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Organic Farming and Heavy Metals

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Abstract

In this article an attempt has been made to know the consequences of organic matter added in the soil-plant system for agriculture with special reference to heavy metal availability and toxicity. In the way the characteristic features of soil-heavy metal from organic matters association was described along with availability. Root absorption, transportation and accumulation in food and other plant parts are also been elaborated. Characteristics of manure, compost and vermicompost are also depicted and the fate of heavy metals in soil-plant system was mentioned. Again, some suggestions were mentioned to improve the conditions by agronomic methods such as addition of biochar, biofilm biofertilizer. Heavy metal health risk was taken in consideration in organic farming.

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1. Introduction

Sir Albert Howard, father of modern organic agriculture in his famous book "An Agricultural Testament" summarized the philosophy of organic agriculture as:

"*Mother earth never attempts to farm without livestock; she always raises mixed crops; great pains are taken to preserve the soil and to prevent erosion; the mixed vegetable and animal wastes are converted into humus; there is no waste; the processes of growth and processes of decay balance one another; ample provision is made to maintain large reserves of fertility; the greatest care is taken to store rainfall; both plants and animals are left to protect themselves against disease*."(Howard, 1943) [14].

FAO Definition

"*Organic agriculture is a unique production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles and soil biological activity, and this is accomplished by using on-farm agronomic, biological and mechanical methods in exclusion of all synthetic off-farm inputs*".

The principal aim of organic farming is to establish and maintain a harmonious and interdependent relationship between soil-plant, plant-animal and animal soil systems to create a sustainable agro- ecological system based on local resources. As per IFOAM (2005b) [16] organic agriculture should be based on following aims:

To interact in a constructive and life-enhancing way with natural systems and cycles.

- To consider the wider social and ecological impact of organic production and processing systems.
- To encourage and enhance biological cycles within the farming system, involving microorganisms, soil flora and fauna, plants and animals.
- To maintain and increase long-term fertility of soils.
- To maintain the genetic diversity of the production system and its surroundings, including the protection of plant and wild life habitats.
- To promote the healthy use and proper care of water resources and all life therein.

- To use, as far as possible, renewable resources in locally organized production systems.
- To create a harmonious balance between crop production and animal husbandry.
- To give all livestock conditions of life with due consideration for the basic aspects of their innate behavior.
- To minimize all forms of pollution.
- To allow everyone involved in organic production and processing a quality of life, which meets their basic needs and allows an adequate return and satisfaction from their work, including a safe working environment.
- To progress towards an entire production, processing and distribution chain which is both socially just and ecologically responsible.

Implementing Principles

1. Management of soil health and fertility through diversified cropping systems, crop rotations, multi/ intercropping, conservation and enhancement of nutrient cycles and resource recycling.
2. Making soils chemical residue free through adoption of conversion period
3. Management of livestock in a way where they can express natural behavior.
4. Ensuring health care system through preventive measures and immunity in animals.
5. Complete prohibition on use of synthetic inputs such as chemical fertilizers, pesticides, hormones and growth stimulants in plants, synthetic feed and feed supplements for animals and avoiding to the extent possible use of hormones, synthetic feed supplements, synthetic drugs and antibiotics.
6. Absolute no to genetically modified organisms, their products and derivatives
7. Prohibition on the use of ionizing radiations (such as gamma rays, X-rays etc)
8. Minimizing use of synthetic food additives, preservatives and nutritional supplements in food processing.

Soil fertility and nutrient management

1. Green manuring, legume cover crop/ intercropping, multi cropping, effective crop rotations and recycling of organic farm generated plant biomass through composting or mulching should form the basis of nutrient management
2. Sufficient quantities of biodegradable material of plant or animal origin should be used
3. Biodegradable material of plant/animal origin must be composted through aerobic composting method where pile temperature has been maintained between 131^0 and 170^0 F for minimum 5 days.
4. Raw dung-urine products should be used only after controlled fermentation
5. Mined mineral fertilizers in their natural composition can be used. In case of micronutrient deficiency, micronutrients can be used mixed with compost.
6. Off-farm/ purchased inputs should be evaluated before use by the group to ensure that no prohibited substances have been used in their making and method of production is physical, mechanical or biological.
7. Off-farm/industry produced inputs approved by NPOP accredited certification body as approved input for use in organic farming can be used without further approval of the group.
8. Microbial preparations such as biofertilizers, biodynamic preparations, EM solutions etc can be used.
9. Use of mineral nitrogen and all synthetic fertilizers, chemical hormones, synthetic growth promoters, directly or indirectly are prohibited.
10. Use of sewage, sludge, human excreta or their products are prohibited

Insect pest, disease and weed management

1. Insect pest and disease management should rely primarily on best management practices such as balanced soil fertility management, use of crops and varieties resistant to pests and adapted to local situations, diversity management, effective crop rotations, multi-cropping/ intercropping, green manures, manipulation of planting and sowing time and habitat manipulation through diversified plats, hedge rows, insectary plants, trap crops etc.
2. Pest problems may also be controlled through physical, mechanical and biological approaches such as (but not limited to):
   - Removal of infested plants/ parts,
   - Collection and destruction of egg masses
   - Use of light traps, yellow and blue sticky traps, pheromone traps
   - Mechanical such as tilling, scrapping, hoeing
   - Biological such release of pest predators' parasites, pathogens, installation of bird perches,
3. In cases where cultural and preventive approaches are not sufficient and there is imminent threat to the crop then plant protection products derived from plant or animal origin and prepared by using physical, mechanical or biological methods can be used. Products approved for use in organic farming by certification bodies accredited under National Programme for Organic Production (NPOP) can also be used.
4. Natural mined products and biological products such as microbial biopesticides can be used.
5. On-farm produced plant extracts, oils or fermented products can be used provided no synthetic ingredients is used in such preparations,
6. Weed management can be done through mulching with biodegradable material, mowing, livestock grazing, hand or mechanical weeding, flame, heat or electrical means or by using plastic or other synthetic mulches, provided that such mulches are removed from the field after harvest.
7. Use of synthetic herbicides, fungicides, insecticides and other chemical preparations including synthetic plant growth regulators and synthetic dyes are strictly prohibited. Use of genetically engineered organisms or products are also prohibited.

Soil-Pant Systems

Soil is the fundamental sustenance of food crops, and it can be greatly perturbed by heavy metals from point sources (e.g., energy-intensive industries, such as thermal power plants and coal mines, and chlor-alkali chemical industries, such as goldmines, smelting, electroplating, textiles, leather, and e-waste processing) and non-point sources (e.g., soil/sediment erosion, agricultural runoff, and open freight storage). In addition to their human health implications, heavy metals adversely affect soil biota through microbial processes and soil–microbe interactions (Gadd, 2010; Gall *et al*., 2015; Rai, 2018a) [12, 13, 26]. Beneficial soil insects (especially in agriculture), invertebrates, and small and large mammals are all affected (Gall *et al*., 2015; Bartrons and Peñuelas, 2017) [13, 4].

The primary sources of heavy metals in the soil environment and agriculture are atmospheric deposition, livestock manure, irrigation with wastewater or polluted water, metallo-pesticides or herbicides, phosphate-based fertilizers, and sewage sludge–based amendments (Chary *et al*., 2008; Cai *et al*., 2009; Luo *et al*., 2009; Mansour *et al*., 2009; Gall *et al*., 2015; Lv *et al*., 2015; Elgallal *et al*., 2016; Woldetsadik *et al*., 2017; El-Kady and Abdel-Wahhab, 2018) [7, 9, 13, 5, 21, 24, 37, 10]. In addition to natural sources, conventional/emerging anthropogenic contaminants pose major human health risks through the dietary intake of food crops contaminated by root transfer from soil to plant tissues or direct atmospheric deposition onto plant surfaces (Samsøe-Petersen *et al*., 2002; Zhuang *et al*., 2009) [30, 39] (Fig. 1). Particulate matter (PM) emitted by industries and vehicles ultimately accumulates in soil and the food chain (Rai, 2016a, Rai, 2016b; França *et al*., 2017) [11]. Coal-fired power plants are one major source of Hg contamination in soil.

Heavy metals, such as cadmium (Cd), lead (Pb), arsenic (As), mercury (Hg), nickel (Ni), and zinc (Zn), pose a serious environmental threat, especially when released into the soil. Their impact on the soil microbiome and plant growth can be negative and far-reaching. Heavy metals can affect microorganisms and plants directly, as well as indirectly alter the entire soil ecosystem (Ugrinov,D.,2024 in a discussion on Research Gate) [33].

Impact of Heavy Metals on the Soil Microbiome

1. **Toxicity to Microbial Species**: The soil microbiome includes a wide range of microorganisms, including bacteria, fungi, archaea, and protozoa, that play important roles in the degradation of organic matter, nutrient cycling, and soil fertility. However, the presence of heavy metals can be toxic to many of these microorganisms. Heavy metals like cadmium can damage microbial cell membranes, inhibit their metabolism, or even cause their death. This leads to a reduction in microbial biomass and disruption of essential functions, such as organic matter decomposition and nitrogen fixation.
2. **Changes in Microbiome Composition**: The presence of heavy metals leads to changes in the composition and structure of the microbiome. Communities of microorganisms resistant to the toxic effects of these metals may dominate, while sensitive microbes are suppressed. Often, there is a dominance of metal-resistant bacteria and fungi that may develop specific mechanisms for detoxification or metal excretion (e.g., excreting metal ions or preventing their entry into cells). This shift in the microbiome composition can affect various biogeochemical processes in the soil, such as the carbon and nitrogen cycles.
3. **Reduced Biological Activity**: Increased heavy metal concentrations can reduce the number and diversity of microbial groups responsible for important processes like organic matter breakdown, fertilization, and nutrient recycling. This can lead to a decline in soil fertility.

Impact of Heavy Metals on Plants

1. **Toxic Effects on Plant Growth**:Heavy metals such as cadmium, lead, and arsenic, when absorbed by plants from contaminated soil, can cause toxic effects on plant growth. These metals can damage roots, reduce their ability to absorb water and nutrients, and inhibit shoot and leaf development. The greatest impact of heavy metals is on processes like photosynthesis, root formation, and mineral nutrient uptake. Metals can interfere with enzyme activities and energy production necessary for plant growth.
2. **Changes in Plant Composition and Structure**:When exposed to heavy metals, plants may exhibit various stress symptoms, such as chlorosis (yellowing of leaves), wilting, reduced leaf and shoot size, or even death. Mechanisms like antioxidant production may be triggered to combat oxidative stress, but if metal levels are too high, these mechanisms may become ineffective. Heavy metals can accumulate in plant tissues (roots, stems, and leaves), leading to toxic effects on the plant and potentially contaminating plant products.
3. **Reduced Yield and Quality of Crops**:On a global scale, soil contamination with heavy metals can lead to reduced crop yields and lower quality agricultural products. This is particularly significant for crops like cereals, vegetables, and fruits, as metal accumulation can cause toxicity and decrease the nutritional value.
4. **Alteration of Plant Nutrient Assimilation Mechanisms**: Metals like cadmium and lead can inhibit the absorption of essential nutrients such as calcium, magnesium, and iron, further slowing plant growth and making them more susceptible to other forms of stress.

Soil

Heavy metals represent a significant challenge to soil health, the microbiome, and plant life. They can directly impact the diversity and activity of microorganisms in the soil, as well as disrupt the fundamental processes that support plant growth and development. As a result, long-term effects such as reduced biodiversity, soil degradation, and decreased agricultural productivity may occur. Managing heavy metal contamination in soil is, therefore, crucial for preserving ecosystem and agricultural system health.

Sorption-desorption processes of trace elements on or from soil components is affected by many factors, such as pH, nature of the sorbents, redox reactions, and presence of organic and inorganic ligands. The behavior of foreign ligands on the sorption of trace elements in cationic form is quite different from that toward elements in anionic form. In fact, complexation reaction of trace elements in cationic form with organic and inorganic ligands have an important role to play in their sorption-desorption processes as well as in their toxicity and phytoavailability, whereas competition for available sites and/or reduction of the surface charge of the sorbents between foreign ligands and trace elements in anionic form affect primarily their mobility. Time of reaction and surface coverage have a great influence on the competitive sorption between trace elements and organic and inorganic ligands. Special sequences of extracting reagents are needed for the fractionation of heavy metals and metalloids in order to identify the species that are more available for plants and microorganisms.

The results indicated that the pollution with As, Cd, and Cr metals of some samples were the most of polluted samples according to the EF and I_{geo} and were subjected to sequential extraction, which indicated that Cd and as are mainly associated with carbonate fraction. On the other hand, Pb, Cr, Ni, and Cu are mainly incorporated in the residual fraction, and calculated RAC cleared the potential availabilities of As, Cd, and Cr.

Soils from the polluted area presented a high buffer capacity. The control samples displayed a distinctly poorer resistance to pH changes in the soil environment. Special focus was placed on cadmium due to its high mobility in soils, even with neutral and slightly alkaline pH. The analyses revealed that in areas heavily polluted by long-term industrial activity ($I_{geo} > 5$ for Zn, Pb and Cd), it is very important to conduct extensive geochemical studies related to the presence and circulation of particularly toxic elements. This is because every environmental factor, especially pH, may significantly affect their mobility, causing metal ions to become more or less active or increasing or decreasing environmental risk related to their presence.

Krishnamurti *et al.* (2007) [18] had studied copper mobility and phyto availability on wheat durum *(Triticum durum)* grown in polluted and unpolluted Italian soils. The study was conducted to determine the solid phase distribution of copper in representative soils of Italy with wide differences in chemical and physicochemical properties. Selected sites varied in location as well as in current vegetation and land use. Samples with a high Cu load (132-253 mg kg"^{1}) from a vineyard cultivation area were also included to study the contamination effect on Cu distribution among solid-phases. The solid phase fractionation of Cu in the soils was determined using a 8-step selective sequential extraction method. The results indicated that Cu was dominantly associated with organic binding sites 62.6-74.8%. The relative importance of solid-phase fractions in assessing Cu phytoavailability by durum wheat in a greenhouse setting and the effectiveness of two soil tests, the DTPA-TEA and NH_4C1 extraction method for predicting the phytoavailable Cu was studied. Most Cu was retained by roots with very limited translocation to the upper plant parts of wheat. A significant correlation (r = 0.960, P = 0.0001) was found between plant Cu content and the Cu associated with the metal-fulvate complexes, indicating that phytoavailable Cu was mainly from metal-fulvate complexes. The contaminated soils had a significantly higher Cu proportion (77%) associated with organic binding sites, in comparison with that of uncontaminated soil (21.3%), resulting in higher proportion of phytoavailable Cu.

The effect of salinity induced by $CaCl_2$, $MgCl_2$, NaCl and Na_2SO_4 on the mobility of Cu, Cd, Pb and Zn was studied. An increase of ionic strength by any salts promoted a higher release of Cd than the others metals. When $CaCl_2$ and NaCl were applied, Cd and Pb showed the highest degree of mobilization. When $MgCl_2$ was applied, Cd and Cu were mobilized the most. Finally, an increase of Na_2SO_4 also promoted the strongest mobilization of Cd and Cu.

As the total heavy metal content was higher, the percentage of Pb and Cu released upon salinization decreased, indicating that these metals are strongly bound to soil constituents. An increase of carbonates in the soil promoted a higher release of Pb for all used salts and for Zn when $MgCl_2$ and NaCl were used. This indicates that Pb and Zn are adsorbed on the surface of carbonate crystals. An increase of fine particles promoted a decrease of percentage of released Cd for all salts, indicating that Cd is strongly retained in the fine fractions.

The main mechanism regulating Pb and Cd mobility was competition with Ca^{2+} for sorption sites followed for metal chloro-complexation, association between the Cd/Pb-sulfates and competition with Mg^{2+}. Mechanism regulating Cu mobility was the formation of Cu-sulfate, followed by competition with cations (Mg > Ca) and chloride. For Zn, competition with Ca^{2+} for sorption sites was the most important process for its mobility; followed by Zn-sulfate association and, finally, chloride and competition with Mg with the same effect (Acosta *et al*.,2011) [1].

The accumulation level of heavy metals differs between and within species (Huang and Cunningham, 1996; McGrath *et al.* 2002) [25]. Baker (1981) [15, 3] suggested that plants could be classified into three categories: (1) *excluders:* those that grow in metal-contaminated soil and maintain shoot concentration at low level up to a critical soil value above which relatively unrestricted root-to-shoot transport result, (2) *accumulators:* those that concentrate metals in the aerial part, and (3) *indicators:* the uptake and transport of metals to the shoot is regulated so that internal concentration reflects external levels, at least until toxicity occurs. A number of biochemical reactions occur in plants stressed by heavy metal/metalloids. Most of these reactions are produced by the displacement of protein cationic centres or the increase of reactive oxygen species. Those plants with better ability to adjust to toxicity effects are able to survive in heavy metal/metalloids impacted sites and are better candidates for phytoremediation purposes.

In a study, the accumulation characteristics of As, Hg, Cd, Cr, and Pb in 63 soil samples from 28 organic farms in Beijing, China, were analyzed to investigate the risk of heavy metal pollution in organic agriculture, and the key related factors were evaluated. The results revealed that the As, Hg, Cd, Cr, and Pb concentrations in the soil samples were below the risk screening values and substantially lower than those in the soil under conventional agriculture. However, the coefficients of variation for Hg and Cd were 112.45% and 38.34%, respectively, indicating a notable anthropogenic impact. Notably, 35.92% of the sampling sites had medium to high potential ecological risk values for Cd, and the Cd concentration increased considerably as the number of planting years increased. Different crop types impacted the soil heavy metal concentrations. The concentrations of Cd and As in the soil of Brassica crops were 0.265 and 12.915 mg/kg, respectively, which were substantially higher than those in the soil of other crop types. The Random Forest model indicated that soil nutrients had the most significant impact on soil heavy metal accumulation, particularly phosphorus. Compared with conventional agriculture, organic agricultural soils have lower heavy metal concentrations and exhibit lower ecological risks, with no significant heavy metal pollution detected. However, there is a risk of Cd accumulation, and preventive measures should be implemented, especially for soils under prolonged cultivation and with potential sources of heavy Cd inputs (Shen *et al*., 2025) [31].

Plant

A study assessed the levels of heavy metals (HM; Hg, Cd, Pb, and Cu) and a metalloid (As) in commonly consumed vegetables (lettuce, tomato, green pepper, chard, and spinach) in Chile and Mexico. In Chile the HM and metalloid concentrations were generally lower than those in Mexico and higher in organic crops than in conventional crops. Moreover, the detection frequency of Cd and As in Chilean vegetables was 100%. In Mexico, the Pb levels in organic vegetables (lettuce, tomato, chili, and spinach) and conventional vegetables (spinach and tomato) exceeded the international regulation (IR). In Chile, only tomato showed Pb levels that exceeded the IR. The estimated dietary intake (EDI) values for Mexico were lower than the reference dose, although the EDI values were higher for as in all age ranges and mainly associated with tomato and lettuce in Chile. The target hazard quotient and hazard index values were < 1 (Chile and Mexico). Although the potential health risk is low, prolonged exposure to average concentrations of as (0.2 mg kg-1) in Chile may constitute a potential risk factor for the development of certain cancers (Calderon *et al*., 2023) [6].

Pb uptake in lettuce was higher than that in tomatoes and beans, and Cd and as uptake in the same plants was lower than Zn uptake (Cobb *et al*. 2000) [8]. Pb, Cd, Cu, Zn, and as bioaccumulated in 22 vegetables grown in China in the following decreasing order: leaves > stalk/root/solanaceous > legume/melon vegetables. The THQ reached 5, indicating that all the vegetables had a high potential to cause severe health risks upon ingestion (Zhou *et al*. 2016) [38]. Heavy metals enter the roots from the soil through the intake of water mixed with minerals and nutrients and then bind to low-methyl-esterified pectins, whose levels increase under metal stress (Krzeslowska, 2011) [19]. Pb binds to the cell wall of the root primarily through esterified pectins, as demonstrated in the protonemata of a moss plant (*Funaria hygrometrica*), and can be remobilized (Krzeslowska *et al*. 2010). Polysaccharides (with –COOH, –OH, and –SH functional groups assisting in binding heavy metals to the root) in the root cell walls of food crops also play an important role in the avoidance and tolerance of metal stress. Polysaccharide remodeling under heavy metal stress in food crops results in perturbations of the structural integrity of the cell membrane and organelles (especially chloroplasts and mitochondria), enzyme inactivation through the replacement of integral components or binding to the sulfhydryl or carboxyl group, and nucleic acid conformation changes (Fig.1).

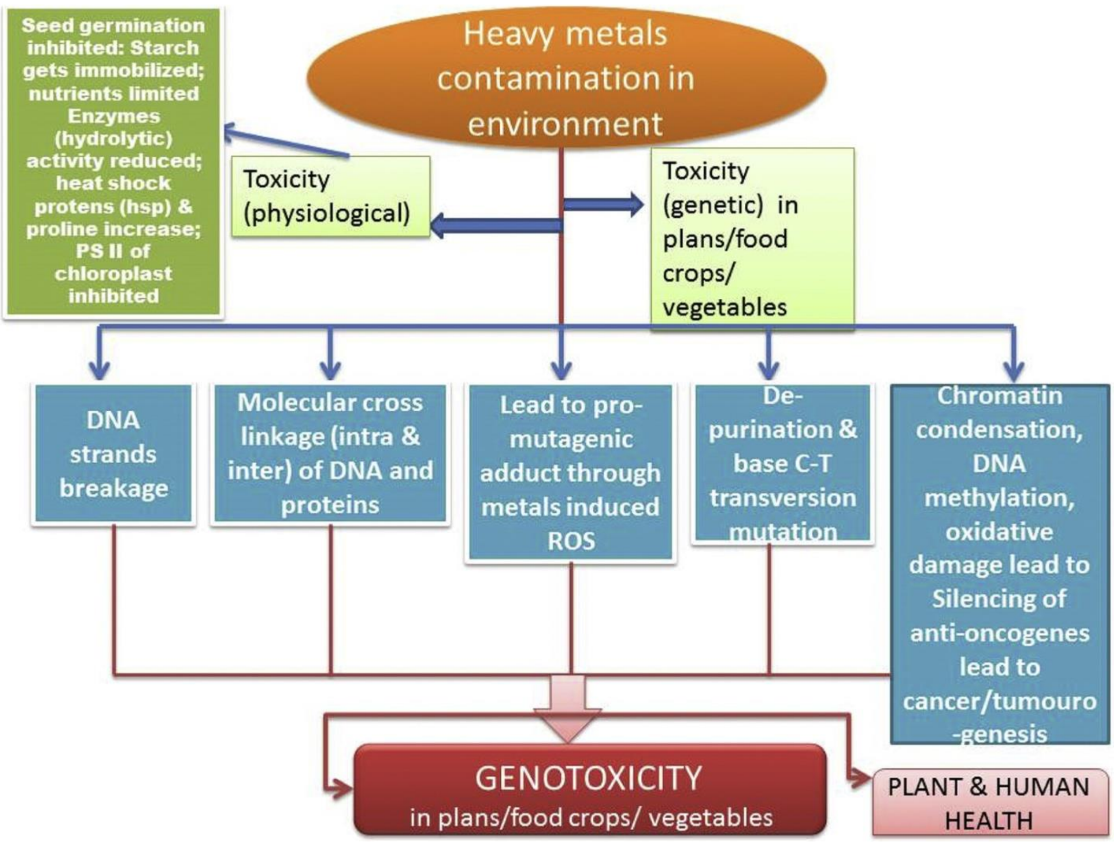

Fig 1: Eco-toxicological impacts (in terms of physiology and molecular alterations) of heavy metal contamination in food crops and ultimately on human health (Rai *et al*.2019) [28].

Manures and Composts

An experiment was carried out to compare changes in heavy metals (HM) [cadmium (Cd), mercury (Hg), nickel (Ni), and lead (Pb)] fractions in five types of livestock manures, namely cow, goat, sheep, chicken, and ostrich. The metals were stepwise fractionated into exchangeable, adsorbed, organically bound, carbonate-precipitated, and residual forms by extracting with 0.5 M KNO_3, de-ionized water, 0.5 M NaOH, 0.05 M Na_2 EDTA, and 4 M HNO_3, respectively. Extractability of HM was found to be highly dependent upon the type of waste as well as extracting agent. Manures differed for the release of HM as chicken > ostrich > sheep > cow > goat. Extractions released HM in the order of Ni > Pb > Cd > Hg(Fig.2) (Irshad *et al*.2013) [17].

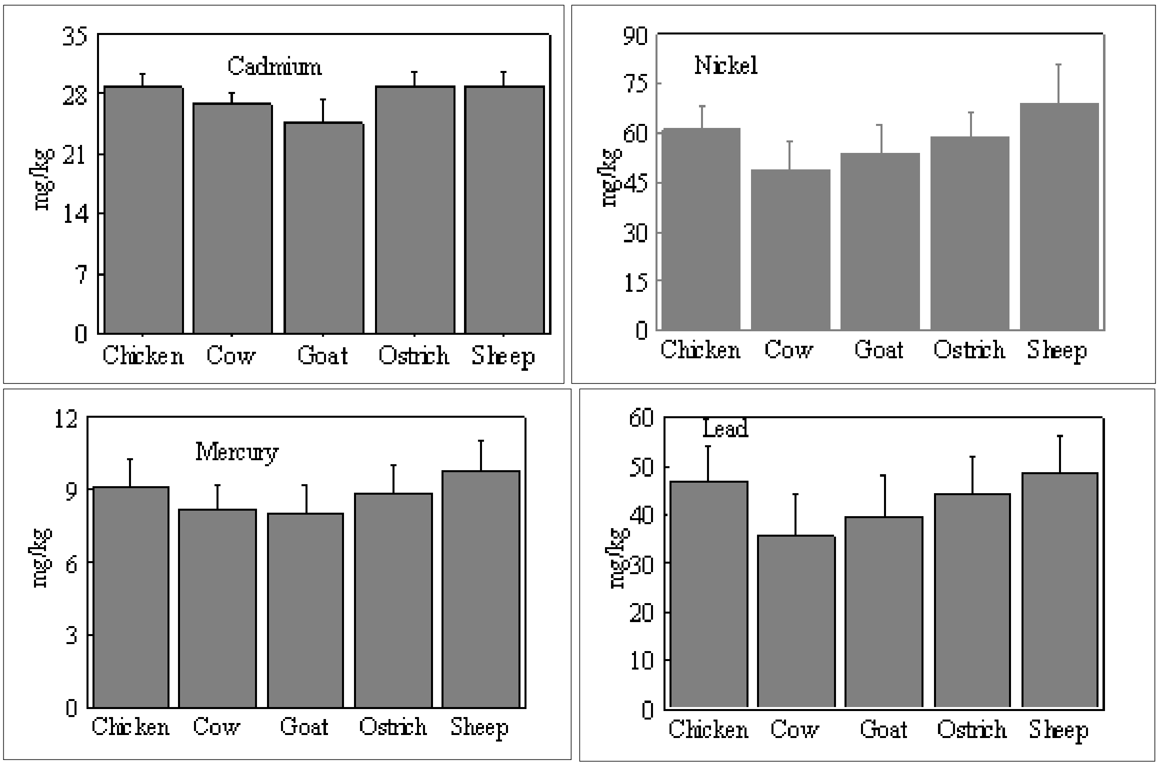

Fig 2: Comparing trace element concentrations in livestock manure (Irshad *et al*.2013) [17]

Experiment was conducted to investigate the responses of heavy metal and nutrient to composting animal manure spiked with mushroom residues with and without earthworms. Results showed that earthworm activities accelerated organic matter mineralization (e.g. reduction in C/N ratio, increase in total concentrations of N, P, K) and humification (e.g. increase in humic acid concentration, humification ratio and humification index). Despite composting increased total heavy metal (i.e. As, Pb, Cu, Zn) concentrations irrespective of earthworm, the availability of heavy metals extracted by DTPA significantly ($P<0.05$) decreased particularly in treatments with earthworms introduced. The shift from available to unavailable fractions of heavy metals was either due to earthworm bioaccumulation, as indicated by total heavy metal concentrations being higher in earthworm tissues, or due to the formation of stable metal-humus complexes as indicated by the promotion of humification. Results suggest that vermicomposting process could magnify the nutrient quality but relieve the heavy metals risk of agricultural organic wastes (Song *et al*., 2014) [32].

Heavy Metals

Biochar has a porous body, charged surface, and many different surface The biochar is highly aromatic, where the functional groups associated with it, which give the biochar a net negative charge, resulting in increased CEC in soil with increased adsorption capacity for both organic and inorganic compounds, and greater nutrient retention functional groups and contains significant amounts of humic and fulvic-like substances(Alfie and Pandoli,2024).

The heavy metals enter into the food chain thus contaminating all resources i.e. air, soil, food, and water. Preventive and remedial measures should be taken to reduce the effects of heavy metals from soil and plants. Organic soil amendments like FYM, Vermicomposting, Biochar, and poultry manure have been used to deactivate heavy metals by changing their forms from highly bioavailable forms to the much less bioavailable forms associated with organic matter (OM), metal oxides, or carbonates. These amendments have significant immobilizing effects on heavy metals because of the presence of humic acids which bind with a wide variety of metal(loid)s including Cd, Cr, Cu, and Pb (Rani and Singh, 2021) [29].

Bioaccumulation and translocation factors were evaluated to assess Toxic Heavy Metal (THM) and micronutrient distribution in soil–plant systems. The human health risk was also estimated. The BFBF (Biofilm Biofertilizer) practice showed a significant reduction in estimated daily intakes in the range of 0.08–0.99 µg kg−1 day−1 for THM such as As, Co, Cd, and Cr compared to the range of 0.16–1.40 µg kg−1 day−1 when using CF (Chemical Fertilizer) alone. Thus, there were significantly low values of hazard quotient (HQ) and hazard index (HI) in the BFBF practice over CF indicating lower health risk. In the CF practice, the translocation of as from panicle to rice seed was significantly increased, and as in rice seeds is reported to exceed the safe level in some cases in Sri Lanka. On the contrary, reduced translocation of As and increased translocation of Cr within the safe level to rice seeds were observed with the BFBF application. Interestingly, the HI had been kept below the threshold value of 1.0 by significantly reducing the HQ values of each THM, only in the BFBF practice. These results highlight the role of increased microbial diversity and abundance induced by the BFBF, in mitigating the health risks and enhancing the sustainability of the soil–plant system Table 1 (Warnakulasooriya *et al*., 2025) [35].

Table 1: Bioaccumulation and translocation factors of the different heavy metals in the biofilm biofertilizer and chemical fertilizer–alone practices (Warnakulasooriya *et al*., 2025) [35].

Factor	Treat.	As	Pb	Cd	Co	Cr	Ni
BaFs-r	BFBF	1.414±0.10	-	0.344±0.02	2.275±0.26	0.302±0.03	0.147
	CF	1.166±0.05	-	0.225±0.01	2.584±0.40	0.190±0.03	0.130
	p-val	0.032	-	0.000	0.519	0.004	0.369
TFr-s	BFBF	-	-	0.720±0.05	0.186±0.04	0.666±0.05	2.257
	CF	-	-	1.350±0.87	0.077±0.00	1.534±0.07	2.531
	p-val	-	-	0.000	0.004	0.000	0.598
TFs-l	BFBF	-	-	2.117±0.15	0.600±0.10	1.752±0.28	1.752
	CF	-	-	2.410±0.21	0.882±0.08	0.981±0.08	1.499
	p-val	-	-	0.026	0.035	0.468	0.412
TFl-p	BFBF	-	-	0.434±0.07	1.009±0.21	0.430±0.06	0.511
	CF	-	-	0.739±0.13	0.664±0.04	0.508±0.02	0.650
	p-val	-	-	0.049	0.188	0.229	0.359
TFp-g	BFBF	0.050±0.01	-	0.173±0.02	0.083±0.02	0.166±0.01	1.540
	CF	0.093±0.01	-	0.218±0.03	0.117±0.02	0.125±0.00	0.734
	p-val	0.003	-	0.176	0.165	0.000	0.090

P-values indicate the probability levels at which the differences between the biofilm biofertilizer and chemical fertilizer–alone practices are significant. BaFs–r is the bioaccumulation factor of a given heavy metal from paddy soil to root. TFr–s, TFs–l, TFl–p, and TFp−g are the translocation factors of a given heavy metal from root to stem, stem to leaf, leaf to panicle, and panicle to seed, respectively. CF, chemical fertilizer; BFBF, biofilm biofertilizer

Heavy metal contamination of soils is one of the main factors contributing to soil quality decline and loss of biodiversity, which is also associated with plant contamination, as metals accumulate in the surface layer of soils and then enter the trophic chain. A study was to assess the mobility and bioavailability of metals in soils to plants, and to estimate the ecological and health risks associated with heavy metal content in soils. 320 topsoil and 206 plant samples were collected. Fractional analysis showed that for most of the samples, there was no or low risk associated with the mobility of Cr, Pb, Cu, Ni, Zn, and low and medium for Cd. High and very high metal release risk was only shown for Cd (28% of samples), and Zn and Pb (2% of samples).

The bioaccumulation factor found moderate levels of accumulation for Cd, Zn, Cu, Ni. High accumulation of Cd and Zn was found in 38% and 15% of plant samples. *Alivibrio fischeri* proved to be a more sensitive indicator of soil ecotoxicity compared to *Sinapis alba*. In the 81% of the soil samples found a low probability of adverse effects on ecological receptors associated with exposure to soil borne metals. In the case of human health risk, no harmful health effects were observed due to accidental ingestion of metal-containing soils in the study area. In assessing metal risks, the choice of indicators is crucial. Moreover, the properties of soils have a significant impact on the mobility of metals and their bioaccumulation by plants. This means that the more varied the choice of indicators, the more comprehensive, reliable and close to reality the risk assessment of heavy metals in soils will be (Fig.3) (Wieczorek *et al*., 2021) [36].

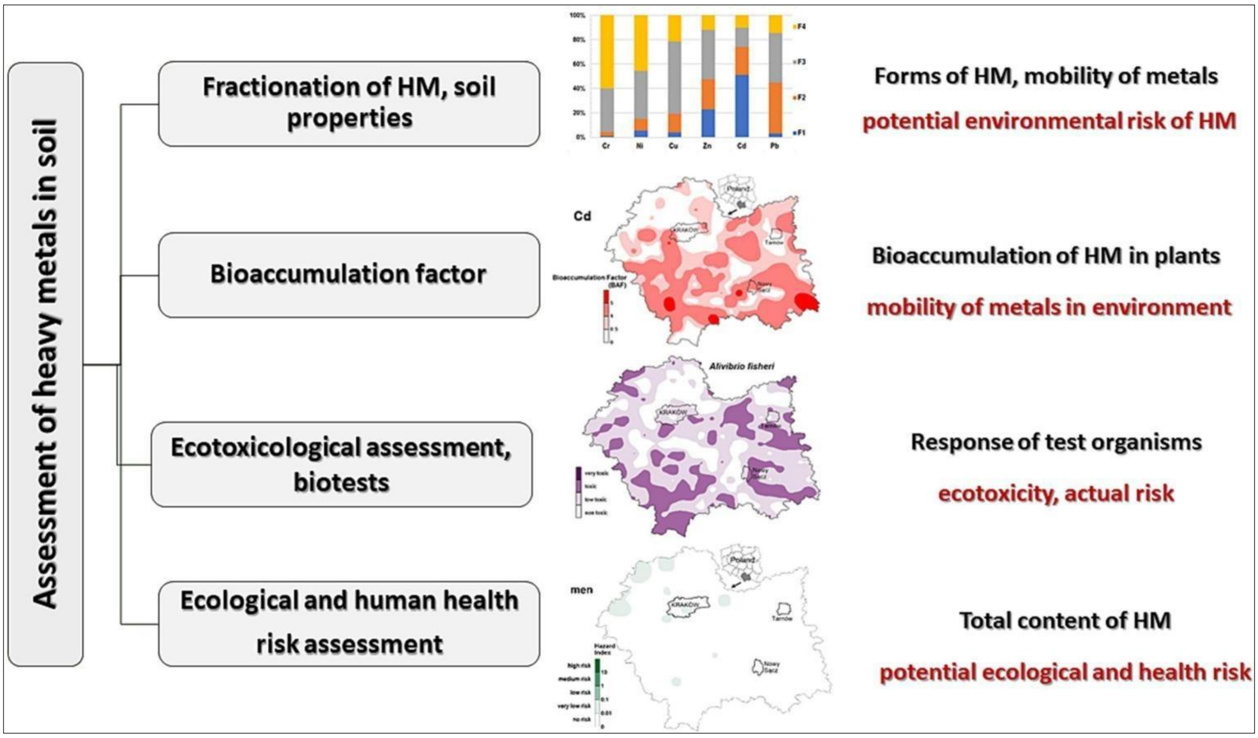

Fig 3: Assesment of heavy metals in soil and ecological and health risk.

Study was to assess the total concentration and speciation variation of heavy metals (Pb, Cd, Cu and Zn) during composting and vermicomposting of industrial sludge with different addition rations of rice husk biochar. Results indicated that pH, EC, total phosphorus (TP) and total potassium (TK) were increased and total organic carbon (TOC) and total nitrogen (TN) were decreased during the composting of industrial sludge with biochar compared with the control (sludge without biochar). The addition of earthworm to the biochar-amended sludge further decreased pH and TOC but highly enhanced the EC, TN, TP and TK. Comparatively lower concentrations of total and DTPA-extractable heavy metals were observed in biochar-amended sludge treatments mixed with earthworm in comparison with the biochar-amended sludge treatments without earthworm or the control. Sequential extraction methods demonstrated that vermicomposting of sludge with biochar converted more metals bound with exchangeable, carbonate and organic matter into the residual fraction in comparison with those composting treatments of sludge with biochar. As a result, the combination of rice husk biochar and earthworm accelerated the passivation of heavy metals in industrial sludge during vermicomposting. Rice husk biochar and earthworm can play a positive role in sequestering the metals during the treatment of industrial sludge (Wang *et al*., 2022) [34].

The application of organic manures like FYM, Vermicomposting, biochar, poultry manure reduced the heavy metal toxicity. Large quantities of organic amendments are used as a source of nutrients and also as a conditioner to improve the soil physical properties and fertility of soils. These organic amendments can be used as a sink for reducing the bioavailability of heavy metals in contaminated soils through their effect on the adsorption, complexation, reduction, and volatilization of metals(Fig.4) (Rani and Singh, 2022) [29].

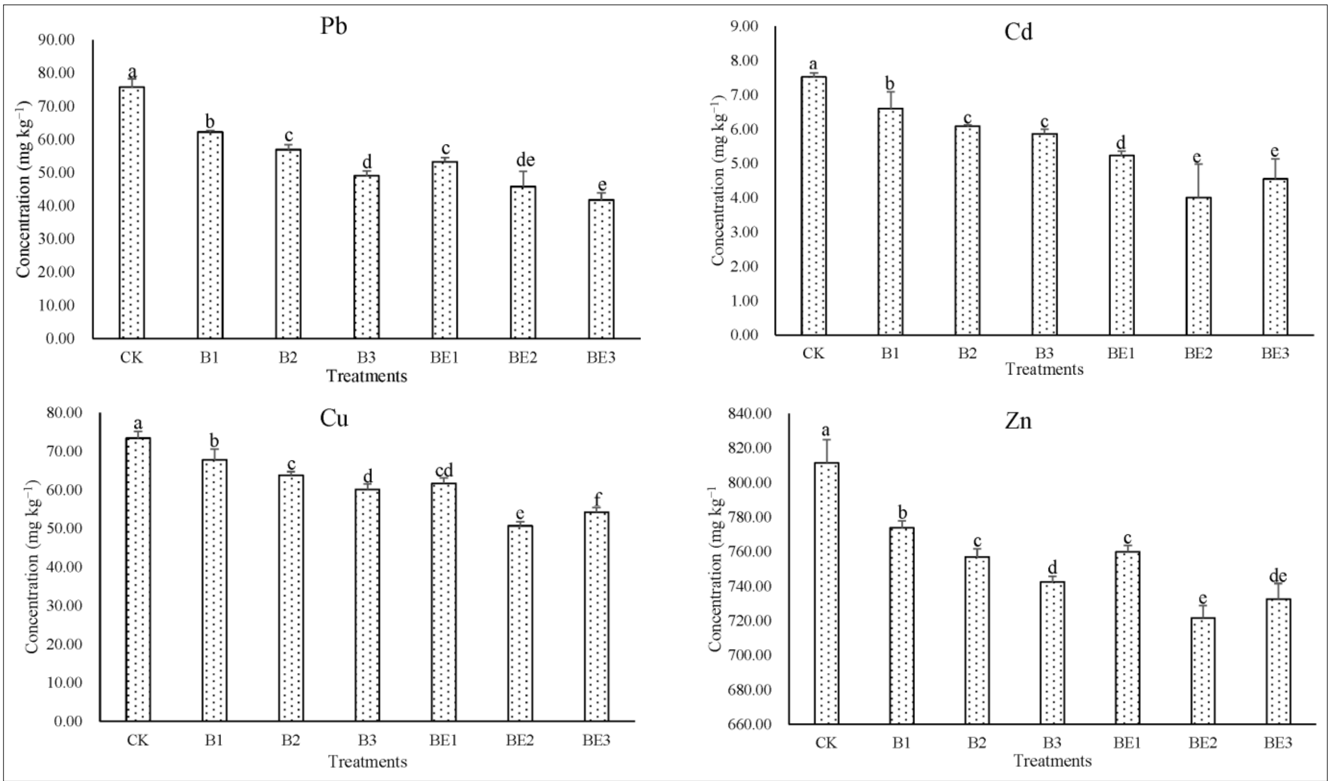

Fig 4: DTPA-extractable heavy metal concentrations in sludge for different treatments. Data are presented as the mean ± SD for three duplicates. Columns with different letters show a significant difference at $p < 0.05$ level.

Conclusion

Presently, organic farming is priority area in agriculture, as the produces may get premium price, with increasing health consciousness on the verge of increasing environmental eco-toxicity. Research works are at its top to find out suitable agro-techniques to look after soil health, efficient supply of plant nutrients and protection using organics also to monitor food chain from toxic heavy metal contamination to avoid health risk of human beings.

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