NUMERICAL DATA

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). (2019)

Cu ion concentrations (mmol L^{-1})	SOD activity (U g^{-1} Fw)	POD activity (ΔOD_{470} min^{-1}	CAT activity (ΔOD_{240} min^{-1} g^{-1} Fw)	APX activity (ΔOD_{290} min^{-1} g^{-1} Fw)	Soluble protein content (mg g^{-1} Fw)
0	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

The increases in the activity of the antioxidant enzymes after the short-term copper stress were followed with an increase of the soluble protein content in the rape seedling leaves. After treatment with 10, 20 and 30 mmol L^{-1} $CuCl_2$ for 12 h, the soluble protein con- tent of the rape seedling leaves was significantly increased by 1.67, 2.11, and 3.26 fold, respectively.

Source: https://sci-hub.tw/https://doi.org/10.1016/j.ecoenv.2019.01.014

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 (2019)

The effects of different concentrations of $CuCl_2$ on the Chl fluorescence parameters and the Chl content of rape seeding leaves.

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

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).

The results showed that, after treatment with 10 mmol L^{-1} $CuCl_2$ for 12 h, the values of Fv′/Fm′, ΦPSII, and ETR of the rape seedling leaves presented significant decreases, while the value of qN of the rape seedling leaves still maintained a level almost similar to that in the control. With further increase in the $CuCl_2$ concentration, the values of ΦPSII, ETR and Fv′/Fm′ were further decreased, while the values of qN of the seedling leaves were significantly increased.

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

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. (2019)

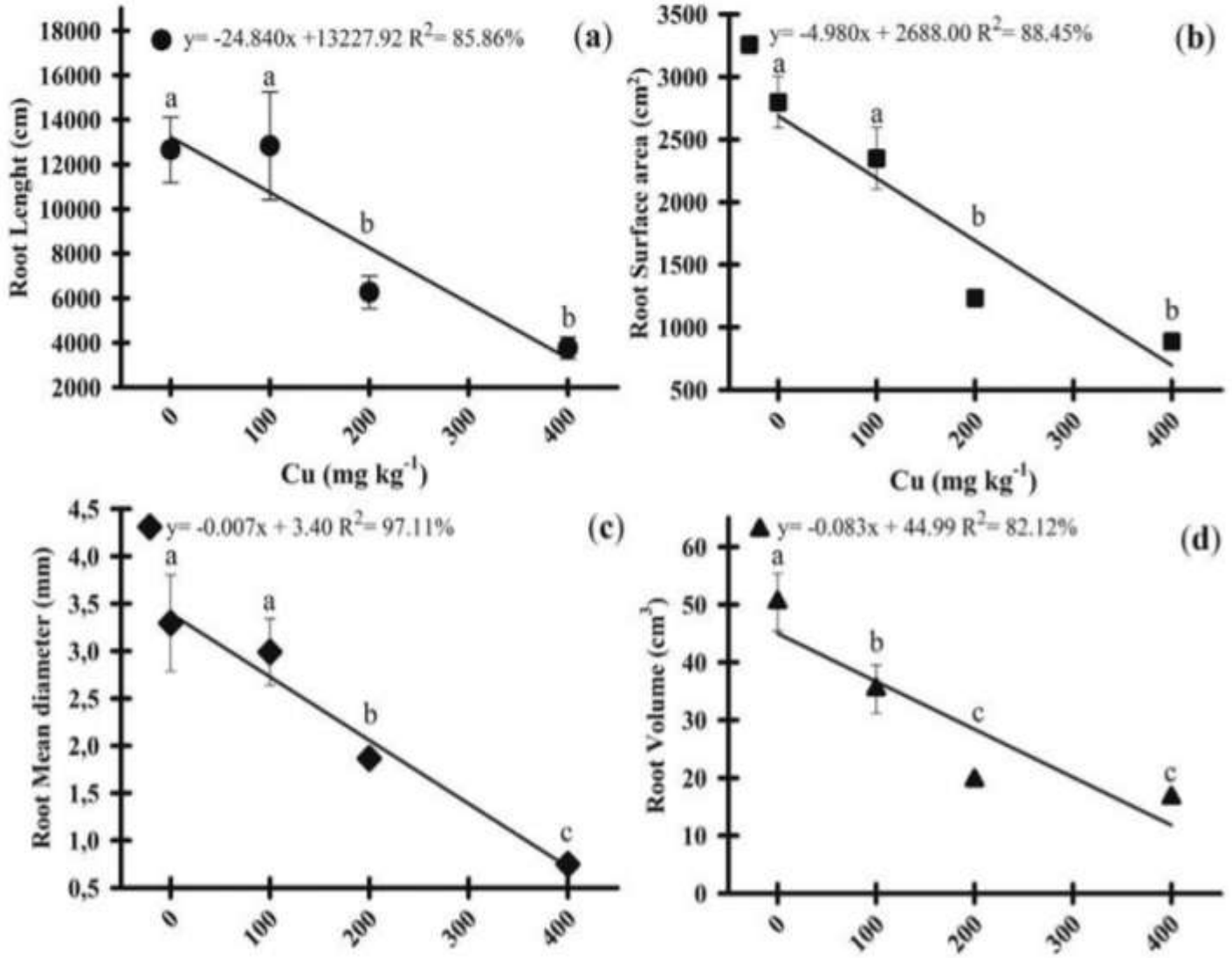
Cu concentrations (mmol L^{-1})	SOD activity (U g−1 Fw)	POD activity (ΔOD470 min−1g−1 Fw)	CAT activity (ΔOD240 min−1 g−1 Fw)	APX (ascorbate peroxidise) activity (ΔOD290 min−1 g−1 Fw)	Soluble protein content (mg g-1 Fw)
0	64.910± 11.922 c	433.333± 37.528 d	16.133± 1.270 c	3.452±0.743 d	4.733 ± 0.544 d
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

superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), and ascorbate peroxidase (APX)

After treatment with 20 and 30 mmol L^{-1} $CuCl_2$ for 12 h, the activities of the measured antioxidant enzymes all significantly increased: the SOD activity was significantly increased by 5.64 and 8.71 fold, respectively; the POD significantly was increased by 2.80 and 5.95 fold, respectively; the CAT activity was significantly increased by 1.56 and 2.25 fold, respectively; and the APX (ascorbate peroxidise) activity was significantly increased by 2.38 and 2.72 fold, respectively. The increases in the activity of the antioxidant enzymes after the short-term copper stress were followed with an increase of the soluble protein content in the rape seedling leaves. After treatment with 10, 20 and 30 mmol L−1 $CuCl_2$ for 12 h, the soluble protein content of the rape seedling leaves was significantly increased by 1.67, 2.11, and 3.26 fold, respectively.

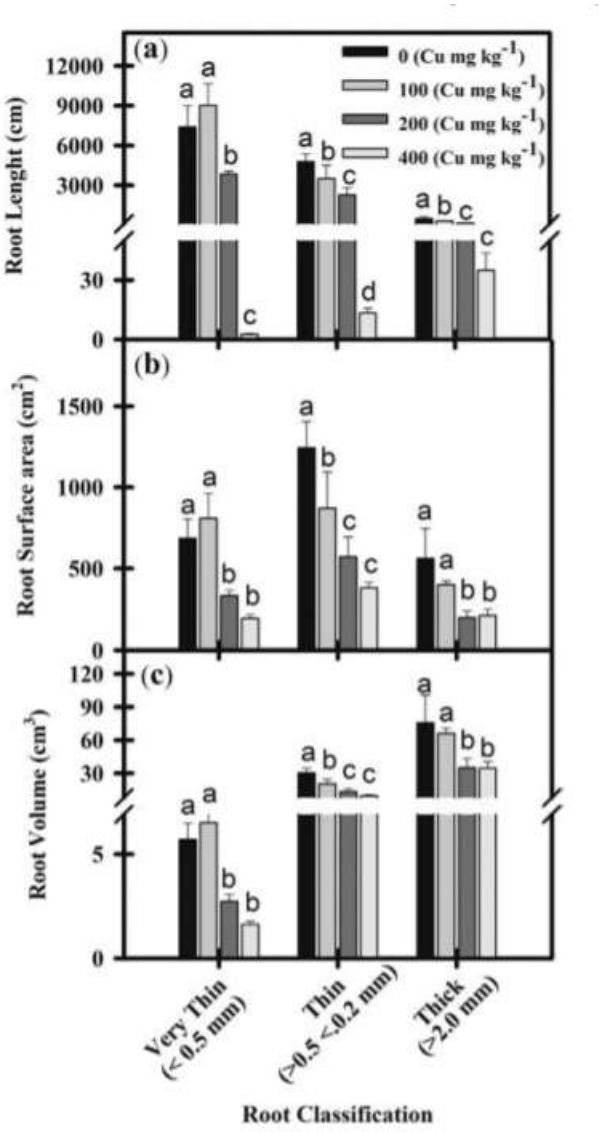
Source: https://www.sciencedirect.com/science/article/pii/S0147651319300132

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: http://sci-hub.tw/https://doi.org/10.1016/j.sajb.2018.11.007

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

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-NO_3	N-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://link.springer.com/content/pdf/10.1007%2Fs11356-018-1529-x.pdf

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

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 a[a]A[b]	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)

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

Effect of copper on nutrients content (mg g^{-1} dry wt.) of radish (45^{th} day) (2017)

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

Changes in the plant height, root length, total dry weight, and leaf area of the lentil plants subjected to different treatments of copper stress and P. vermicola inoculation (2016)

	Plant height (cm)	Root length (cm)	Total dry weight	
T0	34.67 ± 4.5^{a}	14.76 ± 1.3^{b}	11.87 ± 0.75^{ab}	110.00 ± 3.79^{b}
T1	22.78 ± 3.8^{c}	7.34 ± 0.50^{d}	7.20 ± 1.0^{c}	77.00 ± 3.19^{c}
T2	37.30 ± 5.9^{a}	16.80 ± 1.15^{a}	12.40 ± 1.4^{a}	136.00 ± 5.03^{a}
T3	29.90 ± 2.1^{b}	11.21 ± 1.06^{c}	9.90 ± 1.2^{b}	101.00 ± 4.73^{b}

Values are means±S.E. (n=3). Values carrying different letters are significantly different at $P \leq 0.05$ level As determined by Duncan'stestT0 non-contaminated soil, T1 Cu amended soil, T2 non-contaminated soil+P. vermicolainoculation,T3 Cuamended soil+P. vermicolainoculation

Source: Environ Sci Pollut Res (2016) 23:220–233

P. vermicola inoculation and copper induced changes in different photosynthetic attributes of lentil plants (2016)

Treatments	Gs (mol m^{-2} s^{-1})	Ci (ì mol mol^{-1})	E(mmol H2O $m^{-2}s^{-1}$)	A(ì mol CO2 $m^{-2}s^{-1}$)	A/E (ì mol CO2 /mmol H2O)
T0	0.049 ± 0.003^{b}	281 ± 5.568^{b}	0.512 ± 0.012^{b}	10.36 ± 0.606^{b}	0.291 ± 0.011^{b}
T1	0.023 ± 0.001^{d}	190 ± 5.686^{d}	0.255 ± 0.104^{d}	4.48 ± 0.211^{d}	0.103 ± 0.003^{d}
T2	0.079 ± 0.002^{a}	327 ± 8.686^{a}	0.595 ± 0.014^{a}	13.33 ± 0.620^{a}	0.331 ± 0.007^{a}
T3	0.037 ± 0.00^{c}	236 ± 8.386^{c}	0.423 ± 0.012^{c}	7.83 ± 0.500^{c}	0.243 ± 0.006^{c}

Values are means±S.E. (n=3). Values carrying different letters are significantly different atP≤0.05 level as determined by Duncan's testT0non-contaminated soil,T1Cu amended soil,T2non-contaminated soil+P. vermicolainoculation,T3Cu amended soil+P. vermicolainoculation

Source: springer.com/static/pdf/568/art%253A10.1007%252Fs11356-015-5354-1.pdf

Effect of Cu and castasterone on contents of various polyphenols (ìg g-1) in 60 days old B. juncea plants (2016)

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.

Poonam at al.(2016), Castasterone assisted accumulation of polyphenols and antioxidant to increase tolerance of B. juncea plants towards copper toxicity, Cogent Food & Agriculture

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

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 (2015)

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	Ivanova et al. 2010
				Root 297.3–383.7	
	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	Feigl et al. 2013
				Shoot 57.6–82.01	
				Shoot 5.83–594.8	
				Leaves 13.5–160.9	
	10 to 50 µM	14	Indian mustard	Root 686.1–3637	Feigl et al. 2013
				Shoot 49.7–88.2	
	4 to 80 µM	15	Maize	Root 299–7790	Ouzounidou et al. 1995
	75 µM	7	Wheat	Root 618.5	Gajewska and Sklodowska
				Shoot 21.5	2010
	10^{-3} M	6	Maize	Root 1070	Lin et al. 2003
				Shoot 56	
	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	Wani et al. 2007
				Shoot 26.2	
	50 to 250 mg kg^{-1}	45	Green gram	Shoot 46.6–150	Manivasagaperumal et al. 2011

Source:https://www.researchgate.net/profile/Muhammad_Rizwan16/publication/274963313_The_effect_of_excess_copper_on_growth_and_physiology_of_important_food_crops_a_review/links/5711f8c308aeff315ba038e1/The-effect-of-excess-copper-on-growth-and-physiology-of-important-food-crops-a-review.pdf