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Uptake and Translocation of some heavy metals (Nickel, Chromium, Cobalt, Cadmium, Lead) by Rice crop in Paddy soils

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Abstract: The goal of the current study is to assess the translocation of five heavy metals—nickel, chromium, cobalt, cadmium, and lead—from soil to rice and wheat, two significant food crops in India. The research area's soil was sampled between April and November 2021. The presence of heavy metals in the soil was found with the help of a flame atomic absorption spectrophotometer. The result showed that heavy metals concentration in plant root (mg kg-1) was as follows: Ni (0.496 ± 0.045), Co (0.301 ± 0.052),Pb (0.244 ± 0.052), Cr (0.193 ± 0.00), Cd (0.070 ± 0.030), and in plant stem it was: Ni (0.294 ± 0.040), Pb (0.227 ± 0.035), Cr (0.052 ± 0.00), Co (0.106 ± 0.014), Cd (0.030 ± 0.00), and in plant grains it was Pb(0.051 ± 0.013), Ni (0.046 ± 0.012), Co (0.057 ± 0.009), Cd (0.013 ± 0.00), and Cr was zero. The average concentration of all measured heavy metals in crop parts was below permissible levels as per Indian standards.

Keywords: Heavy metals, Atomic Absorption Spectrophotometer, Agricultural Soil, Translocation factor

Introduction: The unconsolidated inorganic and organic material that makes up the soil immediately below the earth's surface serves as a natural environment for plant growth and other developmental processes [1]. Humans occasionally act in ways that have a negative impact on the environment in order to fulfil their needs. These outcomes could be advantageous or detrimental. Things like the degradation of soil quality brought on by waste pollution from commercial, residential, and agricultural operations are examples of how human activity reduces environmental quality. One of the main contaminants or pollutants for soil is heavy

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metals. These poisons permeate into the soil and have a toxicological effect since soil and agriculture are intimately connected [2].

As a result of geological processes such erosion and change of subsurface geological materials, soils naturally contain heavy metals [3,4]. The use of herbicides, high metal-content fertilisers, and air deposition all increase the risk of excessive heavy metal contamination of soils [5]. Heavy metals are harmful because they are persistent environmental pollutants [6,7]. Heavy metals are neither destroyed nor reduced, despite the fact that their chemical forms may change, which is a major cause for concern. Environmental contamination caused by heavy metals has become a major global issue in recent years [8]. Soil pollution is the simplest way to expose individuals to metals [9]. Fruits, grains, and vegetables cultivated in contaminated soil can contain heavy metals that can accumulate in human tissues and pose substantial health hazards [10,11]. The type of plant, the properties of the soil, the selectivity of the crops, and the permissibility of the metals are just a few of the variables that affect how much heavy metals accumulate in crops [12, 13]. The amount of heavy metal contamination in soil that affects plants is referred to as the "accumulation factor" [14,15]. Due to the prevalence of heavy metals in the soil in industrial areas, the general public is concerned about being exposed to metals through the consumption of tainted food crops. Although breathing is another exposure mechanism, eating may be the most significant human exposure route [16,17]. Even in extremely modest doses, heavy metals can have detrimental effects on one's health [18]. Essential metals like Cu and Zn can bioaccumulate in both animal and human bodies and cause serious health problems when their permissible limits are exceeded [19,20]. The body loses a number of essential elements after eating tainted food, which has serious negative health effects [21]. Crop contamination by heavy metals is a serious issue everywhere [22]. In addition to additional hazardous metals, as some plants have a tendency to accumulate excessive levels of heavy metals, the soil also supplies plants with a number of critical nutrients, including N, P, and K [23]. Through plant roots or shoots, heavy metals can move from the soil to crops [24]. Cereal grains absorb and store the dangerous metals Pb, Cd, and As that are found in the soil [25]. Heavy metals' bioaccumulation patterns are biassed because of their propensity to move from soil to crops [26]. The human diet contains significant amounts of wheat and rice [27]. Rice is a source of vitamins, minerals, and amino acids that may be consumed by people everywhere [28]. Currently, there are significant worries about the presence of hazardous metals in arable areas and their transfer to crops like rice [29]. Heavy metal levels can

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significantly build up in the tissues of crops cultivated in contaminated soil [30,31]. This study was conducted to examine the concentrations of a variety of heavy metals in the agricultural soil of the investigated area.

Material and methodology

Study area: For the process of soil and crop sampling, area of a field is selected from Bhiwani district, The normal annual rainfall of the district is 420 mm village. The Indian state of Haryana contains the Bhiwani district. Bhiwani serves as the administrative centre for the Bhiwani District. It is situated 261 kilometres north of Chandigarh, the state capital. The population of Bhiwani District is 1629109. By population, it is the third-largest District in the State.

Soil sampling and Analysis

To determine the concentration of heavy metals in the soil, a total of 40 soil samples were collected throughout many sampling seasons. Four sub-samples of soil were chosen from a rectangular grid with a surface area of 0.5 m2 and dug to a depth of 5–10 cm to give a representative sample. Samples were cleaned, sealed, and removed any foreign bodies before being placed in clean plastic bags. Soil samples were air dried, ground, sieved with a 2.0 mm mesh, and stored in airtight containers in advance of further investigation.

A 5.0 ml (HNO3 and HClO4) diacid mixture was combined with 0.5g of each soil sample. The sample mixture was then put into Teflon containers that had already been cleaned, left outside for a whole night at room temperature, and then digested in a microwave digester (CEM MarsX, USA). Each digestion setup's operating programme for the microwave digestion system was optimised at 800W of power and 170 °C of maximum operable temperature. When digestion was finished, the vessels were quantitatively transferred into glass beakers and allowed to cool to room temperature. The digests were then heated to between 130 and 150 °C, evaporated to dryness, and the residue was dissolved in double-distilled water to create the required volume (50 ml). After being transferred to polypropylene bottles, extracted solutions were stored in the refrigerator until analysis. Atomic absorption spectrophotometer measurements were made to determine the total amounts of Cd, Ni, Cr, Co, and Pb in soil samples. An oxidising flame was employed to detect all of the chosen heavy metals, however a reducing nitrous oxide flame was used to detect chromium.

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Heavy Metal Translocation Factor from Soil to Agricultural Crop Samples

Translocation factor (TF) is defined as the ratio of heavy metals from soil to different parts of the crop. It is calculated as the ratio of the heavy metal concentration in the edible component of agricultural samples to the soil concentration in question (Singh et al., 2014).

$$TF = \frac{C_{parts(root,\ shoot,\ grains)}}{C_{soil}}$$

Where, on a dry weight (DW) basis, Ccrop and Csoil represent the concentrations of heavy metals in the edible portions of agricultural samples (grain, fodder, and vegetables), respectively.

Results and discussion

Heavy metal content in agricultural soil of rice crop

Rice is a staple for nearly half of the world's 7 billion people and more than 90% of this is consumed in Asia. About 55% of the total rice production is accounted by China, Taiwan and India alone (IRRI, 2013). The range of studied heavy metal content in agricultural soil of rice field during Oct - Nov, 2021 was as follows: (Co) 4.3 – 5.9 mg kg-1 , (Cd) 0.15 - 0.45 mg kg-1, (Ni) 7.8 – 8.9 mg kg-1 , (Pb) 6.0 – 6.9 mg kg-1 and (Cr) 0.12 - 0.18 mg kg-1 with mean value of heavy metal content (mg kg-1) in the agricultural soil was in the following order: Ni (8.310 ± 0.348) > Pb (6.404 ± 0.338) > Co (5.284 ± 0.495) > Cd (3.542 ± 0.309) > Cr (0.164 ± 0.020) (Table1).

Table 1: Range and mean of heavy metals (mg kg^{-1}) in agricultural soil in *Oryza sativa*

Statistics	Metals				
	Ni	Pb	Cd	Cr	Co
Min.	7.832	6.004	3.113	0.123	4.389
Max.	8.987	6.983	3.987	0.189	5.999
Mean ± SD	8. 310± 0.348	6. 404± 0.338	3.542±0.309	0.164±0.020	5.284±0.495

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Heavy metal content in root of rice

The range of heavy metal content in root of rice crop collected during Oct - Nov, 2021 were: (Co) 0.09 - 0.62 mg kg-1 , (Cd) 0.03 - 0.40 mg kg-1 , (Fe) 28.54 - 841.54 mg kg-1 , (Cu) 1.45 - 57.00 mg kg-1 , (Ni) 2.38 – 20.00 mg kg-1 , (Zn) 7.63 - 40.63 mg kg-1 , (Pb) 0.45 - 5.17 mg kg-1 and (Cr) 0.03 - 0.33 mg kg-1 with mean value of heavy metal content (mg kg-1) was in the following order: Fe (268.89 ± 183.48) > Cu (23.19 ± 11.00) > Zn (16.27 ± 7.33) > Ni (8.31 ± 3.99) > Pb (2.24 ± 0.91) > Co (0.29 ± 0.11) > Cd (0.21 ± 0.10) > Cr (0.15 ± 0.07) (Table 2).

Table 2: Concentration of heavy metals (mg kg^{-1}) in roots of *Oryza sativa*

S. No.	Heavy Metals	Mean
1	Ni	4.110±0.288
2	Pb	1.567±0.349
3	Cd	0.107±0.013
4	Cr	0.030±0.011
5	Co	1.550±0.278

Translocation factor of heavy metal from soil to root

Translocation factor of heavy metal from soil to root of wheat crop collected in April - May, 2022 was: Pb (0.22 - 0.35), Ni (0.52 - 0.66), Cr (0.05 – 0.13), Co (0.42 - 0.52) and Cd (0.50-0.74) with mean value of translocation factor was as follows: Ni (0.57 ± 0.04) > Cd (0.61 ± 0.23) > Cr (0.41 ± 0.07) > Pb (0.27 ± 0.04) > Co (0.008 ± 0.002) (Table 3). It is clear from the results that highest translocation factor of Nickel and lowest of Chromium was observed in all the studied samples.

Table 3: Translocation factor (soil to root) for metals (mg kg^{-1}) in *Oryza sativa*

S. No.	Heavy Metals	Mean
1	Ni	0.496±0.045
2	Pb	0.244±0.052
3	Cd	0.070±0.030
4	Cr	0.193±0.001
5	Co	0.301±0.069

ISSN PRINT 2319 1775 Online 2320 7876

Research paper UGC CARE Listed (Group -I) Journal Volume 11, Iss 11,Nov 2022

Heavy metal content in shoot of rice

Heavy metals in the shoot samples of rice collected during Oct - Nov, 2021 was: (Pb) 0.287 – 0.423 mg kg^{-1}, (Ni) 0.981 – 1.395 mg kg^{-1}, (Cd) 0.079 – 0.091 mg kg^{-1}, (Cr) 0.001 - 0.008 mg kg^{-1} and (Co) 0.132 – 0.197 mg kg^{-1}. Mean value of heavy metal content (mg kg^{-1}) in shoot of rice crop collected in the following order: Ni (1.201± 0.121) > Pb (0.348 ± 0.065) > Cd (0.084 ± 0.004) > Cr (0.002 ± 0.031) > Cr (0.00 ± 0.00) (Table 4). It is clear from the above results that Nickel content was higher and chromium content was lowest in the shoot.

Table 4:Concentration of heavy metals (mg kg^{-1}) in shoot of *Oryza sativa*

S. No.	Heavy Metals	Mean
1	Ni	1.201±0.121
2	Pb	0.348±0.065
3	Cd	0.084±0.004
4	Cr	0.002±0.001
5	Co	0.163±0.031

Translocation factor of heavy metal from root to shoot

Translocation factor of heavy metal from root to shoot of rice crop collected in October-November, 2021 was: Pb (0.190 - 0.307), Ni (0.245 - 0.340), Cr (0.017 – 0.135), Co (0.082 - 0.116) and Cd (0.010 - 0.015) with mean value of translocation factor was in the following order: Ni (0.294 ± 0.040) > Pb (0.227 ± 0.035) > Co (0.106 ± 0.014) > Cr (0.052 ± 0.004)> Cd (0.030 ± 0.002) (Table 5). It is clear from the results that highest translocation factor of nickel and nil value of chromium was observed in all the studied samples.

Table 5: Translocation factor (root to shoot) for metals (mg kg^{-1}) in *Oryza sativa*

S. No.	Heavy Metals	Mean
1	Ni	0.294±0.040
2	Pb	0.227±0.035
3	Cd	0.030±0.002
4	Cr	0.052±0.004
5	Co	0.106±0.014

ISSN PRINT 2319 1775 Online 2320 7876

Research paper UGC CARE Listed (Group -I) Journal Volume 11, Iss 11,Nov 2022

Heavy metal content in grain of rice crop

Rice crop samples from ten sampling stations from the study area were collected during harvesting season. All the collected samples were analysed for Pb, Ni, Cd, Cr and Co content. Heavy metals in the samples of rice collected during October-November, 2021 was: (Pb) 0.009 - 0.027 mg kg^{-1}, (Ni) 0.014 - 0.075 mg kg^{-1}, (Co) 0.006 - 0.012 mg kg^{-1}, (Cd) 0.001 - 0.008 mg kg-1 and Cr was not measurable. Mean value of these heavy metals (mg kg^{-1}) in rice grain samples collected was in the following order: Ni (0.057 ± 0.017) > Pb (0.018 ± 0.006) > Co (0.009 ± 0.001) > Cd (0.003 ± 0.002) > Cr (0.00) (Table 6). It is clear from the results that the amount of Pb was highest and concentration of Cr was lowest in the above studied crop sample.

Table 6: Concentration of heavy metals (mg kg^{-1}) in fruit of *Oryza sativa*

S. No.	Heavy Metals	Mean
1	Ni	0.057±0.017
2	Pb	0.018±0.006
3	Co	0.009±0.001
4	Cr	00
5	Cd	0.003±0.002

Translocation factor of heavy metal from shoot to grain

Translocation factor of heavy metal from shoot to grain of rice collected in October- November, 2021was: Pb (0.034 - 0.077), Ni (0.014 - 0.057), Co (0.043 - 0.076), Cd (0.011 - 0.088) and Cr (0.00) with mean value was in the following order: Co (0.057 ± 0.009) > Pb (0.051 ± 0.013) > Ni (0.046 ± 0.012) > Cd (0.030 ± 0.007) > Cr (0.00) (Table 7). It is clear from the results that highest translocation factor of Cobalt and zero value of chromium was observed in all the studied samples.

ISSN PRINT 2319 1775 Online 2320 7876

Research paper UGC CARE Listed (Group -I) Journal Volume 11, Iss 11,Nov 2022

Table7: Translocation factor (shoot to fruit) for metals (mg kg^{-1}) in *Oryza sativa*

S. No.	Heavy Metals	Mean
1	Ni	0.046±0.012
2	Pb	0.051±0.013
3	Cd	0.030±0.007
4	Cr	0
5	Co	0.057±0.009

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