**		**Fe**		**Mn**		**Zn**	
	Shoots	**Roots**	**Shoots**	**Roots**	**Shoots**	**Roots**	**Shoots**	**Roots**	**Shoots**	**Roots**
A	2.05 ± 0.5^{a}	3.33 ± 0.6^{a}	131.20 ± 14.0^{a,b}	29.33 ± 5.1^{b,c}	107.77 ± 9.5^{a}	3204.33 ± 1114.0^{b,c}	364.56 ± 103.6^{b}	282.00 ± 103.5^{b}	61.53 ± 5.6^{c}	185.67 ± 23.6^{d}
B	2.18 ± 0.2^{a}	3.03 ± 0.1^{a}	127.81 ± 3.2^{a,b}	27.67 ± 1.5^{b,c}	107.31 ± 22.7^{a}	3478.00 ± 630.2^{b,c}	305.12 ± 13.1^{b}	240.67 ± 30.1^{b}	48.29 ± 12.5^{c}	105.67 ± 29.0^{c}
C	2.45 ± 0.7^{a}	3.02 ± 1.0^{a}	100.50 ± 31.7^{a}	23.67 ± 2.1^{b}	132.84 ± 2.9^{a}	5738.33 ± 1984.3^{c}	272.99 ± 31.6^{b}	196.59 ± 56.0^{b}	28.41 ± 0.8^{b}	84.67 ± 45.0^{b,c}
D	2.58 ± 0.7^{a}	3.81 ± 0.5^{a}	184.01 ± 17.0^{c}	35.57 ± 1.0^{c,d}	84.89 ± 16.0^{a}	2323.03 ± 1061.1^{a,b}	80.03 ± 13.2^{a}	34.72 ± 8.6^{a}	9.68 ± 0.8^{a}	22.60 ± 2.2^{a,b}
E	3.84 ± 0.5^{b}	8.52 ± 0.5^{c}	152.00 ± 12.0^{b,c}	41.77 ± 4.7^{d}	269.71 ± 123.0^{b}	1910.26 ± 255.2^{a,b}	118.25 ± 6.9^{a}	41.26 ± 7.3^{a}	15.50 ± 2.6^{a,b}	46.13 ± 7.7^{a,b,c}
Slag	2.32 ± 0.2^{a}	5.68 ± 0.8^{b}	168.40 ± 2.6^{b,c}	23.08 ± 1.9^{b}	54.91 ± 1.1^{a}	2873.25 ± 87.0^{a,b}	22.53 ± 9.7^{a}	10.64 ± 1.2^{a}	5.62 ± 0.6^{a}	14.90 ± 1.2^{a}
Native	1.94 ± 0.1^{a}	2.45 ± 0.2^{a}	96.82 ± 5.3^{a}	10.58 ± 0.8^{a}	20.53 ± 1.4^{a}	193.77 ± 2.9^{a}	11.98 ± 4.8^{a}	7.45 ± 0.6^{a}	2.69 ± 0.1^{a}	5.52 ± 0.6^{a}

Means ± standard errors (n = 3). Values followed by the same letter(s) within a column are not significantly different at $P \leq 0.05$

Source: https://link.springer.com/article/10.1007%2Fs11356-020-08319-w

Copper toxicity affects phosphorus uptake mechanisms at molecular and physiological levels in Cucumis sativus plants (2020)

Table 1: Root and shoot biomasses and SPAD assessed in cucumber plants 7 days after the treatments. The values reported are means ± SE (n = 12). The statistical significance was determined by ANOVA test with Tukey post-test ($p < 0.001$). Different letters indicate statistically different values.

	Root Biomass (g plant^{-1})			Shoot Biomass (g plant^{-1})			SPAD index		
Cu Concentrations	Mean	SE		Mean	SE		Mean	SE	
0.2 µM	0.96	0.09	c	2.43	0.13	c	36.1	0.6	a
5 µM	0.57	0.06	b	1.87	0.11	b	35.6	0.6	a
25 µM	0.46	0.04	ab	1.62	0.10	ab	37.3	0.6	a
50 µM	0.29	0.03	a	1.25	0.07	a	44.9	0.6	b

Table 1: Macro- and micronutrient concentration detected in the root and shoot tissues of cucumber plants 7 days after the treatments. The data in the table are reported as means ± SE (n = 3). The statistical significance was determined by ANOVA test with Tukey post-test ($p < 0.05$). Different letters indicate statistically different values.

		P (mg g DW^{-1})			Ca (mg g DW^{-1})			K (mg g DW^{-1})			S (mg g DW^{-1})			Mg (mg g DW^{-1})		
	Cu concentration	Mean	SE		Mean	SE		Mean	SE		Mean	SE		Mean	SE	
Shoot	**0.2 µM**	11.04	0.43	a	29.46	3.43	a	31.84	4.39		4.08	0.36		5.12	0.18	a
	5 µM	11.83	0.28	a	25.75	1.82	a	35.57	1.73		4.22	0.44		5.04	0.31	a
	25 µM	9.89	0.98	ab	27.67	2.03	a	35.60	1.88		<LOD			5.29	0.40	a
	50 µM	7.56	0.82	b	8.67	0.20	b	28.06	1.48		<LOD			2.84	0.04	b
Root	**0.2 µM**	10.82	0.67	a	7.62	0.37	b	80.59	6.70	a	14.29	4.24	a	1.40	0.11	
	5 µM	11.75	1.17	a	8.36	0.72	b	81.57	6.87	a	7.23	1.21	ab	1.55	0.09	
	25 µM	9.08	0.82	ab	9.43	1.16	b	41.16	2.92	b	2.87	0.14	b	1.36	0.20	
	50 µM	6.92	0.63	b	12.15	1.69	a	12.15	2.13	c	2.04	0.07	b	1.07	0.25	
		Cu (µg g DW^{-1})			**Fe (mg g DW^{-1})**			**Zn (µg g DW^{-1})**			**Mn (µg g DW^{-1})**			**Mo (µg g DW^{-1})**		
	Cu concentration	Mean	SE		Mean	SE		Mean	SE		Mean	SE		Mean	SE	
Shoot	0.2 µM	20.10	1.92	a	0.15	0.02		100.05	2.09		70.47	9.89	a	13.40	1.31	
	5 µM	26.75	1.75	a	0.14	0.01		94.75	10.64		72.76	1.4	a	13.88	2.11	
	25 µM	56.77	6.36	b	0.16	0.01		137.17	2.38		53.09	2.06	b	14.01	3.49	
	50 µM	81.65	11.42	b	0.13	0.01		84.87	0.28		27.52	2.71	c	20.39	8.11	
Root	0.2 µM	89.91	15.18	c	3.39	0.55	c	169.64	24.84		17.99	3.09		<LOD		
	5 µM	282.86	35.59	c	5.58	0.9	bc	224.72	37.09		12.51	6.15		<LOD		
	25 µM	1177.96	230.36	b	9.36	1.66	ab	163.01	29.3		15.30	2.55		<LOD		
	50 µM	5575.10	916.46	a	13.52	0.61	a	173.43	24.66		9.33	4.93		<LOD		

Source: https://www.sciencedirect.com/science/article/pii/S0981942820305258

Physiological effects of short-term copper stress on rape (*Brassica napus L.*) seedlings and the alleviation of copper stress by attapulgite clay in growth medium (2020)

Table 1: The effects of different concentrations of $CuCl_2$ on the Chl fluorescence parameters and the Chl content of rape seeding leaves. Each value represents the mean ± SD of four individual replications. The means followed by the same letter did not significantly differ at $P < 0.05$. Fw stands for fresh weight of rape seedling leaves, Dm stands for dry weight of rape seedlings (as the same as below figures and tables).

Cu concentrations (mmol L^{-1})	**Copper content in the seedlings (μg g^{-1} Dm)**	**ΦPSII**	**ETR**	**Fv´/Fm´**	**qN**	**Chl content (mg g^{-1} Fw)**
0	59.54 ± 8.25 a	0.44 ± 0.01 a	23.9 ± 0.6 a	0.65 ± 0.01 a	0.506±0.003 a	1.930±0.134a
10	94.02± 22.35 b	0.30± 0.01 b	16.5 ± 0.4 b	0.63 ± 0.01 b	0.510±0.011 a	1.852±0.091a
20	339.08± 47.26 c	0.20 ± 0.01c	10.8 ± 0.5 c	0.61 ± 0.03 bc	0.537±0.003 b	1.590±0.072b
30	662.75± 65.89 d	0.15 ± 0.02 d	8.0 ± 0.8 d	0.58 ± 0.03 c	0.561±0.011 c	1.554±0.060b

Table 2: The effects of different concentrations of $CuCl_2$ on the activities of antioxidant enzymes and the soluble protein content of rape seeding leaves. Each value represents the mean ± SD of four individual replications.

Cu ion concentrations (mmol L^{-1})	**SOD activity (U g^{-1} Fw)**	**POD activity (ΔOD470 min^{-1} g^{-1} Fw)**	**CAT activity (ΔOD240 min^{-1} g^{-1} Fw)**	**APX activity (ΔOD290 min^{-1} g^{-1} Fw)**	**Soluble protein content (mg g^{-1} Fw)**
0(ck)	64.910 ± 11.922 c	433.333 ± 37.528 d	16.133 ± 1.270 c	3.452 ± 0.743 d	4.733 ± 0.544 d
10	353.545±33.243b	606.667 ± 37.528 c	18.160 ± 0.017c	7.381 ± 0.206 c	7.905 ± 0.909 c
20	366.360±20.101b	1213.333 ± 75.056 b	25.117 ± 0.840 b	8.214 ± 0.357 b	10.011 ± 0.380 b
30	565.371 ± 6.878 a	2578.333 ± 99.289 a	36.300 ± 2.910 a	9.405 ± 0.206 a	15.416 ± 1.773 a

Table 3: Effect of AC on chlorophyll fluorescence parameters and the Chl content in the rape seedling leaves with or without $CuCl_2$ application.

AC/vermiculite (v/v)	**Cu^{2+}**	**ΦPSII**	**ETR**	**Fv´/Fm´**	**qN**	**Chl (mg g^{-1} Fw)**
ck	—	0.443±0.013A	23.943±0.715A	0.691±0.004A	0.442±0.044B	**1.959 ±0.071 A**
	+	0.199±0.010d*	10.753±0.54d*	0.589±0.013c*	0.593±0.019a*	**1.576 ±0.134b***
1:80	—	0.440±0.008A	23.822±0.414A	0.691±0.016A	0.446±0.058B	**1.949 ±0.040A**
	+	0.220±0.008d*	11.874±0.408d*	0.597±0.007c*	0.582±0.015a*	**1.769 ±0.108ab***
1:50	—	0.441±0.006A	23.856±0.299A	0.691±0.011A	0.442±0.023B	**1.951 ±0.060A**
	+	0.392±0.006b*	21.230±0.349b*	0.638±0.004b*	0.478±0.017b*	**1.841 ±0.077a**
1:30	—	0.441±0.006A	23.846±0.328A	0.691±0.006A	0.441±0.037B	**1.956 ±0.021A**
	+	0.439±0.002a	23.763±0.129a	0.664±0.012b*	0.472±0.006b	**1.946 ±0.116a**
1:10	—	0.363±0.014B	19.668±0.758B	0.649±0.004B	0.504±0.023A	**1.742 ±0.062B**
	+	**0.297 ±0.002c***	**16.073±0.161c***	**0.615±0.031c**	**0.560±0.027a***	**1.720 ±0.053b**

Table 4: Effects of AC on the activities of antioxidant enzymes and soluble protein content in rape seedling leaves with or without $CuCl_2$ application.

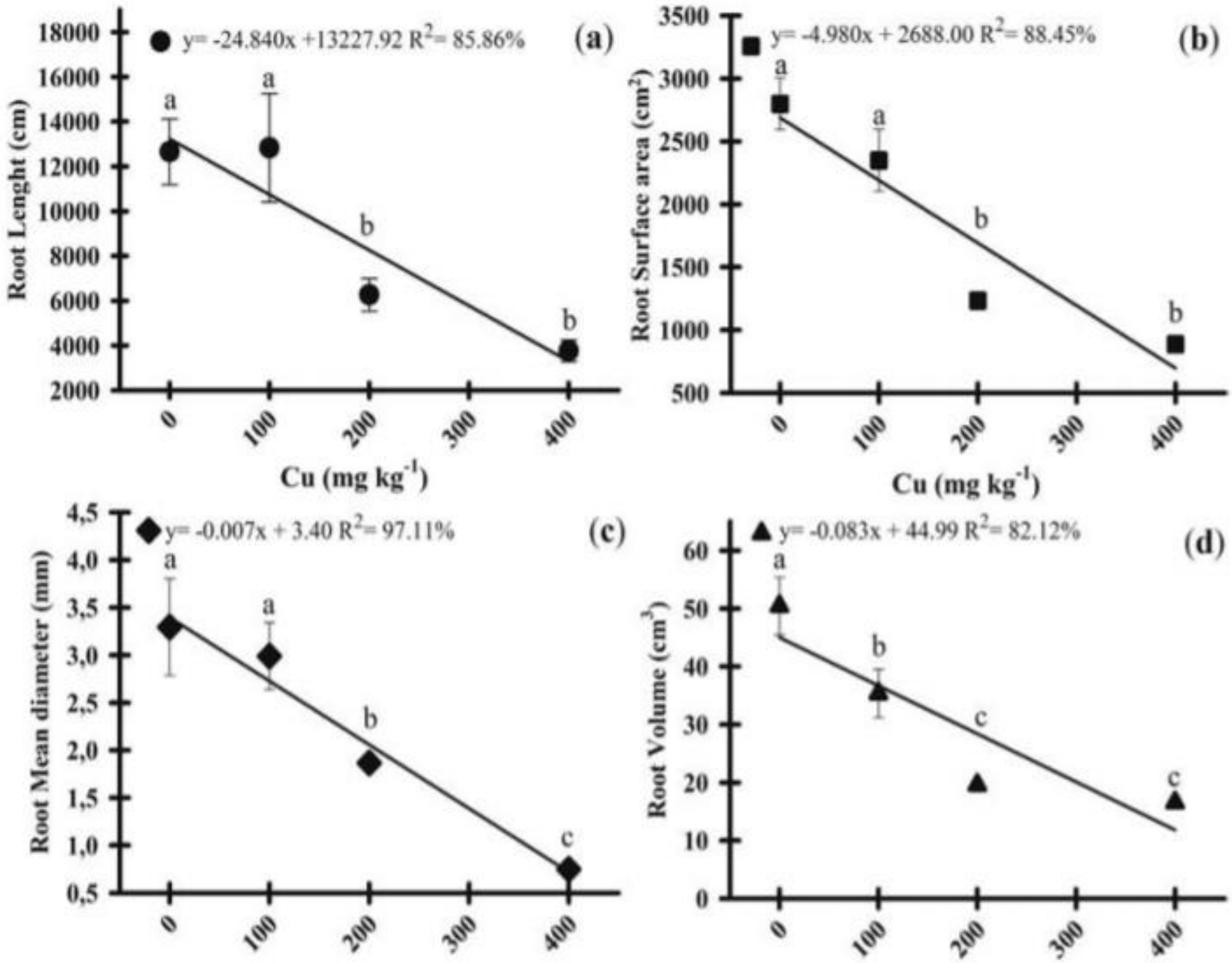
AC/vermiculite (v/v)	Cu^{2+}	SOD activity (U g^{-1} Fw)	POD activity (ΔOD470 min^{-1} g^{-1} Fw)	CAT activity (ΔOD240 min^{-1} g^{-1} Fw)	APX activity (ΔOD290 min^{-1} g^{-1} Fw)	Soluble protein content (mg g^{-1} Fw)
ck	—	64.910±11.922 B	466.667±23.094 B	18.889±0.962B	1.548±0.206B	**4.733±0.544B**
	+	367.199±8.719 a*	1266.667±161.658 a*	25.000±1.667a *	8.810±0.743a*	**10.011±0.380a***
1:80	—	43.871±16.568 B	466.667±184.752 B	20.556±0.962B	1.667±0.412B	**4.844±0.385B**
	+	374.810±3.295 a*	1346.667±197.315 a*	23.889±0.962a *	8.095±0.206a*	**9.567±0.983a***
1:50	—	59.183±11.922 B	440.000 ±160.000B	18.889±0.962B	1.786±0.357B	**5.067±0.691B**
	+	133.181±6.591 c*	693.333±197.315 b	20.000±1.667b	2.619±0.412b	**6.622±0.898b***
1:30	—	43.910±14.414 B	466.667±184.752 B	20.000±1.667B	1.786±0.357B	**4.817±0.106B**
	+	129.376±3.295 c*	693.333±61.101 b	20.000±1.667b	2.500±0.000b*	**5.067±0.559c**
1:10	—	148.912±11.455 A	680.000 ±105.830 A	25.000±2.887A	7.381±0.825A	**6.150±0.777A**
	+	**237.823±8.719 b***	**1173.333±128.582 a***	**26.111±0.962a**	**7.500±0.357a**	**7.456±0.333b***

Table 4: Effects of AC on the chlorophyll fluorescence parameters of rape seedling leaves with or without $CuCl_2$ application with the extension handing time.

AC/vermiculite (v/v)	Cu^{2+}	ΦPSII	ETR	Fv´/Fm´	qN
A. 24 h ck	—	0.45±0.013A	22.91±0.684A	0.70±0.005A	**0.45 ± 0.044 A**
	+	0.15±0.008b*	7.71±0.390b*	0.54±0.017a*	**0.73 ± 0.023 a***
1:80	—	0.44±0.008A	22.79 ±0.396A	0.70 ±0.016A	**0.45 ± 0.059 A**
	+	0.15±0.036b*	7.50±1.87b*	0.54±0.004a*	**0.68 ± 0.029 ab***
1:50	—	0.45±0.006A	22.82±0.29A	0.70±0.012A	**0.45 ± 0.023 A**
	+	0.21±0.005a*	10.57±0.258b*	0.55±0.013a*	**0.63 ± 0.021 b***
1:30	—	0.45±0.006A	22.81±0.314A	0.70±0.006A	**0.45 ± 0.037 A**
	+	0.21±0.006a*	10.70±0.296a*	0.56±0.010a*	**0.56 ± 0.023 c***
1:10	—	0.37±0.014B	18.82±0.725B	0.66±0.004B	**0.51 ± 0.023 A**
	+	0.22±0.019a*	11.48±0.961a*	0.61±0.034a*	**0.49 ± 0.034 c**
B. 48 h ck	—	0.45±0.013A	23.14±0.691A	0.70±0.005A	**0.45 ± 0.044 A**
	+	0.14±0.016b*	7.41±0.845b*	0.52±0.008a*	**0.73 ± 0.019 a***
1:80	—	0.45±0.008A	22.84±0.400A	0.71±0.016A	**0.46 ± 0.059 A**
	+	0.17±0.037ab*	8.95±1.882ab*	0.50±0.0107b*	**0.77 ± 0.051 a***
1:50	—	0.45±0.006A	23.07±0.289A	0.71±0.012A	**0.45 ± 0.023 A**
	+	0.16±0.013ab*	8.45±0.684ab*	0.53±0.008a*	**0.75 ± 0.033 a***
1:30	—	0.45±0.006A	23.06±0.317A	0.71±0.006A	**0.45 ± 0.038 A**
	+	0.20±0.018a*	10.41±0.938a*	0.51±0.014a*	**0.74 ± 0.099 a***
1:10	—	0.37±0.014B	19.00±0.732B	0.66 ±0.004B	**0.51 ± 0.023 A**
	+	0.21±0.050ab*	10.81±2.585ab*	0.52±0.0196a*	**0.73 ± 0.098 a***
C. 72 h ck	—	0.45±0.013A	22.84±0.682A	0.70±0.005A	**0.45 ± 0.044 AB**
	+	**0.11±0.0188a***	**5.39±0.961a***	**0.51±0.012a***	**0.53 ± 0.017 a***
1:80	—	**0.44 ±0.008A**	**18.76±0.723A**	**0.70±0.016A**	**0.45 ± 0.059 AB**
	+	**0.12±0.031a***	**6.25±1.583a***	**0.49±0.010a***	**0.55 ± 0.067 a***
1:50	—	**0.44±0.006A**	**22.74±0.312A**	**0.70±0.012A**	**0.45 ± 0.023 B**
	+	**0.13±0.027a***	**6.66±1.373a***	**0.50±0.033a***	**0.57 ± 0.069 a***
1:30	—	**0.44±0.006A**	**22.75±0.285A**	**0.70±0.006A**	**0.45 ± 0.038 AB**
	+	**0.12±0.011a***	**6.39±0.558a***	**0.50±0.012a***	**0.64 ± 0.035 a***
1:10	—	**0.37±0.014B**	**22.72±0.395B**	**0.66±0.004B**	**0.51 ± 0.023 A**
	+	**0.14±0.010a**	**7.31±0.514a***	**0.49±0.011a***	**0.68 ± 0.058 a***

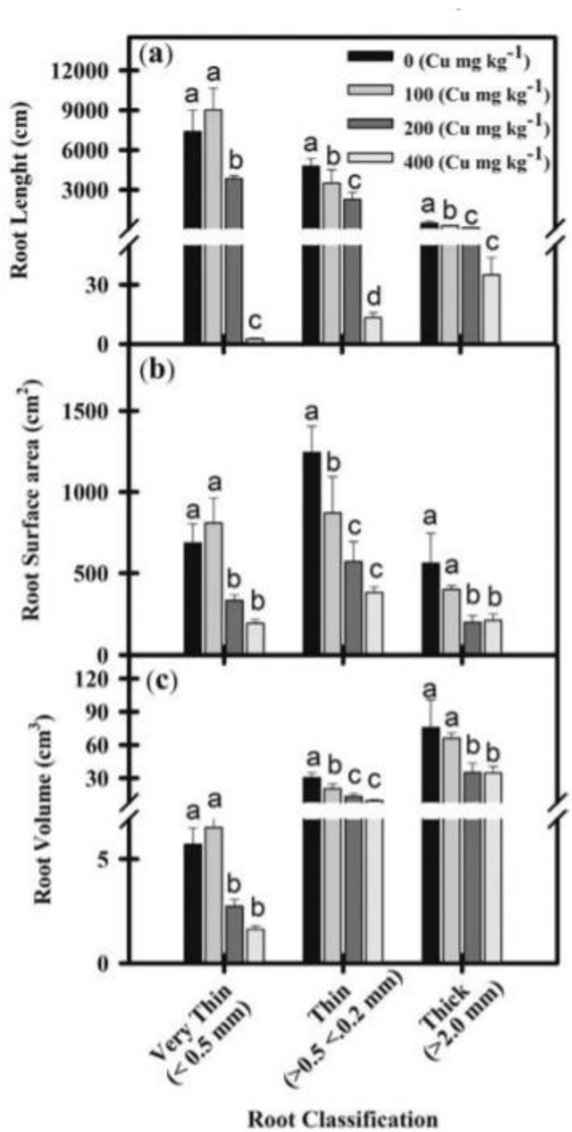
Source: https://www.sciencedirect.com/science/article/abs/pii/S0147651319300132

Root morphology and leaf gas exchange in Peltophorum dubium (Spreng.) Taub. (Caesalpinioideae) exposed to copper-induced toxicity (2019)



Root and dry weight characteristics of P. dubium roots including the (a) length, (b) surface area, (c) mean diameter and (d) volume after plants were exposed to different copper concentrations ($p \leq .05$). Means between treatments followed by the same letter are not statistically different by the Skott-Knott test at 5% probability ($p \leq .05$). Each value indicates mean ± SE.

As soil Cu concentrations increased, there was a linear decrease in length, surface area, mean diameter and root volume in P. dubium ($p \leq .05$). Plants grown in soil that contained 200 and 400 mg kg^{-1} Cu had reduced root length (2.5×), root surface area (2.4×) and root mean diameter (2.4×) compared to plants treated with 100 mg kg^{-1} Cu or the control treatments (Fig. a–c). In addition, plants exposed to 400 mg kg^{-1} Cu presented a significant reduction in their root volume, which was 3× less than that measured in the the control plants (Fig. d).



Root length, (b) root surface area and (c) root volume organized by diameter class in P. dubium exposed to different Cu concentrations. Means between treatments followed by the same letter do not statistically differ from one another by the SkottKnott test at 5% probability ($p \leq .05$). Each value indicates mean ± SE.

Approximately 90% of the P. dubium root system consists mainly of very thin roots (b0.5 mm). These thin roots were significantly reduced in length, surface area and volume (Fig. a–c) when grown in soil with 200 and 400 mg kg^{-1} Cu compared to control plants ($p \leq .05$). Low Cu treatment (100 mg kg^{-1}) affects negatively TR and THR, but improved VTR, although this later effect was not significant. In addition, the number fine (TR) and thick roots (THR) were also reduced with the application of 400 mg kg^{-1} Cu compared to control conditions (Fig. a–c).

Source: https://www.sciencedirect.com/science/article/abs/pii/S0254629918309074

Mechanisms of copper stress alleviation in Citrus trees after metal uptake by leaves or roots (2018)

Table 1: Nutrient concentrations in the sap leakage from trunk and twigs of sweet orange trees 180 days after Cu application via soil or leaf sprays ($CuSO_4$ or $Cu(OH)_2$)

Cu treatment	**$N\text{-}NO_3$**	**$N\text{-}NH_4$**	**P**	**K**	**Ca**	**Mg**	**S**	**Cu**
Cu per plant (g)	mg L^{-1}							
Soil application of $CuSO_4$								
8.0	3.8 ± 0.6§	4.0 ± 1.2	0.6 ± 0.2	100 ± 18	277 ± 30	76 ± 9	3.8 ± 0.5	1.5 ± 0.3
Foliar application of $CuSO_4$								
0.5	2.7 ± 0.4	4.7 ± 0.7	3.0 ± 0.9	9 ± <1	410 ± 26	36 ± 1	8.9 ± 2.2	10.3 ± 1.3
2.0	3.0 ± 0.2	4.3 ± 0.3	2.0 ± 0.9	9 ± 3	405 ± 12	55 ± 11	3.8 ± 0.3	15.5 ± 1.7
Foliar application of $Cu(OH)_2$								
2.0	3.1 ± 0.3	4.9 ± 0.8	1.7 ± 0.6	8 ± 2	459 ± 14	41 ± 4	6.9 ± 2.2	10.3 ± 0.4

Standard deviation of the mean (n = 4)

Source: https://www.researchgate.net/publication/323342881_Mechanisms_of_copper_stress_alleviation_in_Citrus_trees_after_metal_uptake_by_leaves_or_roots

Copper excess reduces nitrate uptake by *Arabidopsis* roots with specific effects on gene expression (2018)

Table 1: Elevated copper (Cu) affected the concentration of phosphorus (P), calcium (Ca), iron (Fe), manganese (Mn) and boron (B) in the shoots and Fe and Mn in the root of Arabidopsis thaliana supplied with different Cu levels in the nutrient solution for 72 h or 15 days (15d).

Cu concentrations	**Shoot**					**Root**		
	P	Ca	Fe	Mn	Zn	B	Fe	Mn
μM	g kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
0.16	6.7 aaAb	30 aA	114 aA	115 aA	31 aA	31 aA	19 aA	1.6 aA
5.0	6.7 a	26 ab	95 b	113 a	30 a	28 a	31 b	1.3 ab
10.0	6.5 a	24 b	94 b	102 ab	29 a	29 a	29 b	0.7 bc
20.0	5.5 b	23 b	95 b	85 b	23 b	22 b	32 b	0.4 c
5.0 (15d)	6.3 A	25 B	84 B	90 B	30 A	31 A	29 B	0.2 B

Elevated copper (Cu) affected the concentration of phosphorus (P), calcium (Ca), iron (Fe), manganese (Mn) and boron (B) in the shoots and Fe and Mn in the root of Arabidopsis thaliana supplied with different Cu levels in the nutrient solution for 72 h or 15 days (15d).

a

For the Cu treatments for 72 h different lowercase letters indicate mean values are significantly different among the [Cu] (0.16, 5.0, 10.0 and 20.0 μM) by Tukey's test ($p < 0.05$).

b

For the Cu treatments for 15 days different uppercase letters indicate mean values are significantly different between the [Cu] (0.16 and 5.0 μM) by Tukey's test ($p < 0.05$).

Source: https://www.sciencedirect.com/science/article/pii/S0176161718302888

Copper toxicity and date palm (*Phoenix dactylifera*) seedling tolerance: Monitoring of related biomarkers (2017)

Table 1: Copper (Cu) effect on different physiological parameters of date palm (Phoenix dactylifera) seed germination

Cu (mM)	SG (s/d)	MDG (s/d)	MGT (d)	PV (s/d)	SLM (%)	GI (%)
0	159.36 ± 5.6	0.163 ± 0.01	287.77 ± 6.4	0.49 ± 0.16	2.78 ± 0.33	100
0.02	167.2 ± 4.3	0.164 ± 0.04	289.28 ± 4.6	0.49 ± 0.03	2.78 ± 0.33	98.04
0.2	172.32 ± 5.3	0.166 ± 0.00	293.93 ± 2.4	0.66 ± 0.00	0 ± 1	84.36
2	138.09 ± 5.9	0.134 ± 0.01	234.11 ± 3.3	0.40 ± 0.02	3.05 ± 2.5	8.37

SG = speed of germination; MDG = mean daily germination; MGT = mean germination time; PV = peak value; SLM = seedling mortality; GI = germination index.

Source: https://setac.onlinelibrary.wiley.com/doi/full/10.1002/etc.4007

Changes in nutrients content of Radish (Raphanus sativus) under copper toxicity. (2017)

Table 1: Effect of copper on nutrients content (mg g^{-1} dry wt.) of radish (45th day)

Copper added in the soil (mg kg^{-1})	N	P	K	Na	Ca	Mg
Control	32.66	6.31	43.52	1.70	13.56	3.99
50	37.35(+14.36)	6.97(+10.45)	52.09(+19.69)	2.11 (+24.11)	15.98 (+17.84)	4.91 (+23.05)
100	25.28 (22.59)	5.71 (-9.50)	36.78 (-15.48)	1.39 (-18.23)	12.25 (-9.66)	3.48 (-12.78)
150	23.73 (27.34)	5.06 (-19.80)	32.17 (-26.07)	1.28 (-24.70)	11.14 (-17.84)	3.05 (-23.55)
200	20.98 (35.76)	4.81 (-23.77)	30.37 (-30.21)	1.16 (-31.76)	11.30 (-19.05)	2.75 (-31.07)
250	18.07 (44.67)	3.90 (-38.19)	25.11 (-42.30)	1.10 (-35.29)	10.68 (-21.23)	2.11 (-47.11)

Average of five replications
Per cent over control values are given in parentheses

Source: https://ijarbs.com/pdfcopy/apr2017/ijarbs12.pdf

Castasterone assisted accumulation of polyphenols and antioxidant to increase tolerance of *B. juncea* plants towards copper toxicity (2016)

Table 1: Effect of Cu and castasterone on ROS indicators (superoxide anion and hydrogen peroxide content), photosynthetic pigments (chlorophyll a, b, total chlorophyll and carotenoids content) and anthocyanin content in 60 days old *B. juncea* plants

Treatments		Superoxide anion radical content ($\mu g\ g^{-1}$ FW)	Hydrogen peroxide content ($\mu mol\ g^{-1}$ FW)	Chlorophyll a content ($mg\ g^{-1}$ FW)	Chlorophyll b content($mg\ g^{-1}$ FW)	Total chlorophyll content($mg\ g^{-1}$ FW)	Carotenoids content ($mg\ g^{-1}$ FW)	Anthocyanin content ($\mu g\ g^{-1}$ FW)
Cu (mM)	**CS (M)**							
0	0	6.74 ± 0.31	1.23 ± 0.03	1.76 ± 0.06	0.64 ± 0.04	2.38 ± 0.04	0.047 ± 0.001	5.25 ± 0.06
0.25	0	7.84 ± 0.81	1.36 ± 0.05	1.49 ± 0.05	0.55 ± 0.02	2.02 ± 0.06	0.070 ± 0.010	5.82 ± 0.01
0.50	0	8.03 ± 0.43	1.81 ± 0.05	1.38 ± 0.08	0.52 ± 0.07	1.89 ± 0.07	0.068 ± 0.004	6.50 ± 0.98
0.75	0	9.87 ± 0.19	2.07 ± 0.6	1.33 ± 0.06	0.51 ± 0.06	1.83 ± 0.04	0.064 ± 0.005	6.09 ± 0.06
0	10^{-11}	6.63 ± 0.41	1.10 ± 0.03	1.75 ± 0.09	0.57 ± 0.01	2.31 ± 0.08	0.084 ± 0.006	5.47 ± 0.07
0	10^{-9}	6.60 ± 0.27	1.18 ± 0.06	1.60 ± 0.15	0.68 ± 0.01	2.26 ± 0.01	0.071 ± 0.003	5.43 ± 0.06
0	10^{-7}	6.84 ± 0.16	1.15 ± 0.02	1.72 ± 0.09	0.63 ± 0.08	2.33 ± 0.08	0.072 ± 0.006	6.13 ± 1.04
0.25	10^{-11}	7.15 ± 0.48	1.30 ± 0.11	1.59 ± 0.07	0.57 ± 0.10	2.15 ± 0.07	0.070 ± 0.012	7.55 ± 0.10
0.25	10^{-9}	7.13 ± 0.15	1.21 ± 0.10	1.64 ± 0.05	0.60 ± 0.03	2.22 ± 0.08	0.075 ± 0.001	7.63 ± 0.08
0.25	10^{-7}	6.95 ± 0.29	1.22 ± 0.02	1.63 ± 0.03	0.62 ± 0.08	2.23 ± 0.05	0.072 ± 0.002	7.78 ± 0.08
0.50	10^{-11}	7.63 ± 0.56	1.80 ± 0.07	1.51 ± 0.04	0.55 ± 0.01	2.05 ± 0.03	0.071 ± 0.002	9.54 ± 0.09
0.50	10^{-9}	7.89 ± 0.48	1.65 ± 0.07	1.50 ± 0.06	0.55 ± 0.02	2.03 ± 0.05	0.075 ± 0.007	9.16 ± 0.98
0.50	10^{-7}	7.71 ± 0.90	1.75 ± 0.06	1.64 ± 0.01	0.60 ± 0.05	2.22 ± 0.04	0.077 ± 0.010	9.14 ± 0.99
0.75	10^{-11}	7.65 ± 0.05	1.83 ± 0.08	1.43 ± 0.05	0.51 ± 0.06	1.93 ± 0.09	0.066 ± 0.007	11.53 ± 0.09
0.75	10^{-9}	9.24 ± 0.13	1.82 ± 0.05	1.41 ± 0.05	0.52 ± 0.04	1.92 ± 0.08	0.068 ± 0.003	11.59 ± 0.06
0.75	10^{-7}	8.47 ± 0.22	1.89 ± 0.07	1.42 ± 0.03	0.53 ± 0.04	1.93 ± 0.06	0.070 ± 0.001	11.68 ± 0.07
***F*-ratio (Cu) *df* 3,32**		51.43**	399.42**	42.74**	6.01**	97.89**	8.24**	186.64**
***F*-ratio (CS) *df* 3,32**		8.55**	13.21**	5.75**	1.34	12.07**	0.073	83.19**
***F*-ratio (Cu × CS) *df* 9,32**		3.16**	2.42*	2.95*	0.49	4.76**	3.24*	14.14**
HSD (p < 0.05)		1.310	0.192	0.209	0.200	0.192	0.019	1.521

Note: Data represent the mean ± SD of three replicates.

* $p < 0.05$.

** $p < 0.01$.

Table 2: Effect of Cu and castasterone on specific activities of enzymes (CAT, POD, SOD, APOX, DHAR and PPO) in 60 days old *B. juncea* plants

Treatments		Specific activity (UA $mg\ g^{-1}$ FW)					
Cu (mM)	**CS (M)**	**CAT**	**POD**	**SOD**	**APOX**	**DHAR**	**PPO**
0	0	2.62 ± 0.13	62.31 ± 3.99	1.60 ± 0.17	114.32 ± 9.52	22.87 ± 1.95	15.58 ± 0.35
0.25	0	3.97 ± 0.17	76.97 ± 6.27	2.68 ± 0.14	178.29 ± 4.69	36.39 ± 0.72	15.25 ± 0.66
0.50	0	4.70 ± 0.05	88.08 ± 6.15	3.25 ± 0.15	246.48 ± 3.84	41.45 ± 2.36	15.47 ± 0.78
0.75	0	5.46 ± 0.16	110.25 ± 3.77	3.55 ± 0.14	252.52 ± 2.66	57.30 ± 2.07	14.89 ± 0.90
0	10^{-11}	2.49 ± 0.10	61.42 ± 6.15	1.69 ± 0.06	117.17 ± 5.35	17.06 ± 2.67	18.30 ± 0.44
0	10^{-9}	2.58 ± 0.03	61.70 ± 2.39	1.64 ± 0.13	118.29 ± 1.58	22.43 ± 4.00	19.55 ± 0.62
0	10^{-7}	2.63 ± 0.09	65.36 ± 2.54	1.70 ± 0.18	114.56 ± 4.10	19.45 ± 2.84	20.02 ± 0.58
0.25	10^{-11}	4.48 ± 0.12	91.17 ± 8.80	2.97 ± 0.12	172.81 ± 5.42	38.41 ± 2.68	21.57 ± 0.81
0.25	10^{-9}	4.55 ± 0.14	105.13 ± 2.47	3.05 ± 0.16	193.08 ± 3.86	39.50 ± 0.77	21.97 ± 1.11
0.25	10^{-7}	4.59 ± 0.07	110.61 ± 4.46	3.29 ± 0.14	206.81 ± 4.83	39.28 ± 3.20	23.51 ± 0.45
0.50	10^{-11}	5.48 ± 0.17	115.89 ± 4.27	3.78 ± 0.19	252.52 ± 3.97	46.36 ± 108	26.12 ± 1.04
0.50	10^{-9}	5.47 ± 0.13	108.96 ± 2.19	3.82 ± 0.07	256.18 ± 2.97	45.62 ± 1.08	24.59 ± 0.90
0.50	10^{-7}	5.73 ± 0.13	110.74 ± 0.88	3.79 ± 0.07	232.97 ± 7.50	50.81 ± 1.99	29.02 ± 0.85
0.75	10^{-11}	5.77 ± 0.47	156.87 ± 3.48	3.82 ± 0.16	264.90 ± 5.98	58.37 ± 2.30	32.27 ± 1.81
0.75	10^{-9}	6.12 ± 0.31	153.02 ± 5.16	4.03 ± 0.15	251.17 ± 13.56	60.36 ± 2.55	34.04 ± 1.40
0.75	10^{-7}	5.96 ± 0.17	149.32 ± 1.75	4.04 ± 0.13	240.71 ± 8.52	59.60 ± 1.97	34.84 ± 1.41
***F*-ratio (Cu) *df* 3,32**		739.22**	210.54**	599.16**	407.82**	558.05**	696.20**
***F*-ratio (CS) *df* 3,32**		21.49**	26.39**	21.86**	0.96	4.13**	21.87**
***F*-ratio (Cu × CS) *df* 9,3 2**		3.84**	5.049**	2.37*	3.38**	3.29**	5.28**
HSD (p < 0.05)		0.553	23.727	0.428	33.06	7.14	2.916

Note: Data represent the mean ± SD of three replicates.

* $p < 0.05$.

** p < 0.01.

Table 3: Effect of Cu and castasterone on contents of various polyphenols (μg g^{-1}) in 60 days old *B. juncea* plants

Polyphenol detected	Control	10^{-7} M CS	0.50 mM Cu	0.50 mM Cu +10^{-7} M CS
Catechin	nd	nd	32.348	161.128
Chlorogenic acid	96.824	108.236	91.516	63.064
Epicatechin	nd	nd	32.94	48.188
Caffeic acid	509.832	443.156	482.524	416.696
Coumaric acid	0.6	0.3	5.14	0.824
Rutin	37.9	31.548	44.676	55.04
Quercetin	2.524	0.832	nd	nd
Umbelliferone	nd	1.544	47.752	7.436
Ellagic acid	61.248	87.732	41.288	338.328
Kaempferol	nd	22.832	28.584	42.592
Tert-butyl hydroquinone	nd	nd	1.332	nd
Total content	708.928	696.18	808.1	1,133.296

Note: nd—not detected.

Source: https://www.tandfonline.com/doi/full/10.1080/23311932.2016.1276821

The effect of excess copper on growth and physiology of important food crops: a review (2015)

Table 1: Relationship between copper concentration in growth medium and its uptake in crops. Copper was mainly accumulated in roots and less translocated to shoots. Cu in plant parts did not linearly increase with increasing Cu levels in the growth medium

Exp.	Cu concentration in medium	Duration (days)	Crop type	Uptake and accumulation (mg kg^{-1})	References
Hydroponics	50 to 150 μM	10	Rapeseed	Leaves 107.9–203.1 Root 297.3–383.7	Ivanova et al. 2010
"	0.1 to 10 mM	6	Maize	Root 5.9–1668.2	Benimali et al. 2010
"	10 to 50 μM	14	Rapeseed	Root 740.40–2478 Shoot 57.6–82.01 Shoot 5.83–594.8 Leaves 13.5–160.9	Feigl et al. 2013
"	10 to 50 μM	14	Indian mustard	Root 686.1–3637 Shoot 49.7–88.2	Feigl et al. 2013
"	4 to 80 μM	15	Maize	Root 299–7790	Ouzounidou et al. 1995
"	75 μM	7	Wheat	Root 618.5 Shoot 21.5	Gajewska and Sklodowska 2010
"	10^{-3} M	6	Maize	Root 1070 Shoot 56	Lin et al. 2003
"	1.6 to 192 μM	35	Soybean	Leaves 67	Sanchez-Pardo et al. 2014
Sand	20 mg kg^{-1}	20	Cucumber	Root 299	Alaoui-Sossé et al. 2004
Soil	1338 mg kg^{-1}	50	Green gram	Root 60 Shoot 26.2	Wani et al. 2007
"	50 to 250 mg kg^{-1}	45	Green gram	Shoot 46.6–150	Manivasagaperumal et al. 2011

Source : https://link.springer.com/article/10.1007/s11356-015-4496-5