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EFFECT OF ORGANIC AND INORGANIC AMENDMENTS ON THE HEAVY METAL CONTENT OF SOIL AND WHEAT CROP IRRIGATED WITH WASTEWATER

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ABSTRACT

Field experiment was conducted to study the effect of wastewater irrigation and different organic and inorganic amendments on the phytoavailability of metals to wheat crop. Wheat was grown in (2x1 m plot) irrigated with wastewater generated from HIE (Hayatabad Industrial Estate, Peshawar, Pakistan) and municipal wastes during 2008. Five different amendments viz farm yard manure (FYM), poultry manure (PM), diammonium phosphate (DAP), triple super phosphate (TSP) and humic acid (HA) were applied and mixed with soil prior to crop growing. In addition, a control (Tubewell irrigation TW) and only wastewater (WW) irrigation plot (without amendments) was also set up for comparison. The FYM and PM were applied at the rate of 10 tons ha^{-1}. The DAP and TSP were added @ of 150 kg ha^{-1} as P where as HA was added @ of 1.5 kg ha^{-1}. A Basal dose of N and K @ of 120 and 60 kg respectively were also added to all experimental plots except control. The results showed that wheat yield and yield components were significantly increased with the addition of all the amendments compared to control and the higher increase was noted in HA treated plots. The effect of different amendments applied on AB-DTPA extractable metals was significant for Cu, Fe, Mn, Ni and Pb ($P<0.05$) and non significant for Cd, Cr and Zn. Higher concentration were noted in the wastewater applied plots with exception of Zn that was lowest in wastewater irrigated plots. The effect of all the amendments on AB-DTPA extractable metals was comparable with exception of Pb that was significantly reduced by DAP. It was concluded that all the metals under study were below the toxicity level in soil and none of the essential nutrient was deficient. The leaves metal concentrations showed that higher values of all the metal under study were noted in leaves when irrigated with WW and TW irrigated plants resulted minimum accumulation of metals in leaves. The effect of different amendments on the plant uptake of metal was variable. Addition of HA reduced the uptake of Cd, Cr, Mn whereas DAP was effective in reducing the phytoavailability of Pb and Zn.

Key Words: **Wastewater, Tubewell water, Amendments, Wheat yield, Soil extractable metals, Leaves metal uptake**

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INTRODUCTION

Pakistan is extremely vulnerable to the adverse impact of climate change among the developing countries. The most serious concerns identified by Task Force of Climate Change (2010) includes threats to its water supply, besides threats to food and energy security, vulnerability of coastal area, increased risks of extreme events (Flood, drought) land degradation due to salinity, water logging and adverse impact on forest, biodiversity and human health. There are very limited choices to address the climate change issues. In Pakistan we need adaptation by changing production technologies and using water efficiently by minimizing water losses. Under the pressure of increasing population, the overall per capita water availability is less than 1800 cubic meter and is now heading to become a water scarce country. As populations continue to grow and more freshwater is diverted to cities for domestic use of which about 70% later returns as wastewater thus making the use of wastewater increased both in terms of the areas irrigated and in the volumes applied (Scott *et. al.,* 2004).

It is estimated that more than 20 million hectares in 50 countries are currently irrigated with urban wastewater (Ensink *et al*. 2004). Untreated wastewater is used for irrigation in over 80% of all Pakistani communities with a population of over 10,000 inhabitants. The absence of a suitable alternative water source, wastewater's high nutrient value, reliability, and its proximity to urban markets are the main reasons for its use (Ensink *et al*. 2004). The findings of Ensink *et al,* from a country-wide survey in the four main provinces of Pakistan showed that untreated wastewater was used in 50 out of 60 visited cities. The three main reasons for the use of wastewater were the high salinity of groundwater, recent droughts that have led to a decline in groundwater tables, and the nutrient value of wastewater. Other important reasons were the proximity of urban markets and the reliability of wastewater, which unlike regular irrigation water is not subjected to a rotational schedule

The use of untreated waste water in the immediate surroundings for the growing of crops and vegetables is a common practice. When such water is used for growing of crops for a long period, being consider as a rich source of nutrients also become a source of heavy metals build up in soil and that may be toxic to the plants and also cause deterioration of soil (Kirkham, 1983). The disposed waste waters are contaminated with trace elements like lead (Pb), copper (Cu), zinc (Zn), boron (B), cobalt (Co) chromium (Cr), arsenic (As), molybdenum (Mo), manganese (Mn) etc. many of which are non essential and over time toxic to plants, animals and human beings. This causing undesirable change in the physical, chemical and biological characteristics of air, water and soil and affects human life, lives of animals and plants. Pre-treatment of wastewater is always recommended before agricultural application but due to the high costs involved, in most places around the globe and more specifically in the developing countries, wastewater, irrespective of its origin is applied to the crops untreated. Therefore, ways needs to be found out to decrease the mobility of toxic heavy metals, rendering them less mobile and more stable, thereby decreasing their availability to the plant. One such method is the phytostabilization of heavy metals. Soil amendments are the major requirement for the successful establishment of vegetation in the metal-contaminated soils. The addition of amendment such as fly ash, sewage sludge, pig manure, is effective in lowering the metal toxicity of the soil and provide slow release of nutrient sources such as N, P, K to support plant growth (Chiu *et al* ., 2006). Cow manure, poultry manure and pig manure were found to be effective in reducing lead availability to plants, leading to lower uptake of lead (Scialdone *et al.*, 1980, Wong and Lau, 1985). In addition, fertilizers are an essential ingredient for successful restoration of mine wastes (Bradshaw and Chadwick, 1980). Transmission of Cd, Pb, and Zn through the food chain is affected by the soil-plant barrier (Chaney and Giordano, 1977). The barrier limits transmission of metals through the food chain either by soil chemical processes that limit the solubility or by the plant senescence from phytotoxicity. Phosphate amendments that can immobilize Pb in contaminated soils include hydroxyapatite (Boisson *et al.,* 1999, Laperche *et al.*, 1997, Khan and Jones, 2008 and 2009).

A rapidly growing population, saline groundwater, a poorly performing irrigation distribution system, and recurrent droughts have led to increased water shortages in Pakistan. Under these conditions, the use of untreated urban wastewater for agriculture has become a common and widespread practice. This experiment aims at investigating the wastewater use looking at environmental and health risks together with the nutritive value of wastewater. In addition to this, the effectiveness of different chemical and organic amendments to immobilize heavy metals and decrease the potential entry of heavy metals into food chain, in an effort to find a safe and cheap way for using untreated wastewater for agricultural crops.

MATERIAL AND METHODS

The mini plots experiments were established on the west side of the main building of The University of Agriculture, Peshawar, Pakistan with the objective to see the long term effect of wastewater irrigation and see the soil build up of heavy metals if any. Wheat crop was grown in November19, 2008 and irrigated with waste water generated from Hayatabad Industrial Estate (HIE) mixed with municipal wastes. The plots were fenced with wire and 4 tanks of 500 L capacity were placed for storing waste water.

The soil was ploughed and good seed bed was prepared manually. Five different amendments viz FYM, PM, DAP, TSP and HA were applied and mixed with soil prior to crop growing. In addition to the treatments plots, a control (Tubewell irrigation) and only WW irrigation plot (without amendments) was also set up for comparison. The FYM and PM (collected from the dairy and poultry farm of Khyber Pakhtunkhwa Agricultural University Peshawar) were applied at the rate of 10 tons ha^{-1}. The DAP and TSP were added at the rate of 150 kg ha^{-1} as P whereas HA was added at the rate of 1.5 kg ha^{-1}. Humic acid was procured from the Department of Soil and Environmental Sciences, The University of Agriculture, Peshawar, Pakistan. Basal dose of N and K at the rate of 120 and 60 kg respectively were also added to all experimental plots except control.

Wheat crop cv *Ghaznavi* was grown in rows 25 cm apart. Prior to the crop growing, the field was irrigated uniformly with wastewater collected from Malakandhere Khwar that drains the effluent from HIE admix with municipal and household waste water. The waste water was stored in tanks for subsequent irrigation when needed throughout the experimental period. The experiment was laid out in RCB design with three replications. The wastewater sample was analyzed for metal content using atomic absorption spectrophotometer (Table 1).

Soil and Plant Analysis

A composite soil sample (0-15 cm depth) from experimental plot was collected air dried, crushed and passed through $\leq$ 2 mm sieve and analyzed for various metals using AB-DTPA extractant (Havlin and Soltanpour (1981). Particle size analysis was determined (Table I) using hydrometer method (Gee and Bauder, 1986). Soil pH and electrical conductivity (EC) were determined (Table 1) in 1:1 (w/v) soil: water extracts (Smith and Doran, 1996). Lime content was determined by acid neutralization method (Richard, (1954) whereas organic matter content was determined by Nelson and Sommer (1982) method. Leaves samples of wheat (third leaf from the bottom fully matured at heading stage) were collected, dried in oven, grinded and metal content was determined by using atomic absorption spectrophotometer following wet digestion procedure as given by Zarcinas *et al*., (1987).

Wheat was grown up to maturity and the yield and yield component data including fresh and dry biomass, plant height and grain yield data was recorded. At harvest, soil samples from each treatment plot were collected to assess the effect of amendments on immobilization of metals.

Statistical Analysis

Replicated data were analyzed using Genstat Discovery Edition 3, package. Means were compared by using least significant difference (LSD) test (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Soil and Water Properties

The soil of the experimental site was silt loam with pH value slightly alkaline and moderately calcareous ($CaCO_{3}$ = 12.5 %). The EC was 0.54 d Sm^{-1} with the organic matter content of 1.02 % (total organic nitrogen less then 0.2 g kg^{-1}) that may not sustain crops without fertilizers addition (Table 1). According to the National Environmental Quality Standards (NEQS)- EPA (1998) for liquid industrial effluents and municipal wastes, the level of Cr, Cd, Cu, Fe, Ni and Pb were above the permissible limits in HIE wastewater whereas the tubewell water is of good quality. The pH of the wastewater was slightly alkaline with EC of 1.01 d Sm^{-1} that is considered marginal for irrigation (Table I).

Table 1. ***Physicochemical characteristics of soil of experimental site and waste/tube-well water used for irrigation***

Parameters	Soil	Wastewater	Tubewell water
Texture	Silt Loam	-	-
pH	7.74	7.41	7.66
EC d Sm^{-1}	0.54	1.01	0.3
OM (%)	1.03	-	-
$CaCO_3$ (%)	12.5	-	-
Cd (mg L^{-1})	ND*	0.19	ND
Cr (mg L^{-1})	0.06	0.83	ND
Cu (mg L^{-1})	2.36	0.97	0.09
Fe (mg L^{-1})	7.42	1.77	0.17
Mn (mg L^{-1})	5.91	1.23	0.06
Ni (mg L^{-1})	2.13	0.36	ND
Pb (mg L^{-1})	2.34	1.08	0.05
Zn (mg L^{-1})	1.97	0.64	0.07

ND = Not detected

Effect of Amendments on Yield and Yield Component of Wheat Irrigated with Wastewater

The yield and yield component of wheat as affected by various organic and inorganic amendments were significantly affected by the addition of various amendments. Minimum yield (0.84 kg $plot^{-1}$) of fresh biomass was harvested from plots receiving only tube well water whereas the higher yield (2.21 kg) was obtained from plots supplied with humic acid (HA) followed by poultry manure (Fig.1). The fresh biomass produced by fertilizers (DAP and TSP) and wastewater irrigation was non significant (among themselves) indicating the nutritive value of wastewater irrigation. The dry biomass followed similar trend as was noted for fresh matter yield being maximum (1.44 kg) in HA treated plot and minimum (0.41 kg) in plots irrigated with tube well water (Fig. 2). The variations in dry biomass with respect to different treatments were significant ($p < 0.05$). Haroon (2009) reported 27 % yield increase of wheat due to the addition of 1.0 kg ha^{-1} HA addition. Humic Acid is thought to improve yield due to its capability of supplying N and P to plants but the total amount of HA added is generally 1 or 2 kg ha^{-1} which will hardly supply 0.04 to 0.08 kg N and 0.001 kg ha^{-1} P to soil. This amount is far below the overall nutrient requirements (Khattak and Mohammad, 2008; and Sharif *et al.*, 2002 b). However, the beneficial effect of HA addition may be associated with improvement in the physico-chemical and biological environment of soil (Brannon and Sommers, 1985).

Plant height (Fig. 3) also followed similar trend as was recorded for biomass (both fresh and dry) production. Shorter plants (60 cm) were recorded in tube well irrigated plots without any fertilizers and taller plants (90 cm) being maximum with humic acid additions in addition to wastewater irrigation. Khan *et al*. (2009) reported higher biomass and taller plants of tomato when irrigated with effluents with or without supplemental NP and K additions.

Grain yield was significantly increased by the addition of organic and inorganic amendments. Significantly higher yield was noted in HA treated plot irrigated with wastewater followed by PM amended plot whereas minimum yield was recorded in control (TW irrigated plot). The results of the FYM, DAP and TSP on grain yield production were comparable. Segura *et al.* (2004) advocated the re-use of waste water in arid and semiarid region of the world and reported that significantly higher yield of melon and tomato were obtained when the crops were irrigated with effluents in the greenhouse crops. The positive effect of the effluents (ozone treated waste water) was due to its significantly higher amount of N, P and K. In another study, Akitaka *et al*. (2002) reported that tomato growth, yield and quality were not effected by the addition of treated wastewater compared to tape water. The effect of both phosphatic fertilizers (DAP and TSP) in the present study was comparable with FYM or PM indicating that P was not a yield limiting factor. Khan and Jones (2008) reported the adverse effect of DAP on yield of tomato but this was mainly due to the initially acidic pH (3.35) in their study and a very high dose of DAP (23 g kg^{-1} soil).

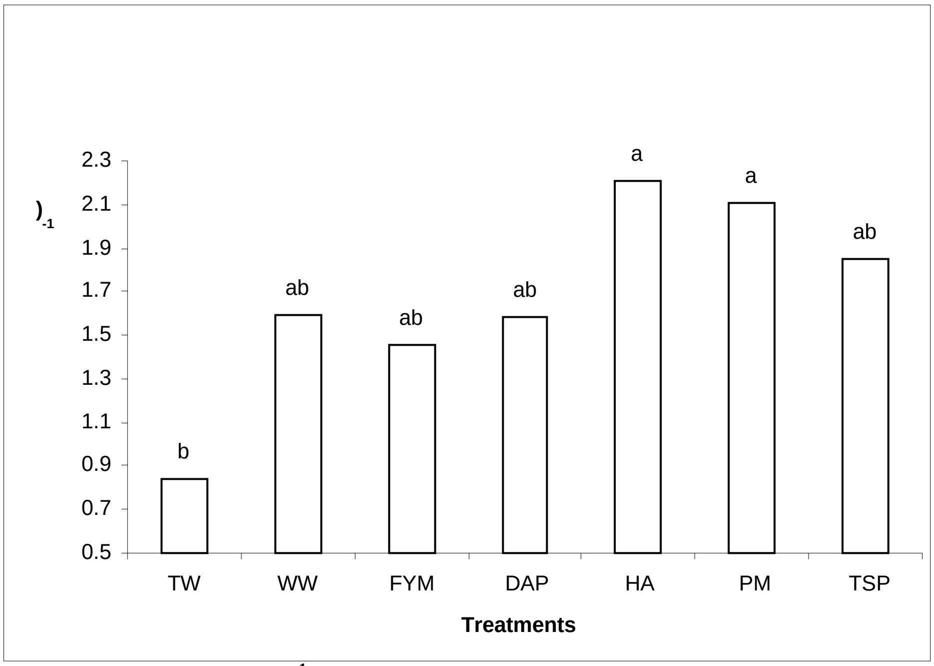

Fig.1. Fresh biomass (kg plot^{-1}) of wheat as influenced by different treatments and wastewater irrigation

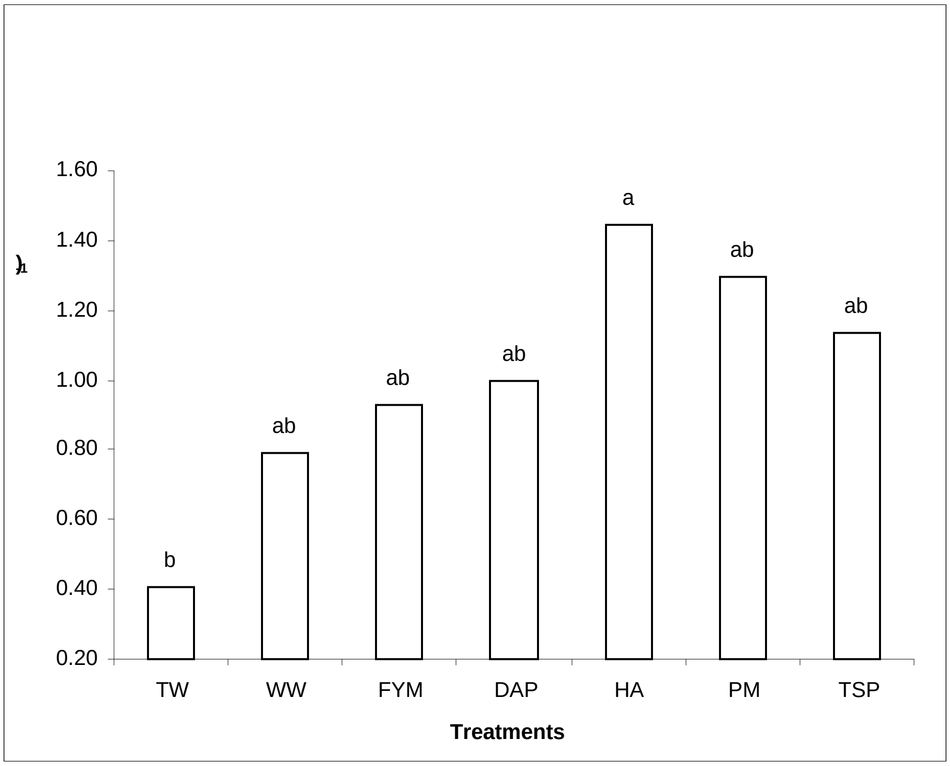

Fig.2. Dry biomass of wheat (kg plot^{-1}) of wheat as influenced by treatments and wastewater irrigation

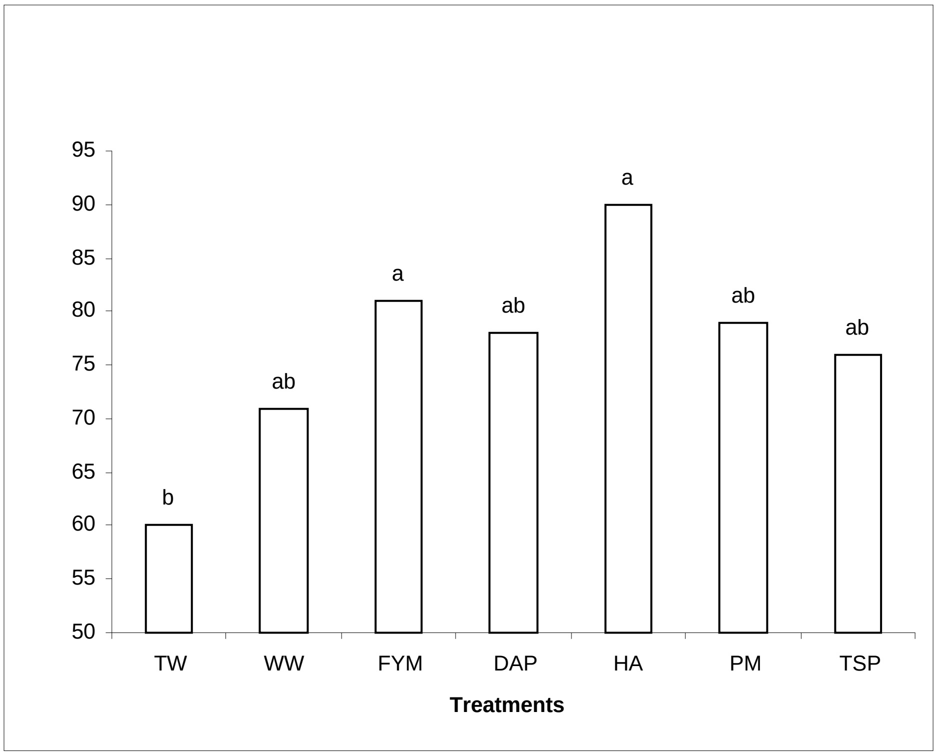

Fig.3. Plant height (cm) of wheat as influenced by different treatments and wastewater irrigation

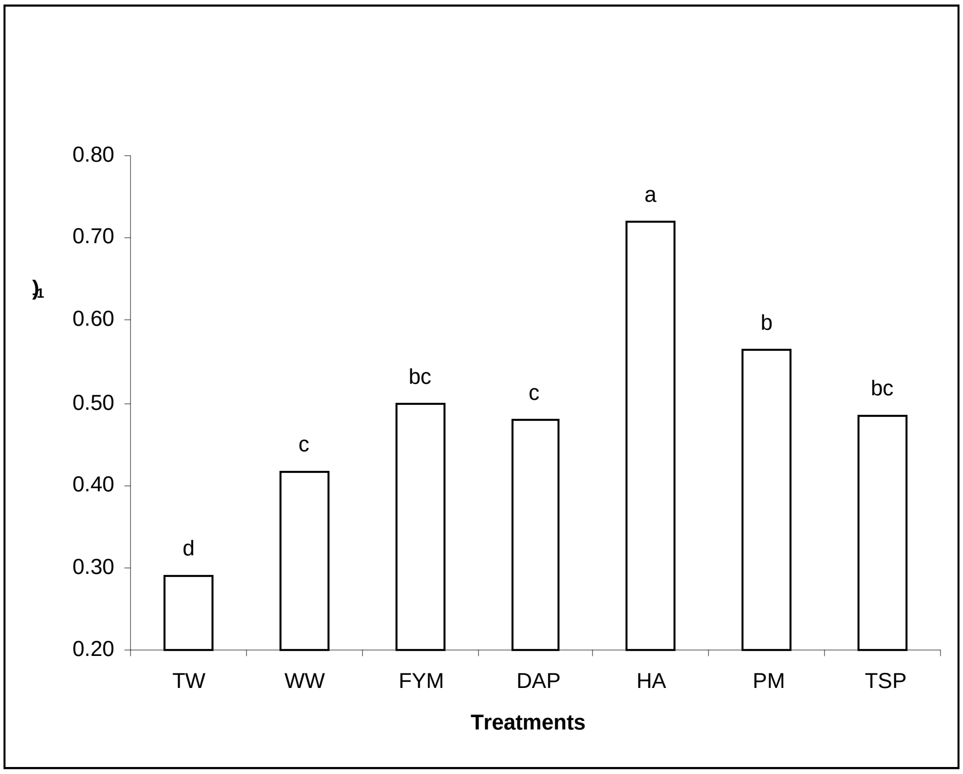

Fig.4 Grain yield of wheat (kg plot-1) as influenced by different treatments and wastewater irrigations

Effect of Amendments on AB-DTPA Extractable Metal Content of Soil Irrigated with HIE Wastewater

The effect of different amendments applied on AB-DTPA extractable metal content was significant for Cu, Fe, Mn, Ni and Pb ($P<0.05$) and non significant for Cd, Cr and Zn. Average AB-DTPA Cd concentration ranged from 0.84 mg kg^{-1} in the wastewater applied soil to 0.11 mg kg^{-1}, in the FYM amended soil, a decrease of about 86 % in extractable

Cd (Table 2) compared to control. Although non significant (compared to other amendments), the addition of FYM was more effective in reducing the extractability of Cd followed by DAP application. The effectiveness of FYM on reducing Cd availability may be due to the formation of insoluble Cd and organic matter complexes that might have reduced its extractability. Karaca (2004) reported a decrease in extractable Cd in soil when amended with compost and this decrease was attributed to the formation of organic matter complex with Cd in soil.

The AB-DTPA extractable Cr followed similar trend as was noted for Cd concentration (Table 2). The effect of the amendments application (within) was not significant ($P < 0.05$). However, higher concentration of Cr (0.24 mg kg^{-1} was noted in wastewater irrigated soil. According to the critical soil test values reported by Kabata-Pendias and Pendias (1995), it was noted that both Cd and Cr were below the level considered to be toxic in soil for plant growth. Bolan and Duraisamy (2003) in their review indicated that phosphate compounds are effective in reducing the phytoavailability of Cd whereas organic amendments are effective for phytostabilizing Cr and Cu in soil.

Average AB-DTPA extractable Cu concentration ranged from 3.53 mg kg^{-1} in the wastewater irrigated soil to 2.62 mg kg^{-1} in the FYM amended soil, a decrease of 26 % in extractable Cu (Table 2). Overall, the maximum AB-DTPA extractable Cu reduction was by the addition of FYM and HA and the lowest reduction was from TSP and DAP. Khan and Jones (2008) reported the superiority of liming on the reduction in phytoavailability of Cu that was attributed to the significant increase in soil pH by liming in their study. This apparent contradiction with the present study is mainly because the soil used in their experiment was acidic (pH 3.39) while in the present study the pH was above 7. Sabir *et a.l* (2008) reported an increase in extractable Cu by the addition of FYM and press mud whereas activated carbon reduced the Cu extractability. In the present study, there were no significant differences between the amendments with respect to extractable Cu but were significantly different from plots receiving wastewater or tubewell water.

Iron, one of the essential micronutrients and usually less studied as a pollutant was significantly ($p<0.05$) affected by the different amendments. Like Cu, the addition of amendments reduced the extractability of Fe by all the amendments and HA was more effective compared to all other treatments. The maximum Fe concentration was noted in soil irrigated with wastewater. All the amendments were non significant (P >. 0.05) among themselves. Reduction of extractable Fe by different treatments is plausible due to binding of Fe (as well as Cu, Pb and Zn) on organic matter in the compost treatment and the precipitation of metals with $CaCO_3$ as the soil was moderately calcareous.

The concentration of extractable Mn also varied significantly ($P < 0.05$) and the higher value (22.86 mg kg^{-1}) was noted in soil irrigated with wastewater with no addition of amendments and the lowest value (3.94 mg kg^{-1}) was recorded in TSP amended plot. The addition of HA enhanced the extractability of Mn. According to the critical test values reported by Havlin and Soltanpour (1981) the concentration of Mn was in the adequate range and according to the USEPA (1999) standard of irrigation, the wastewater had much lower concentration of Mn to be a problem for irrigation. Sabir, *et al*. (2008) in their incubation studies reported reduction of Mn with addition of activated carbon but AB-DTPA extractable Mn increased with FYM and poultry manure (PM). In the present study, PM increase the Mn content in soil compared to FYM indicating enrichment of Mn in poultry manure whereas the addition of TSP reduced its extractability.

The AB-DTPA extractable Ni content in soil was significantly affected by the addition of different amendments. According to the NEQS (1998), the wastewater irrigated plots had higher Ni concentration (below the permissible limits) compared to all other treatments and tubewell irrigated plots showing its build up in soil. The addition of amendments significantly reduced the Ni concentration and the lowest values were recorded in plots treated with TSP and poultry manure. Sabir, *et al*. (2008) reported decrease in Ni concentration with the addition of FYM and activated carbon and this decrease in Ni were attributed to its immobilization with humified OM in soil. The significant reduction in Ni by TSP may be due to presence of Ca that has reduced its bioavailability. Robinson *et al*. (1999) reported a significant reduction in both cobalt and Ni by the addition of $CaCO_3$.

Lead is one of the most widely studied and most frequent polluting metal. Unlike Cr and Cd, AB-DTPA extractable Pb was significantly ($P < 0.05$) affected by the addition of different amendments. DAP showed the greatest reduction compared to unamended wastewater and tubewell irrigated plots, while the addition of FYM and HA increased the extractability of Pb. The effect of P containing amendments on Pb stabilization is well documented in the literature (Ma *et al*., 1995; Hettiarachchi and Pierzynski, 2002). The application of soluble phosphate (DAP) and its effect on immobilizing Pb and Cd is reported by McGowen *et al*. (2001). Ruby *et a*l. (1994) indicated that adequate levels of phosphate were responsible for the formation of insoluble complexes and the reduction in potentially phytoavailable Pb. Basta and McGowen, (2004) while comparing lime, rock phosphate and DAP reported that DAP was most effective in immobilizing Cd, Pb and Zn and lime was the least.

Unlike Pb, the AB-DTPA extractable Zn concentration was not affected significantly by either treatment. Interestingly, the wastewater irrigated plots had lower values than the plots irrigated with tubewell water. This was because the concentration of Zn was much lower in the wastewater to be considered toxic according to NEQS (1998) for irrigation. All the amendments enhanced the extractable Zn compared to control and wastewater irrigated plots. Unlike Sabir, *et al.* (2008), the non significant variations in Zn content of soil may be due to the low level of Zn present in soil as well as in water. Shuman (1999) observed that Zn retention by soil increased in the presence of organic material.

Table 2. ***Effect of organic and inorganic amendments on the AB-DTPA extractable metal content (mg kg^{-1}) of soil irrigated with HIE wastewater***

Treatments	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
TW	0.17	0.07	3.01	11.46	4.58	1.97	2.15	2.13
Wastewater	0.84	0.24	3.53	22.86	7.94	3.69	2.10	1.87
FYM	0.11	0.12	2.62	12.26	4.28	1.85	3.12	3.23
DAP	0.15	0.09	2.86	13.68	4.14	1.31	0.79	3.13
HA	0.19	0.09	2.62	10.47	6.53	1.25	3.54	3.10
PM	0.25	0.09	2.71	13.05	5.76	0.35	1.49	2.90
TSP	0.23	0.15	2.96	15.85	3.94	0.21	1.15	2.63
LSD	NS	NS	0.47	8.53	1.21	1.53	2.15	NS

Effect of Amendments on Phyto-availability of Metal Irrigated with HIE Wastewater

The results of heavy metal concentration of plants as affected by various amendments (Table 3) were significantly ($P < 0.05$) variable. The overall results suggest that higher concentrations of all the metal under study were noted in leaves when irrigated with wastewater while tube well irrigated plants resulted minimum accumulation of metals in leaves. Higher values in the wastewater may be due to the fact that wastewater was composed of various types of industrial, municipal and domestic effluents that contained varieties of chemicals and suspended solid having a variety of metals. This can be confirmed from the water analysis given in Table I. These results are in line with the results obtained by Kansal and Singh (1983), Schirado *et al.* (1986) and Lone *et a*. (2003) who studied the effect of waste water on maize, berseem, cauliflower, spinach and okra and found considerable higher concentration of heavy metals compared to soil receiving tubewell irrigation.

The effect of different amendments on the plant uptake of metal was variable (Table 3). Addition of HA reduced the uptake of Cd, Cr, Mn whereas DAP was effective in reducing the phytoavailability of Pb and Zn. The reason of lower concentration of Cd, Cr and Mn may be due to dilution effect as significantly higher biomass was produced when HA was applied. Addition of TSP significantly reduced the phytoavailability of Fe and Cu availability was reduced by the addition of poultry manure. The addition of FYM with exception of Ni enhanced the phytoavailability of metals (due to the binding of metals on organic matter and its subsequent release to plant as reported by Geebelen *et al*. (2002). This seems contradictory when viewed in light of the extractable metals reported in Table 2, suggesting that the extractable metals not necessarily mean phytoavailable as phytoavailability is governed by other soil factors like soil pH and lime content. The superiority of DAP or TSP as Pb and Zn stabilizing agent as reported by Hettiarachchi and Pierzynski (2002) and McGowen *et al.* (2001).

From the Table 3, it can be further seen that plant accumulated higher concentration of Cd, Cr, Fe, Ni and Pb in plots irrigated with wastewater and these values are considered to be excessive or toxic in mature leaf tissues generalized for various species (Kabata-Pendias and Pendias, 1995). However, the values for all the metals were within the permissible range in tubewell irrigated plots or in many cases the addition of amendments reduced the phytoavailability. The concentration of Mn and Zn was within the safe limits (Kabata-Pendias and Pendias, 1995) regardless of the irrigation water supply and amendments used.

Table 3. ***Effect of organic and inorganic amendments on the heavy metal content (mg kg^{-1}) of plants irrigated with HIE wastewater***

Treatments	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
TW	3.60	4.33	14.13	318.0	102.5	68.7	65.3	77.0
Wastewater	8.67	31.33	18.27	484.0	115.3	98.7	127.3	92.3
FYM	6.07	18.00	16.20	322.0	76.5	24.0	83.3	79.1
DAP	5.13	24.00	11.88	352.0	124.9	88.0	55.7	42.2
HA	4.60	16.00	12.67	326.0	60.4	46.0	58.0	75.5
PM	4.33	21.33	9.33	385.0	80.7	97.2	83.3	63.2
TSP	4.23	19.45	12.53	277.0	96.2	79.6	80.7	83.6
LSD	4.47	7.66	3.21	84.2	49.2	50.3	59.0	28.4

CONCLUSIONS AND RECOMMENDATION

Wheat yield and yield components were significantly affected by the addition of various amendments. Minimum yield was harvested from plots receiving only tube well water whereas the higher yield was harvested from plots supplied with humic acid (HA). Tissue heavy metals results revealed that higher concentrations of all the metal under study were noted in leaves when irrigated with wastewater. Addition of HA reduced the uptake of Cd, Cr, Mn whereas DAP was effective in reducing the phytoavailability of Pb and Zn. The need for ways to reduce health and environmental risks while at the same time safeguarding positive impacts of using wastewater can be achieved by using amendments such as HA, DAP or FYM to reduce the heavy metal uptake of metals.

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