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Effect of Heavy Metals on Morphology of Plants: A Review

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ABSTRACT

Heavy metals refer to any metallic element that has relatively high density and is toxic or poisonous even at low concentration. Soils polluted with heavy metals have become come due to increase in anthropogenic and geological activities. Heavy metals enter the food chain through plants. Plants are most important source for humans as well as animals in terms of food medicine etc. Because without plants a man cannot live a long healthy life on earth as plants have a long history for using curing disease of living creatures on earth. This review focuses on the heavy metal stress that makes changes in the morphology of plants like reduction in the growth and productivity and even the production is unsafe for the use.

1. Introduction

Heavy metals belong to a group of non biodegradable, persistent inorganic chemical constituents with atomic mass over 20 and the density higher than 5g/cm^3 that have cytotoxic, genotoxic and mutagenic effects on animals and plants. Heavy metals have largest availability in soil and aquatic ecosystems and to a relatively smaller proportion in atmosphere as particulate or vapours. Heavy metals in soil may move towards the root surface either through diffusion along with the water or by ion exchange between clay particles and the root surface. Release of metals from soil particles can be facilitated by root/microbial exudates and activities within the rhizosphere. Movement of the elements into roots occurs either by passive diffusion mediated by the cell membrane, or via the more common processes of active transfer against concentration and/or electrochemical potential gradients (Clarkson and Luttge 1989; Fergusson, 1990; Stroinski, 1999). The active uptake has been adapted by plants for absorption of essential trace metals but, simultaneously, the other available elements are also taken up (Silver, 1983). Metals can move inside the cell along a concentration gradient through cation channels located within the cell membrane (Kochian, 1995).

Heavy metal toxicity 'to plants vary with plant species, specific metal, concentration, chemical form, and soil composition and pH, as many heavy metals are considered to be essential for plant growth. Similarly many heavy metals are essential trace nutrients of animals and human body (Wintz *et al.,* 2002). Some of these heavy metals like Cu and Zn serve either as cofactor and activators of enzyme reactions e.g. informing enzymes/substrate metal complex (Mildvan, 1970) or exert a catalytic property such as prosthetic group in metalloproteins. These essential trace metal nutrients take part in redox reactions, electron transfer and structural functions in nucleic acid metabolism. Some of heavy metal such as Cd, Hg and As, etc are strongly poisonous to metal sensitive enzymes, resulting in growth inhibition and death of organisms. Despite this problem and limited knowledge of its dangers by consumer, demands for better quality and less expensive agricultural products are increasing especially in urban cities (Mapanda et al., 2007). Some consumers consider undamaged, dark green and big leaves as characteristics of good quality leafy vegetables. However, the external morphology of vegetables cannot guarantee safety from contamination especially when farming activities are carried out around industrial areas. Evidence of severe poisoning caused by some metal compounds and the proven carcinogenicity of some metal ions has fostered intensive research into the different uptake and translocation pattern in food crops (Velez et al., 2004).

Heavy metals make a significant contribution to environmental pollution as a result of human activities such as mining, smelting, electroplating, fuel production power transmission, intensive agriculture and sludge dumping (Nedelkoska and Doran, 2000). However, elevated concentrations of both essential and non-essential heavy metals in the soil can lead to toxicity symptoms and growth inhibition in most plants (Hall, 2002; Li *et al.,* 2010). Heavy metals such as Co, Cu, Fe, Mn, Mo, Ni, and Zn are required in minute quantities by organisms, excessive amount of these elements can become harmfull to organisms. Whereas heavy metals such as Pb, Cd, Hg do not have any beneficial effect on organisms and are thus regarded as main threats, since they are very harmfull to both plants and animals. The content of heavy metals in the environment has increased considerably in recent years due to the improper discard of industrial waste, to intensification of agricultural activities, and to the expansion of urban areas, resulting in serious socio environmental problems (Zalewska, 2012). In most cases, uptake of metals causes a reduction of biomass production by plants, but in extreme cases in which the content of these metals is too high, the area may become desertified (Koptsik, 2014). Heavy metals have different effect on different growth stages of plants. In the early stage, Cd inhibits the photosynthesis and growth of rice, then inhibits the reproductive organs' differentiation, and finally distributes the nutrients transport and mobilization (Wang, 1996), but a low concentration of Hg (10 -s mol/L) stimulated the growth of wheat seedlings. The reason for this may be that low concentrations of Hg increased the activities of amylase, proteinase and lipase, sped up the decomposition of endosperm and the respiration rate, so that the germination was more rapid (Ma and Hong, 1998).

Heavy metal (HM) toxicity is thought to be one of the major abiotic stresses leading to hazardous effects in plants. Worldwide agricultural soils are slightly to considerably contaminated from heavy metals that limit the crop plants to achieve their full genetic potential and also reduce their productivity. Soil pollution by heavy metals has reasonably increased in last few decades due to discharge of wastewater and waste from anthropogenic sources. In spite of its potential physiological and economical significance, morphological alterations induced by heavy metals in plants have so far been grossly overlooked. It is one of the main current environmental health problems and potentially harmfull due to its bioaccumulation through food chain and plant products for human consumption. When penetrating the roots, heavy metals are predominantly accumulated and translocated in the cell wall system (MacFarlane and Burchett, 2000), with the exodermis and the endodermis constituting an effective barrier to the movement of these ions (Ederli *et al.,* 2004; Lux *et al*., 2004; Wojcik *et al.,* 2005). Studying changes in leaf tissues also helps understand the process of metal accumulation and tolerance, since the absorption of these ions from the soil solution is closely related to the leaf transpiration rate.

The accumulation of potentially toxic elements may vary from plant to plant and soil (Kishu, *et al.,* 2000). Agricultural soils are usually rich in heavy metals due to fungicides, herbicides, phosphate fertilizers, organic manures and the decaying plants and animals residue. The use of sewage sludge and waste water for irrigation further increases the concentration of heavy metals in agricultural soils. Agricultural runoff together with soil erosion is the potential sources of heavy metals in aquatic bodies (Agrawal, 2002). World Health Organization (WHO) has recognized health hazards of these metals in food chain even at low concentration (WHO, 1984). The deposition of metals in soil and water find their way to human being via plant uptake process.

The presence of heavy metals in soil solution or in nutrient solution firstly modifies the uptake of nutrients by plants, especially of cationic micronutrients Cu2+, Fe2+, Mn2+, and Zn2+ due to their competition for the same uptake sites located in the roots (Zhang *et al.,* 2014a,b). After they are absorbed, heavy metals can alter the process of transfer of electrons existing in cell organelles, providing favourable conditions to the generation of reactive-oxygen species (ROS), which cause lipid peroxidation of membranes2 in all plant tissues (Farmer & Mueller, 2013). Alteration in the process of uptake of micronutrients associated with the generation of ROS, such as hydroxyl (OH-), superoxide (O2 -), and singlet oxygen ($1O_2$), which are the most reactive ROS present in the cell medium, are within the main factors resulting in decreased biomass production by plants (Gill & Tuteja, 2010; Zhang *et al.,* 2014a,b). Thus, it is essential that plants exposed to heavy metals have an efficient antioxidant system so as to lessen the injuries caused by the ROS (Gratao *et al*., 2005; Luo *et al*., 2011).

The phytotoxic effect of heavy metals in plants manifests itself through visual symptoms such as chlorosis, necrosis and wilting, and through reduced growth and biomass accumulation (Marques *et al.,* 2000; Sanita di Troppi and Gabbrielli, 1999). Physiological effects have also been noted in plants exposed to contamination at various levels of the photosynthetic process, including the chlorophyll biosynthesis (Chugh and Sawhney, 1999), the dynamics of photochemical reactions (Skorzynska- Polit *et al.,* 2003) and the activity of Calvin cycle enzymes (Cagno *et al.,* 1999).

2. Effect of some heavy metals on morphology of plants

The heavy metals available for plant uptake are those present as soluble components in the soil solution or those solubilised by root exudates (Blaylock and Huang, 2000). Like every living organisms, plants are often sensitive both to the deficiency and to the excess availability of some heavy metal ions as essential micronutrient, while the same at higher concentrations and even more ions such as Cd, Hg, as are strongly poisonous to the metabolic activities. Research has been conducted throughout the world to determine the effects of toxic heavy metals on plants (Hussain *et al.,* 2013; Reeves and Baker, 2000).

Copper: Copper is an essential micronutrient that plays important role in normal plant growth and development. Copper participates in the electron transport chain in photosystem I and photosystem II and in the fixation of nitrogen and also plays an important role in carbondioxide assimilation and ATP synthesis. However, Cu becomes toxic when its concentration in the tissue of plants rises above optimal levels (Lombardi and sebastiani, 2005). Cu exists in many states in soils but is mainly taken up by plants in the form of Cu2+

(Maksymeic, 1997). The concentration of copper in soil is typically between 2 and 250 μg·g−1 and healthy plants can absorb 20–30 μg·g−1 DW (Azooz *et al.,* 2012). But copper availability depends greatly on soil pH and its phytoavailability increases with declining pH (Sheldon and Menzies, 2005). Excess of copper in soil induces stress and causes injury to plants, which leads to plant growth retardation and leaf chlorosis(Katare *et al.,* 2015; Lewis *et al.,* 2001). Copper stress leads to reduced germination rate and induces biomass mobilization by release of glucose and fructose thereby inhibiting the breakdown of starch and sucrose in reserve tissue by inhibition in the activities of alpha-amylase and invertase isoenzymes (Pena *et al.,* 2011; Sfaxi *et al.,* 2010; Singh *et al* 2007).

Nickel: Nickel is an essential micronutrient for plants. The amount of nickel required for normal growth and development of plants is very low. However, with the level of Ni pollution in the environment increasing, it is essential to understand the functional roles and toxic effects of Ni in plants. Ni+2 concentration in polluted soil may range from 20 to 30 fold (200–26,000 mg/kg)

Higher than the overall range (10–1,000 mg/kg) found in natural soil (Izosimova, 2005). Nickel deficient plants accumulate urea in their leaves and, consequently, show leaf tip necrosis. Plants grown in soil seldom, if ever, show signs of nickel deficiency because the amount of nickel required are minuscule. Ni, especially at high concentrations, can readily move through phloem and xylem vessels, thereby translocating smoothly from the root to the upper parts of plants (Ishtiaq and Mahmood, 2011). This ease of movement towards shoots is due to the pattern by which Ni is distributed within the tissue of roots, which differs from some other HMs such as Pb and Cd so that it can pass through the endodermal barrier and amass in the pericycle cells (Seregin and Kozhevnikova, 2006). Several studies in plants including maize (Seregin and Kozhevnikova, 2003) and cowpea (Kopittke *et al.,* 2007) have confirmed this phenomenon and indicated that Ni toxicity can result in inhibited lateral root formation and development.

Lead: Lead (Pb) is one of the ubiquitously distributed most abundant toxic elements in the soil. The toxic level of Pb in soil results from disposal of municipal sewage sludge, mining and smelting activities, Pb containing paints, paper and pulp, gasoline and explosives. It exerts adverse effect on morphology, growth and photosynthetic processes of plants. A high lead level in soil induces abnormal morphology in many plant species. For example, lead causes irregular radial thickening in pea roots, cell walls of the endodermis and lignification of cortical parenchyma (Paivoke, 1983). Lead (Pb) has been reported to strongly affect the seed morphology and physiology. It inhibits germination, root elongation, seedling development, plant growth, transpiration, chlorophyll production, and water and protein content, causing alterations in chloroplast, obstructing electron transport chain, inhibition of Calvin cycle enzymes, impaired uptake of essential elements, Mg and Fe, and induced deficiency of CO_2 due to stomatal closure (Pourrut *et al.,* 2011).

Mercury: Mercury is not essential for plant growth. Contamination of soils by Hg is often due to the addition of this heavy metal as part of fertilizers, lime, sludges, and manures. The dynamics between the amount of Hg that exist in the soil and its uptake by plants is not linear and depends on several variables (e.g., cation-exchange capacity, soil pH, soil aeration, and plant species). Mercury poisoning has become a problem of current interest as a result of environmental pollution on a global scale. Mercury is a strong phytotoxic as well as genotoxic metal (Fridovich, 1986; Suszeynsky & Shann, 1995). It is ubiquitous in the environment and is inevitable for both humans and animals to avoid its exposure in some form or forms on a regular basis. Mercury occurs widely in the biosphere (Clarkson, 1987). Toxic effects of mercury in plants include abscission of older leaves, growth reduction, decreased, vigor inhibition of root and leaf development, and decreased chlorophyll content and nitrate reductase activity (Vyas and Puranik, 1993). In rice (*Oryza sativa*) excess of mercury decreases plant height, reduces tiller and panicle formation, yield reduction and increase of its bioaccumulation in shoot and root of seedling (Kibra, 2008; Du *et al.,* 2005). Further, in tomato (*Lycopersiconesculentum*) show reduction in germination percentage, reduced plant height; reduction in flowering and fruit weight and finally resultant chlorosis appears on the whole plant (Shekar *et al*., 2011).

Cadmium: Cd is highly toxic, often disposed of improperly in the environment and may reach the soil, aquatic media or the air by the burning of municipal waste and fossil fuels, thus contaminating the environment and altering the ecosystem (Pino, 2005). Cd is a non-essential nutrient for plants, and excessive Cd has not only significant adverse effects, but also endangers human health via food chain. Cadmium cause negative effects in plants such as decrease in leaf chlorophyll content, inhibition of photosynthesis etc (e.g. reduction in photosynthesis or growth as well as chloroplast in leaves). Cadmium toxicity causes reduction in biomass which could be due to inhibition of chlorophyll synthesis and photosynthesis (Padmaja *et al.,* 1990). According to Shah and Dubey(1998) cadmium ranks highest amongst all the metals in terms of damage to plant growth and human health. According to Moya *et al.,* (1993) large amount of cadmium in the soil induces many stress symptoms in plants like reduction in root growth, disturbances in mineral nutrition and carbohydrate metabolism, because of which biomass production is drastically reduced. In wheat (*Triticum* sp.) excessive of cadmium reduces the seed germination; decrease in plant nutrient content; reduced shoot and root length (Ahmad *et al.,* 2012; Yourtchi and Bayat, 2013). Whereas in garlic (*Allium sativum*) Cd accumulation reduced shoot growth (Jiang *et al.,* 2001). Lastly in Maize (*Zea mays*) it reduces shoot growth and inhibition of root growth (Wang *et al.,* 2007).

Chromium: Chromium is a toxic metal that can cause serve damage to plants and animals. Chromium is mostly used in industry, such as steel production, alloy preparation, wood preservation, leather tanning, paints, pigments, metal plating, electroplating and other industrial applications. Oxidative stress induced by chromium initiates the degradation of photosynthetic pigments causing decline in growth. Chromium toxicity inhibits the cell division and elongation of plant roots, thus shortening the overall length of roots (Shankar *et al*., 2005).Accumulation of Cr by plants can reduce growth, induce chlorosis in young leaves, reduce pigment content, alter enzymatic function, damage root cells and cause ultrastructural modifications of the chloroplast and cell membrane (Choudhury and Panda, 2004) in onion (*Allium cepa*) chromium toxicity shows the inhibition of germination process and reduction of plant biomass(Nematshahi *et al.,* 2012). Moreover, in wheat (*Triticum sp*.) Reduction of shoot and root growth were noticed (Sharma and Sharma, 1993); Panda and Patra, 2000).

Zinc: Zn has important functions as a cofactor in more than 300 proteins (Palmgren *et al.,* 2008). However, it may become toxic to plants under supra-optimal concentrations (Lin et al., 2005; Broadley *et al.,* 2007; Ricachenevsky *et al.,* 2015). For most soils, Zn is found at adequate concentrations (around 60 mg kg-1) for plant growth, but anthropogenic activities can increase its concentration by industrial processes such as mining and smelting or by agricultural techniques such as addition of biosolid fertilizes, mineral fertilization and pesticides Zn can promote severe physiological and morphological changes, including the inhibition of root elongation (Broadley *et al.,* 2007; Disante *et al.,* 2010. It has been indicated that Zn toxicity depends on plant species and growth stage, and that growth inhibition and biomass reduction are common responses of plants to excess Zn (Li *et al.,* 2009). Zinc in excess reduces the germination, chlorophyll, carotenoid, sugar, amino acid and growth of cluster beans (*Cyamopsis tetragonoloba*) (Manivasagaperumal *et al.,* 2011).

Whereas, in pea (*Pisum sativum*) reduces chlorophyll, photosynthesis and plant growth (Doncheva *et al.,* 2001).

3. Conclusion

From the above discussion and study we conclude that heavy metals have great effect on the morphology of plants. Thus it is obvious from several research reports that percipient use and presence of heavy metals have toxic effects on the plant. It is well needed to escalate the research programmes for better understanding of heavy metal toxicity on plants and allied areas to maintain the ecological harmony of the globe.

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