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REGULAR ARTICLE

CHEMICAL CONSTITUENTS AND HEAVY METALS CONTENTS OF BARLEY FODDER PRODUCED UNDER HYDROPONIC SYSTEM IN GCC COUNTRIES USING TERTIARY TREATED SEWAGE EFFLUENTS

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SUMMARY

In this study, fodder barley was irrigated with pure tertiary treated sewage effluent (TTSE) and TTSE mixed with different amounts of tap water (20, 40, 60, and 80% tap water) using pure tap water as a check in a hydroponic system. The objective was to evaluate the effect of TTSE on heavy metals content (Pb, Cd and Ni) in barley biomass and some other nutrient elements (N, P, K, Ca and Fe). All these elements were present in much higher concentrations in TTSE compared to tap water. Heavy metal concentrations in barley biomass increased with an increase in the concentration of TTSE. Cadmium levels ranged between 0.06 (barley grown in tap water) and 0.1 ppm for barley grown in pure TTSE. These figures are lower than the limits set by the Commission of the European Union and WHO. Lead levels in biomass also increased with an increase in TTSE level. Ranging between 0.33 (tap water) to 0.7 (TTSE) ppm on dry weight basis, these levels are within acceptable limits for fodder. Nickel concentrations in barley biomass ranged between 6 (tap water) and 9 (TTSE) ppm. The toxic or excessive nickel concentrations in mature leaf tissue ranged between 10 to 100 ppm. The concentrations of N, P, K, Ca and Fe in barley biomass were within normal limits. The study revealed that fodder barley grown hydroponically could be irrigated safely with TTSE, as a useful alternative disposal method of waste water without the risk of accumulation of heavy metals in the soil.

Keywords: Treated sewage effluent, heavy metals, barley, hydroponics.

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1. Introduction

The use of treated sewage effluents (TSE) as water and nutrient source have been introduced as a viable alternative destination for waste water in many parts of the world. Irrigation with TSE can be used as a complementary treatment method for wastewater [1], as an irrigation water source for agriculture or as a source of nutrients associated with mineral fertilizer savings and high crop yields [2,3]. Uptake of nutrient elements by plants from TSE can reduce the concentration of these elements in the soil and surface waters. With good management of the soil plant system, the risk of elements such as nitrogen and phosphorus that can pollute ground water can be minimized by uptake of these elements by plants [4]. In the Gulf Cooperation Countries (GCC), water is the major limitation to crop production and over extraction of ground water has lead to deterioration in the quality of irrigation water. Use of treated water was largely limited to irrigation of landscape areas and most of the water is discharged in the sea. The popular treatment process for sewage in the region is the use of stabilization pond to separate sewage sludge from TSE. The secondary stage is an oxidation stage where most of the organic matter is converted into more stable forms by bacteria [5]. A tertiary treatment stage is used to reduce the risks associated with the use of secondary treated effluent mainly bacteria and heavy metals concentrations. Many studies, however, suggest the use of TSE as a water and nutrient source for agriculture as it is a low cost [2]. The current study aimed at using tertiary treated sewage effluent TTSE as (i) an available water resource for barley fodder production under hydroponic systems in the GCC region; (ii) as a cheap nutrient source associated with high yields without the risks of harmful accumulation of heavy metals in plant biomass.

2. Materials and methods

The experimental set up and protocols were covered in a previous paper [6]. Trays were irrigated daily with either tap water (T1, control), or tap water mixed with tertiary treated sewage effluent (TTSE) at 20%, 40%, 60%, 80% (T2 to T5) and with TTSE only (T6). The experiment was terminated 9 days after sowing by harvesting the plants. Representative fresh green fodder samples (100g each) from each treatment were taken in four replicates at harvest, oven-dried at 70 0C for 48 hours, ground to pass a 0.5 mm sieve and saved for chemical analysis. Nitrogen was determined using Kjeldahl method [7]. Samples for the determination of macro and microelements were prepared using dry ashing method [8]. Phosphorus was determined using spectrophotometer (Varian UV 50), potassium by flame photometer, Ca, and Fe by Atomic Adsorption Spectrometer (Varian AA 240 FS) and heavy metals (Pb, Cd and Ni) were analyzed using Graphite Tube Atomizer (GTA 120).

Transfer factors (TF) of elements [9,10] were calculated for heavy metals according to the following formula:

TF = Ps (μg g-1 dry wt)/St (μg g-1dry wt),

Where Ps is the plant metal content and St is the total metal content in the growth medium.

Chemical analyses for various irrigation waters were also carried out separately for some nutritional elements (N, P, K, Ca, Fe) and heavy metals (Cd, Ni and Pb).

The experimental design used was completely randomized design with four replications. Data were statistically analyzed using analyses of variance (ANOVA) by SAS Statistical Package [11]. Probabilities of significance among treatments and interaction and LSDs ($P<0.05$) were used to compare means within and among treatments.

3. Results and discussion

Treated sewage effluent characteristics:

The salinity levels and pH values for irrigation waters for the various treatments used in this study are discussed in a previous paper [6]. Nitrogen, phosphorus, potassium, calcium, and iron are present in significantly higher concentrations in TTSE compared to tap water (Table 1). However, their concentrations are lower than those recommended for nutrient solutions according to Benton [12] with the exception of N. However, these elements are essential nutrients for improving plant growth and productivity levels and are considered safe elements in hydroponic systems even at high concentrations [13].

Table 1:Chemical constituents of TTSE and tap water used for irrigation.

Type of water	Nutrients and their concentrations (ppm)				
	N	P	K	Ca	Fe
Tap water	10	21	1	14.6	0.085
TTSE	290	31.5	30	172.7	0.463
Significance	***	**	**	***	**
Recommended concentration In nutrient solutions*	100-200	30-50	100-200	200-300	2-12

*According to Benton [12]

Wastewater normally contains low amounts of phosphorus, and is therefore beneficial in irrigation and does not negatively impact the environment [14]. This is the case even when wastewater effluents with high amounts of phosphorus are applied over long periods of time [15]. Similarly, potassium concentrations in wastewater are low and insufficient to cover the theoretical demand of crops [12]. Potassium does not normally cause negative environmental impact [16]. Calcium and iron concentrations are also below the sufficient levels recommended for nutrient solutions [12].

To know the potential risk of heavy metals to plants, animals and human beings, it is necessary to evaluate their concentrations in TTSE. Researchers have tried to correlate plant content of metals with extractable soil content to predict and assess element deficiency and toxicity [17]. Under hydroponic growing systems, however, the risk of heavy metal accumulation does not exist since no growing medium is used. The analytical results presented in Table 2 show that nickel and lead contents in irrigation waters for various treatments are within the acceptable levels for waste water reuse for irrigation according to WHO guidelines [18]. Cadmium concentrations are, however, higher than WHO standards when the TTSE proportion in water exceeds 20%. Based on these guidelines, Cd, Ni and Pb become toxic to sensitive crops (but not barley) at concentrations that exceed 0.01, 0.50 and 5.00 ppm, respectively (Table 2).

Table 2: Heavy metals contents in water used for irrigation.

Treatments	TTSE in irrigation water (%)	Heavy metals concentrations (ppm)		
		Cd	Ni	Pb
T1	Tap water only	0.001	0.001	0.005
T2	20	0.007	0.058	0.021
T3	40	0.014	0.113	0.037
T4	60	0.020	0.170	0.053
T5	80	0.026	0.226	0.069
T6	TTSE only	0.032	0.282	0.085
WHO standards*		0.01	0.50	5.00

WHO [18]

Chemical composition of barley biomass:

Chemical concentration of some nutrients elements in barley biomass are presented in Table 3. Except for Ca, there is no significant increase in the concentration of these elements with the increased ratio of TTSE to tap water. This may be due to the short duration of the experiment (9 days).

Table 3: Nutrients concentrations in fodder barley biomass

Treatments	Nutrients concentrations in plant biomass (% dry matter)					
	N	P	K	Ca	Mg	Fe
T1	2.24 a	2.99 a	4.43 a	1.27 c	1.30 a	0.061 a
T2	2.19 a	2.80 a	4.23 a	1.62 bc	1.22 a	0.064 a
T3	2.21 a	3.32 a	4.50 a	1.77 abc	1.38 a	0.062 a
T4	2.24 a	3.12 a	4.23 a	1.99 ab	1.34 a	0.067 a
T5	2.22 a	3.00 a	4.57 a	1.93 ab	1.28 a	0.066 a
T6	2.57 a	3.05 a	4.30 a	2.30 a	1.29 a	0.053 a

Means followed by the same letter in a column are not significantly different at $P<0.05$.

The nutrient requirements of the seedlings are quite low and partially satisfied from the seeds. The reported nutrient concentrations are normal for plants [12].

Heavy metals content

Heavy metal accumulation in the food chain is specifically important for cadmium, nickel and lead. Anthropogenic activities may have an adverse impact on human health due to the discharge of industrial waste and domestic sewage [19]. These effluents usually contain elevated levels of heavy metals that are known to accumulate in macro-particles which form the basis of many food chains [20, 21]. Accumulation ultimately causes toxic effects on: (i) humans by affecting food quality of crops [22] and animal products as well as drinking water quality; and (ii) animal health by affecting fodder quality due to direct intake of contaminated soil [23]. Many investigators have determined concentrations of these elements in edible animal tissues such as muscles, liver and kidneys. It has been proved that lead interferes with hemoglobin synthesis and is able to inhibit several enzymes [24]. Cadmium accumulates strongly in the kidneys and it has an extremely long biological half-life in humans of approximately 20-30 years.

Cadmium concentration in barley biomass increased significantly as the ratio of TTSE to tap water increases (Table 4).

Table 4: Heavy metals contents in barley fodders for the various treatments.

Treatments	Heavy metals concentrations (ppm)		
	Cd	Ni	Pb
T1	0.054^{b}	6.75^{b}	0.329^{b}
T2	0.069^{ab}	7.68^{ab}	0.395^{ab}
T3	0.070^{ab}	7.02^{b}	0.482^{ab}
T4	0.090^{ab}	7.18^{b}	0.393^{b}
T5	0.102^{a}	7.93^{ab}	0.478^{ab}
T6	0.084^{ab}	8.96^{a}	0.709^{a}

Means followed by the same letter in a column are not significantly different at $P<0.05$.

Cadmium levels found in barley tissue ranged between < 0.06 (in tap water) and less than 0.1 ppm (in TTSE). These are below the limits set by the Commission of the European Union [25] which are 0.2 mg/kg fresh weight for leafy vegetables and fresh herbs and 0.1 mg/kg for stem and root vegetables. The low accumulation of cadmium in barley tissue may be attributed to the slightly basic nature of the TTSE water. Nickel concentrations in barley biomass ranged between 6.75 (tap water) and around 9 (pure TTSE) ppm. Nickel is considered an essential element for both legumes and small grains (e.g., barley). Brown et al [26] have shown that its deficiency meets the requirements for essentiality set by Arnon and Stout [27]. The toxic or excessive nickel concentrations in mature leaf tissue ranged between 10 to 100 ppm [27]. Lead levels in biomass also increased significantly with an increase in TTSE levels, ranging between 0.33 (tap water) and 0.71 (TTSE) ppm on dry matter basis. This level is lower than that reported by Kabata-Pendias [28] and Finister et al. [29] for edibles.

Table 5: Transfer factors (T) of heavy metal for irrigation water to barley biomass

Treatments	Transfer factor (TF) values		
	Nickel	Lead	Cadmium
T1	24.22	6.8	3.91
T2	12.45	1.9	0.92
T3	7.04	1.3	0.51
T4	4.49	0.7	0.47
T5	3.80	0.6	0.42
T6	3.14	0.8	0.25

Figures 1 depicts good correlation between Cd, Ni and Pb concentrations in barley biomass and their respective concentrations in TTSE ($R2$= 0.7, 0.64 and 0.68, respectively). These regression equations can be helpful in predicting the uptake of these heavy metals in barley biomass. Several studies have demonstrated good correlation between total metal content and uptake of plants [30].

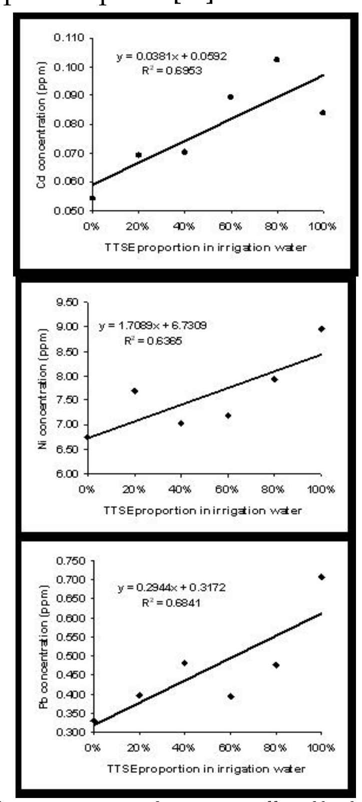

Fig. 1. Cd, Ni and Pb concentrations in plant tissue as affected by their corres levels in irrigation water.

On the basis of these results, the individual transfer factor (TF), defined as the ratio between heavy metals concentrations in barley biomass and TTSE, were evaluated (Table 5). TF was found to be highest for nickel followed by lead and cadmium. This is normal since T values represent an inverse image mirror of the R2 values obtained from the correlations in figure 1.

Table 5: Transfer factors (T) of heavy metal for irrigation water to barley biomass.

Conclusions

This study indicated that TTSE is a good source of nutrients needed for plant growth to promote high yields and highlights the potential accumulation of heavy metals. These heavy metals include Cd, Ni and Pb in hydroponically produced fodder barley irrigated with TTSE, tap water or a mixture of tap water and TTSE. The contamination of the fodder with heavy metals was apparent, yet below internationally accepted limits. TTSE may be considered a viable irrigation water source for production of fodder in the Gulf region. It is also considered an environmentally sound waste water disposal practice compared to direct disposal into surface or ground water bodies. These findings encourage further research in this field and should take into consideration variations between different plant species and levels of heavy metals present in the environment. The use of TTSE in hydroponic systems may reduce the risk of heavy metal accumulation in the soil with prolonged use.

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