Title	**Efficacy of copper foliar spray in preventing copper deficiency of rainfed wheat (*Triticum aestivum L.*) grown in a calcareous soil**
Author Name	Amlal Fouad, Drissi Saad, Makroum Kacem, Maataoui Abdelwahed, Dhassi Khalid, Rahmani Abderrahim & Aït Houssa Abdelhadi
Journal Name	Journal of Plant Nutrition
Year	2020
Volume and Issue	43(11)
Pages	1617-1626
Abstracts	Field experiments were conducted to evaluate the response of rainfed wheat (*Triticum aestivum L.*) to foliar copper (Cu) application in correcting Cu deficiency in calcareous soils. Two native soil Cu contents were tested in successive growing seasons. The soil "1" contained 0.35 mg kg^{-1} of Cu (Diethylenetriamine Pentaacetic Acid extraction). It was evaluated during the 2016-17 season. The soil "2" contained 0.61 mg kg^{-1}. It was studied during the 2017-18 season. The rainfall amount was around 289 mm and 429 mm, respectively, for 2016-17 and 2017-18 seasons. For the soil "1", the Cu treatments were: control, 0.2%, 0.4%, 0.6%, 0.8%, and 1%. For the soil "2", the Cu tested levels were: control, 0.01%, 0.03%, 0.05%, 0.1%, and 0.2%. Cu was applied at the early boot growth stage in the sulfate form. The results showed that the response of grain yield to Cu foliar feeding was not related to the tested native soil Cu content. A significant grain yield increase, due to Cu spray, was revealed during the rainfall season (429 mm) in soil "2". This increase was around 8% at 0.018% of Cu compared to control. However, Cu foliar application higher than 0.03% induced leaf damage. The Cu content of flag leaf and kernels showed a linear response to Cu supply. Flag leaf Cu content was around 5 mg kg^{-1} in control and exceeded 30 mg kg^{-1} at Cu application over than 0.03%.
Keywords	calcareous soil; copper deficiency; foliar spray; phytotoxicity; wheat

Title	**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**
Author Name	Muhammad Hamzah Saleem, Shah Fahad, Muhammad Adnan, Mohsin Ali, Muhammad Shoaib Rana, Muhammad Kamran, Qurban Ali, Inas A. Hashem, Parashuram Bhantana, Mubassir Ali & Reem M. Hussain
Journal Name	Environmental Science and Pollution Research
Year	2020
Volume and Issue	27
Pages	37121–37133
Abstracts	Copper (Cu) is an abundant essential micronutrient element in various rocks and minerals and is required for a variety of metabolic processes in both prokaryotes and eukaryotes. However, excess Cu can disturb normal development by adversely affecting biochemical reactions and physiological processes in plants. The present study was conducted to explore the potential of gibberellic acid (GA3) on fibrous jute (*Corchorus capsularis L.*) seedlings grown on Cu mining soil obtained from Hubei Province China. Exogenous application of GA3 (10, 50, and 100 mg/L) on 60-day-old seedlings of *C. capsularis* which was able to grow in highly Cu-contaminated soil (2221 mg/kg) to study different morphological, physiological, and Cu uptake and accumulation in different parts of *C. capsularis* seedlings. According to the results, increasing concentration of GA3 (more likely 100 mg/L) alleviates Cu toxicity in *C. capsularis* seedlings by increasing plant growth, biomass, photosynthetic pigments, and gaseous exchange attributes. The results also showed that exogenous application of GA3 reduced oxidative stress in C. capsularis seedlings by the generation of extra reactive oxygen species (ROS). The reduction in oxidative stress in *C. capsularis* seedlings is because that plant has strong enzymatic antioxidants [superoxidase dismutase (SOD), peroxidase (POD), ascorbate peroxidase (APX), and catalase (CAT)], which ultimately increased their activities to overcome oxidative damage in the cells/tissues. In addition to the plant growth, biomass, and photosynthesis, foliar application of GA3 also helps to increase metal (Cu) concentration in different parts of the plants when compared to 0 mg/L of application of GA3. From these findings, we can conclude that foliar application of GA3 plays a promising role in reducing ROS generation in the plant cells/tissues and increased phytoextraction of Cu in different plant parts. However, more investigation is needed on field experiments to find a combination of GA3 with a very higher concentration of Cu using fibrous *C. capsularis*.
Keywords	Antioxidants; Fibrous crop; Heavy metals; Plant hormone; Reactive oxygen species

Title	**Investigating the potential of different jute varieties for phytoremediation of copper-contaminated soil**
Author Name	Muhammad Hamzah Saleem, Muzammal Rehman, Muhammad Kamran, Javaria Afzal, Hamza Armghan Noushahi & Lijun Liu
Journal Name	Environmental Science and Pollution Research
Year	2020
Volume and Issue	27
Pages	30367–30377
Abstracts	Copper (Cu), with many documented cases of Cu toxicity in agriculture lands, is becoming an increasingly common issue in and elsewhere in China. However, fibrous crop such as jute is being used as phytoremediation candidate in Cu-contaminated soils due to its huge biomass. A pot experiment was conducted using four different varieties (HT, C-3, GC, and SH) of jute grown in highly Cu-contaminated soil (2221 mg kg−1), collected from Hubei Province, China. Results from this study showed that C-3 and HT were more resistant to Cu stress, while GC and SH had a serious effect due to high concentration of Cu and a significant decrease in growth and biomass. Furthermore, Cu in roots, leaves, stem core, and bast were higher in C-3 and HT compared with GC and SH. Likewise, at post-harvesting stage, maximum Cu concentration from Cu-contaminated soil was extracted by C-3 and HT while small amount was accumulated by GC and SH. The high content of malondialdehyde (MDA) in the leaves of GC and SH indicated that Cu induced oxidative damage while the antioxidative enzyme activities of superoxidase dismutase (SOD) and peroxidase (POD) were increased to scavenge reactive oxygen species (ROS) formed during oxidative stress in the plants. Conclusively, it can be identified that when grown in Cu-contaminated soil, C-3 and HT have greater ability to grow in polluted soils and possible phytoremediation materials to revoke a large amount of Cu.
Keywords	Antioxidants; Copper-contaminated soil; Fibrous crop; Growth; Phytoextraction

Title	**Effect of copper oxide nanoparticles on two varieties of sweetpotato plants**
Author Name	N.J.Bonilla-Bird, Y.Ye, T.AkterbC.Valdes-Bracamontes, A.J.Darrouzet-Nardi, G.B.Saupe, J.P.Flores-Marges, L.Ma, J.A.Hernandez-Viezcas, J.R.Peralta-Videa, J.L.Gardea-Torresdey
Journal Name	Plant Physiology and Biochemistry
Year	2020
Volume and Issue	154
Pages	277-286
Abstracts	Little information is available on the interaction of CuO nanoparticles (nCuO) with tuberous roots. In this study, Beauregard-14 (B-14, low lignin) and Covington (COV, high lignin) sweetpotato varieties were cultivated until maturity in soil amended with nCuO, bulk copper oxide (bCuO) and CuCl2 at 25–125 mg/kg. The Cu treatments had no significant influence on chlorophyll content. Gas exchange parameters were not affected in B-14. In COV, however, at 125 mg/kg treatments, bCuO reduced the intercellular CO2 (11%), while CuCl2 increased it by 7%, compared with control ($p \leq 0.035$). At 25 mg/kg nCuO increased the length of COV roots (20.7 ± 2.0 cm vs. 14.6 ± 0.8 cm, $p \leq 0.05$). In periderm of B-14, nCuO, at 125 mg/kg, increased Mg by 232%, while the equivalent concentration of CuCl2 reduced P by 410%, compared with control ($p \leq 0.05$). The data suggest the potential application of nCuO as nanofertilizer for sweetpotato storage root production.
Keywords	copper oxide; nanofertilizer; sweetpotato varieties; chlorophyll

Title	**Evaluating the potential use of Cu-contaminated soils for giant reed (Arundo donax, L.) cultivation as a biomass crop**
Author Name	Eleonora Coppa, Stefania Astolfi, Claudio Beni, Monica Carnevale, Davide Colarossi, Francesco Gallucci & Enrico Santangelo
Journal Name	Environmental Science and Pollution Research
Year	2020
Volume and Issue	27
Pages	8662–8672
Abstracts	Over the past decades, the important topic of environmental sustainability, impact, and security of the fossil fuel supply has stimulated interest in using lignocellulosic feedstocks as biofuel to partially cover energy demands. Among energy no-food crops, giant reed (*Arundo donax, L.*), a perennial rhizomatous grass has been identified as a leading candidate crop for lignocellulosic feedstock, due to its positive energy balance, and low ecological/agro-management demands. The aim of the present study was to characterize the physiological response of *Arundo donax (L.)* to artificial soil contamination with three different Cu levels (200, 400, and 800 ppm), and to assess the relationship between plant Cu tolerance and S assimilation rate. The present study not only confirms the ability of *Arundo donax L.* to cope with Cu stress and therefore to grow in marginal, degraded lands abandoned by mainstream agricultural, but also shows that plant performance might be likely ascribed to a modulation of sulfate metabolism resulting in increased thiols content.
Keywords	Arundo donax L.; Bioenergy; Copper; Energy crops; Sulfur

Title	Predicting copper contamination in wheat canopy during the full growth period using hyperspectral data
Author Name	Guodong Wang, Qixin Wang, Zhongliang Su & Jinheng Zhang
Journal Name	Environmental Science and Pollution Research
Year	2020
Volume and Issue	27
Pages	39029–39040
Abstracts	The rapid and efficient determination of heavy metal content in food crops is essential for human health and environmental protection. The use of hyperspectral data has become a popular way to predict heavy metal content in plants; however, many challenges remain. One challenge is that lab conditions differ from actual agricultural production conditions. Another challenge is that spectral data characteristics are not universally applicable to all situations. Therefore, in this study, the field test method was adopted to conduct experiments during the full growth period of wheat, and the spectrum data of wheat canopy were processed by the first derivative method to screen-sensitive spectral bands as the basis for the prediction model of the copper content in wheat. The results showed that the copper content increased with an increase in the soil copper content, and there were dissimilar subtle differences in the spectral reflectance of wheat canopy under different stressed soil copper concentrations; sensitive spectral indices and wavelengths were screened based on good correlation with the copper content in the wheat canopy. Different optimal predicting models in different periods were built and verified. The established linear regression models, which were based on NDVI/SIPI and W728, were the most suitable predicting models during the tillering stage with R2 = 0.669 and 0.818; Rg, W741, and multiple bands were the most suitable predicting models during the jointing stage with R2 = 0.548, 0.830, and 0.868; the optimal model during the heading stage was based on W480 (R2 = 0.625). This study demonstrated that the constructed models had good potential for estimating the copper content in wheat leaves during full growth periods, and this method had the potential to be applied to the actual agricultural production process.
Keywords	Wheat canopy; Copper content; Spectral indices; Spectral bands; Prediction models

Title	**Phytoremediation potential of castor (*Ricinus communis L.*) in the soils of the abandoned copper mine in Northern Oman: implications for arid regions**
Author Name	Thenmozhi Murugaian Palanivel, Bernhard Pracejus & Reginald Victor
Journal Name	Environmental Science and Pollution Research
Year	2020
Volume and Issue	27
Pages	17359–17369
Abstracts	Contamination levels of copper (Cu) and other heavy metals are very high in the soils of the abandoned copper mine of Lasail in the north western Hajar Mountains of Oman. Environment-friendly approaches such as phytoremediation are needed to clean and rehabilitate these areas to their natural status. In the present study, the phytoremediation potential of castor, *Ricinus communis L.*, was evaluated for copper and other heavy metals by growing it in different types of Cu-mine soils and slags. Growth parameters such as shoot height and biomass weight (fresh and dry) were evaluated. Castor showed a high tolerance index (TI) in Cu-mine soils. The highest TI was calculated for the fresh mass of castor shoots in E soil with a percentage of 405.99. The translocation factor (TF) of all the metals except boron (B) and manganese (Mn) was < 1, which reveals that these metals are stabilised in the root portion of the castor. Bioconcentration factor (BCF) value < 1 for Cu indicates that castor is not a hyperaccumulator plant for copper. In addition to high concentrations of copper, other heavy metals such as arsenic (As), iron (Fe), and zinc (Zn) were observed in the roots than in shoots. Castor grown in slag accumulated Cu in the shoots, roots, and entire plant with the values of 25, 1184, and 1209 mg kg^{-1}, respectively. Similarly, castor cultivated in A soil accumulated 18, 901, and 919 mg kg^{-1} of copper in shoots, roots, and entire plant, respectively. The calculated plant effective number (PENt) indicated the need for 253 castor plants to remove 1 g of Cu from E soil. The ability of castor to grow well in Cu-mine soils suggests that it can be used for the removal of Cu and other heavy metals. Additionally, the shoot portion could potentially be used for oil production since the phytoaccumulation levels of heavy metal concentration in the shoots were below the standard toxicity limits.
Keywords	Mine soils; *Ricinus communis L.*; Heavy metals; Tolerance index; Translocation factor; Phytostabilisation

Title	**Copper toxicity affects phosphorus uptake mechanisms at molecular and physiological levels in Cucumis sativus plants**
Author Name	Sebastian B. Feil, Youry Pii, Fabio Valentinuzzi, Raphael Tiziani, Tanja Mimmo, Stefano Cesco
Journal Name	Plant Physiology and Biochemistry
Year	2020
Volume and Issue	157
Pages	138-147
Abstracts	Due to the deliberate use of cupric fungicides in the last century for crop-defence programs, copper (Cu) has considerably accumulated in the soil. The concentrations of Cu often exceed the safety limits of risk assessment for Cu in soil and this may cause toxicity in plants. Copper toxicity induces nutritional imbalances in plants and constraints to plants growth. These aspects might be of paramount importance in the case of phosphorus (P), which is an essential plant macronutrient. In this work, hydroponically grown cucumber plants were used to investigate the influence of the exposure to different Cu concentrations (0.2, 5, 25 and 50 μM) on i) the phenotypic traits of plants, particularly at root level, ii) the nutrient content in both roots and shoots, and iii) the P uptake mechanisms, considering both the biochemical and molecular aspects. At high Cu concentrations (i.e. above 25 μM), the shoot and root growth resulted stunted and the P influx rate diminished. Furthermore, two P transporter genes (i.e. CsPT1.4 and CsPT1.9) were upregulated at the highest Cu concentration, albeit with different induction kinetics. Overall, these results confirm that high Cu concentrations can limit the root acquisition of P, most likely via a direct action on the uptake mechanisms (e.g. transporters). However, the alteration of root plasma membrane permeability induced by Cu toxicity might also play a pivotal role in the observed phenomenon.
Keywords	fungicides; plants growth; phenotypic traits; Copper toxicity

Title	**The combined and single effect of salinity and copper stress on growth and quality of Mentha spicata plants**
Author Name	Antonios Chrysargyris, Eleftheria Papakyriakou, Spyridon A.Petropoulos & Nikolaos Tzortzakis
Journal Name	Journal of Hazardous Materials
Year	2019
Volume and Issue	368
Pages	584-593
Abstracts	Copper is essential for plant growth, but in excess may cause adverse effects on plant physiology. Harmful effects are also caused by plant exposure to salinity (NaCl) due to the excessive use of fertilizers, soil degradation and/or the quality of the water used for irrigation. The impact of single and combined salinity (Sal) and copper (Cu) stress on spearmint metabolism were studied in hydroponics. Spearmint plants (*Mentha spicata L.*) were subjected to salinity stress (150 mM NaCl) and/or excessive Cu concentration (60 μM Cu) via the nutrient solution. Not only Sal and Cu, but also their combination suppressed plant growth by decreasing plant biomass, root fresh weight and plant height. Chlorophyll content decreased mainly for the combined stress treatment (Sal + Cu). Polyphenols and antioxidants (FRAP, DPPH, ABTS) increased in single stress treatments (Sal or Cu), but decreased in the combined stress (Sal + Cu). The application of Sal or Cu stress decreased Zn, N and K (leaves), K, Ca, P and Mg (roots) content. Copper application increased Ca and Mg in leaves. In conclusion, salinity stress and Cu exposure may change the primary metabolic pathways in favor of major volatile oil components biosynthesis, resulting in significant changes of essential oil yield and composition.
Keywords	Essential oils; Heavy metals; Oxidative stress; Salinity stress; Spearmint

Title	**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**
Author Name	Mudan Zhang, Ruilan Ran, Wangqing Sai Nao, Yuan Feng, Lingyun Jia, Kun Sun, Rongfang Wang & Hanqing Feng
Journal Name	Ecotoxicology and Environmental Safety
Year	2019
Volume and Issue	171
Pages	878 - 886
Abstracts	Rape (*Brassica napus L.*) seedlings grown in vermiculite-based medium were subjected to short-term copper stress. With the increase of exogenous $CuCl_2$ concentration, photosystem II (PSII) photochemistry and the chlorophyll (Chl) content of rape seedling leaves decreased, while Cu (copper) content of the seedlings, the levels of the soluble protein content, reactive oxygen species (ROS) production, and activities of antioxidant enzymes of the seedling leaves increased. Under the condition without copper stress, there was no significant differences in the measured physiological indexes between the seedlings grown in vermiculite and those grown in the attapulgite clay (AC)/vermiculite mixture with the volume ratio at 1:80, 1:50, or 1:30. After subjected to short-term copper stress, the rape seedlings grown in the mixture of AC/vermiculite had higher levels of Chl content and PSII photochemistry but lower levels of the Cu content, soluble protein content, ROS production, and activities of antioxidant enzymes, compared with the leaves of the seedlings grown in vermiculite. The volume ratio of AC/vermiculite at 1:50 or 1:30 seemed to be the most optimized content in alleviating the physiological effects by the short-term copper stress. These results indicate that AC at moderate content in the growth medium can alleviate the physiological stress of the rape seedlings when excess Cu emerges in the growth medium.
Keywords	Alleviation; Attapulgite clay; Copper stress; Rape seedlings

Title	**A new vegetation heavy metal pollution index for detecting the pollution degree of different varieties of maize under copper stress**
Author Name	Chao Zhang, Keming Yang, Min Wang, Peng Gao, Feng Cheng, Yan Lia and Tian Xia
Journal Name	Remote Sensing Letters
Year	2019
Volume and Issue	171
Pages	878 - 886
Abstracts	This study proposed a new vegetation heavy metal pollution index VHMPI to detect the pollution degree of different varieties of maize under copper stress, which provides a new idea for the detection of heavy metal pollution in vegetation. In order to ensure the outdoor growth environment of maize, we put all maize into outdoor greenhouse. The spectral reflectance interval of 450 nm–850 nm of maize leaves was processed by the first order differential (D) and continuum removal (CR), and the DCR spectral curve was obtained. The Pearson correlation coefficient (R) was used to analyze the DCR data and the biochemical data and select characteristic bands that sensitive to heavy metal Cu. The calculated Pearson correlation coefficients suggested that the DCR value at 490 nm–520 nm and 680 nm–700 nm presented a linear positive correlation close to 1 with the Cu2+ contents in soil and leaves, and a linear negative correlation close to −1 was present in the range of 630 nm–650 nm and 710 nm–750 nm. We selected the DCR value of wavelengths 505 nm, 640 nm, 690 nm and 730 nm to establish VHMPI, and compared it with conventional vegetation indices (VIs) by calculating Pearson correlation coefficient between them and Cu contents in soil and leaves, Vegetation indices include WBI (Water Band Index), PSNDa (Pigment Specific Normalized Difference a), PRI (Photochemical Reflectance Index), NDVI (Normalized Difference Vegetation Index). Maize leaf spectral data obtained from experiments in 2017 were used for verification, VHMPI was also compared with WBI, PSNDa, PRI and NDVI.The results suggested that VHMPI showed a significant correlation with Cu2+ stress concentration,and the correlation of VHMPI was much stronger than that of other vegetation indices. The proposed VHMPI detects the pollution degree of maize with different varieties and in different periods under copper stress has advantages of straightforward calculation, robustness, and high effectiveness. This study focused on the laboratory leaf scale, so it is expected that future work extends it to a wide range of field scale and image scale.
Keywords	pollution index; copper stress; greenhouse; wavelengths; vegetation indices (VIs)

Title	**Hydrogen peroxide modulate photosynthesis and antioxidant systems in tomato (Solanum lycopersicum L.) plants under copper stress**
Author Name	Faroza Nazir, Anjuman Hussain & Qazi Fariduddin
Journal Name	Chemosphere
Year	2019
Volume and Issue	230
Pages	544 - 558
Abstracts	Plant growth and development could be modulated by minute concentrations of hydrogen peroxide (H_2O_2) which serves as a signaling molecule for various processes. The present work was conducted with an aim that H_2O_2 could also modify root morphology, morphology and movement of stomata, photosynthetic responses, activity of carbonic anhydrase, and antioxidant systems in tomato (*Solanum lycopersicum L.*) plants under copper stress (Cu; 10 or 100 mg kg^{-1} soil). Roots of 20 d old plants were dipped in 0.1 or 0.5 mM of H_2O_2 solution for 4 h and then transplanted to the soil filled in earthen pots. High Cu stress (100 mg kg^{-1} soil) altered root morphology, reduced chlorophyll content and photosynthetic capacity and also affected movement of stomata and generation of antioxidant species at 40 d after transplantation. Further, root dipping treatment of H_2O_2 to plants under stress and stress-free conditions enhanced accumulation of proline and activity of catalase, peroxidase, and superoxide dismutase, whereas production of superoxide radical ($O_2•^-$) and H_2O_2 were decreased. Overall, H_2O_2 treatment improved growth, photosynthesis, metabolic state of the plants which provided tolerance and helped the plants to cope well under Cu stress.
Keywords	Antioxidant; Copper; Hydrogen peroxide; Photosynthesis; Tomato

Title	**Copper excess reduces nitrate uptake by Arabidopsis roots with specific effects on gene expression**
Author Name	Franz W.R. Hippler, Dirceu Mattos-Jr, Rodrigo M. Boaretto & Lorraine E.Williams
Journal Name	Journal of Plant Physiology
Year	2018
Volume and Issue	228
Pages	158-165
Abstracts	Nitrate uptake by plants is mediated by specific transport proteins in roots (NRTs), which are also dependent on the activity of proton pumps that energize the reaction. Nitrogen (N) metabolism in plants is sensitive to copper (Cu) toxicity conditions. To understand how Cu affects the uptake and assimilation processes, this study assesses the inhibitory effects of elevated Cu levels on the expression of genes related to N absorption, transport and assimilation in roots of Arabidopsis. Plants were grown hydroponically for 45 days, being exposed to a range of Cu concentrations in the last 72 h or alternatively exposed to 5.0 μM Cu for the last 15 days. High Cu levels decreased the uptake and accumulation of N in plants. It down-regulated the expression of genes encoding nitrate reductase (NR1), low-affinity nitrate transporters (NRT1 family) and bZIP transcription factors (TGA1 and TGA4) that regulate the expression of nitrate transporters. Cu toxicity also specifically down-regulated the plasma membrane proton pump, AHA2, whilst having little effect on AHA1 and AHA5. In contrast, there was an up-regulation of high-affinity nitrate transporters from the NRT2 family when exposed to medium level of Cu excess, but this was insufficient for restoring N absorption by roots to control levels. These results demonstrate that plants display specific responses to Cu toxicity, modulating the expression of particular genes related to nitrate uptake, such as low-affinity nitrate transporters and proton pumps.
Keywords	Nitrate transporter; Proton pump; Metal toxicity; Nutrient uptake

Title	**A methionine-R-sulfoxide reductase, OsMSRB5, is required for rice defense against copper toxicity**
Author Name	Tengwei Xiao, Mengmeng Mi, Changyong Wang, Meng Qian, Yahu Chen, Luqing Zheng, Hongsheng Zhang, Zhubing Hu, Zhenguo Shen & Yan Xia
Journal Name	Environmental and Experimental Botany
Year	2018
Volume and Issue	153
Pages	45 - 53
Abstracts	Methionine sulfoxide reductases (MSRs), a family of enzymes catalyzing the conversion of methionine from its oxidized form into its reduced form, has a pivotal role in responding to oxidative stress. In the present study, we found that OsMSRB5 plays a crucial role in rice adaption to Cu stress. OsMSRB5 was mainly expressed in leaves, with low transcriptional levels of OsMSRB5 observed in seeds, stems, and roots; this gene was also induced by the excess copper (Cu) treatment. The functions of OsMSRB5 were analyzed through ectopic expression in Escherichia coli and functional disruption in rice. An in vitro enzymatic activity assay showed that OsMSRB5 had the ability to reduce free methionine-R-sulfoxide (Met-R-SO) and protein-bound-like Met-SO (dabsyl-Met-SO) to Met and dabsyl-Met, respectively. Ectopic expression of OsMSRB5 conferred E. coli cells higher tolerance to excess Cu and methyl viologen (MV). Furthermore, OsMSRB5 mutation decreased Cu and MV tolerance in rice. Our results demonstrate that rice OsMSRB5 is a functional methionine sulfoxide reductase and is involved in defense against Cu toxicity. In addition, rice seedlings responding to MV-induced oxidative stress showed a similar phenotype with excess Cu.
Keywords	Methionine sulfoxide reductase; Rice; Copper toxicity; Oxidative stress; Substrate specificity

Title	**Physiological and biochemical responses of Salix integraThunb. under copper stress as affected by soil flooding**
Author Name	Yini Cao, Chuanxin Ma, Guangcai Chen, Jianfeng Zhang, BaoshanXing
Journal Name	Environmental Pollution
Year	2017
Volume and Issue	225
Pages	644-653
Abstracts	To explore the joint effect of copper (Cu) and flooding on Salix integra Thunb. (*S. integra*), the physiological and biochemical parameters of the seedlings grown in Cu amended soil (50, 150, 450 mg kg^{-1}) with or without the flooding for 60 days were evaluated. The results suggested that the flooding significantly inhibited the root growth in terms of root length and root tips. The Cu exposures of 50 and 150 mg kg^{-1} notably enhanced the root growth as compared to the control. Majority of Cu was accumulated in *S. integra* roots, while flooding significantly reduced the Cu content, except the 150 mg kg^{-1} Cu treatment, but the iron (Fe) and manganese (Mn) content on the root surface were both markedly increased relative to non-flooded control. The malonaldehyde (MDA) and glutathione (GSH) contents in leaves showed a dose-response upon Cu exposure. Soil flooding enhanced the GSH level, which displayed 4.50–49.59% increases compared to its respective non-flooded treatment, while no difference was evident on MDA contents between the flooding and the non-flooded treatments. Both superoxide dismutase (SOD) and peroxidase (POD) activities were boosted while the catalase (CAT) was suppressed with increasing Cu exposure dose, and soil flooding reduced the POD and CAT activities. The elevated Cu level caused the evident increases of root calcium (Ca), potassium (K), and sulfur (S) concentrations and decreases of root phosphorus (P), sodium (Na), and zinc (Zn) concentrations. Soil flooding increased the concentrations of Fe, S, Na, Ca, and magnesium (Mg) in *S. integra* root. Taken together, our results suggested *S. integrahas* high tolerance to the joint stress from Cu and flooding.
Keywords	Willow; Copper; Flooding; Oxidative; Stress; Nutrients; Phytoremediation

Title	**Morphophysiological, ultrastructural, and nutritional changes induced by Cu toxicity in young Erythrina fusca plants**
Author Name	Vania L. Souza, Alex-Alan F. de Almeida, Pedro A. O. Mangabeira, Delmira da C. Silva, Raildo M. de Jesus & Raúl René Valle
Journal Name	International Journal of Phytoremediation
Year	2017
Volume and Issue	19, (7)
Pages	621–631
Abstracts	*Erythrina fusca* is an important legume used for shade cover in cacao plantations in Brazil. Cacao plantations receive large quantities of copper (Cu)-containing agrochemicals, mainly for control of diseases. Therefore, Cu toxicity was investigated in seedlings grown in hydroponics with increasing concentrations of Cu (0.005–32 mg L¡1) in a greenhouse. Ultrastructural analyses showed cell plasmolysis in the root cortical area and changes in thylakoid membranes at 8 mg Cu L¡1 and higher. There were changes in epicuticular wax deposition on the leaf surface at the 16 and 32 mg Cu L¡1 treatments. Leaf gas exchanges were highly affected 24 hours after application of treatments beginning at 8 mg Cu L¡1 and higher Cu concentrations. Chemical analyses showed that Cu content in E. fusca roots increased as Cu concentration in the nutrient solution increased, whereas the shoot did not show significant changes. It is also observed that excess Cu interfered with Zn, Fe, Mn, Mg, K, P, and Ca content in the different E. fusca organs. Investigation of Cu toxicity symptoms focusing on morphophysiological, ultrastructural, gas exchange, and nutritional changes would be useful to alleviate Cu toxicity in E. fusca under field conditions, an important agroforestry species in cacao plantation.
Keywords	Heavy metal; photosynthesis; shade cover species

Title	**Comprehensive Analysis of Rice Laccase Gene (OsLAC) family and Ectopic Expression of OsLac 10 Enhances Tolerance to copper stress in *Arabidopsis***
Author Name	Yini Cao, Chuanxin Ma, Guangcai Chen, Jianfeng Zhang, BaoshanXing
Journal Name	Environmental Pollution
Year	2017
Volume and Issue	225
Pages	644-653
Abstracts	To explore the joint effect of copper (Cu) and flooding on *Salix integra Thunb. (S. integra*), the physiological and biochemical parameters of the seedlings grown in Cu amended soil (50, 150, 450 mg kg^{-1}) with or without the flooding for 60 days were evaluated. The results suggested that the flooding significantly inhibited the root growth in terms of root length and root tips. The Cu exposures of 50 and 150 mg kg^{-1} notably enhanced the root growth as compared to the control. Majority of Cu was accumulated in *S. integra* roots, while flooding significantly reduced the Cu content, except the 150 mg kg^{-1} Cu treatment, but the iron (Fe) and manganese (Mn) content on the root surface were both markedly increased relative to non-flooded control. The malonaldehyde (MDA) and glutathione (GSH) contents in leaves showed a dose-response upon Cu exposure. Soil flooding enhanced the GSH level, which displayed 4.50–49.59% increases compared to its respective non-flooded treatment, while no difference was evident on MDA contents between the flooding and the non-flooded treatments. Both superoxide dismutase (SOD) and peroxidase (POD) activities were boosted while the catalase (CAT) was suppressed with increasing Cu exposure dose, and soil flooding reduced the POD and CAT activities. The elevated Cu level caused the evident increases of root calcium (Ca), potassium (K), and sulfur (S) concentrations and decreases of root phosphorus (P), sodium (Na), and zinc (Zn) concentrations. Soil flooding increased the concentrations of Fe, S, Na, Ca, and magnesium (Mg) in S. integra root. Taken together, our results suggested *S. integrahas* high tolerance to the joint stress from Cu and flooding.
Keywords	Rice; Laccase; OsLAC 10; Copper Tolerance; Copper uptake; Arabidopsis

Title	**Copper (Cu) stress affects carbon and antioxidant metabolism in *Coffea arabica seedling***
Author Name	Dos Santos, Jacqueline Oliveria, de Faria, Marico Espinosa, da Silva, Dayane Meireles, de Oliveria Silveria, Helbert Rezende, Campos, Cleide Nascimento, Alves Jose Donizeti
Journal Name	Australian Journal of Crop Science
Year	2017
Volume and Issue	11, 8
Pages	960-967
Abstracts	Although copper is a micronutrient essential for the normal development of plants, both insufficient and supra optimal doses can disrupt the functioning of metabolism and the production of biomass. To study the biochemical and physiological impacts of deficiency and excess of copper in coffee, we treated 6-month-old seedlings of *Coffea arabica L. Catua* cultivar to three copper treatments: control (0.03 ppm), excess (0.12 ppm) and deficiency (0 ppm) for 60 days. The changes in levels of photosynthetic pigments, biomass allocation, carbohydrate partitioning, antioxidant system and proline levels were evaluated. Under deficiency and excess of copper coffee seedlings showed lower levels of chlorophyll, reduction on dry weight of shoot, lower sugar levels and higher content of hydrogen peroxide. We also observed increased levels of proline and enzymatic activity of the antioxidant system, providing conditions for the reduction of oxidative stress triggered by nutritional imbalance. In general, the results showed that coffee plants invest in antioxidant defense system as an alternative to maintain redox balance when exposed to deficiency or excess copper. However, it is not effective to prevent an increase in lipid peroxidation. Authors may indicate an optimum range for application of copper in coffee.
Keywords	Antioxidant system; Proline; Carbohydrate

Title	The Effect of Copper on Plant Regeneration in Barley Microspore
Author Name	Katarzyna Makowska, Sylwia Oleszczuk and Janusz zimny
Journal Name	Czech J. Genet. Plant Breed
Year	2017
Volume and Issue	53, 1
Pages	17–22
Abstracts	Isolated microspore culture is an excellent system for the production of doubled haploids in many crops, including barley. In a more traditional barley anther culture method copper sulphate is known to enhance plant regeneration. Here we report that one hundred times higher concentration of copper sulphate in the isolated microspore culture of two spring barley genotypes compared to the standard content in the induction medium resulted in a 34% increase of total plant regeneration. Detailed analysis of plant regeneration showed that additional supplementation of copper sulphate increased not only the regeneration of green plants but also proportionately that of albino plants. Hence, the results from two studied genotypes do not support an assumption that the addition of copper reduces albinism in barley microspore culture. Keywords: albinism; androgenesis; doubled haploid; Hordeum vulgare; regenaration efficiency.
Keywords	Albinism; Androgenesis; Doubled haploid; Hordeum vulgare; Regenaration efficiency

Title	**Anatomical peculiarities in wheat (Triticum aestivum L.) varities under copper stress**
Author Name	Saule Atabayeva1, Akmara nurmahanova , Aygul Akhmetova , Meyramkul Narmuratova , Saltanat Asrandina , Aizhan Beisenova , Ravilya Alybayeva and Tamara Lee
Journal Name	Pak. J. Bot
Year	2016
Volume and Issue	48, 4
Pages	1399-1405
Abstracts	The effect of different concentrations (0.25 mM, 0.5 mM) of Cu^{2+} on anatomical parameters of leaves and roots was investigated in hydroponically grown five wheat (*Triticum aestivum L.*) varieties (Kazakhstanskaya rannaya, Kazakhstanskaya-3, Melturn, Kaiyr and Shagala). The results showed that wheat varieties exposed to 0.5 mM Cu^{2+} exhibited significant alterations in anatomical structure of leaves and roots. The thickness of the upper and lower epidermis, diameter of vascular bundles of leaves of almost all varieties showed a tendency to decrease under copper stress. Our experiments showed an activation of defense responses in the root anatomical structure like exodermis thickening in some varieties in the presence of copper in growth medium as compared to the control. This indicates that copper ions increase the thickness of exodermis, which reduce the absorption of toxic elements by root cells. Copper stress caused a decrease in the thickness of the lower and upper epidermis to varying degrees and reduction in the diameter of vascular bundles of wheat leaves. Copper stress caused a reduction in endodermis thickness thereby decreasing the diameter of the central cylinder of wheat roots. Key words: Wheat, Copper, Anatomical structure, Exodermis, Endodermis, Vascular bundles, Central cylinder.
Keywords	Wheat; Copper; Anatomical structure; Exodermis; Endodermis; Vascular bundles; Central cylinder.

Title	**Effects of copper-induced stress on seed germination of Maize (*Zea Mays L.*)**
Author Name	Boroş Melania-Nicoleta, V. Micle
Journal Name	Agriculture - Science and Practice
Year	2015
Volume and Issue	95
Pages	17-23
Abstracts	The existence of heavy metals in polluted soils requires remediation technologies that can solve the problem of contamination in an environmentally friendly way. Plants used in phytoremediation projects can clean the contaminated areas and can become a solution for green approaches to this issue. One of the plants with great potential in phytoremediation is Zea mays, a very common crop plant. This experiment aimed to determine the effect of the variation in concentration of copper sulphate on the germination and growth of seeds of Zea mays. We wanted to establish which is the highest concentration of copper that seeds of Zea mays can tolerate. Seedlings growth investigation and measurements were made after 7 days. The seed germination rate was high for the low concentration and control and decreased dramatically with the increase in concentration. At high concentration the abnormal development of seeds was visible, shoots and roots growing much shorter. Keywords: copper stress, crop plant, seed germination, Zea mays.
Keywords	Copper stress; Crop plant; Seed germination; Zea mays

Title	Evaluating wild grapevine tolerance to copper toxicity
Author Name	J. Cambrollé, J.L. García , M.E. Figueroa, M. Cantos
Journal Name	Chemosphere
Year	2015
Volume and Issue	120
Pages	171 - 178
Abstracts	We evaluate copper tolerance and accumulation in Vitis vinifera ssp. sylvestris in populations from a copper contaminated site and an uncontaminated site, and in the grapevine rootstock “41B”, investigating the effects of copper (0–23 mM) on growth, photosynthetic performance and mineral nutrient content. The highest Cu treatment induced nutrient imbalances and inhibited photosynthetic function, causing a drastic reduction in growth in the three study plants. Effective concentration was higher than 23 mM Cu in the wild grapevines and around 9 mM in the “41B” plants. The wild grapevine accessions studied controlled root Cu concentration more efficiently than is the case with the “41B” rootstock and must be considered Cu-tolerant. Wild grapevines from the Cu-contaminated site present certain physiological characteristics that make them relatively more suitable for exploitation in the genetic improvement of vines against conditions of excess Cu, compared to wild grapevine populations from uncontaminated sites.
Keywords	Copper; Tolerance; Toxicity; Wild grapevine

Title	**The effect of excess copper on growth and physiology of important food crops: a review**
Author Name	Muhammad Adrees, Shafaqat Ali, Muhammad Rizwan, Muhammad Ibrahim, Farhat Abbas, Mujahid Farid, Muhammad Zia-ur-Rehman, Muhammad Kashif Irshad, Saima Aslam Bharwana
Journal Name	Environmental Science and Pollution Research
Year	2015
Volume and Issue	22
Pages	171 - 178
Abstracts	In recent years, copper (Cu) pollution in agricultur- al soils, due to arbitrary use of pesticides, fungicides, indus- trial effluent and wastewater irrigation, present a major con-cern for sustainable agrifood production especially in devel-oping countries. The world's major food requirement is ful-filled through agricultural food crops. The Cu-induced losses in growth and yield of food crops probably exceeds from all other causes of food safety and security threats. Here, we review the adverse effects of Cu excess on growth and yield of essential food crops. Numerous studies reported the Cu-induced growth inhibition, oxidative damage and antioxidant response in agricultural food crops such as wheat, rice, maize, sunflower and cucumber. This article also describes the toxic levels of Cu in crops that decreased plant growth and yield due to alterations in mineral nutrition, photosynthesis, enzyme ac- tivities and decrease in chlorophyll biosynthesis. The response of various crops to elevated Cu concentrations varies depend- ing upon nature of crop and cultivars used. This review couldbe helpful to understand the Cu toxicity and the mechanism of its tolerance in food crops. We recommend that Cu-tolerant crops should be grown on Cu-contaminated soils in order to ameliorate the toxic effects for sustainable farming systems and to meet the food demands of the intensively increasing population.
Keywords	Copper; Growth; Mineral nutrition; Photosynthesis; Yield

Title	**Experimental determinations of soil copper toxicity to lettuce (*Lactuca sativa*) growth in highly different copper spiked and aged soils**
Author Name	Karen S. Christiansen, Ole K. Borggaard, Peter E. Holm, Martina G. Vijver, Michael Z. Hauschild, Willie J. G. M. Peijnenburg
Journal Name	Environmental Science and Pollution Research
Year	2014
Volume and Issue	22
Pages	5283–5292
Abstracts	Accurate knowledge about factors and conditions determining copper (Cu) toxicity in soil is needed for predicting plant growth in various Cu-contaminated soils. Therefore, effects of Cu on growth (biomass production) of lettuce (*Lactuca sativa*) were tested on seven selected, very different soils spiked with Cu and aged for 2 months at 35 °C. Cu toxicity was expressed as pEC50 (Cu^{2+}), i.e., the negative logarithm of the EC50(Cu^{2+}) activity to plant growth. The determined pEC 50(Cu^{2+}) was significantly and positively cor- related with both the analytically readily available soil pH and concentration of dissolved organic carbon [DOC] which to- gether could explain 87 % of the pEC50(Cu^{2+}) variation ac-cording to the simple equation: pEC50 (Cu^{2+})=0.98×pH+ 345×[DOC]−0.27. Other soil characteristics, including the base cation concentrations (Na^{+}, K^{+},Ca^{2+}, Mg^{2+}), the cation exchange capacity at soil pH (ECEC), and at pH 7 (CEC7), soil organic carbon, clay content, and electric conductivity as well as the distribution coefficient (Kd) calculated as the ratio between total soil Cu and water-extractable Cu did not corre- late significantly with pEC50(Cu^{2+}). Consequently, Cu toxic-ity, expressed as the negative log of the Cu2+ activity, to plant growth increases at increasing pH and DOC, which needs to be considered in future management of plant growth on Cu- contaminated soils. The developed regression equation allows identification of soil types in which the phytotoxicity potential of Cu is highest.
Keywords	Cu; DOC; pH; EC50; Soilcontamination; LCA

Title	**Copper toxicity in Chinese cabbage is not influenced by plant sulphur status, but affects sulphur metabolism-related gene expression and the suggested regulatory metabolites**
Author Name	M. Shahbaz, C. E. E. Stuiver, F. S. Posthumus, S. Parmar, M. J. Hawkesford and L. J. De Kok
Journal Name	Plant biology
Year	2014
Volume and Issue	16, 1
Pages	68–78
Abstracts	The toxicity of high copper (Cu) concentrations in the root environment of Chinese cabbage (*Brassica pekinensis*) was little influenced by the sulphur nutritional status of the plant. However, Cu toxicity removed the correlation between sulphur metabolism-related gene expression and the suggested regulatory metabolites. At high tissue Cu levels, there was no relation between sulphur metabolite levels viz. total sulphur, sulphate and water-soluble non-protein thiols, and the expression and activity of sulphate transporters and expression of APS reductase under sulphate-sufficient or-deprived conditions, in the presence or absence of H_2S. This indicated that the regulatory signal transduction pathway of sulphate transporters was overruled or by-passed upon exposure to elevated Cu concentrations.
Keywords	Abiotic stress; APS reductase; H_2S; heavy metals; sulphate deprivation; sulphate reduction; sulphate transporters; sulphur assimilation; thiol compounds

Title	**Exogenous sodium nitroprusside and glutathione alleviate copper toxicity by reducing copper uptake and oxidative damage in rice (*Oryza sativa L.*) seedlings**
Author Name	Mohammad Golam Mostofa, Zeba Islam Seraj, Masayuki Fujita
Journal Name	Protoplasma
Year	2014
Volume and Issue	251
Pages	1373 – 1386
Abstracts	Nitric oxide (NO) and glutathione (GSH) regulate a variety of physiological processes and stress responses; how- ever, their involvement in mitigating Cu toxicity in plants has not been extensively studied. This study investigated the interactive effect of exogenous sodium nitroprusside (SNP) and GSH on Cu homeostasis and Cu-induced oxidative dam-age in rice seedlings. Hydroponically grown 12-day-old seed- lings were subjected to 100µ MCuSO4 alone and in combination with 200µ M SNP (an NO donor) and 200µ MGSH. Cu exposure for 48 h resulted in toxicity symptoms such asstunted growth, chlorosis, and rolling in leaves. Cu toxicity was also manifested by a sharp increase in lipoxygenase (LOX) activity, lipid peroxidation (MDA), hydrogen peroxide (H_2O_2), proline (Pro) content, and rapid reductions in bio-mass, chlorophyll (Chl), and relative water content (RWC). Cu-caused oxidative stress was evident by overaccumulation of reactive oxygen species (ROS; superoxide (O_2•–)and H_2O_2). Ascorbate (AsA) content decreased while GSH and phytochelatin (PC) content increased significantly in Cu- stressed seedlings. Exogenous SNP, GSH, or SNP+GSH decreased toxicity symptoms and diminished a Cu-induced increase in LOX activity, O_2•–, H_2O_2, MDA, and Pro content.They also counteracted a Cu-induced increase in superoxide dismutase (SOD), ascorbate peroxidase (APX), glutathione reductase (GR), monodehydroascorbate reductase (MDHAR), and glyoxalase I and glyoxalase II activities, which paralleled changes in ROS and MDA levels. These seedlings also showed a significant increase in catalase (CAT), glutathione peroxidase (GPX), dehydroascorbate re- ductase (DHAR), glutathione S-transferase (GST) activities, and AsA and PC content compared with the seedlings stressed with Cu alone.
Keywords	Cu toxicity; Oxidative stress; Nitric oxide; Glutathione; Antioxidant system; Cu homeostasis