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Neha Gawde
Ph.D. Scholar, Department of Soil Science and Agricultural Chemistry, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India

Dr. Alok Tiwari
Dean, Kumari Devi Choubey Smriti College of Agriculture and Research Station, Saja, Bemetara, Chhattisgarh, India

Dr. Vinay Smadhiya
Professor, Department of Soil Science and Agricultural Chemistry, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India

Dr. Major GK Shrivastava
Professor and Head, Department of Agronomy, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India

Corresponding Author:
Neha Gawde
Ph.D. Scholar, Department of Soil Science and Agricultural Chemistry, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India

Quantification of heavy metals concentration in long term fertilizer experiment under rice-wheat cropping system on Vertisol

Neha Gawde, Dr. Alok Tiwari, Dr. Vinay Smadhiya, and Dr. Major GK Shrivastava

Abstract
The present investigation entitled "Quantification of heavy metals concentration in long term fertilizer experiment under rice-wheat cropping system on Vertisol" during the *kharif* and *rabi* seasons of 2018-19 and 2019-20 at research farm of College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh. The objective of the study were to determine cadmium, cobalt, nickel, lead and chromium content in soil under long-term application of inorganic fertilizer applied plots. The experiment was laid in a Randomized Block Design with ten treatments i.e. T_1-Control, T_2-50% NPK, T_3-100% NPK, T_4-150% NPK, T_5-100% NPK+Zn, T_6-100% NP-K, T_7-100% N-PK, T_8-100% NPK+FYM (5 t ha^{-1}), T_9-50% NPK+BGA (10 kg ha^{-1}), T_{10}-50% NPK+GM (Sunhemp). The above treatments were randomized with three replications. The experimental soil was Vertisol, locally called as *kanhar.* It is dark brown to black in colour, deep, heavy clay (50%) and neutral to alkaline in the reaction due the to presence of lime concentration.
The AICRP on long-term fertilizer experiment was initiated in the year 1999-2000 at Raipur (C.G.) and after two decades of study indicated that phosphatic fertilizers like single super phosphate derived from the phosphatic rocks were the chief sources of heavy metals like cadmium and lead. Results showed that cadmium, cobalt, nickel, lead and chromium content in soil were at par amongst graded doses of inorganic fertilizer application (50, 100 and 150% NPK) as well as in integrated nutrient management (FYM, BGA and GM) practices. It can be concluded from the study that all the available heavy metals content in different treatments was higher in surface than the subsurface soil in all the treatments. The heavy metals content found in rice and wheat in soil under safe and within the maximum permissible limit as reported by WHO.

Keywords: Heavy metals, integrated nutrient management, long term, rice-wheat cropping system, Vertisol

Introduction
The cropping system refers to the crops, crop sequences and management techniques used on a particular agricultural field over a period of years. It includes all spatial and temporal aspects of managing an agricultural system. Cropping systems have been designed to maximize yield, but modern agriculture is increasingly concerned with promoting environmental sustainability in cropping systems. The rice–wheat cropping system focuses on the precision management options for achieving high productivity, profitability and sustainability. Rice (*Oryza sativa* L.) – Wheat (*Triticum aestivum* L.) crops are major staple foods, contributing a key portion of digestible energy and protein in human intake and occupying a premium position among all food communities. The rice–wheat cropping system (RWCS) is one of the most prominent emerging cropping systems prevailing on the Indian subcontinent as well as in Chhattisgarh plains and is considered to be of utmost importance for food security and livelihood. In India, the rice–wheat cropping system occupies 13.5 M ha area. Effect of heavy metal on RWCS leads in the reduction of rice and wheat production, affect the density composition and physiological activities of microbiota. The uptake of heavy metals into roots occurs mainly through two pathways, the apoplastic pathway (Passive diffusion) and symplastic pathway (Active transport against electrochemical potential gradients and concentration across the plasma membrane). The common uptake of heavy metal via symplastic pathway is an energy–dependent process mediated by metal ion carriers or complexing agents (Peer *et al*., 2005) [9].
Heavy metals are the metals with relatively high densities (>5 g cm^{-3}), atomic weights, or atomic numbers (>20).

Heavy metal contamination of agricultural ecosystems can result through overuse of pesticides and fertilisers, irrigation, atmospheric deposition, and waste-related pollution. The concentration of heavy metals, particularly Cadmium (Cd), Cobalt (Co), Nickel (Ni), Lead (Pb) and Chromium (Cr) and its potential impact on humans health after entering the food chain through crops grown in such heavy metal contaminated soils are topics of increased environmental concern these days. Accumulation of heavy metal is higher in rice soil than wheat soil. Among the heavy metal, Cd, Co, Ni, Pb and Cr are the metals of greatest concern because they may cause serious problems throughout food chain (Jackson and Alloway, 1992) [4].

The earliest long-term experiments called permanent manurial experiments were started at Rothamsted Experimental Station, Harpenden, Herts, England between 1843 and 1856 by J.B. Laws and J.H. Gilbert and are known as "Rothamsted Classical Experiments". Based on the Rothamsted model many such experiments were started in several parts of the world. All India Coordinated Research Project on Long Term Fertilizer Experiments (AICRP – LTFE) launched by the Indian Council of Agricultural Research in September 1970 at 11 centers, currently 18 experiments located in different agro-ecological zones (AEZ) with important cropping systems. The project aims to study the long–term impact of fertilizers on soil quality, crop productivity and sustainability and to monitor the changes in soil properties and yield responses and soil environment due to the continuous application of plant nutrient inputs through fertilizers and organic sources and management of fertilizers to improve soil quality and to minimize environmental degradation (Wanjari and Singh, 2019) [10]. RWCS is practiced in different agroclimatic zones of Chhattisgarh, but most prominent in Chhattisgarh plains. The Long-Term Fertilizer Experiment started at Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.) in the year 1999-2000 and still continues on same site in Vertisol (taxonomic classification is Typic Haplusterts).

Materials and Methods

The experiment was carried out on Vertisol*s* in AICRP- Long Term Fertilizer Experiment at Research Farm, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh), during *kharif* and *rabi* seasons of 2018-19 and 2019-20. The experimental soil was Vertisol is *Typic Haplustert* locally called as *kanhar*. These are uniform, thick (at least 50cm) tropical black and other dark colour, cracking clay mineral soils that have high content (>30%) of clay and neutral to alkaline in the reaction due to presence of lime concentration. These soils swell on wetting and shrink on drying. The swell shrink process induces the development of wide, deep cracks associated with gilgai microrelief or intersecting slickensides. Smectite-type (Montmorillonite) minerals dominant in Vertisol*s* and these soils are occur in peninsular India. The experiment was laid in a Randomized Block Design with ten treatments i.e. Control, 50% NPK, 100% NPK, 150% NPK, 100% NPK+Zn, 100% NP-K, 100%N-PK, 100% NPK+FYM (5 t ha^{-1}), 50% NPK+BGA (10 kg ha^{-1}), 50% NPK+GM (Sunhemp).

Heavy metals i.e., Cd, Co, Ni, Pb and Cr were extracted by using 0.005 M diethylene triamine penta acetic acid (DTPA), 0.01 M calcium chloride dihydrate and 0.1 M triethanol amine (TEA) buffered at pH 7.3. The concentrations of the nutrients in the filtrate were analyzed by atomic absorption spectrophotometer (Lindsay and Norvell, 1978) [5].

Results and Discussion

Heavy metals content in soil after harvest of rice

Available Cadmium in soil after harvest of rice

The data on available cadmium status in surface (0-15 cm) and sub-surface (15-30 cm) soils as affected by 2 decades of long-term application of organic (FYM, BGA and GM) and inorganic fertilizers after the harvest of rice during 2018, 2019 and on pooled mean basis are presented in Table 1. The results showed that the effect of different treatments on available cadmium content in soil after the harvest of rice was found non-significant at both the depths (0-15 and 15-30 cm) during both the years and on a pooled mean basis. However, at 0-15 cm soil depth, the highest available cadmium status (0.75, 0.79 and 0.77 mg kg^{-1}) was noted under T_4- 150% NPK during 2018, 2019 and on pooled mean basis, respectively. Whereas, at 15-30 cm soil depth, the highest available cadmium status (0.44, 0.49 and 0.47 mg kg^{-1}) was noted under T_4- 150% NPK during 2018, 2019 and on pooled mean basis, respectively. While, the lowest cadmium status (0.59, 0.62 and 0.61 mg kg^{-1} at 0-15 cm and 0.35, 0.38 and 0.37 mg kg^{-1} at 15-30 cm) was noted under T_1- control during 2018, 2019 and on pooled mean basis, respectively. The available cadmium status in surface (0-15 cm) and sub-surface (15-30 cm) soils in rice was found within the safe and/or maximum permissible limit as reported by WHO.

Datta *et al*. (2000) [1] revealed that the distribution pattern of metals is governed by various soil physical and chemical factors like particle size distribution, pH, EC, organic matter, $CaCO_3$, cation exchange capacity, exchangeable cations etc. reported that concentration of heavy metals declined with depth which might be due to lowest permeability and vertical movement of the metals. The results also indicated that organic carbon plays a major role in the mobility and transport of Cd, Ni, Cr and Pb in the soils. Immobilization of metals might have been due to adsorption and occulation on the surface by hydroxides and oxides in soils and tend to remain in the zone of incorporation. Increasing doses of phosphatic fertilizers showed increasing status of Cd content. The Cd status was higher at the surface than the sub-surface depth.

Available Cobalt in soil after harvest of rice

The data on available Cobalt status in surface (0-15 cm) and sub-surface (15-30 cm) soils as affected by 2 decades of long-term application of organic manure and inorganic fertilizers after the harvest of rice during 2018, 2019 and on pooled mean basis are given in Table 2. The results showed that the effect of different treatments on available cobalt in soil after the harvest of rice was found non-significant at both the depths (0-15 and 15-30 cm) during both the years and on pooled mean basis. However, at 0-15 cm soil depth, the highest available cobalt status (0.95, 0.98 and 0.97 mg kg^{-1}) was noted under T_4- 150% NPK during 2018, 2019 and on pooled mean basis, respectively. Whereas, at 15-30 cm soil depth, the highest available cobalt status (0.68, 0.71 and 0.70 mg kg^{-1}) was noted under the T_4- 150% NPK during 2018, 2019 and on pooled mean basis, respectively. While, the lowest cobalt status (0.78, 0.79 and 0.79 mg kg^{-1} at 0-15 cm and 0.57, 0.59 and 0.58 mg kg^{-1} at 15-30 cm) was noted under

T_1- control during 2018, 2019 and on pooled mean basis, respectively.

The increasing doses of inorganic fertilizers showed increasing status of soil-available cobalt. Higher cobalt was observed in 150% NPK dose in soil depth surface (0-15 cm) with a similar trend in sub-surface (15-30 cm) soil. Phosphatic fertilizers like superphosphate derived from the phosphatic rocks are the chief sources of heavy metals. Mostly, plant absorbs heavy metals from the surface zone (0-15 cm). The surface zone is mostly affected by pollutants like heavy metals resulting from anthropogenic activities (Machiwa, 2010) [7]. The available cobalt status in surface (0-15 cm) and sub-surface (15-30 cm) soils in rice was found within the maximum permissible limit as reported by WHO.

Available Nickel in soil after harvest of rice

The data on available nickel status in surface (0-15 cm) and sub-surface (15-30 cm) soils as affected by 2 decades of long-term application of organic manure and inorganic fertilizers after the harvest of rice during 2018, 2019 and on pooled mean basis are tabulated in Table 3. The results showed that the effect of different treatments on available nickel in soil after the harvest of rice was found non-significant at both the depths (0-15 and 15-30 cm) during both the years and on pooled mean basis. However, at 0-15 cm soil depth, amongst various treatments. Whereas, the highest available nickel status (1.15, 1.19 and 1.17 mg kg^{-1}) was found on super optimal dose T_4- 150% NPK during 2018, 2019 and on pooled mean basis, respectively. Whereas, at 15-30 cm soil depth, the highest available nickel status (0.88, 0.95 and 0.92 mg kg^{-1}) was noted under the T_4- 150% NPK during 2018, 2019 and on pooled mean basis, respectively. While, the lowest nickel status (0.98, 1.01 and 1.00 mg kg^{-1} at 0-15 cm and 0.72, 0.79 and 0.76 mg kg^{-1} at 15-30 cm) was noted under T_1- control during 2018, 2019 and on pooled mean basis, respectively.

Eskew *et al*. (1983) [2] and Marschner (2002) [8] resulted that the nickel is a major environmental contaminant and one of the wide spread heavy metals, defined as ultra micronutrient. It is considered to be essential for possibly all plant species in small quantities (0.01 to 5 µg g^{-1} dry wt.), being important component of many enzymes especially urease. However, at higher concentrations this metal becomes toxic for majority of plant species. The increasing doses of inorganic fertilizers showed increasing status of soil-available nickel. The available nickel in soil was higher in surface (0-15 cm) than sub-surface (15-30 cm).The available nickel status in surface (0-15 cm) and sub-surface (15-30 cm) soils in rice was found within the maximum permissible limit as reported by WHO.

Available Lead in soil after harvest of rice

The data on available lead status in surface (0-15 cm) and sub-surface (15-30 cm) soils as affected by 2 decades of long-term application of organic manure and inorganic fertilizers after the harvest of rice during 2018, 2019 and on pooled mean basis are presented in Table 4. The results showed that the effect of different treatments on available lead in soil after the harvest of rice was found non-significant at both the depths (0-15 and 15-30 cm) during both the years and on pooled mean basis. However, at 0-15 cm soil depth, the highest available lead status (0.75, 0.79 and 0.77 mg kg^{-1}) was noted under T_4- 150% NPK during 2018, 2019 and on pooled mean basis, respectively. Whereas, at 15-30 cm soil depth, the highest available lead status (0.47, 0.50 and 0.49 mg kg^{-1}) was noted under the T_4- 150% NPK during 2018, 2019 and on pooled mean basis, respectively. While, the lowest lead status (0.58, 0.61 and 0.60 mg kg^{-1} at 0-15 cm and 0.37, 0.39 and 0.38 mg kg^{-1} at 15-30 cm) was noted under T_1- control during 2018, 2019 and on pooled mean basis, respectively.

The increasing doses of inorganic fertilizers showed increasing status of the soil-available lead. The available lead in soil was higher in surface (0-15 cm) than sub-surface (15-30 cm). There was an increase in the lead content of soil over a period of eight years due to the application of zinc sulphate and single super phosphate. All the studied heavy metals exhibited higher concentrations in surface soil than subsurface in DTPA extractable metals. This may be due to less vertical mobility of heavy metals in clay soils reported by Williams (1977) [11]. The available lead status in surface (0-15 cm) and sub-surface (15-30 cm) soils in rice was found within the maximum permissible limit as reported by WHO.

Available Chromium in soil after harvest of rice

The data on available chromium status in surface (0-15 cm) and sub-surface (15-30 cm) soils as affected by 2 decades of long-term application of organic manure and inorganic fertilizers after the harvest of rice during 2018, 2019 and on pooled mean basis are presented in Table 5. The results showed that the effect of different treatments on available chromium in soil after the harvest of rice was found non-significant at both the depths (0-15 and 15-30 cm) during both the years and on pooled mean basis. However, at 0-15 cm soil depth, the highest available chromium status (1.22, 1.26 and 1.24 mg kg^{-1}) was noted under T_4- 150% NPK during 2018, 2019 and on pooled mean basis, respectively. Whereas, at 15-30 cm soil depth, the highest available chromium status (0.92, 0.94 and 0.93 mg kg^{-1}) was noted under the T_4- 150% NPK during 2018, 2019 and on pooled mean basis, respectively. While, the lowest chromium status (1.12, 1.14 and 1.13 mg kg^{-1} at 0-15 cm and 0.82, 0.83 and 0.83 mg kg^{-1} at 15-30 cm) was noted under T_1- control during 2018, 2019 and on pooled mean basis, respectively.

The increasing doses of inorganic fertilizers showed increasing status of soil-available chromium. The available chromium in soil was higher in surface (0-15 cm) than sub-surface (15-30 cm). The available chromium status in surface (0-15 cm) and sub-surface (15-30 cm) soils in rice was found within the maximum permissible limit as reported by WHO.

Table 1: Effect of different treatments on available cadmium in soil after the harvest of rice

Treatment	Available Cadmium (mg kg^{-1})					
	0-15 cm			15-30cm		
	2018	2019	Pooled mean	2018	2019	Pooled mean
T_1-Control	0.59	0.62	0.61	0.35	0.38	0.37
T_2-50% NPK	0.65	0.68	0.67	0.38	0.41	0.40
T_3-100% NPK	0.68	0.70	0.69	0.42	0.46	0.44
T_4-150% NPK	0.75	0.79	0.77	0.44	0.49	0.47
T_5-100% NPK+Zn	0.73	0.77	0.75	0.43	0.48	0.46
T_6-100% NP-K	0.66	0.69	0.68	0.41	0.45	0.43
T_7-100% N-PK	0.60	0.63	0.62	0.36	0.39	0.38
T_8-100% NPK+FYM	0.64	0.67	0.66	0.40	0.43	0.42
T_9-50% NPK+BGA	0.62	0.65	0.64	0.39	0.42	0.41
T_{10}-50% NPK+GM	0.61	0.64	0.63	0.37	0.40	0.39
SEm ±	0.06	0.06	0.06	0.03	0.04	0.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS
MPL (mg kg^{-1})	**3***					

MPL: Maximum Permissible Limit, NS: Non-significant, *- Source: WHO (1996)

Table 2: Effect of different treatments on available cobalt in soil after the harvest of rice

Treatment	Available Cobalt (mg kg^{-1})					
	0-15 cm			15-30cm		
	2018	2019	Pooled mean	2018	2019	Pooled mean
T_1-Control	0.78	0.79	0.79	0.57	0.59	0.58
T_2-50% NPK	0.90	0.93	0.92	0.64	0.67	0.66
T_3-100% NPK	0.93	0.96	0.95	0.66	0.69	0.68
T_4-150% NPK	0.95	0.98	0.97	0.68	0.71	0.70
T_5-100% NPK+Zn	0.94	0.97	0.96	0.67	0.70	0.69
T_6-100% NP-K	0.92	0.95	0.94	0.65	0.68	0.67
T_7-100% N-PK	0.81	0.83	0.82	0.58	0.60	0.59
T_8-100% NPK+FYM	0.88	0.90	0.89	0.63	0.65	0.64
T_9-50% NPK+BGA	0.86	0.88	0.87	0.62	0.64	0.63
T_{10}-50% NPK+GM	0.84	0.86	0.85	0.61	0.63	0.62
SEm ±	0.06	0.07	0.07	0.06	0.06	0.06
CD (P=0.05)	NS	NS	NS	NS	NS	NS
MPL (mg kg^{-1})	**70***					

MPL: Maximum Permissible Limit, NS: Non-significant, *- Source: WHO (1996)

Table 3: Effect of different treatments on available nickel in soil after the harvest of rice

Treatment	Available Nickel (mg kg^{-1})					
	0-15 cm			15-30cm		
	2018	2019	Pooled mean	2018	2019	Pooled mean
T_1-Control	0.98	1.01	1.00	0.72	0.79	0.76
T_2-50% NPK	1.08	1.11	1.10	0.79	0.86	0.83
T_3-100% NPK	1.12	1.16	1.14	0.82	0.89	0.86
T_4-150% NPK	1.15	1.19	1.17	0.88	0.95	0.92
T_5-100% NPK+Zn	1.13	1.17	1.15	0.84	0.90	0.87
T_6-100% NP-K	1.11	1.15	1.13	0.80	0.87	0.84
T_7-100% N-PK	1.01	1.04	1.03	0.73	0.80	0.77
T_8-100% NPK+FYM	1.14	1.18	1.16	0.85	0.92	0.88
T_9-50% NPK+BGA	1.05	1.07	1.06	0.76	0.83	0.80
T_{10}-50% NPK+GM	1.04	1.06	1.05	0.74	0.81	0.78
SEm ±	0.06	0.06	0.06	0.05	0.05	0.05
CD (P=0.05)	NS	NS	NS	NS	NS	NS
MPL (mg kg^{-1})	80*					

MPL: Maximum Permissible Limit, NS: Non-significant, *- Source: WHO (1996)

Table 4: Effect of different treatments on available lead in soil after the harvest of rice

Treatment	Available Lead (mg kg^{-1})					
	0-15 cm			15-30cm		
	2018	2019	Pooled mean	2018	2019	Pooled mean
T_1-Control	0.58	0.61	0.60	0.37	0.39	0.38
T_2-50% NPK	0.70	0.73	0.72	0.42	0.45	0.44
T_3-100% NPK	0.73	0.77	0.75	0.44	0.47	0.46
T_4-150% NPK	0.75	0.79	0.77	0.47	0.50	0.49
T_5-100% NPK+Zn	0.74	0.78	0.76	0.46	0.49	0.48
T_6-100% NP-K	0.68	0.72	0.70	0.43	0.46	0.45
T_7-100% N-PK	0.60	0.63	0.62	0.38	0.40	0.39
T_8-100% NPK+FYM	0.66	0.69	0.68	0.41	0.43	0.42
T_9-50% NPK+BGA	0.65	0.68	0.67	0.40	0.42	0.41
T_{10}-50% NPK+GM	0.64	0.67	0.66	0.39	0.41	0.40
SEm ±	0.06	0.06	0.06	0.04	0.04	0.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS
MPL (mg kg^{-1})	10*					

MPL: Maximum Permissible Limit, NS: Non-significant, *- Source: WHO (1996)

Table 5: Effect of different treatments on available chromium in soil after the harvest of rice

Treatment	Available Chromium (mg kg^{-1})					
	0-15 cm			15-30cm		
	2018	2019	Pooled mean	2018	2019	Pooled mean
T_1-Control	1.12	1.14	1.13	0.82	0.83	0.83
T_2-50% NPK	1.15	1.19	1.17	0.88	0.90	0.89
T_3-100% NPK	1.18	1.22	1.20	0.90	0.92	0.91
T_4-150% NPK	1.22	1.26	1.24	0.92	0.94	0.93
T_5-100% NPK+Zn	1.20	1.24	1.22	0.91	0.93	0.92
T_6-100% NP-K	1.17	1.21	1.19	0.89	0.91	0.90
T_7-100% N-PK	1.13	1.16	1.15	0.83	0.84	0.84
T_8-100% NPK+FYM	1.16	1.19	1.18	0.87	0.88	0.88
T_9-50% NPK+BGA	1.15	1.18	1.17	0.86	0.87	0.87
T_{10}-50% NPK+GM	1.14	1.17	1.16	0.85	0.86	0.86
SEm ±	0.05	0.04	0.05	0.04	0.04	0.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS
MPL (mg kg^{-1})	100*					

MPL: Maximum Permissible Limit, NS: Non-significant, *- Source: WHO (1996)

Available Cadmium in soil after harvest of wheat

The data on available cadmium status in surface (0-15 cm) and sub-surface (15-30 cm) soils as affected by long-term application of organic manure and inorganic fertilizers after the harvest of wheat during 2018-19, 2019-20, and on pooled mean basis are presented in Table 6. The results showed that the effect of different treatments on available cadmium in soil after the harvest of wheat was found non-significant at both the depths (0-15 and 15-30 cm) during both the years and on pooled mean basis. However, at 0-15 cm soil depth, the highest available cadmium status (0.46, 0.48 and 0.47 mg kg^{-1}) was noted under T_4- 150% NPK during 2018-19, 2019-20 and on pooled mean basis, respectively. Whereas, at 15-30 cm soil depth, the highest available cadmium status (0.35, 0.37 and 0.36 mg kg^{-1}) was noted under T_4- 150% NPK during 2018-19, 2019-20 and on pooled mean basis, respectively. While, the lowest cadmium status (0.37, 0.39 and 0.38 mg kg^{-1} at 0-15 cm and 0.26, 0.28 and 0.27 mg kg^{-1} at 15-30 cm) was noted under T_1- control during 2018-19, 2019-20 and on pooled mean basis, respectively.

Lokhande and Kalkar (1999) [6] reported that studies have demonstrated that high concentrations of toxic heavy metals such as cadmium (Cd),and lead (Pb) reduce soil fertility and agricultural output. Indeed cadmium (Cd) concentration above 20 µgg^{-1} in soil reduces rice plant biomass by poisoning the roots and restricting growth (Herawati *et al*., 2000) [3]. The available cadmium status in surface (0-15 cm) and sub-surface (15-30 cm) soils in rice was found within the maximum permissible limit as reported by WHO.

Available Cobalt in soil after harvest of wheat

The data on available cobalt status in surface (0-15 cm) and sub-surface (15-30 cm) after the harvest of wheat during 2018-19, 2019-20 and on pooled mean basis are presented in Table 7. The results showed that effect of different treatments on available cobalt in soil after the harvest of wheat was found non-significant at both the depths (0-15 and 15-30 cm) during both the years and on pooled mean basis. However, at 0-15 cm soil depth, the highest available cobalt status (0.75, 0.78 and 0.77 mg kg^{-1}) was noted under T_4- 150% NPK during 2018-19, 2019-20 and on pooled mean basis, respectively. Whereas, at 15-30 cm soil depth, the highest available cobalt status (0.64, 0.66 and 0.65 mg kg^{-1}) was noted under T_4- 150% NPK during 2018-19, 2019-20 and on pooled mean basis, respectively. While, the lowest cobalt status (0.66, 0.68 and 0.67 mg kg^{-1} at 0-15 cm and 0.55, 0.57 and 0.56 mg kg^{-1} at 15-30 cm) was noted under T_1- control during 2018-19, 2019-20 and on pooled mean basis, respectively.

The available cobalt in soil was higher in surface (0-15 cm) than sub-surface (15-30 cm). The available cobalt status in surface (0-15 cm) and sub-surface (15-30 cm) soils in wheat was found within the maximum permissible limit as reported by WHO.

Available Nickel in soil after harvest of wheat

The data on available nickel status in surface (0-15 cm) and sub-surface (15-30 cm) soils as affected by long-term application of organic manure and inorganic fertilizers after the harvest of wheat during 2018-19, 2019-20 and on pooled mean basis are presented in Table 8. The results showed that effect of different treatments on available nickel in soil after the harvest of wheat was found non-significant at both the depths (0-15 and 15-30 cm) during both the years and on pooled mean basis. However, at 0-15 cm soil depth, the highest available nickel status (0.85, 0.88 and 0.87 mg kg^{-1}) was noted under T_4- 150% NPK during 2018-19, 2019-20 and on pooled mean basis, respectively. Whereas, at 15-30 cm soil depth, the highest available nickel status (0.76, 0.78 and 0.77 mg kg^{-1}) was noted under T_4- 150% NPK during 2018-19, 2019-20 and on pooled mean basis, respectively. While, the lowest nickel status (0.75, 0.79 and 0.77 mg kg^{-1} at 0-15 cm and 0.63, 0.65 and 0.64 mg kg^{-1} at 15-30 cm) was noted under T_1- control during 2018-19, 2019-20 and on pooled mean basis, respectively.

The available nickel amongst various treatments of LTFE experiment was found highest in super optimal doses of inorganic fertilizers as well as in organic manures. The available nickel status in surface (0-15 cm) and sub-surface (15-30 cm) soils in wheat was found within the maximum permissible limit as reported by WHO.

Available Lead in soil after harvest of wheat

The data on available lead status in surface (0-15 cm) and sub-surface (15-30 cm) soils as affected by long-term application of organic manure and inorganic fertilizers after the harvest of wheat during 2018-19, 2019-20 and on pooled mean basis are presented in Table 9. The results showed that effect of different treatments on available lead in soil after the harvest of wheat was found non-significant at both the depths (0-15 and 15-30 cm) during both the years and on pooled mean basis. However, at 0-15 cm soil depth, the highest available lead status (0.47, 0.50 and 0.49 mg kg^{-1}) was noted under T_4- 150% NPK during 2018-19, 2019-20 and on pooled mean basis, respectively. Whereas, at 15-30 cm soil depth, the highest available lead status (0.35, 0.38 and 0.37 mg kg^{-1}) was noted under T_4- 150% NPK during 2018-19, 2019-20 and on pooled mean basis, respectively. While, the lowest lead status (0.36, 0.37 and 0.37 mg kg^{-1} at 0-15 cm and 0.25, 0.27 and 0.26 mg kg^{-1} at 15-30 cm) was noted under T_1- control during 2018-19, 2019-20 and on pooled mean basis, respectively.

The available lead in soil was higher in surface (0-15 cm) than sub-surface (15-30 cm). The available lead status in surface (0-15 cm) and sub-surface (15-30 cm) soils in wheat was found within the maximum permissible limit as reported by WHO.

Available Chromium in soil after harvest of wheat

The data on available chromium status in surface (0-15 cm) and sub-surface (15-30 cm) soils as affected by long-term application of organic manure and inorganic fertilizers after the harvest of wheat during 2018-19, 2019-20 and on pooled mean basis are presented in Table 10. The results showed that effect of different treatments on available chromium in soil after the harvest of wheat was found non-significant at both the depths (0-15 and 15-30 cm) during both the years and on pooled mean basis. However, at 0-15 cm soil depth, the highest available chromium status (0.95, 0.97 and 0.96 mg kg^{-1}) was noted under T_4- 150% NPK during 2018-19, 2019-20 and on pooled mean basis, respectively. Whereas, at 15-30 cm soil depth, the highest available chromium status (0.86, 0.88 and 0.87 mg kg^{-1}) was noted under T_4- 150% NPK during 2018-19, 2019-20 and on pooled mean basis, respectively. While, the lowest chromium status (0.85, 0.86 and 0.86 mg kg^{-1} at 0-15 cm and 0.74, 0.73 and 0.74 mg kg^{-1} at 15-30 cm) was noted under T_1- control during 2018-19, 2019-20 and on pooled mean basis, respectively.

The available chromium status in surface (0-15 cm) and sub-surface (15-30 cm) soils in wheat was found within the maximum permissible limit as reported by WHO. Evaluation of the experimental soil's characteristics in a variety of categories. Using a screw auger, soil samples were taken from the surface (at a depth of 0-15 cm) and from below the surface (at a depth of 15-30 cm), and composite samples were then created. Heavy metals such as Cd, Co, Ni, Pb, and Cr were isolated and examined using an atomic absorption spectrophotometer. After the samples were digested with various acids and salt solutions, the total levels of Cd, Co, Ni, Pb, and Cr were determined using established techniques. The physical examination was performed on the soil samples obtained from a depth of 0 to 15 centimeters from each treatment during the growth stage.

Table 6: Effect of different treatments on available cadmium in soil after the harvest of wheat

Treatment	Available Cadmium (mg kg^{-1})					
	0-15 cm			15-30cm		
	2018-19	2019-20	Pooled mean	2018-19	2019-20	Pooled mean
T_1-Control	0.37	0.39	0.38	0.26	0.28	0.27
T_2-50% NPK (50% NPK)	0.42	0.44	0.43	0.31	0.33	0.32
T_3-100% NPK (100% NPK)	0.44	0.46	0.45	0.33	0.35	0.34
T_4-150% NPK (150% NPK)	0.46	0.48	0.47	0.35	0.37	0.36
T_5-100% NPK (100% NPK+Zn)	0.45	0.47	0.46	0.34	0.36	0.35
T_6-100% NP (100% NP)	0.43	0.45	0.44	0.32	0.34	0.33
T_7-100% N (100% N)	0.38	0.40	0.39	0.27	0.29	0.28
T_8-100% NPK (100% NPK+FYM)	0.41	0.43	0.42	0.30	0.32	0.31
T_9-50%NPK (50% NPK+BGA)	0.40	0.42	0.41	0.29	0.31	0.30
T_{10}-50% NPK (50% NPK+GM)	0.39	0.41	0.40	0.28	0.30	0.29
SEm ±	0.03	0.03	0.03	0.03	0.03	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS
MPL (mg kg^{-1})	**3***					

MPL: Maximum Permissible Limit, NS: Non-significant, Figures in subscript and parenthesis showed *kharif* experiment treatments, *- Source: WHO (1996)

Table 7: Effect of different treatments on available cobalt in soil after the harvest of wheat

Available Cobalt (mg kg^{-1})						
Treatment	0-15 cm			15-30cm		
	2018-19	2019-20	Pooled mean	2018-19	2019-20	Pooled mean
T_1-Control	0.66	0.68	0.67	0.55	0.57	0.56
T_2-50% NPK (50% NPK)	0.71	0.74	0.73	0.60	0.62	0.61
T_3-100% NPK (100% NPK)	0.73	0.76	0.75	0.62	0.64	0.63
T_4-150% NPK (150% NPK)	0.75	0.78	0.77	0.64	0.66	0.65
T_5-100% NPK (100% NPK+Zn)	0.74	0.77	0.76	0.63	0.65	0.64
T_6-100% NP (100% NP)	0.72	0.75	0.74	0.61	0.63	0.62
T_7-100% N (100% N)	0.67	0.69	0.68	0.56	0.58	0.57
T_8-100% NPK (100% NPK+FYM)	0.70	0.72	0.71	0.59	0.61	0.60
T_9-50%NPK (50% NPK+BGA)	0.69	0.71	0.70	0.58	0.60	0.59
T_{10}-50% NPK (50% NPK+GM)	0.68	0.70	0.69	0.57	0.59	0.58
SEm ±	0.04	0.04	0.04	0.04	0.04	0.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS
MPL (mg kg^{-1})	70*					

MPL: Maximum Permissible Limit, NS: Non-significant, Figures in subscript and parenthesis showed *kharif* experiment treatments, *- Source: WHO (1996)

Table 8: Effect of different treatments on available nickel in soil after the harvest of wheat

Available Nickel (mg kg^{-1})						
Treatment	0-15 cm			15-30cm		
	2018-19	2019-20	Pooled mean	2018-19	2019-20	Pooled mean
T_1-Control	0.75	0.79	0.77	0.63	0.65	0.64
T_2-50% NPK (50% NPK)	0.81	0.83	0.82	0.69	0.71	0.70
T_3-100% NPK (100% NPK)	0.82	0.85	0.84	0.73	0.75	0.74
T_4-150% NPK (150% NPK)	0.85	0.88	0.87	0.76	0.78	0.77
T_5-100% NPK (100% NPK+Zn)	0.83	0.86	0.85	0.74	0.76	0.75
T_6-100% NP (100% NP)	0.79	0.84	0.82	0.72	0.74	0.73
T_7-100% N (100% N)	0.76	0.80	0.78	0.64	0.66	0.65
T_8-100% NPK (100% NPK+FYM)	0.84	0.87	0.86	0.75	0.77	0.76
T_9-50% NPK (50% NPK+BGA)	0.78	0.82	0.80	0.67	0.69	0.68
T_{10}-50% NPK (50% NPK+GM)	0.77	0.81	0.79	0.66	0.68	0.67
SEm ±	0.03	0.04	0.04	0.05	0.05	0.05
CD (P=0.05)	NS	NS	NS	NS	NS	NS
MPL (mg kg^{-1})	80*					

MPL: Maximum Permissible Limit, NS: Non-significant, Figures in subscript and parenthesis showed *kharif* experiment treatments, *- Source: WHO (1996)

Table 9: Effect of different treatments on available lead in soil after the harvest of wheat

Available Lead (mg kg^{-1})						
Treatment	0-15 cm			15-30cm		
	2018-19	2019-20	Pooled mean	2018-19	2019-20	Pooled mean
T_1-Control	0.36	0.37	0.37	0.25	0.27	0.26
T_2-50% NPK (50% NPK)	0.43	0.46	0.45	0.30	0.32	0.31
T_3-100% NPK (100% NPK)	0.45	0.48	0.47	0.32	0.35	0.34
T_4-150% NPK (150% NPK)	0.47	0.50	0.49	0.35	0.38	0.37
T_5-100% NPK (100% NPK+Zn)	0.46	0.49	0.48	0.34	0.37	0.36
T_6-100% NP (100% NP)	0.44	0.47	0.46	0.31	0.33	0.32
T_7-100% N (100% N)	0.37	0.39	0.38	0.26	0.28	0.27
T_8-100% NPK (100% NPK+FYM)	0.42	0.44	0.43	0.29	0.31	0.30
T_9-50%NPK (50% NPK+BGA)	0.41	0.43	0.42	0.28	0.30	0.29
T_{10}-50% NPK (50% NPK+GM)	0.40	0.42	0.41	0.27	0.29	0.28
SEm ±	0.04	0.04	0.04	0.03	0.04	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS
MPL (mg kg^{-1})	10*					

MPL: Maximum Permissible Limit, NS: Non-significant, Figures in subscript and parenthesis showed *kharif* experiment treatments, *- Source: WHO (1996)

Table 10: Effect of different treatments on available chromium in soil after the harvest of wheat

Available Chromium (mg kg^{-1})						
Treatment	0-15 cm			15-30cm		
	2018-19	2019-20	Pooled mean	2018-19	2019-20	Pooled mean
T_1-Control	0.85	0.86	0.86	0.74	0.73	0.74
T_2-50% NPK (50% NPK)	0.90	0.92	0.91	0.81	0.83	0.82
T_3-100% NPK (100% NPK)	0.92	0.94	0.93	0.83	0.85	0.84
T_4-150% NPK (150% NPK)	0.95	0.97	0.96	0.86	0.88	0.87
T_5-100% NPK (100% NPK+Zn)	0.94	0.96	0.95	0.85	0.87	0.86
T_6-100% NP (100% NP)	0.91	0.93	0.92	0.82	0.84	0.83
T_7-100% N (100% N)	0.86	0.87	0.87	0.75	0.77	0.76
T_8-100% NPK (100% NPK+FYM)	0.89	0.91	0.90	0.79	0.81	0.80
T_9-50%NPK (50% NPK+BGA)	0.88	0.90	0.89	0.78	0.80	0.79
T_{10}-50% NPK (50% NPK+GM)	0.87	0.89	0.88	0.77	0.79	0.78
SEm ±	0.04	0.05	0.05		0.05	0.05
CD (P=0.05)	NS	NS	NS		NS	NS
MPL (mg kg^{-1})	100*					

MPL: Maximum Permissible Limit, NS: Non-significant, Figures in subscript and parenthesis showed *kharif* experiment treatments, *- Source: WHO (1996)

Conclusions

Based on the experiment result, it may be concluded that the effect of 20 years of different treatments of inorganic fertilizer application and integrated nutrient management practices on all the heavy metals i.e. cadmium, cobalt, nickel, lead and chromium content in soil were at par amongst graded doses of inorganic fertilizer application as well as in integrated nutrient management practices. The heavy metals content found in rice and wheat in soil under safe and within the maximum permissible limit as reported by WHO.

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