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Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters

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Abstract

In this study, sites irrigated with wastewater for 10, 5, and 2 years and site not irrigated were sampled for soil and plant chemical analysis to evaluate its long term effect. Long term wastewater irrigation increased salts, organic matter and plant nutrients in the soil. Soil pH was not consistently affected. Soil Cu was not affected by wastewater application while Zn, Fe and Mn was not consistently affected. Wastewater irrigation had no significant effect on soil heavy metals (Pb and Cd) regardless of duration of wastewater irrigation. The barley biomass increased with added wastewater and nutrients provided with the wastewater. However, longer period of wastewater application (10 years) resulted in lower biomass production but remained higher than that of the control plants. Plant essential nutrients (Total-N, NO_3, P, and K) were higher in plants grown in soils irrigated with wastewater. Plant Cu, Zn, Fe, Mn increased with 2 years of wastewater irrigation, then reduced with longer period. Plant Pb and Cd increased with wastewater irrigation and their levels were higher the longer the period of wastewater irrigation. Based on these results, it can be concluded that proper management of wastewater irrigation and periodic monitoring of soil and plant quality parameters are required to ensure successful, safe, long-term wastewater irrigation.

Keywords: Treated wastewater; Long-term effect; Barley; Soil

1. Introduction

Water is a vital resource but a severely limited one in most countries of the Mediterranean region such as Jordan. Therefore, there is an urgent need to conserve and protect fresh water and to use the water of lower quality for irrigation [1]. The use of treated municipal wastewater in countries poor in water resources is less expensive and considered an attractive source of irrigation

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water and the interest in reusing wastewater for irrigation is rapidly growing in these countries [2]. Consequently the reuse of wastewater for agriculture is highly encouraged [3,4].

Irrigation with treated municipal wastewater is considered an environmentally sound waste-water disposal practice compared to its direct disposal to the surface or ground water bodies [3]. In addition, wastewater is a valuable source of plant nutrients and organic matter needed for maintaining fertility and productivity levels of the soil [5]. On the other hand, wastewater may contain undesirable chemical constituents and pathogens that pose negative environmental and health impacts [6]. Consequently, mismanagement of wastewater irrigation would create environmental and health problems to the ecosystem and human beings [7].

When wastewater will be used continuously as the sole source of irrigation water for field crops in arid regions, excessive amounts of nutrients and toxic chemical substances could simultaneously be applied to the soil-plant system. This would cause unfavorable effects on productivity and quality parameters of the crops and the soil [8]. Therefore, management of wastewater irrigation should consider the wastewater nutrient content, specific crop nutrient requirements, soil nutrient content and other soil fertility parameters [3].

Wastewater is recognized to have direct effect on soil chemical properties. It affects supply of mineral macro and micro nutrients for plant growth, soil pH, soil buffer capacity, and soil CEC. Mohammad and Mazahreh [3] at the end of the growing season found that soil pH was significantly lower when wastewater application, and they attributed this decrease to the high content of ammonium in wastewater, which its nitrification would serve as a source of hydrogen ions thus causing a decrease in soil pH. It has also been found that wastewater irrigation increased the level of soil salinity due to the wastewater salt content.

Other researchers found that wastewater irrigations increased soil nitrogen N, phosphorus P and potassium K, while heavy metal levels tended to generally increase in soil with increasing number of years of irrigation [9]. In contrary, Mohammad and Mazahreh [3], found that soil Zn and Cu were not significantly affected by wastewater irrigation.

The majority of the research conducted on wastewater reuse in agriculture focuses mainly on its short-term effect on plant growth and development with little attention to the changes induced in the soil fertility and chemistry parameters. The objective of this study was to evaluate the impact of long-term land application of wastewater on soil fertility parameters and possible accumulation of heavy metals in the soil-plant system.

2. Materials and methods

The study was conducted at Ramtha Wastewater Treatment Plant, Jordan. The Plant was established in 1987 where municipal wastewater is treated with biological stabilization bonds. The treated wastewater has been used to irrigate several forage crops (Sudan grass, barley, corn etc.). There are sites that have been irrigated with wastewater for about 10, 5, or 2 years. In this study, soil and plant samples were taken from the following sites:

Site 1: Soils not irrigated with wastewater (control).
Site 2: Soils irrigated with wastewater during the last 10 years.
Site 3: Soils irrigated with wastewater during the last 5 years.
Site 4: Soils irrigated with wastewater during the last 2 years.

Each site was divided into three locations or blocks, and composite soil sample from 0–20, 20–40, and 40–60 cm soil depth was taken from each block. Soil Samples were air dried, ground, and then sieved to pass through a 2-mm sieve screen, then analyzed for chemical and physical properties.

Soil samples were then analyzed for pH and for electrical conductivity (EC) in the 1:5 soil:water extract [10]; for total Kjeldahl nitrogen [11]; for phosphorus by extraction with 0.5 M $NaHCO_3$ [12]; for $CaCO_3$ by acid neutralization method [13]; for exchangeable K by extraction with 1 M NH_4OAc [14]; for cation exchange capacity (CEC) by Polemio and Rhoades [15] and for soil texture by hydrometer method [16]. Soil organic matter was measured by rapid oxidation [17], and Fe, Zn, Cu, and Mn by extractions with DTPA [18]. Some of the major soil characteristics are presented in Table 1. The average values of physical and chemical characteristics of the treated wastewater are reported in Table 2.

Plant (Hordeum vuljare L.) samples were also taken from each location at the maturity stage before anthesis. The fresh weight of vegetative parts (Biomass) was recorded, then oven-dried at 70°C, for dry-weight determination. Plant samples then were ground to a fine power using a laboratory mill with (0.5 mm) sieve. Plant samples were analyzed for total nitrogen by Kjeldahl apparatus; for NO_3 [19]; total phosphorus, sodium, potassium, zinc, copper, iron, manganese, magnesium, cadmium, and lead were measured in the dry ash digestion by Atomic Absorption Spectrophotometer [20].

Table 1
Selected properties of the treated wastewater

Parameters	Units	2003
pH	–	7.3
Total dissolved salts (TDS)	mg L^{-1}	952
NO_3-N	mg L^{-1}	29.5
PO_4	mg L^{-1}	15.5
K	mg L^{-1}	33.3
SAR	–	4.6
Zn	mg L^{-1}	0.19
Cu	mg L^{-1}	0.01
Mn	mg L^{-1}	0.07
Fe	mg L^{-1}	0.87
Pb	mg L^{-1}	0.77
Cd	mg L^{-1}	0.02

3. Results and discussion

3.1. Treated wastewater characteristics

The characteristics of wastewater used for irrigation varied within and among the years of application. In the average, the wastewater is alkaline with basic pH value of 7.3 and had a moderate level of total dissolved solids (TDS) of 952 mg L^{-1} (Table 1). The wastewater contains considerable amount of nitrate, phosphate and potassium which are considered essential nutrients for improving plant growth and soil fertility and productivity levels. On the other hand, the concentrations of micronutrients and heavy metals in the wastewater are relatively low and meet the standards for wastewater reuse in

Table 2
Barley biomass (fresh weight and dry weight) and plant macronutrient content as affected by duration of wastewater application (years)

Years	Fresh weight (g m^{-2})	Dry weight (g m^{-2})	NO_3-N (mg kg^{-1})	N total (%)	P (%)	K (%)
10	1944	528	92.7	1.10	0.28	3.7
5	2349	591	89.3	1.04	0.22	3.0
2	2039	496	50.7	1.08	0.19	4.0
0 (Control)	1405	481	8.7	0.66	0.18	2.0
$LSD_{.05}$	306	51	10.2	0.32	0.02	0.3

irrigation. Given the fact that these metals could be accumulated in soil and plants with continuous use of wastewater in irrigation, therefore, their periodic monitoring should be an important component of wastewater management.

3.2. Soil characteristics

The soil is characterized by being basic and calcareous with pH value of 7.8 and has a fine texture. The soil is moderately saline with high cation exchange capacity (CEC = 32.1 cmol kg^{-1}) and high potassium content, but poor in nitrogen and phosphorus content.

3.3. Soil chemical properties

Soil pH, electrical conductivity (EC) and organic mater content as affected by duration of wastewater application (years) and soil depth are shown in Fig. 1. The treatments effect on soil pH was not consistent. The lowest value of soil pH was observed in the 2 years of wastewater irrigation. The inconsistency in wastewater irrigation effect on soil pH was reported by other researchers. Schipper et al. [21] found that soil pH increased following long term wastewater irrigation and they attributed this increase to the chemistry and high content of basic cations such as Na, Ca and Mg in the wastewater applied for a long period. Other researchers found that soil pH decreased with wastewater irrigation due to the oxidation of organic compounds and nitrification of ammonium [3,22,23].

Soil salinity, measured as electrical conductivity (EC) of the 1:5 soil extract in dS m^{-1}, was significantly higher with wastewater irrigation (Fig. 1). Mohammad and Mazahreh [3] stated that the increase in EC for soil irrigated with wastewater compared with soil irrigated with potable water attributed to the original high level of (TDS) of the wastewater. The highest value was observed with 10 years of wastewater irrigation with tendency to be the higher with longer period of wastewater irrigation. In addition, salts were accumulated more in the deeper soil layers due leaching the soluble salts into deeper soil [24]. Since these salts are water soluble, wastewater irrigation management should consider ensuring leaching them below the root systems with leaching fraction of the irrigation rate. Otherwise, continuous build up of salts in the topsoil will adversely affect the activity of the soil microorganisms [25], plant growth and soil productivity [6].

Soil organic content (OM) significantly increased with wastewater irrigation application and with increasing the period of application (Fig. 1), which is attributed directly to the contents of the nutrients and organic compounds in the wastewater applied. The soil OM contents

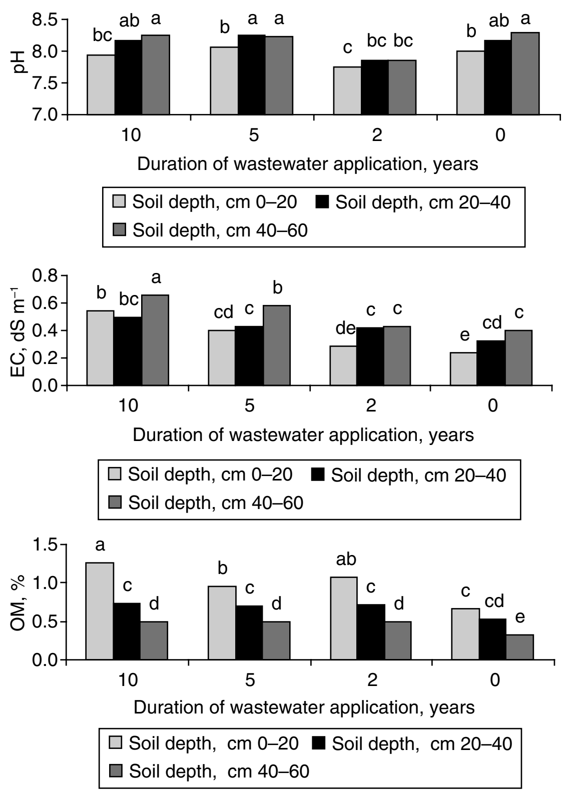

Fig. 1. Soil pH, electrical conductivity (EC) and organic mater content as affected by duration of wastewater application (years) and soil depth.

accumulated more in the topsoil in all treatments. Vazquezmontiel et al. [22] found no positive effect on soil organic matter content with wastewater irrigation, while other researchers reported an increase in the soil organic matter following wastewater irrigation [26] where more was accumulated in the topsoil [3].

3.4. Soil macronutrients

Wastewater irrigation increased significantly the soil N, P, and K (Fig. 2). This increase was the highest in the top soil (0–20 cm) and for the longer period of wastewater application.

Several researchers reported accumulation of N, P, and K in the soil with wastewater application which was attributed to the original contents of these nutrients in the wastewater applied [27]. Wastewater can provide N, P, and K in amount equal to 4, 10 and 8 time of the fertilizers requirement of the forage crops [28]. These results agree with those reported by [3,29] who found that extractable phosphorus was higher in soils irrigated with wastewater than in soil irrigated with fresh water or rainfall water.

Nyamangara and Mzezewa [30] found in their experiment that the concentration of K on the control treatment was decreased within depth. And this increase in the soil surface was attributed to their high content in the wastewater used [3].

Considering the variation in the chemical composition of the wastewater, management of wastewater reuse should account for the N, P, and K content prior to determination of the rate of wastewater application.

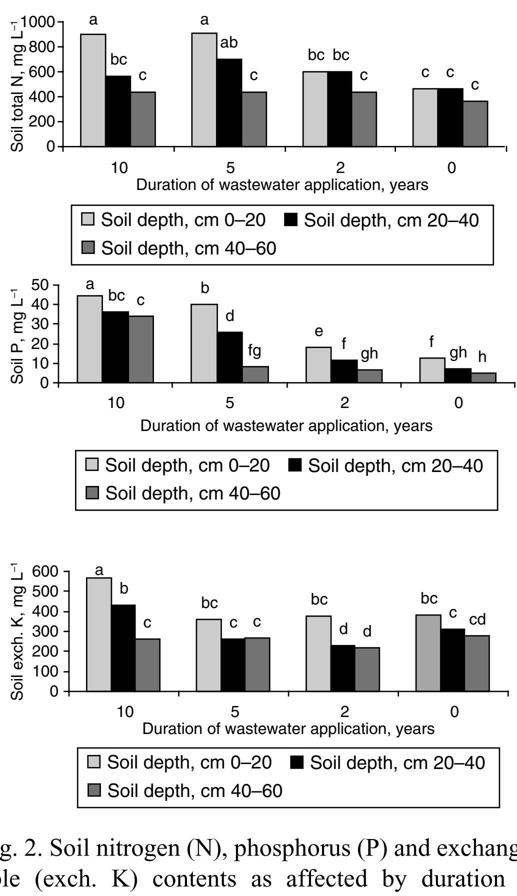

Fig. 2. Soil nitrogen (N), phosphorus (P) and exchangeable (exch. K) contents as affected by duration of wastewater application (years) and soil depth.

3.5. Soil micronutrients and heavy metals

Soil micronutrients (Cu, Zn, Fe and Mn) and heavy metals (Pb and Cd) as affected by the duration of wastewater irrigation and soil depths are shown in Fig 3. There was no significant differences in the treatment effects on soil Cu content. The response of other micronutrients, namely Zn, Fe and Mn was in general not inconsistent. However, it can be observed that these micronutrients being immobile in the soil tended to accumulate in the topsoil. Other researchers found that soil micronutrients were higher and mainly in the top soil then decreased within depth [31]. There is inconsistency on research findings on the impact of wastewater irrigation on soil micronutrients. Mohammad and Mazahreh [3] reported an increase in soil Fe and Mn with wastewater irrigation and no response with regard to the soil Cu and Zn. On the other hand, Mancino and Pepper [32] found no effect on soil micronutrients. Soil Cu and Zn had accumulated significantly in the upper (25–30 cm) of soil with wastewater irrigation [33]. In a long term wastewater

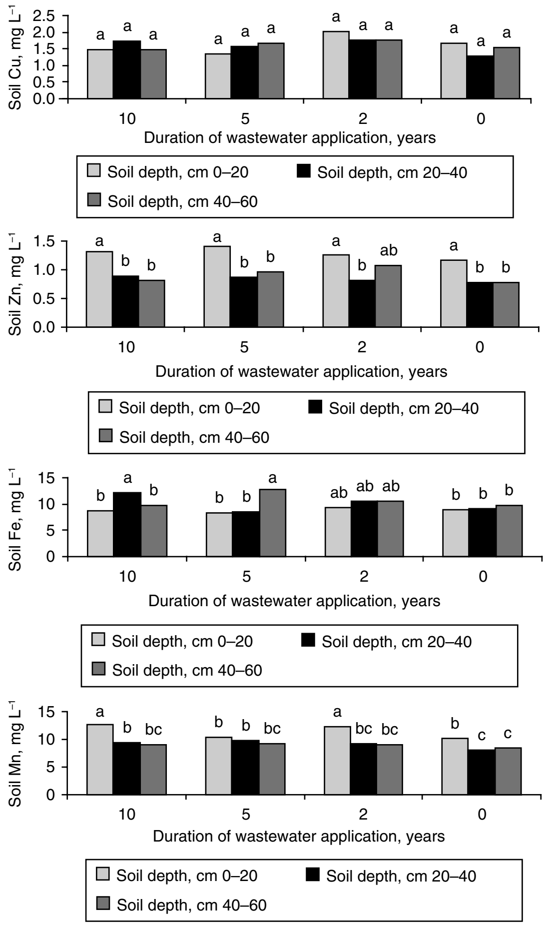

Fig. 3. Soil copper (Cu), zinc (Zn), iron (Fe) and manganese (Mn) contents as affected by duration of wastewater application (years) and soil depth.

irrigation (80 years), Christina Siebe [34] found that the contents of soil Cu, Zn, Mn, and Fe after 80 were increased compared to the soil irrigated with potable water.

Wastewater irrigation had no significant effect on soil heavy metals (Pb and Cd) regardless of duration of wastewater irrigation nor on soil depth (Fig. 4). Christina Siebe [34] reported that the concentration of (Pb, Cd) in soil horizon (0–30 cm) that has been irrigated for more than 80 years were increased than that irrigated under well water. Similar results were obtained by

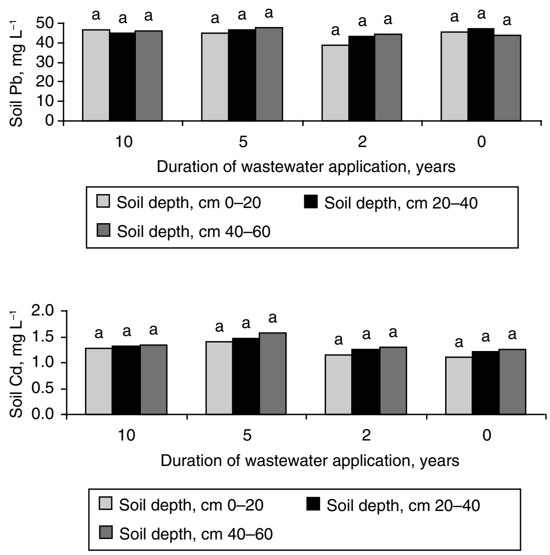

Fig. 4. Soil lead (Pb) and cadmium (Cd) contents as affected by duration of wastewater application (years) and soil depth.

Brar et al. [31]. On the other hand, Mohammad and Mazahreh [3] mentioned that the concentrations of the soil Pb and Cd were not affected significantly by the wastewater irrigation.

It should be mentioned that mismanagement of wastewater irrigation especially under long-term application can lead to toxicity problems by heavy metals and high levels of nutrient accumulation, and deterioration of soil and crop quality parameters. Accumulation of micronutrients and heavy metals from wastewater application could be caused directly from the wastewater composition or indirectly through increasing solubility of the indigenous insoluble soil heavy metals as a result of the chelation or acidification action of the applied wastewater [6].

3.6. Biomass and macronutrient contents of barley plant

The effect of different years of wastewater irrigation on fresh and dry weight (biomass) and macronutrient (N, P and K) contents are shown in Table 2.

The biomass production of barley as an animal feed measured as fresh weight and dry weight in farm per one meter as shown in Table 2, compared to crops grown in the control (where wastewater was never applied) biomass production was significantly higher. Both added wastewater and nutrients provided with wastewater application can be attributed to such increase in biomass production [7]. Similar results were reported by Day et al. [35] who observed that wheat irrigated with wastewater produced taller plants, more heads per unit area, heavier seeds, higher grain yields than did wheat grown with pump water alone. They attributed this increase to the nitrogen and phosphorus in the added wastewater. The highest biomass was produced in soil under 5 years at annual wastewater application.

However, longer period of wastewater application (10 years) resulted in lower biomass production but remained higher than that of the control plants. Accumulation of salts and some nutrients and heavy metals, where their levels were the highest after 10 years of wastewater irrigation, could have caused such reduction in the plant biomass. Hussain and Al-Saati [36] found that wheat and barley yield decreased with irrigation with saline water.

Plant essential nutrient (total N, NO_3, P, and K) were higher in plants grown in soils irrigated with wastewater for different periods. Nitrogen content increased from 0.66% in the control to 1.1% in the 10 years irrigation. In addition, nitrate concentration increased with longer period of wastewater irrigation where, it increased from 8.7 mg kg^{-2} in the control to the 92.7 mg kg^{-2} in the 10 years irrigated with wastewater. Enhancement of plant N content with wastewater application indicates that wastewater application provided the soil with these nutrients which enhanced required for plant growth and soil fertility. However, nitrate content should be monitored periodically to avoid its accumulation to critical levels that might affect its quality for animal feeds.

Nitrogen concentration in plant shoots was reported to be higher when grown with wastewater [35], who found that N recovery in plants with wastewater was higher than the N recovery in plant material grown with well water. These results were attributed to significant increase in soil nitrogen with wastewater irrigation compared with the control. On the other hand, Papadopoulos and Stylianou [37] reported that during the third irrigation season for trickle irrigation cotton (*Gossypium hirsutum* L. cv.), the NO_3-N in petioles was greater with the treated effluent supplemented with no nitrogen, also in lamina; NO_3-N was greater at sampling of the lower N level.

Phosphorus concentration in barley shoot increased significantly as years of wastewater irrigation increased. It increased from (0.18%) in the control treatment to (0.28%) in the 10 years irrigated with wastewater. There was no significant difference in phosphorus concentration between the control and the 2 years irrigated with wastewater. Predicated that the efficacy of phosphorus uptake by plants was controlled predominantly by the concentration of HPO_4^{-2} and $H_2PO_4^-$ in the soil solution, which was in turn affected by the addition of wastewater to soil. Potassium concentration in barley shoot was decreased significantly from (2%) in the control treatment to (4%) in the 2 years irrigated with wastewater. There was no significant difference between 10 and 5 years irrigated with wastewater. Other researchers, have reported an increase in P and K uptake by the plants irrigated with treated wastewater [3,37].

3.7. Micronutrients and heavy metals content in barley plant

Micronutrient contents (Cu, Zn, Fe, Mn) of the plants as affected by duration at wastewater application are shown in Table 3. These micronutrients are essential for plant nutrition although they are required by the plants in relatively much smaller amounts compared to macronutrients.

Table 3
Plant micronutrient and heavy metal contents as affected by duration of wastewater application (years)

Years	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Pb (mg kg^{-1})	Cd (mg kg^{-1})
10	5.16	17.4	1074.7	56.07	7.64	0.33
5	5.58	12.0	1476.1	49.63	5.71	0.29
2	8.90	32.2	1914.8	93.87	5.89	0.33
0 (Control)	6.33	29.8	1503.8	74.23	4.85	0.24
$LSD_{.05}$	0.66	1.34	82.32	4.49	0.31	0.01

The results indicate that Cu, Zn, Fe, Mn contents in the plant were the highest in the plant grown in the soil receiving wastewater in the previous 2 years. Other researchers reported an increase in micronutrients uptake by the plant increased in leaves of plants irrigated with sewage water than that irrigated with ground water [3,31].

However the concentrations of these micronutrient significantly reduced in the plants grown in the soil received wastewater for longer period namely for 5–10 years. It is not clear why such drops in micronutrient concentration was observed with longer period at wastewater application. One possible explanation is that with longer period at wastewater application, higher organic competes could have been provided to the soil that has higher at stronger affinity to these micronutrient thus revamp foamy insolated complex that are unavailable for plant absorption [7]. The relatively higher micronutrient content in the control plant can be explained by the "concentration/dilution effect" induced with relatively lower biomass. Such phenomenon was observed by other researchers.

On the other hand, the concentration of heavy metals (lead and cadmium) was higher with wastewater application indicating concern about possible accumulation in the plant (Table 3). Although, these concentration remain within the acceptable level for animal feed [38], their monitory when wastewater is used for irrigation should be considered. Lead (Pb) increased from 4.85 mg kg^{-2} for the control treatment to 7.64 mg kg^{-2} for the 10 years wastewater irrigation. For Cd, it increased from 0.24 mg kg^{-2} for the control treatment to 0.33 mg kg^{-2} for the 10 years irrigated with wastewater.

4. Conclusion

Soil and crop quality parameters are significantly affected by long-term wastewater irrigation. This is mainly determined by the management of wastewater irrigation and its composition. In addition, continuous irrigation with wastewater may lead to accumulation of salts, plant nutrients and heavy metals beyond crop tolerance levels. Therefore, these concerns should be essential components of any management of wastewater irrigation. On the other hand, plant growth, soil fertility and productivity can be enhanced with properly managed wastewater irrigation, through increasing levels of plant nutrients and soil organic matter. It can be concluded, based on these results that proper management of wastewater irrigation and periodic monitoring of soil fertility and quality parameters are required to ensure successful, safe and long term reuse of wastewater for irrigation.

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