TOXIC EFFECTS OF HEAVY METALS ON CROP PLANTS

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Abstract

Accumulation of heavy metals in agricultural soils in high concentration can be toxic to crops. Their effects and bioavailability depend on soil p^H, organic acids in the soil, presence of other elements and plant species. Seed germination, number of roots, root length and shoot height of rice (*Oryza sativa*), barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*) are affected by various concentrations of copper (Cu) and zinc (Zn). Cu has a higher effect than Zn and the inhibiting effect of Cu on seed germination is more pronounced on rice than on wheat and barley. Heavy metals reduce grain yields and dry weight of wheat plants, with Cadmium (Cd) having the highest effect and Chromium (Cr) the lowest. Plants resist heavy metal effects by producing metal binding proteins, the storage of heavy metals in trichomes of epidermis and increase in anti-oxidation enzyme activities. There is need to reduce human activities generating heavy metals to prevent heavy metal pollution.

Heavy metal is a term used to describe more than a dozen elements that are metals or metalloids. Many different definitions have been proposed based on density, atomic number, atomic weight, chemical properties and toxicity. Generally, heavy metals have densities above $5g/cm^3$. Examples of heavy metals include lead (Pb), copper (Cu), nickel (Ni), cadmium (Cd), chromium (Cr) and mercury (Hg). (Hawkes, 1997: Duffus, 2002)

Heavy Metal Pollution

A major feature of heavy metal is non-degradability and persistence in all parts of the environment causing air, water and soil pollution. Heavy metals occur naturally in the ecosystem but anthropogenic sources are 4the major cause of pollution. The primary sources of heavy metal are point sources such as mines, factories, smelters, power plants and industries. Diffuse sources include combustion by-products and vehicle emissions (Yaunas and Shahzad, 1998).

Heavy metal pollution is erroneously thought to be a problem associated with area of intense industry. However, roadsides and automobiles are now considered to be among the largest sources of heavy metals. Common metals in road runoff include:

1. Lead: leaded gasoline, tyre wear, lubricating oil, grease and bearing wear.
2. Zinc: tyre wear, motor oil, grease, brake emission, corrosion of galvanized parts.
3. Iron: auto body rust, engine parts.
4. Copper: bearing wear, engine parts and brake emission.
5. Cadmium: tyre wear, fuel burning and batteries.
6. Chromium: air conditioning coolants, engines and brake emissions.
7. Nickel: diesel fuel and gasoline, lubricating oil and brake emission.
8. Aluminium: auto body corrosion (Hawkes, (1997)

Heavy Metals in Agricultural Soil

Metals are important for their influence on development and growth of plants. A toxic concentration of heavy metals is not known in agricultural soils, however, human activities such as land disposal of wastes as soil amendments for crop production is responsible for accumulation of heavy metals in soils. Due to high cost of chemical fertilizers, the land disposal of agricultural, municipal and industrial wastes is widely practiced as a major economic source of nutrients and organic matter for growing cereal crops in many countries (Jamal, Ayub, Usman and Khan, 2002). Zinc, copper and lead are three of the most common heavy metals in waste amended agricultural soils. Copper is an important micronutrient essential for plant growth while zinc has a structural and catalytic role in many proteins and enzymes involved in energy metabolism. Lead is neither an essential nor a beneficial element for plant growth (Hall and Williams, 2003).

Accumulation of heavy metals on agricultural soils in high concentration can be toxic to plants. Most heavy metals are cations, they carry positive charges. Zinc and copper both carry a 2+ charges. Soil particles and loose dust also carry charges. Most clay minerals have net negative charge, soil organic matter have a variety of charges on their surfaces some positive and some negative. The negative charges of the various soil particles tend to attract and bind metal cations and prevent them from becoming soluble and dissolved in water. The soluble form of metals is more dangerous because it is easily transported and available to plants while soil bound metals tend to stay in place. (Munzuroglu and Geckil, 2002).

Poultry manure and mineral fertilizers contain various proportions of heavy metals.

Table 1: Heavy Metals in Samples of Poultry Manure and Mineral Fertilizer (N P K)

Fertilizer	**Zn(µg/g)**	**Pb(µg/g)**
Poultry manure	284.2	110.5
Super phosphate	266	30
Ammonium nitrate	0.7	20
Potassium sulphate	1.3	23

Source: Ramadan and Al-Ashakar (2007)

Samples of poultry manure were found to contain Zn (284.2µg/g) and Pb (110.5µg/g). The concentrations of Zn and Pb in super phosphate were 266 and 30µg/g, in Ammonium nitrate, 0.7 and 20µg/g and potassium sulphate, 1.3 and 23µg/g respectively.

Factors that Determine Heavy Metal Bioavailability and Effects on Crops.

Heavy metals may be present in the soil but not available to plants and hence have no effects on plants. Several factors determine bioavailability and effects of heavy metal on plants. They include the following:

i. pH

pH which is the measure of the concentration of hydrogen (H^+) ions dissolved in water impacts on the behaviour of many metals. H^+ is a cation and is attracted to the negative charges of the soil and sediment particles. In acidic conditions there are enough H^+ ions to occupy many of the negative charge surfaces of clay and organic matter thereby leaving no room for binding of heavy metals hence the metals are in a soluble phase and become available to plants (Meng and Li, 1998).

Table 2: Extractable Heavy Metals Obtained From Soil As Influenced By Soil pH.

Soil pH	Fe (µg/g)	Cu(µg/g)	Cd(µg/g)	Zn(µg/g)	Mn(µg/g)
4.3	106	4.1	14.5	398	97.2
5.3	76.4	3.5	13.3	332	52.7
6.0	35.0	3.0	13.0	287	26.7
6.7	21.6	2.9	12.3	249	21.8
7.2	15.8	2.4	11.0	218	8.90

Source: EL-Kherbawy, Angle, Heggo and Chaney (1989).

Heavy metal extractability was strongly influenced by soil pH. At pH of 4.3, the extractable Fe, Mn, Zn, Cu and Cd was 106, 97.2, 398, 4.1 and 14.5**µ**g/g respectively. At a soil pH of 7.2, extractable concentrations of the same metals were 158, 8.90, 218, 2.4 and 11.0**µ**g/g. Metals extracted at a soil pH of 5.3, 6.0 and 6.7 were between the concentrations stated above. The concentrations of extracted Fe and Mn were more dependent on soil pH than those of Zn, Cu and Cd.

ii. Organic Substances

Organic and amino acids such as citric acid, tartaric and, oxalic acid which are excreted by roots of plants form soluble complexes with heavy metals such as Cd, Cu, Pb and Zn in the soil (Cheng, 2003).

iii. Other Elements

Some elements affect the absorption of heavy metals in plants. When the concentration of Zn was lower than 25mg/kg, Zn shared synergism with the absorption of Cd, but when the content of Zn was higher than 25mg/kg, Zn shared an antagonism with Cd. There is interaction between P, Zn and Cd in plants. The accumulation and transport of Zn and Cd from roots to above ground parts in plants is raised by increasing the content of phosphorus (P) in the media. (Yang, Zheng and Hu, 1999).

iv. Fertilizers

Continuous composting decreases the heavy metal bioavailable contents for plant. Organic amendment application led to an effective immobilization of Pb, Cu, Zn and Cd phytoaccessible forms in the soil (Xue, Zhang and Meng, 2000).

v. Plant Species

The effects of Cd and Pb in the soil on rice and cotton indicated that the ability of genetically modified cotton to resist heavy metal damages is stronger than is found for common cotton under the same condition. Compared with cotton's absorbing ability at the same treated level, the absorption of Cd and Pb in rice leaves was lower (Qin, Tie and Zhou, 2001).

Effects of Heavy Metals on Seed Germination and Growth of Crop Seedlings.

Mahmood, Islam and Muhammad (2007) studied the effect of Cu, Zn and Pb on seed germination and seedling growth of barley, (*Hordeum vulgare*) rice (*Oryza sativa*) and wheat (*Triticum aestivum*). The inhibitory effect of Cu on seed germination is more pronounced on rice than on wheat and barley respectively (Table 3). In the 10uM treatment, the wheat and rice seed germination was reduced more than 35 and 60% respectively over the control treatment

Table 3: Seed Germination, Root Growth, Shoot Height and Root: Shoot Ratio of Barley, Rice and Wheat in Response to Copper Concentration.

Cu conc. (µM)	Germination of seeds (%)	Number of roots/plant	Root length (mm)	Shoot height (mm)	Root/shoot ratio
			Barley		
Control	73	6	135.5	87. 1	1.55
1	70	6	110.1	93.3	1.18
5	70	7	85.6	98.7	0.87
10	68	7	60.6	100.0	0.60
[illegible]	71	6	104.3	92.9	1.15
			Rice		

	93	**2**	**80.3**	**34.2**	**2.35**
Control	**78**	**2**	**76.0**	**33.1**	**2.30**
1	**55**	**2**	**60.7**	**32.1**	**1.89**
5	**34**	**3**	**50.1**	**32.3**	**1.56**
10	**71**	**2**	**70.5**	**33.8**	**2.08**
			Wheat		
Control	**82**	**4**	**102.1**	**87.1**	**1.17**
1	**86**	**5**	**70.5**	**87.0**	**0.80**
5	**60**	**5**	**45.9**	**60.8**	**0.75**
10	**50**	**6**	**30.3**	**50.2**	**0.60**
	72	**5**	**69.9**	**74.1**	**0.90**

Source: Mahmood, Islam and Mohammed (2007)

In wheat, the number of roots per seedling increased significantly by 50% at 10**µ**M Cu over the control seedlings but root numbers of barley and rice seedling did not increase significantly in response to Cu. Root length of all crop seedlings was significantly affected by increasing Cu. On the average, the effect of Cu on seedlings root length was more pronounced than Pb and Zn respectively. The 10**µ**M Cu significantly reduced the root length of both barley and wheat by 50% and rice by 40% than the control seedlings. Shoot height of wheat seedlings decreased significantly at 10uM Cu, however barley shoot height increased by 15% than that of the control seedlings. The root: shoot ratio of barley, wheat and rice seedlings at 10uM Cu were 60, 50, 30% less respectively than that of the control seedlings.

Table 4*:* Seed Germination, Root Growth, Shoot Height and Root: Shoot Ratio of Barley, Rice and Wheat in Response to Zinc Concentration.

Zn cone. (uM)	Germination of seeds (%)	Number of roots/plant	Root length (mm)	Shoot height (mm)	Root/shoot ratio
			Barley		
Control	85	6	120.0	85.1	1.41
1	89	6	115.	83.0	1.39
5	*90*	6	170.1	108.2	0.65
10	85	7	60.3	100.2	0.60
Mean	83	6	98.6	93.2	1.09
			Rice		

	93	2	75.1	47.3	1.60
Control 1	94	2	78.2	46.2	1.70
5	92	3	68.1	37.1	1.84
10	93	3	52.2	36.1	1.44
Mean	93	2	716	43.2	1.65
			Wheat		
	96	4	132.4	100.0	1.32
Control 1	90	4	131. l	95.2	1.38
5	95	5	80.2	92.1	0.87
10	95	6	55.2	90.1	0.61
Mean	92	5	106.6	96.6	1.09

Source: Mahmood *et al.* (2007)

Zn has less effect compared to cu (Table 4). Seed germination did not respond significantly to Zn concentration. Progressive increases in Zn significantly increased by 50%, the root number of wheat seedlings as compared to seedlings grown in control treatment. Root length of all crop seedlings was significantly affected by increasing Zn. At 10**µ**M Zn, the root length of barley, rice and wheat seedlings reduced more than 50, 40 and 60% respectively than the root length of the control seedlings. The shoot height of rice seedlings of both 5 and 10**µ**M Zn was about 18% less than those of the control seedlings. A significant inhibition of shoot height of wheat was also observed at 10**µ**M Zn. Also a significant inhibition in root::shoot ratio of barley (55-65%) and wheat (28–50%) was found at both 5 and 10uM Zn concentration than control seedlings.

Pb did not significantly affect seed germination but it increased by 100% the root number of rice seedlings at 10**µ**M

At higher concentration of Cu, Pb and Zn, the root tips of all the crop seedlings change their colour from brown to dark brown and the roots were found hairless, stunted, thick, curled and brittle with numerous small lateral branches. While the roots of the seedlings growing in control or lower concentration of metal treatments were white with profuse root hairs and longer lateral branches (Mahmood *et al.,* 2007).

Effects of Heavy Metals on Dry Matter and Grain Yield of Wheat.

Athar and Ahmad (2001) studied the effect of heavy metals on wheat (*Triticum aestwum)*

Table 5: Dry Matter and Grain Yield of Wheat Plant Exposed to Various Concentrations of Heavy Metals Added Either Separately or in Combination

Heavy metal treatment	Dry shoot weight			Dry root weight (g/pot)			Grain weight (g/pot)		
	0.5 0.5 x	1x	2x	0.5 x	1 x	2x	0.5 x	1x	2x
PB	3.02	2.50	1.80	2,41	1.81	1.30	4.02	3.75	3.03
ZN	2.80	2.10	1.73	2.05	1.71	0.91	3.64	3.16	2.51
CU	1.70	1.30	1.00	1.50	1.10	0.68	2.28	1.54	1.05
CR	3.40	2.70	2.21	2.93	2.05	1.78	4.71	4.09	3.53
NI	2.00	1.70	1.50	1.83	1.60	0.82	2.83	2.34	2.05
CD	1.50	1.10	0.90	1.00	0.80	0.63	1.87	1.30	0.85
NI+CD	1.50	1.10	0.86	1.05	0.85	0.49	1.78	0.94	0.55
NI+CR	2.60	2.00	1.75	2.05	1.45	1.08	2.71	2-30	1.77
CR+CD	1.74	1.40	1.01	1.23	0.91	0.85	205	1.74	1.16
NI+CR+CD	1.05	0.84	0.63	0.83	0.45	0.35	1.06	0.77	0.40
NI+CR+CD+CU+ZN+ PB	0.80	0.75	0.43	0.40	0.31	0.19	0.70	0.36	0.29
CONTROL	-	4.10	-	-	3.40	-	-	5.30	-

Source: Athar and Ahmad (2001)

The reduction in dry weight of wheat plants as a result of treatment with heavy metals was minimum with Cr and Pb but most obvious in treatment containing Cd alone and a combination of all the heavy metals. The phytotoxic effect of heavy metals was in the following order Cd > Cu > Ni > Zn > Pb > Cr. The higher the concentration of heavy metals in the soil, the greater was the toxic effect on the plant. The effects of combinations of two metals were not additive, rather the effects were only as severe as the most toxic metal alone.

The lowest reduction in the grain yield was recorded with Cr at the test doses and the highest was recorded in the plants having been treated with all the test metals. Decrease in the grain yield was less than 40% with Cr as against 83.9% by Cd at 2 x Concentration. Table 4 shows that the dry weights of shoot and roots of wheat plant respectively were reduced 63.4% and 70.5% by Cd, 58.5% and 55.8% by Cu, 51.2% and 46.1% by Ni, 26.3% and 29.1% by Pb, 31.7% and 39.7% by Zn, 17.0% and 13.8% by Cr at 0.5 x Concentration.

Physiological and Structural Effects of Heavy Metals

i. Cell Division Cycle

Heavy metals affect cell division in plants and the effects are different and depend on the concentration. When the root tips of beans were treated with Cd, Pb and Zn, cell division was extended under low concentration of 0.01, 1.0 and 10 ppm of Cd, Pb and Zn respectively while cell division was shortened but cell cycle was extended by increasing the dose.

ii. Chromosomes

When exposed to Cd, Pb and Hg, the chromosomes of beans, garlic and onions were injured and revealed chromosome fragmentation and nuclear decomposition.

iii. Ultrastructure of Cells

The grana cascade of chloroplast and mitochondria of maize decreased or disappeared under low concentration of Cd stress but decomposed under high concentration.

iv. Cell Membranes

Cd damages the enzyme system and increases the penetration of cell membrane and electrolyte leakages.

v. Photosynthesis

Heavy metals affect the functions of PSI and PSII. The chlorophyll proteins which took protons for photosynthesis in PSII were decomposed and decreased under Cd stress resulting in decrease in photosynthesis (Cheng 2003).

Resistance of Crops to Heavy Metals

Plants use the following mechanisms to detoxify heavy metals.

i. Production of metal – binding proteins in rice, beans and tobacco limited the behaviour of Cd and abated the injury of Cd to plants.
ii. Storage of absorbed heavy metals in trichomes of epidermis to avoid the direct effect of the metal on the chlorophyll.
iii. Rise in activity of anti-oxidation enzyme activities to remove free radicals produced by plants during heavy metal stress.
iv. Expression of enzymes and genes

Gene gap change, gene mutation and gene exchange are sources of anti-pollution genes in plants which maintain the enzymes activities to avoid injury resulting from heavy metals (Cheng 2003).

Conclusion and Recommendations

The major sources of heavy metal pollution are anthropogenic. The accumulation of heavy metals has serious implication for human health and the ecosystem. The effect of heavy metals on crops results in decline of physiological and biochemical activities, germination and growth inhibition, structural damage and reduced yield.

It is therefore necessary that there should be regular monitoring of the environment to detect heavy metal pollution. Steps should also be taken to reduce human activities that generate heavy metals. Crops should be tested to determine their heavy metal content and ensure that they are within safe limits for human consumption.

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