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Toxicity of Cadmium and Nickel in Soil and Vegetables

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ABSTRACT

Heavy metals like cadmium, nickel, lead, chromium, mercury etc are important environmental pollutants in areas with anthropogenic pressure. Their presence in the atmosphere, soil and water, even in traces can cause serious problems to all organisms. Heavy metal accumulation in soils is of great concern in agricultural production due to the adverse effects on food quality, crop growth (Ma *et al.*, 1994) and environmental health. Heavy metal bioaccumulation in the food chain can be especially highly dangerous to human health.

Cadmium concentration in soil

The total concentration of Cd in soils was found to vary between 0.01 to 0.70 mg kg^{-1} as reported by Lindsay (1979). However, higher value to the extent of 2.44 mg kg^{-1} has also been reported by Wang Lixia (1979). The Cd concentration also increased with time. Mean Cd concentrations in soil increased form 1.13 mg kg^{-1} in 1979 to 1.94 mg kg^{-1} in 1987.

Cadmium in agricultural soil is likewise relatively immobile under normal conditions, but could become more mobile under certain conditions such as increased soil acidity and its cadmium level may be enhanced by the usage of phosphate fertilizers manure or sewage sludge (Table 1).

Nickel concentration in soil

Contributions of nickel to soil arise from both natural and man-made sources. Among the farmer are parent bedrocks deposits enriched in nickel, micrometeorites and cosmic dust. The last two are of relatively little importance. Man-made source of nickel include smelting of nickel ferrous areas, metal refining, burning of coal, burning of petroleum products, disposal of waste sewage and sludge and fertilizer applications. The effects of man-made sources on the nickel contents of soil in generally local, although in certain cases industrial and other man made plumes of pollution combined with unusual climate condition may, disperse nickel over large regions of the earth.

The average nickel content of soil as given by Vinogradov (1959) is 40 mg kg^{-1}. Swaine (1955) given a wide range from 5 to 500 mg kg^{-1} Ni, our estimate of the average nickel content of soil calculated from a large number of analyses done in the Geological survey of Canada and those in the available world literature is 35 mg kg^{1}.

According to Page (1974), heavy metal constitutes only 0.1% of the sludge solids but, its content in soil may be significantly raised through long term land application of sludge Mahdy *et al.,* (2007) reported that application of biosolids increases DTPA-extractable nickel. The levels of extractable Ni reach to 25.12 mg kg^{-1} in clay soil at the highest application rate where as in sandy soil the levels of extractable Ni was 17.18 mg kg^{-1}, while in calcareous soil it reached to 22.08 mg kg^{-1} at the highest application rate.

Cadmium concentration and uptake in different vegetables

Cadmium is taken up from soil by the plant roots. The plants grown on soils that are very sandy, acidic and are low in organic matter more easily absorb cadmium in soil attaches to clay particles & sandy soils with low clay content and organic matter induces higher uptake of cadmium. Lagarwerff (1971) studied Cd, Pb, and Zn uptake by radish grown on soil near a busy highway and observed a decrease in yield and metal content with increasing pH. An increase in Cd uptake by eight food crops due to the application of $CdCl_2$ has been reported by John (1973). The result was supported by Jone *et al.,* (1973) who showed that Cd either in salt form or sludge borne was readily available to soybean but never observed seed. Cd levels more than 1 mg $kg^{-1}$with addition of 87.1 mt ha^{-1} of digested sludge containing 129 mg kg^{-1}Cd. Satyaprakash (1992) reported that all crop species accumulated higher amount of Cd in their roots. Considering the average value, the Cd accumulation in different crop species was found in the order: Potato> Toria> Cauliflower> Faba bean> Cabbage> Amaranthus. Guttormsen *et al.,* (1995) were conducted field trails over three year period with Chinese cabbage and carrots grown in a sandy soil. The NPK fertilizers containing 1, 30, 90 and 400 mg Cd kg^{-1} P were applied at the rate of 0.07, 2.1, 6.3 and 28 g Cd ha^{-1} yr^{-1}. The amounts of Cd added through phosphate rock also ranged between 0.1 and 28 g ha^{-1} yr^{-1}. The increased Cd application rates through NPK fertilizers increased the Cd concentration in both vegetables. The Cd uptake by both crops was significantly higher. Chinese cabbage exhibited lower Cd concentration than carrots. Carrot leaves contained higher Cd than its roots. Cadmium removals by Chinese cabbage and carrot were about 0.7 and 1.3 g ha^{-1} yr^{-1}, respectively. At pH 5.5, Cd concentrations in the two crops, based on a three year average, were 23 and 46% higher than at pH 6.5. Cadmium uptake by Chinese cabbage from different sources of phosphate rock was affected to a very limited extent. Cadmium concentration generally increased over the years. Cadmium concentration in shoots and roots varied both with different cadmium levels and type of vegetables. Generally cadmium accumulations in various plant parts in vegetables crops increased with the increasing cadmium concentration in the growth medium. Root cadmium increased more sharply than shoot cadmium. Celery contained higher Cd in the edible parts than other vegetable species (Ni *et al.,* 2002). The cadmium concentration in each of the three parts varied with the level of cadmium and highest being in treatment receiving 100 mg kg^{-1} Cd. In this treatment, the level of cadmium accumulation in the stem, leaf and root was 3.36, 2.60 and 1.78 mg kg^{-1} dry weight, respectively. The results also show that Cd accumulation was the least in the root and most in the stem of all species (Table 2 and 3).

Nickel concentration and uptake in different vegetables

Banin *et al.,* (1981) reported higher content of Ni in plant with sewage water application than irrigation water and explained that the uptake of a given element appeared to be largely determined by its solubility in the soil solution and can be generally predicted by its ionic strength. Sailed and Kardos (1977) suggested that crop tolerance to Ni application varied with plant species and metal species. The Ni content of most species of vegetables usually didn't exceed 10µg g^{-1} except for taxa growing on nickel rich soils where 10-100 µg g^{-1}Ni level was common. Use of Ni up to 125 mg kg^{-1}increased Ni content in alfalfa but did not exert pronounced influence on yield depression. 250 mg kg^{-1}ppm Ni treatment significantly increased Ni content and depressive effect on alfalfa yields (Taylor and Allinson, 1981). The Ni content in alfalfa varied from 0.5 to 9.4 mg kg^{-1}however, 300 mg kg^{-1}Ni in plants was recorded with the addition of 200 mg kg^{-1}Ni in soil. The linear relationship between Ni uptake by plants and the amount of applied Ni was reported (Valdares *et. al.,* 1983). The maximum concentration of metal was found in spinach leaves followed by berseem, cauliflower and maize leaves, while the cauliflower heads had the lowest concentration (Kansal and Singh, 1983). The highest Ni contents was found in roots. Plant grown in pots absorbed more Ni than from the same soils in the field. The uptake of Ni in the shoots of all the crops increased significantly with increasing levels of Ni application. The nickel uptake in spinach increased from 19.4 μg pot in control to 37.0.2 μg pot^{-1} with 80 mg kg^{-1} soil but at higher levels of Ni application, there was decrease in Ni uptake. Similarly Ni uptake in fenugreek and coriander increased upto 60 and 120 mg kg^{-1} soil application and showed decreasing trend there after (AR MNS, Ludhiana 2004-05). Kumar (2005) reported that the Ni-concentration in different vegetable crops depended on the distance of the cropped site with respect to discharge point of sewage-sludge. Higher Ni concentration in different crop species grown on sewage irrigated soils were obtained as compared to those grown on the ground water irrigated soils. Different plant species varied in their Ni concentration in the sequence; Potato> Toria> Cauliflower> Amaranthus> Cabbage.

The Nickel uptake by corn plants was significantly increased at all application rates in all soil studies and the corn plants grown in the clay soil had a higher assimilative capacity for uptake of Ni than other soils. The uptake values of heavy metals followed the following order; clay > calcareous > sandy soils. The Ni concentrations in all plant parts were higher in the biosolids treatment than in the control for all soils. Nickel concentration accumulated in parts of corn plants in the following order: roots> shoots. In general, application of biosolids significantly increased Ni concentration in shoots and roots of corn plants grown in all studies soils. The increase in Ni concentration peaked at the high level of biosolids application rate (3%) (Mahdy *et al.,* 2007) (Table 4–7).

Response of cadmium application

Bingham *et al.,* (1976) reported that soybean is most Sensitive crop where 25% reduction in yield by the soil application of as low as 5 to 15 ppm Cd. An increase in Cd content in soybean seed has also been reported by Ham and Dowdy (1978) due to sludge application. They observed that Cd addition through inorganic salt did not affect soybean yield but increased its concentration in soybean seed. Addition of cadmium to the soil lowered the dry matter yield of ryegrass and also reduced the yield of oat grain as reported by Allison and Dzialo (1980).

Table.1 The contamination level of trace elements in rural soils of the world

Country	Australia	China	S. Africa	U.K	U.S.A	Japan	Taiwan
Cd Con. (mg kg^{-1})	1	20	2	3	38	-	4

Source: Chan *et al.*, 1999.

Table.2 Major anthropogenic inputs of Cd to soil are following

	Source of Cd	Concentration in soil (mg kg^{-1})	Input to soil (kg ha^{-1} yr^{-1})
A	Atmospheric		
1	Wet/dry deposition general	-	<1.1-9.0
2	Wet/dry deposition general smelters	-	25-1000
B	Street dust	1.5-12	-
C	Rubber tyre wear	20-90	-
D	Incinerator fly-ash	2.6-68	-
E	Direct application		
i	P-fertilizer	0.2-345/1.0-641	0.3-8.9/-
ii	By product gypsum	<6.0	-
iii	Sewage-sludge	<1-3410	Up to 150
Iv	Compost	0.26-11.7	-

Source: McLaughlin and Singh, 1999

Table.3 Maximum permissible concentration of Cd in sludges and sludge treated agricultural soils in different countries

Country	year	Maximum concentration in sludges (mg Cd kg^{-1} dm)	Concentration in sludge treated soil (mg Cd kg^{-1})	Annual loading limit kg Cd ha^{-1} yr^{-1}
EU	1986	20-40	1-3	0.15
France	1988	20	2.0	0.15
Germany	1992	10	1.5	0.15
Spain	1990	20	1.0	0.15
Denmark	1990/95	1.2/0.8	0.5	0.008
Finland	1995	1.5	0.5	0.0015
Sweden	1995	2.0	0.5	0.002
U.K.	1989	-	3.0	0.15
USA	1993	85	20	1.9

Source: Mc Grath *et al.*, (1994)

Table.4 Heavy metals concentration in soils of Bihar

District		Pb(ppm)	Ni(ppm)	Cd(ppm)	Co(ppm)
Saharsa	Mean	1.87	4.51	0.05	0.65
	Range	0.05-4.28	0.40-12.36	0.00-0.15	0.12-1.27
Madhepura	Mean	2.63	6.40	0.02	0.48
	Range	0.07-8.36	0.14-11.35	0.00-0.06	0.01-1.00
Begusarai	Mean	1.52	4.15	0.05	0.55
	Range	0.42-2.90	0.20-9.81	0.01-0.09	0.07-1.36
Bhagalpur	Mean	2.05	4.86	0.39	1.41
	Range	0.90-3.88	3.02-29.01	0.11-0.91	0.04-4.14
Purnea	Mean	0.51	5.31	0.09	0.22
	Range	0.02-1.72	1.26-9.05	0.00-0.17	0.00-0.48
Dharbhanga	Mean	1.20	5.42	0.03	0.55
	Range	0.37-5.08	0.07-9.99	0.01-0.40	0.24-0.78
Patna	Mean	0.80	4.29	0.03	1.56
	Range	0.04-2.10	0.06-9.87	0.00-0.09	0.03-3.96
Vaishali	Mean	0.56	3.35	0.03	0.84
	Range	0.02-1.20	1.09-10.21	0.02-0.05	0.45-1.16
Muzaffarpur	Mean	0.87	5.59	0.30	-
	Range	0.38-1.55	2.14-9.92	0.26-0.37	-
Samastipur	Mean	0.78	0.25	0.07	0.37
	Range	0.12-2.47	0.10-0.48	0.04-0.15	0.24-0.50

Source: Annual Report (MNS), 2007-08

Table.5 Sources of concentration of Ni in soil through fertilizers, animal manures and minerals

Source	Nickel (mg kg^{-1})
A. Fertilizer	
Nitrogen	tr - 80
Phosphorous	tr - 300
Potassium	tr - 80
Mixed compounds	tr - 800
B. Animal sources	tr - 130
Animal wastes	-
Cattle manure	-
Poultry waste	-
Pig waste	-
Farmyard manure	17
Cow manure	29
C. Mines	
Coal	15
Lignite	13
Flash	12.8

Source: Robert and Boyle, 1988.

Table.6 Average and/or range of nickel content of natural waters, precipitates from natural waters and drainage sediments

Description	Ni content (mg kg^{-1})
Rain water and snow	Up to 0.001
Hot springs	0.0005 – 0.4
Ground waters, cold spring and mine waters	0.000-4.5
Stream, river and lake waters	0.0005-4.5
Ocean and sea waters	0.0015
Normal Fe-Mn precipitates (dry matter) from spring	7-100
Stream and river sediments (dry matter)	1-150

Source: Robert and Boyle, 1988.

Table.7 Nickel contents (mg kg^{-1}) in some vegetables grown on dry riverbed of Ganges

Vegetable	Nickel (mg kg^{-1})
Bottle gourd	1.1
Bitter gourd	15.5
Garden spinach	13.2
Radish	10.1
Snake cucumber	4.2
Sponge gourd	7.5
Tinda	8.2

Source: Farooq *et al.,* (2000).

Table.8 Permissible limits of cadmium

Element (mg kg^{-1})	Deficient	high	Excessive/Toxic
Cadmium	0.5-1.0	1-2	2

Source: AR (MNS), Haryana, 2001-02

Poschenrieder *et al.*, (1983) conducted an experiment in nutrient culture with 0, 10, 80 or 160 ppm, Cd and it was observed that plant growth, pigment (chlorophyll + carotenoid) content, seed number and size and protein content of *P. vulgaris* were reduced by Cd. There was no effect on germination up to 80 mg kg^{1} Cd. Increasing levels of cadmium in soil significantly decreased the mean shoot dry matter yield of wheat from 20.20 to 5.47 g/pot when levels of cadmium were increased from 0 to 200 mg kg^{-1} soil. The percent decrease in mean shoot dry matter yield of wheat was 72.9 at 200 mg Cd kg^{-1} soil over control (AR MNS, Haryana 2002-03). Shentu *et al.*, (2008) in a greenhouse experiment on three vegetable crops (Pakchoi, tomato and radish), observed that shoot growth was not inhibited by Cd except for radish grown on red yellow soil. A small amount of Cd stimulated growth of the vegetables.

Response of nickel application

No reduction in yield of crops grown on calcareous soil up to 200 ppm Ni application along with sludge was observed by Valdares *et al.*, (1983) and it was suggested that the acceptable sludge load in the calcareous soil may be predicted by metal uptake. The poor correlation between yield and applied heavy metal was observed. Nadia *et al.,* (2007) found that nickel improved shoot and root growth of tomato compared with control. Adding 15 and 30 mg kg^{-1} soil caused significantly increase in tomatoes fresh and dry weights of shoots and roots. These increases were found in the two seasons over that of untreated plants or those received 45 and 60 mg Ni kg^{-1} soil. The highest and significant increase was obtained with 30 mg Ni kg^{-1} soil. On the other hand, higher nickel concentration, namely 45 and 60 mg Ni kg^{-1} soil, resulted in significant reduction in tomato, fresh & dry weight. The vegetables (Okra, lettuce and pepper) did not show visible sign of physiological disorder and the growth rates for higher concentration of metal were comparable to the control suggesting that they tolerated the metals up to a concentration of 100µg dm^{-3}.

Critical level of toxicity of cadmium

The increasing problem of environmental pollution by heavy metals necessitates study on the toxicity of heavy metals to plants and subsequently to animals and human health. The toxicity of heavy metals to crop plants varied from metal to metal (Chino and Kitagishi, 1996) and from crop species in witch rice appeared to be most tolerant species (Tanaka et. al., 1975; Bingham et. al., 1976) Reduction in crop growth and yield are generally indicative symptoms of metal toxicity in plants. Heavy metal phytotoxicity has been demonstrated with plants grown in solution culture (Page et. al., 1972; Turner, 1973), greenhouse experiments (Bingham *et al.,* 1975 Cunningham *et al.,* 1975) and in field experiments (King and Morris, 1972).Cadmium was found to be most toxic for lettuce and wheat followed by Ni (Mitchell *et al.,* 1978). Cadmium toxicity depend on plant species metal concentration range. At relatively low soil treatments Cd was more toxic to lettuce grown in calcareous soil than in acid soil. As reported by Chino (1981) the Cd toxicity symptom in rice is characterized by usually decrease in number of tillers and root growth is severely depressed. He recorded the toxicity levels of Cd in rice leaves as 5-10 mg kg^{-1}whereas those in rice root were 100-600 mg kg^{-1}. A pot experiment was conducted to study the effect of Cd concentration on the yield of wheat and soybean and evaluated the phytotoxicity limit (Singh and Rattan, 1987). The guideline value for cadmium content in agriculture soils is 5.0 mg kg^{-1}. The WHO standard for cadmium in food items is 0.07 mg day^{-1} (WHO, 1992). In a duplicate study, Cd intake amounted to 10 ug day^{-1} in men and to 9 ug day^{-1} in women, which is only 12 and 15 % of the WHO limit value, hence it follows that the Cd exposure of soils and flora is not reflected in the food chain of the inhabitations of Bad Liebenstein and health risks caused from Cd can excluded (Muller and Anke, 1994) (Table 8).

Critical level of toxicity of nickel

Although Ni is a such an element for which phytotoxicity is seldom observed and there is no danger of entry into food chain in toxic amounts and ruminants tolerates at least 50 mg kg^{-1}Ni (NRC, 1980), however, forage crop show visual symptoms of toxicity at 50-100 mg kg^{-1} level. Cattle suffered no effects from forage diets with 250 mg Ni kg^{-1} as $NiCO_3$, while soluble Ni salts caused the animals to reduced food consumption. Reduction in yield of rye grass with Ni application beyond 30 mg kg^{-1} in soil was reported by Khalid and Tinaley (1980) who observed that leaf concentration of 50 µg Ni g^{-1} was not sufficient to reduce the yield, though slight chlorosis did appear at this level. Hofer and Schutz (1980) also observed that 50 mg kg^{-1}

of Ni application reduced the oats grain and straw yield by 39 and 50 %, respectively and that of potato tuber by 65 % causing leaf chlorosis and reduction in plant growth. However, Wallace (1980) observed that when 100 mg Ni kg^{-1} was added, maize showed sever toxicity symptoms and all the metal concentration in leaves were highest for this treatment. It was further reported that roots tended to concentrate in the non-contaminated part of the soil. In a similar study, Wallace (1989) observed that barley was most tolerate among maize, barley and soybean of the trace metals and yield depression occurred with this crop only when six metals were applied simultaneously, probably because of the metal induced P-deficiencies. Davis and Beckett (2006) reported that, though the concentration of Cu, Ni or Zn in the tissue of young (five leaf) spring barley grown in nutrient solution containing one of the elements varies considerably with the growing conditions, the minimum concentration of Cu, Ni or Zn in plant tissue (Cu 19, Ni 12, Zn 210 mg kg^{-1} dry weight) necessary to cause toxic reactions are relatively independent of the growing conditions.

Effect of organic matter availability and utilization of cadmium and nickel by crops

Experiment conducted at Hisar (AR MNS, Hissar 2002-03) revealed that Ni uptake by wheat shoot decreased with the application of FYM, but significant decrease were observed only at 3 and 4 per cent FYM levels when compared with control. A significant decrease in Ni uptake by wheat shoot was also observed between 3 and 4 per cent FYM levels. The interaction effect of Ni X FYM with respect to Ni uptake by wheat shoot was found to be significant. Data again reveal that in the control soil (without FYM), Ni uptake increased upto 100 mg Ni Kg^{-1} soil level thereafter it decreased and likewise in case of 4 per cent FYM soil it increased upto 200 mg Ni kg^{-1} soil level because of increased shoot dry matter yield in later soil and decreased in former soil. They further added that the application of FYM significantly decreased the Cd uptake by wheat shoot over control (no FYM). The mean Cd uptake by wheat shoot decreased from 401.68 to 358.63 µg pot^{-1} when levels of FYM in soil were increased from 0 to 4 per cent. The per cent decrease in Cd uptake by wheat shoot was 10.7 due to application of 4% FYM when compared over control. The interaction effect of Cd × FYM with respect to Cd uptake by wheat shoot was found to be non-significant. Gondek *et al.*, (2008), reported that the mean cadmium content in oat dry matter (from the three years of the experiment) depend on plant organ and applied fertilization. The highest cadmium content was detected in the roots. While in case of Nickel on the basis of results obtained no excessive accumulation of Ni in organs of plants fertilized with composts was detected, which resulted from its small concentration in composts.

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