PLANT RESPONSE TO EXCESS CONCENTRATIONS OF HEAVY METALS

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ABSTRACT

Parent material rich in heavy metals, mineral deposits, disposal of industrial wastes and unscrupulous use of plant protection and fertilizer practices cause high concentrations of heavy metals in soils that affect plant growth. Plant species and often varieties within species show differential response to excess concentrations of heavy metals. While some tolerate high concentrations of heavy metals, others show toxic effects, some of which resemble iron deficiency others are specific to the metals. Visual and metabolic changes resulting from excess supply of manganese ,copper, zinc, molybdenum, chromium, cobalt, and nickel are described and explanations for the bio-chemical changes discussed.

INTRODUCTION

The term 'heavy metal' is widely used in agriculture, nutrition and physiology for the metal ions having atomic number roughly more than 23 (atomic weight 50). Apart from manganese, copper, zinc, molybdenum and cobalt, for which plants have a specific requirement, several other metal ions when present above a certain concentration, adversely affect plant growth and metabolism causing what is referred as 'heavy metal toxicity,

Heavy metal toxicity in plants was first identified as a field problem in 1668 by Granvil (cited by Phillips, 1821) who described the toxic effects in plants grown on high lead soils of the Mendip Hill area in Great Britain. Since then heavy metal toxicities have been reported in a wide variety of plants from several areas of the world (Table 1).

Apart from rich deposits of heavy metals or their ores in the soil parent material, several other soil and environmental factors may contribute to heavy metal toxicities in plants. Russell and Russell (1961) gives a vivid account of soil conditions conducive to toxicity of heavy metals. High solubility at low pH contributes to manganese and aluminium toxicity in acid soils (Hewitt, 1946-50; Wallace, Hewitt & Nicholas, 1945; Evans, 1956; Johnson, 1966). Plants grown on acid moor soils of USA are reported to suffer from lead toxicity (Wieler, 1938) and those grown on acid peat soils of Ireland and New York from zinc toxicity (Walsh & Clarke, 1945; Staker, 1943). Poor soil aeration causes marked increase in the availability of manganese to plants grown under flooded conditions. This can largely be attributed to increased reduction of manganic to the manganous form (Bradfield, Batjer & Oscamp, 1934) due to the reducing environment prevailing in soils subjected to flooding. Kanwar and Randhawa (1974) have reported manganese toxicity to rice in Punjab soils subjected to poor aeration.

Excessive and prolonged micronutrient fertilization may result in a build up of these elements in soils to concentrations that may prove toxic to plants. Excessive copper fertilization of fruit trees in Florida rendered the soils unfit for the growth of gladiolus and spinach (Drouineau & Mazoyer, 1953). Excessive use of other micronutrients has been

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Table 1—Spread of heavy metal toxicities in the world

Toxicity	Country
Mn	.. Hawaii (Kelley, 1912; McGeorge, 1923; Johnson, 1924; Ferguson, 1954). U.S.A. (Neal & Lovett, 1938; Sherman, 1957). Puerto Rico (Hopkins *et al.*, 1944). Australia (Guthrie & Cohen, 1910). India (Kanwar & Randhawa, 1974).
Cu	.. U.S.A. (Bateman & Wells, 1917; Forbes, 1917). Germany (Freytag, 1882; Hasselhoff, 1882).
Zn	.. Great Britain (*Granvil, 1668; Griffiths, 1918; Jones, 1940). Belgium (Rossels, 1924). U.S.A. (Staker & Cunnings, 1941; Staker, 1942). Germany (*Freytag, 1868; Storb, 1883).
Ni	.. Italy (Minguzzi & Vergnano, 1948). Rhodesia (Hunter, 1954; Soan & Saunder, 1959). Great Britain (Hunter & Vergnano, 1952). New Calendonia, N. Z. (Birrel & Wright, 1945).
Pb	.. Great Britain (*Granvil, 1668; Griffiths, 1918; Newton, 1944).
Cr	.. U.S.A. (Robinson *et al.*, 1935). South Africa (Vander-Merwe & Anderson, 1937). Italy (Minguzzi & Vergnano, 1953). Rhodesia (Soan & Saunder, 1959).
Ba	.. U.S.A. (Crawford, 1908).
Mo**	.. England (Lewis, 1943). U.S.A. (Dye & O'hara, 1959; Cunningham, 1950).

**Cited by Phillips* (1882); ** *Toxic to Animals.*
For reference see Forster (1954), Cannon (1960), Schutte (1964) and Chapman (1966).

reported to cause field toxicity problems in many countries, e.g. manganese toxicity in Florida (Reuther & Smith, 1952), zinc toxicity in USA (Gall, 1936; Gall & Barnett, 1940), and molybdenum toxicity in Australia and USA (Johnson, 1966). Heavy doses or repeated applications of even macronutrient fertilizers may cause a heavy metal toxicity. In certain areas of Great Britain high use of phosphatic fertilizers has been reported to cause molybdenum toxicity (Channell, Bingham & Garber, 1960).

Over the recent decades industrial pollution has further aggravated the problem of heavy metal toxicities, especially in the more highly industrialised countries of the world. Sewage and effluents from industrial and mining areas have been shown to contribute such excessive amount of heavy metals as may cause phytotoxic effects (Patterson, 1971). Effluents from industries have greatly contributed to toxicity of lead and zinc in certain areas of Great Britain (Davies, 1941; Wallace, Hewitt & Nicholas, 1945) and tin in Germany (Dorn, 1937).

PHYTOTOXIC EFFECTS OF EXCESS OF HEAVY METALS

While some plants, the *accumulator plants* accumulate high concentrations of heavy metals without showing any apparent injury (Table 2), most of them show toxic effects in response to excess concentrations of heavy metals in the soil environment.

Table 2—Accumulator plants for heavy metals (adapted from Cannon, 1960; Schutte, 1964; Miller & Flemion, 1973)

Element	Plant species	Country
Cu	*Gypsophila patrini*	U.S.S.R.
	Polycarpaea spirostylis	Australia
	Aerocephalus roberti	Katanga
	Escholtzia haichowensis	China.
	E. maxicana	Arizona
	Ocimum homblei	Rhodesia
	Merceya latifolia	Sweden
	Armeria meritima	Scotland
	Viscaria alpina	Norway
Fe	*Betula* sp.	Germany
	Clusia rosea	Venezuela.
Zn	*Viola calamineria*	Belgium, Germany.
	Philadelphis sp.	Washington, U.S.A.
Co	*Silene cobalticola*	Katanga
	Nyssa sylvetica	Arkansas (U.S.A.)
	Clithera burbinervis	Hawaii
Ni	*Alyssum bertolonii*	Italy, Georgia.
	A. murale	U.S.S.R.
Pb	*Erianthus gigenteus*	Tennessee (U.S.A.)
Au	*Equisetum arvense*	Czechoslovakia
Hg	*Arenaria setacea*	U.S.A.
Ag	*Eriogonum ovalifolium*	Montana (U.S.A.)
U	*Astragalus prenssi*	Western U.S.A.
	Astragalus sp.	Andes

One of the most common effects of excess concentrations of heavy metals in plants is induction of *iron chlorosis* (Hewitt, 1948, 1950, 1951, 1954, 1963; Brown, 1956, 1961; Wallace & Lunt, 1960; Hewitt & Nicholas, 1963). The pattern and severity of chlorosis resulting from heavy metal excess varies from metal to metal, growth stage of the plant, leaf morphology, genotype and the root and shoot environment. The specific effects of chromium toxicity are also more marked when it is supplied in the hexavalent (Cr^{6+}) anionic form then when supplied in the cationic (Cr^{3+}) form (Koenig, 1911, Coupin, 1900; Voelcker, 1921; Hewitt, 1948).

Induction of chlorosis or decrease in chlorophyll content of plants subjected to heavy metal toxicity is often associated with impairment of iron utilization in plants (Hewitt 1954; Nicholas, 1950; Agarwala & Kumar, 1962; Agarwala, 1963; Bisht, 1972). Recovery of plants from iron type effects on discontinuation of excess supply of heavy metal (Bisht, 1972) and their recovery from such effects on application of iron chelates (Hunter & Vergnano, 1953; Forster, 1954; DeKock, 1956; Agarwala & Kumar, 1962) lends support to the above view.

While chlorosis is one of the most conspicuous effects of heavy metal toxicity, yet it is not a universal phenomenon. It has been observed that nickel toxicity in cucumber and zinc toxicity in maize does not produce any chlorosis (BISHT, 1972). In muskmelon, excess of chromium produces chlorosis only when supplied as anion and not when supplied as cation (BISHT, 1972).

Apart from inducing chlorosis of young leaves, excess supply of heavy metals produces certain effects which are specific to the toxic metal and are influenced by the concentration of the metal in the rooting medium, the duration of the period to which plants are exposed to the excess concentrations of the metal, and the plant genotype.

The visual symptoms of heavy metal toxicity in plants are reported to result from disturbance in plant metabolism caused by excess concentrations of heavy metals. The appearance of brown necrotic areas on the leaves of plants subjected to toxic concentrations of manganese has been attributed to accumulation of phenols resulting from decreased activity of phenolase in such plants (KENTEN & MANN, 1956). Plants subjected to copper toxicity are reported to accumulate sulfhydryl complexes in the meristematic tissues (SMITH, 1953; DEKOCK, 1956). In case of molybdenum toxicity, the golden yellow pigmentation of foliage can be ascribed to a 'molybdenum-tannin complex' and the deep blue pigmentation to 'molybdenum-anthocyanin complex' (WARINGTON, 1937).

Some of the better known phytotoxic effects specific to particular heavy metals are given in Table 3. In certain instances the visual symptoms of particular heavy metal

Table 3—Some common visual symptoms of heavy metal toxicity in plants

Heavy metal	Toxicity symptoms
Mn	Leaves chlorotic; presence of buff, pink or brown coloured spots on leaves, petioles and stem; distortion, necrosis and disintegration of lamina.
Cu	Loss of turgor resulting in wilting or rolling of leaves; chlorosis and necrosis of leaves, tips of the older leaves being more severely affected; appearance of purple tints on the stem; roots markedly stunted with dark necrotic tips.
Zn	Leaves chlorotic and markedly reduced in size; necrosis of leaf tips and shoot apices; appearance of reddish tints near the basal part of leaves, particularly on the midrib; curling and distortion of foliage.
Mo	Stunting of growth; golden yellow pigmentation of the young growths; epidermal hairs on leaves, petiole and stem exhibit orange or golden yellow coloration; localised bleaching and necrosis of lamina; loss of pigmentation in flowers; apetalous flowers.
Co	Leaves reduced in size with fringed or dissected leaf margins; failure of young leaves to unroll and their entanglement in subtending leaves; death of apical meristem; localised bleaching and necrosis of leaves; appearance of brown, pink, red or reddish-brown necrotic spots on the leaves; lamina brittle.
Ni	Wilted appearance of foliage; patchy discoloration of leaves; scorching of old leaves; greyish or brown necrotic spots on leaves and petioles.
Cr (cation)	Chlorotic leaves with irregular necrotic areas; veins bluish green to dark bluish black.
Cr (anion)	Loss of turgor in leaves followed by their severe discoloration; pink pigmentation on the petiole of young leaves (sugar beet); dark blue veins standing out prominently against green interveinal areas; necrosis of interveinal areas near the leaf base and leaf apices.
Pb	Reduction in growth; upward curling of leaf margins; and appearance of purple tints in the interveinal areas (tomato).
U	Deformation of fruits; sterile or apetalous flowers; stalked leaf rosettes.
Hg	Reduction in the size of internodes, leaves and fruits; chlorosis and necrosis of foliage.

toxicities in plants are so characteristic that they can be used as indicator plants for mineral prospecting (Table 4). Discoloration of *Acer* (maple) leaves is associated with high soil copper and its chlorosis with high zinc concentration in soils. Double whorls of petals in *Papaver macrostomium* is indicative of high copper and zinc in soils. *Papver commutatum* grown in copper and molybdenum rich areas in Armenia (USSR) exhibits special colour patterns. *Protea goetzcana* grown in areas of copper and cobalt deposits in Katanga show markedly stunted growth. Unusual whiteness of *Pulsatilla patens* and *Lynosyris villosa* is associated with cobalt and nickel ores in South Ural (USSR). In USA, apetalous and stamenless flowers of *Stanleya pinnata* are associated with uranium and thorium deposits. *Crotolaria striata* and *Catharanthus roseus* growing in monosite coastal areas of India show several special morphological features.

Table 4—Indicator plants or geobotanical indicators for ore deposits (Adapted from Schutte, 1964)

Element	Plant	Country
Fe	*Epidendrum o'breintianum*	Venezuela
	Calamogrostis sp. (Tree)	Venezuela.
Mn	*Digitalis purpurea*	Switzerland, Germany.
Cu	Member of Caryophyllaceae	Australia
	Arenaria verna	Australia
	Mielihofera nitida	Australia
	Scopelophila liguta	Australia
	Lychnis alpina, L. dioica	Norway
	Silene sp.	U.S.A.
	Polycarpaea spirostylis	Australia
	Alsine verna—Cu, Zn	Germany
	Armeria vulgaris	Germany
	Viscaria alpina (Serpentine soils)	Norway
	Merceya latifolia	Sweden
Zn	*Thlaspi alpestre*	Germany
	Viola tricolor	Austria
	V. lutea	Germany
	Ruta graveolens, R. latifolia	Brazil
	Matricaria americana	Brazil
	Senecio brasieliensis	Brazil
	Populus deltiodes	U.S.A.
	Ambrosia elatior, A. maculata	U.S.A.
	Viola maculata	Belgium
Au	*Cercropia laetevirens*	Brazil
Pb	*Tussilago farfar*	Germany
	Amorpha canescens	US..A.
Hg	*Arenaria setacea*	Spain
Ag	*Eriogonum ovalifolium*	U.S.A.
Sn	*Sempervivum ovalifolium*	Germany
	Pluchea quifoc	Brazil

Besides the universal ore plants, which indicate the presence of a particular ores irrespective of the geographical barriers, some plants are adapted to particular ore zones and these may be used as '*local indicator plants*'. *Alyssum bertolonii* is a local indicator plant for nickel ore in Italy and Georgia and *Escholtzia haichowensis* a local indicator plants for copper ore in China. SWAINE (1955) and BOWEN (1966) have listed a wide range of indicator plants helpful in locating mineral deposits or ores in the different regions of the world.

GROWTH EFFECTS

In general, effectiveness of heavy metal in depressing plant growth and proudcing toxic effects follow the order of their organo-metal stability constants (HEWITT, 1948; Table 5). We found that the effectivity of heavy metals Mn, Cu, Zn, Co, Ni, Mo and Cr in producing toxicity effects in barley, maize, muskmelon and cucumber followed the order of organo-metal stability constants (Table 5). Similar results were earlier obtained by HUNTER and VERGNANO (1953) for oats, and HEWITT (1948) for sugarbeet. While what has been observed above is largely true for a wide variety of plants, it is not universally so. It has been observed that the relative effectivity of a particular metal in inducing toxicity may vary in different plant species. Unlike other plants in rice (MITSUO, 1967)

Table 5—Effectiveness of heavy metals in inducing phytotoxic effects and iron chlorosis

Plant	Order of effectivity in inducing	
	Growth & Toxicity Effects	Chlorosis
Sugar beet .. (Hewitt, 1948)	Ni > Co > Zn > Cu > CrO^{2-}_4 > Mn ..	(*a*) Co > Cu > Zn = $CrO_4^{=}$ > Ni > Mn (*b*) Severe chlorosis: Cu, Cd, Co Moderate chlorosis: Ni > $CrO_4^{=}$ > Zn, > Cr, > Mo Mild chlorosis: Mn
Oat .. (Hunter & Vergnano, 1953)	Ni > Co > Cu > Cr > Zn > Mo > Mn ..	Ni > Cu > Co > $CrO_4^{=}$ > Zn > Mo > Mn
Mustard .. (DeKock, 1956)	Cu > Ni > Co > Zn > Cr > Mn	Cu > Ni > Co > Zn > Cr > Mn
Rice .. .. (Mitsuo, 1967) ..	Cu > Ni > Co > Zn > Mn	Co > Ni > Zn > Mn > Cu
Barley ..	Ni > Co > Zn Mn = Cu	Cu > Ni = Co > Mn > Zn
Maize ..	Ni > Co = Cu > Mn > Zn	Cu > Co > Ni > Mn > Zn
Cucumber ..	Ni > Co > Zn > Cu > Mn	Co > Zn > Cu > Mn > Ni*
Muskmelon ..	Co > Ni > $Cr_2O_7^{2-}$ > MoO_4^{2-} > Cr^{3+} ..	(Young leaves) Co > Ni > $MoO_4^{=}$ > Cr_3+ > Cr_2O_7
	(Co > Ni > $Cr_2O_7^{=}$ > Cu > Zn > $MoO_4^{=}$ > Mn) ..	$Cr_2O_7^{=}$ > Co > $MoO_4^{=}$ > Ni > Cr^{3+}

**Plants died within two days of metal supply.*

and mustard (DeKock, 1956) copper was found to be more toxic in producing toxicity than cobalt and nickel in barley copper was found less effective in inducing toxic effects than zinc (Agarwala, Bisht & Sharma, In press). On the basis of their studies of toxic effects of iron, manganese and cobalt Somers and Shive (1942) and Somers, Gilbert & Shive (1942) suggested that effectiveness of heavy metals in inducing phytotoxic effects was a function of its redox potential. Results obtained subsequently, however, did not lend support to this view.

Enzymes

In general excess supply of heavy metals has been reported to cause decreas e in the activity of catalase and an increase in the activity of peroxidase (Weinstein & Robbins, 1955; Wallace & Clark, 1956; Wallace, 1957; Eyster, 1954; Agarwala & Kumar, 1962; Agarwala *et al.*, 1964; Agarwala, 1963; Bisht, 1972), but it is not always so. Instances are known wherein excess supply of certain heavy metals increased the activity of catalase and decreased that of peroxidase. Agarwala, Kumar and Sharma (1961) reported a stimulation in the activity of catalase in barley seedlings supplied excess cobalt and Bisht (1972) observed a stimulation in the activity of catalase in muskmelon plants supplied excess chromium and molybdenum (Table 6). Earlier, Weinstein and Robbins

Table 6—Effect of excess (1.0 m mole/L) supply of certain heavy metals on dry matter yield, chlorophyll content and specific activity of certain enzymes in barley (B) and musk melon (M) plants grown in sand culture.

Treatment	Plant	Yield	Chlorophyll	Soluble protein	Catalase	Peroxidase	B-Glycerophosphatase	Ribonuclease	Aldolase
		% decrease (—) or increase (+) over control							
Excess Mn	Barley	—37	—12	—5	+6	+33	+12	+24	+3
Fxcess Cu	Barley	—34	—62	—31	—28	+83	+15	+306	+24
Excess Zn	Barley	—44	—15	—3	—14	—13	—32	+41	—30
Excess Co	Barley	—57	—37	—24	—9	+20	+11	+124	+26
	Maize	—16	—63	—39	—10	+7	—2		
Excess Ni	Barley	—60	—41	—15	+6	+141	+15	+88	+26
	Maize	—13	—41	—7	—22	—187	+6		
Excess MoO_4^{2-}	Maize	—13	—37	—4	+54	+20	—92		
xcess $Cr_2O_7^{2-}$	.. ..	—38	—6	—32	+4	+113	+14		
Excess Cr^{3+} ..	Maize	—15	—18	—27	—43	+147	—42		

(1955) reported a decreased in the activity of cytochrome oxidase in sunflower plants receiving excess manganese but AGARWALA (1963) did not find it to be so in green gram seedlings. While a decrease in the activity of catalase ,peroxidase and cytochrome oxidase, as also the decrease in the total heme in plants subjected to excess supply of heavy metals as observed by DEKOCK, COMMISIONG, FARMER AND INKSON (1960), could be attributed to heavy metal induced iron deficiency, the stimulation in peroxidase and cytochrome oxidase or in some cases that in catalase cannot be reconciled in terms of interference of heavy metals in iron metabolism. Many enzymes other than the iron enzymes have also been reported to be affected by excess supply of heavy metals (Table 6) .Several workers have found a decrease in the activity of acid phosphatase in response to excess chromium and molybdate (SPENCER, 1954; HEWITT & TATHAM, 1962; ALEXANDER, 1965; MISLVEA & MAHANTY, 1967; BISHT, 1972). This would suggest that when supplied to plants at excess concentrations, heavy metals may induce changes in the normal balance of functional proteins inhibiting the synthesis or activity of some and stimulating that of others.

Study of the effect of excess cobalt on the activity of aldolase, B-glycerophosphatase, starch phosphorylase, pyrophosphatase, alanine and aspartate-amino-transferases, invertase and ribonuclease in plants (AGARWALA *et al.*, in press) indicate that the genotype and the stage of plant growth may also influence plant reaction to excess concentration of heavy metals.

CARBOHYDRATES METABOLISM

Not much work has been done on the effect of excess concentrations of heavy metals on the carbohydrate metabolism of plants. We observed that excess supply of heavy metals like manganese, copper, zinc, cobalt and nickel caused an accumulation of the reducing and non-reducing sugars in plants (Table 7). In certain plants like barley, starch also accumulated as a result of heavy metal toxicity. These results would suggest that high concentrations of heavy metals in plant tissues either inhibit the utilization of sugars and starch or promote the hydrolysis of cell constituents leading to their increased accumulation.

Table 7—Effect of excess (0.5 m mole/L) supply of certain heavy metals on carbohydrate and nitrogen fractions of maize plants grown in sand culture

Treatment	Nitrogen			Sugars		
	Protein	Non-Protein	Total	Reducing	Non-reducing	Total
	% Fresh wt.					
Basal	0.456	0.060	0.517	0.090	0.250	0.340
Excess Mn	0.353	0.055	0.408	0.114	0.362	0.472
Excess Cu	0.286	0.128	0.415	0.052	0.122	0.172
Excess Zn	0.446	0.030	0.476	0.117	0.395	0.412
Excess Co	0.329	0.091	0.420	0.137	0.331	0.468
Excess Ni	0.307	0.125	0.432	0.187	0.649	0.836
LSD (P=0.05)	0.077	0.0116	0.077	0.017	0.133	0.133

Nitrogen Metabolism

There are several reports that indicate that excess supply of heavy metals cause changes in the nitrogen fractions in plants (Crooke & Inkson, 1955; Bisht, 1972). In most cases, heavy metal toxicities are reported to have resulted in increased accumulation of non-protein nitrogen (Holley & Cain, 1955; DeKock & Morrison, 1958; Hewitt, *et al.*, 1949; Agarwala, 1963; Ved Prakash *et al.*, 1964) including the free aminoacids. The extent of the accumulation of individual amino acids under particular heavy metal toxicities, however, vary with the genotype and the stage of plant growth (Table 8). We observed that except in the cotyledons of young germinating seedlings the protein nitrogen content markedly decreased as a result of heavy metal toxicity (Table 7). These result would also suggest that excess cellular concentrations of heavy metals either inhibit the utilization of amino acids or promote protein hydrolysis, thus affecting normal balance of cellular proteins.

Table 8—Effect of excess supply of heavy metals on free amino acids in maize plants and green gram seedlings (after Agarwala, 1963 and Bisht, 1972)

Plant	Excess heavy metal	Amino acids: Increased	Amino acids: Decreased
Maize ..	Mn	Alanine, Glutamic acid ..	Methionine
	Cu ..	Glycine, Alanine, Leucine, Serine, Arginine Threonine, Aspartic acid, Methionine	
	Zn	Leucine, Aspartic acid ..	Alanine, Valine, Methionine
	Co	Serine, Arginine	Valine, Methionine, Threonine
	Ni ..	Serine, Arginine	Valine, Threonine, Methionine
Green gram (seedlings) ..	MoO_4^{2-}	Glycine, Alanine, Valine, Lysine, Leucine, Arginine	
	$Cr_2O_7^{2-}$	Glycine, Threonine, Alanine, Valine, Leucine, Arginine	Aspartic acid, Glutamic acid, Serine, Lysine
	Co	Serine, Glycine, Alanine ..	Threonine
	Ni ..	Glycine, Alanine, Valine, Leucine, Arginine, Phenylalanine	Aspartic acid, Glutamic acid Serine, Lysine.

Mineral Nutrient Composition of Plants

Crooke and Inkson (1955), DeKock and Inkson (1962), and Sirohi and Pushpalata (1968) have reported that uptake of macronutrient elements was decreased as a result of nickel, manganese and cobalt toxicities in oats, mustard and soybean plants respectively. We observed that in maize plants supplied excess cobalt, total content of all macro and micronutrient elements except zinc was decreased. Experiments with other plants largely confirmed this. The tissue zinc (and less frequently phosphorus and copper) generally showed an accumulation in plants subjected to toxicity of heavy metals. It has also been observed that effect of excess supply of heavy metals on tissue concentration of the different macro and micronutrient elements can be largely counteracted by discontinuation of the excess heavy metal supply or by supplying high concentrations of iron to plants (BISHT, 1972).

CONCLUSIONS

Studies on the effect of excess supply of heavy metals on growth, chlorophyll, enzymes, carbohydrates, nitrogen and tissue concentration of essential macro and micronutrient elements in plants suggest that excess concentration of heavy metals affects growth and several aspects of plant metabolism. In many, but not all, respects the effects of excess concentration of heavy metals resemble the metabolic effects of iron deficiency. Diverse effects of heavy metal toxicities on enzymes, accumulation of non-protein nitrogen including individual aminoacids and decrease in protein nitrogen content of plants subjected to excess concentrations of heavy metals, suggest that cellular concentrations of the heavy metals may determine the normal balance of the functional proteins and other cellular metabolites. In this respect, the observation that heavy metals may form organo-metallic complexes including the metal-proteinates (BALLENTYNE & STEPHENS, 1951; BALLENTYNE, 1953; DIXON & WEBB, 1964; VALLEE & WACKER, 1970) is of special significance for such compounds may affect the synthesis or activity of the cellular enzymes, and thus, indirectly that of other cellular metabolites like sugars and starch.

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