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Heavy metal content of alfalfa irrigated with waste and tubewell water

***Mohammad Jamal Khan*[*1], *Mohammad Tariq Jan*[2] *and Dost Mohammad*[1]**
[1]Department of Soil and Environmental Sciences, KPK Agricultural University, Peshawar
[2]Department of Agronomy, KPK Agricultural University, Peshawar

Abstract

A field experiment was conducted to study the effect of wastewater on yield and heavy metal uptake of alfalfa along with a tubewell irrigated crop as control at the Agricultural University Peshawar during 2009. The experiment was conducted in small plots (2 x 1m) replicated thrice with fertilizer additions. The crop was either irrigated with Hayatabad Industrial Estate (HIE) wastewater or tubewell water. The yield data revealed that shoot dry weight was significantly affected by the irrigation water supplies and higher yield was recorded in wastewater irrigated plots and the increase was consistent with time (different cutting). By comparing the total dry biomass of the two treatments, it was observed that there was about 37% increase in yield over control with application of wastewater. The shoot dry weight increased by a factor of about two to three times from first cutting to third cutting in both the treatment plots and the magnitude of increase in yield was higher in wastewater irrigated plots. The heavy metal uptake by the crop was much higher in wastewater irrigated plots compared to tubewell water. The order of metal uptake was Fe> Mn>Zn>Cu>Pb>Ni>Cr>Cd. Shoot analysis showed no metal toxicity because the concentration of the metal was less than phytotoxic level and all the metals were within the permissible limits.

Key Words: *Alfalfa, wastewater, cutting, metal concentration, dry biomass*

Introduction

It is estimated that up to one-tenth of the world's population eats food produced by using wastewater. As population continue to grow and more freshwater is diverted to cities for domestic use, of which about 70% later returns as wastewater thus increasing the use of wastewater both in terms of the areas irrigated and in the volume applied (Scott *et. al.,* 2004).

Although a common and often ancient practice of using wastewater that is often untreated or inadequately treated in irrigated agriculture is receiving attention because of the increasing scarcity of clean water resources and the growing volumes of urban wastewater in developing countries. It is estimated that more than 20 million hectares in 50 countries are currently irrigated with urban wastewater (Scott *et al.*, 2004). Untreated wastewater is used for irrigation in over 80% of all Pakistani communities with a population of over 10,000. 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 results of Ensink *et al.* (2004) from a country-wide survey in the four main provinces 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 major sources of the wastewater includes urban wastewater comes from domestic sewage (black water from the toilet, i.e. human waste and grey water from kitchen and washroom sinks, showers and laundry), from commercial establishments and institutions, including hospitals, from industry and from storm water and other urban runoff.

The use of untreated wastewater 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, not only considered as a rich source of nutrients but also become a source of heavy metals build up in soil and that may be toxic to the plants and also causes deterioration of soil (Kirkham, 1983).

The disposed wastewater is contaminated with trace elements like lead (Pb), copper (Cu), zinc (Zn), boron (B), cobalt (Co), chromium (Cr), arsenic (As), molybdenum (Mo) and manganese (Mn) etc. many of which are non essential and over time toxic to plants, animals and human beings (Ensink *et al.,* 2004). This can cause undesirable change in the physical, chemical and biological characteristics of air, water and soil and affects human life, lives of related other useful living things like animals and plants (Mahmood, 2010).

Pre-treatment of wastewater is always recommended prior to agricultural application but due to high costs involved,

*Email: jamalk6t@hotmail.com

in most places around the globe and more specifically in the developing countries, wastewater, irrespective of its origin is applied to the crops untreated. This application inflicts much of the unseen hazards into the food chain to which the farmers are oblivious, e.g. pathogenic infections, heavy metal accumulation and other toxic elements in the agricultural produce. Therefore, it is needed to find out ways to decrease the mobility of toxic heavy metals, rendering them less mobile and more stable, thereby decreasing their availability to the plant.

Pakistan has a population of over 160 millions and is one of the few countries that are almost completely dependant on a single river system for all its agricultural water demands. The Indus River and its tributaries provide water to over 16 million hectares of land, situated in the mainly arid and semi-arid zones of the country. A rapidly growing population, saline groundwater, a poorly performing irrigation distribution system, and recurrent droughts have led to increased water shortages. 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.

Materials and Methods

A field experiment (located adjacent to the main building of Agricultural University Peshawar) was conducted to see the long term effect of wastewater on crop and soil build up of heavy metal if any. The field was fenced and planned for long term experimentation (10 years). Alfalfa (*Medicago Sativa* L.) was grown in rows and was irrigated either with wastewater (collected from the wastewater drain of HIE) or tubewell water (located in the Agricultural University, Peshawar) in 1 m x 2 m plot. Both the treatments were replicated thrice in randomized complete block design (RCBD). The crop was grown in February, 2009 and the data collection was started in late March and continued till May, 2009. The plots were separated through strong demarcation to avoid the overflow or mixing the two water supplies. The plots only received either wastewater or tubewell water and were protected from rain by spreading plastic sheets during the rainfall event. The plots were not supplied with any commercial fertilizers. Plant dry biomass data was determined on the basis of three cutting (i.e. sum of the three cuttings) started at the beginning of the flowering (Ben Rebah *et al.,* 2002) that was done after 56 days of growth. The second cutting was done a month later and the third one was 35 days after the second cut. Shoot samples were collected, dried at 80 ^{0}C for 72 hours, ground and analysed for heavy metals following wet digestion (Zarcina *et al.,* 1987). The leaves samples of first and 3rd cutting were analyzed for the metals only.

A composite soil sample was collected from the experimental field and analysed for various physico-chemical properties. Particle size was determined using the hydrometer method (Gee and Bauder, 1986). Moisture content was determined by oven drying (105^{0}C, 24 h) whilst pH and electrical conductivity (EC) were determined in 1:1 (w/v) soil water extracts (Smith and Doran, 1996). Calcium carbonate content was determined by acid neutralization method as given by Richard (1954) whereas organic matter content was determined by method given by Nelson and Sommer (1982).

Heavy metals in soil were determined by using AB-DTPA (ammonium bicarbonate diethylene triamine penta acetic acid) extractant according to the method given by Havlin and Soltanpour (1981) using atomic absorption spectrophotometer. The wastewater samples were collected in bulk from Hayatabad Industrial Estate (HIE) wastewater (passing through Agricultural University) that were subsequently used for irrigating the crop and the heavy metals were determined using atomic absorption spectrophotometer.

Results and Discussion

Physico-chemical characteristics of soil

The selected physical and chemical properties are summarized in Table 1. The soil was silt loam with alkaline pH (7.73). The electrical conductivity was low (0.54 dS m^{-1}) with organic matter content of 1.03%. The soil was moderately calcareous having 12.5% calcium carbonate. All the essential micronutrients (Cu, Fe, Mn and Zn) were well above the adequate levels of crops (0.5, 4, 1.8 and 1.5 mg kg^{-1}, respectively) according to the AB-DTAP extractable soil test (Havlin and Soltanpour, 1981), whereas other metal, (Cr, Cd, Ni and Pb) were within the permissible (8, 0.31, 8.10 and 13 mg kg^{-1} for Cr, Cd, Ni and Pb, respectively) limits in soil (Kabata-Pendias and Pendias, 1995; EPA, 1998). The tubewell water is of good quality with heavy metal load well below permissible limits whereas the level of Cr and Pb were slightly higher in wastewater (USEPA, 1999). According to the NEQ standards for liquid industrial effluents and municipal wastes (EPA, 1998), the level of Cr, Cd, Cu, Fe, Ni and Pb (1, 0.1, 1, 8, 1 and 0.5 mg L^{-1}, respectively) were above the permissible limits in HIE effluents.

Alfalfa shoot dry weight

The shoot dry weight was significantly ($p \leq 0.05$) affected by the irrigation water supplies and higher yield (Table 2) was recorded in wastewater irrigated plots and the increase was consistent with time (different cutting). By comparing the total dry biomass of the two treatments, it was observed that there was about 37% increase over control (plots receiving only tubewell water) in weight with application of wastewater. The shoot dry weight increased by a factor of about two to three times from first cut to third cut in both the treatment plots and the magnitude of increase was significantly higher in wastewater irrigated plots. The increase of dry biomass weight in wastewater irrigated plots may be attributed to higher organic matter content, and high macro- and micronutrients concentration. Ben Rebah *et al.* (2002) reported similar results when alfalfa was grown on soil amended with sewage sludge. Segura *et al.* (2004) also advocated the re-use of wastewater in arid and semiarid region of the world. They reported significantly higher yield of melon and tomato when irrigated with effluents. The positive effect of the effluents was due to its significantly higher amount of N, P and K. Akitaka *et al.* (2002) reported that tomato growth, yield and quality was not affected by the addition of treated wastewater compared to tap water.

Table 1: Physicochemical characteristics of soil of experimental site and waste/tubewell water used for irrigation

Parameter	Soil**	Wastewater	Tubewell water
Texture	Silt Loam	-	-
pH	7.74	7.41	7.66
EC dS m^{-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 ** unit of metal conc. in soil is mg kg^{-1}

Heavy metal uptake by alfalfa

From the Table 3, it can be seen that the heavy metal content was much higher in wastewater irrigated plots compared to tubewell water. The order of metal uptake was: Fe>Mn>Zn>Cu>Pb>Ni>Cr>Cd. The results of the metal uptake by alfalfa are shown graphically in Fig. 2-9. The trend of metal accumulation by plants seems to be governed by the criteria of essentiality of nutrients and its presence in the substrate (soil and water). As the concentration of Fe was higher both in soil as well as in water, thus higher value of Fe was noted in alfalfa shoots (Table 3, Figure 5). This order of nutrient uptake is similar to trend noted by Ben Rebah *et al.* (2002) and Lone *et al.* (2003). Moreover, Lone *et al.* (2003) reported significantly higher values of Ni uptake by okra and spinach compared to Ni uptake by the present study (Ni in alfalfa Figure. 7)) and that were probably due to initially high concentration of Ni in wastewater. It was further noted that with exception of Cr and Fe, the concentration of all other

Table 2 Shoot dry weight (g $plot^{-1}$) of alfalfa irrigated with waste/tubewell water

Treatment	1st cut	2nd cut	3rd cut	Total	Mean
Tubewell water	280.11	374.34	533.42	1188.78	396.3 b*
wastewater	345.25	542.08	724.24	1612.21	537.4 a
Mean	312.7 c	458.2 b	628.8 a	1400.5	

** Letters show level of significance at 5 % level of probability*

Table 3: Heavy metal concentrations in alfalfa shoot irrigated with waste/tubewell water

Treatment	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
First Cut (mg kg^{-1})								
TW	0.30	0.08	12.34	87.57	49.97	0.26	1.30	23.00
WW	1.41	2.78	17.20	286.46	85.60	8.03	13.53	45.72
Third Cut (mg kg^{-1})								
TW	0.21	1.63	9.35	102.43	37.66	0.67	0.56	18.90
WW	0.99	2.04	15.80	298.58	62.10	7.98	12.44	36.48

metals was higher in the first cutting than at the third cutting (Ben Rebah *et al.,* 2002). The reason of higher values during first cutting may be attributed to metal uptake through leaves as initially more water was used for irrigation and the leaves were in direct contact with water whereas the comparatively lower levels in later stage may be due to metal fixation in soil or leaching. The higher concentration in later stage (3rd cut) may also be due to the dilution effect as more biomass was produced in 3rd cut compared to 1st cut.

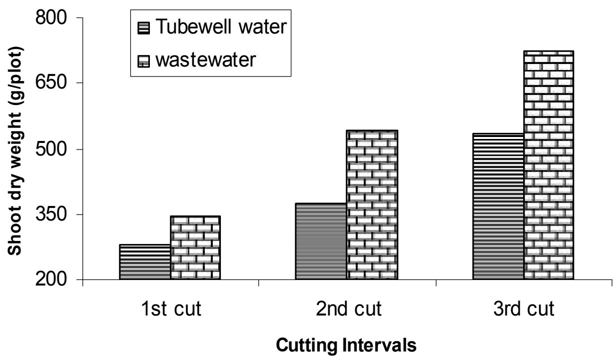

Figure 1: Shoot dry weight (g plot^{-1}) of alfalfa irrigated with waste/tubewell water

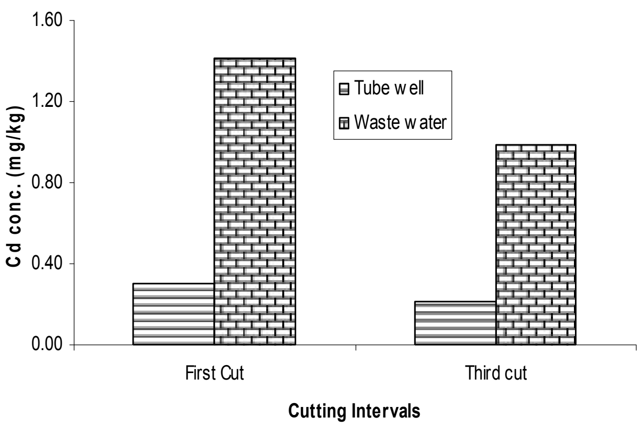

Figure 2: Effect of irrigation source and cutting interval on Cd concentration of alfalfa

Shoot analysis showed no toxicity because the concentration of the metal was less than phytotoxic level. According to the Chaney *et al*. (1978), the phytotoxicity levels for small legumes are 500, 500, 40 and 50 mg kg^{-1} for Mn, Zn, Cu and Ni, respectively. Based on these criteria, all the 4 metals were within the permissible levels.

The soil metal concentration was not affected significantly by the addition of wastewater application thus the data is not reported. The reason of non variation of metals compared with tubewell may be due to the very short period during which the soil was exposed to wastewater application. Therefore, heavy metals were not negative factor in this study due to short period of time.

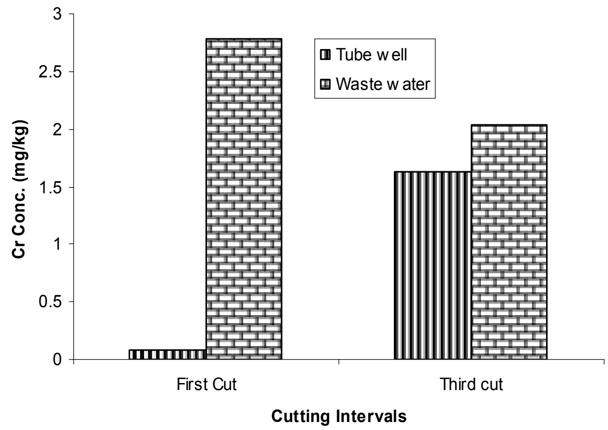

Figure 3: Effect of irrigation water and cutting interval on Cr concentration of alfalfa

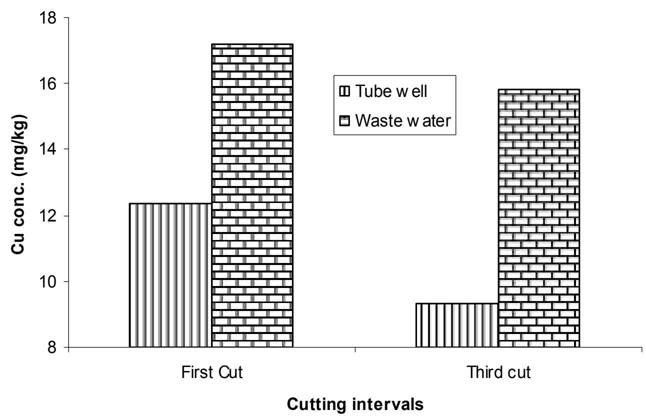

Figure 4: Effect of irrigation water and cutting interval on Cu concentration of alfalfa

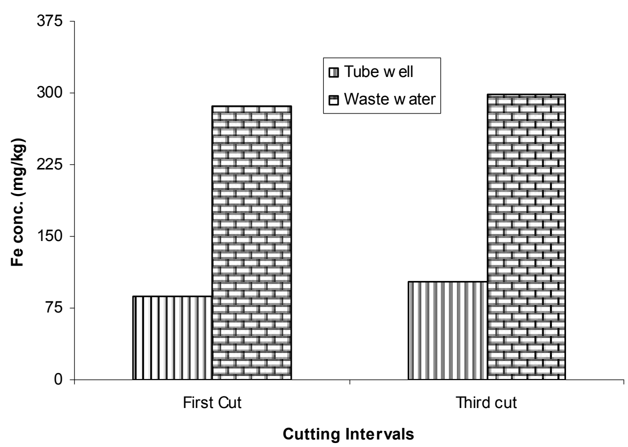

Figure 5: Effect of irrigation water and cutting interval on Fe concentration of alfalfa

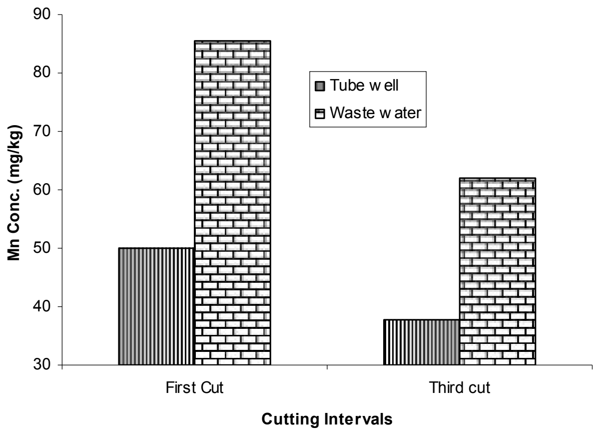

Figure 6: Effect of irrigation water and cutting interval on Mn concentration of alfalfa

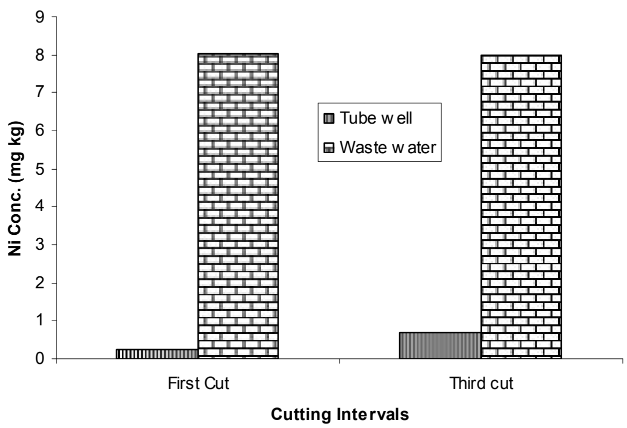

Figure 7: Effect of irrigation water and cutting interval on Ni concentration of alfalfa

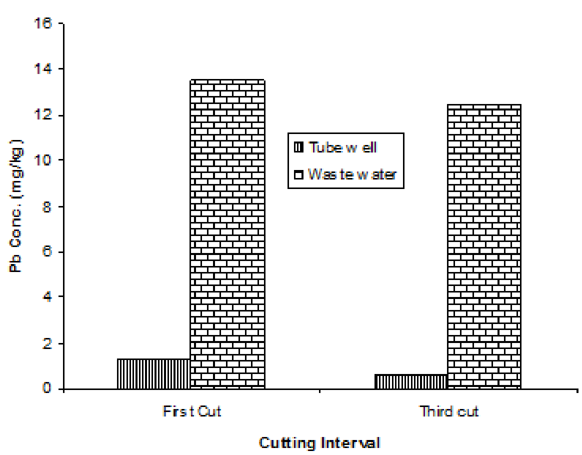

Figure 8: Effect of irrigation water and cutting interval on Pb concentration in alfalfa

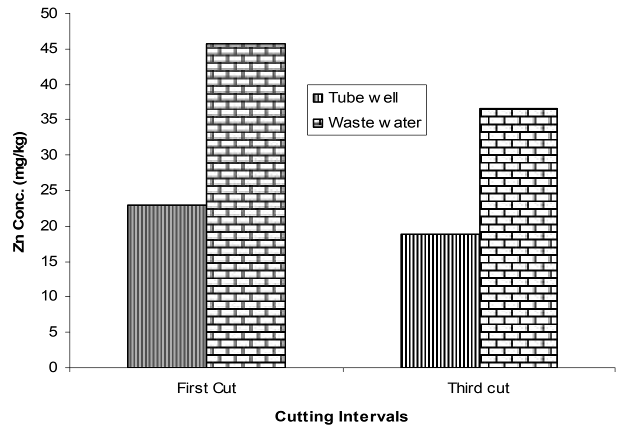

Figure 9: Effect of irrigation water and cutting interval on Zn concentration of alfalfa

Conclusion

The study aimed at determining the long term environmental conditions which result from land application of untreated wastewater (effluent) with particular interest in the potential for growing crops such as alfalfa. The results of the first year results showed that the shoot dry weight was significantly increased when irrigated with wastewater that was attributed to the high nutritive value of wastewater. The shoot dry weight increased by a factor of about two to three times from first cut to third cut in both the treatment plots and the magnitude of increase was higher in wastewater irrigated plots. The heavy metal uptake by the crop was much higher in wastewater irrigated plots compared to tubewell water. The order of metal uptake was Fe > Mn > Zn > Cu > Pb > Ni > Cr >Cd. Shoot metal analysis showed no toxicity because the concentration of the metal was less than phytotoxic level and all the metals were within the permissible limits of WHO (1996) standard.

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