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Yield and nutrient status of wheat plant (*T. aestivum*) influenced by municipal wastewater irrigation

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Abstract

The aim of this study was to test if wastewater irrigation can increase fertilizer use efficiency and improve soil fertility without affecting the quality of soils and plants. A greenhouse experiment was conducted to investigate the effects of irrigation municipal wastewater (MWW) on macro and micro nutrient content of soil, yield and mineral contents of wheat (*Triticum aestivum*). The studies were done using Ustorthents soil sampled to a depth of 0-15 cm from agricultural fields in Erzurum province (39°55'N, 41º61'E) in Turkey. Pot experiment was designed based on the randomized complete block with five MWW ratio of 100, 75, 50, 25 and 0% (diluted with irrigation water) and five replicates. Plants were harvested 90 d after planting. Municipal wastewater irrigation affected significantly soil chemical properties especially in rhizosphere soil and plant nutrient contents after one growing season. Application of MWW increased soil salinity, organic matter, exchangeable Na, K, Ca, Mg, plant available phosphorus and micro elements, and decreased soil pH. Wastewater irrigation treatments also increased the yield as well as N, P, K, Ca, Mg, Na, Fe, Mn, Zn, Cu, Pb, Ni and Cd contents of plants. Undesirable side effects such as heavy metal contamination in soil and plant and salinity were not observed with the application of MWW. It can be concluded that MWW can be used confidently in the short term in agricultural land both as fertilizer source and to increase fertilizer use efficiency for economical aspect.

Key words: Municipal wastewater irrigation, wheat, heavy metal.

Introduction

The continuous growth of world population along with industrial and agricultural activities for increasing the food supply, and consecutive droughts in recent years have caused the consumption of existing water resources to reach their maximum amount in the arid and semi-arid countries. Therefore, demand for water is continuously increasing in arid and semi arid countries. So, water of higher quality is preserved for domestic purpose while that of lower quality is recommended for irrigation. Especially in arid and semi arid countries municipal wastewater is less expensive and considered as an attractive source of irrigation [2, 25]. Turkey, as a semi-arid country, suffers from shortages in water supply for domestic, industrial, and agricultural purposes. Hence, limited water supplies require careful management for successful agricultural production. In this context, the use of non-conventional water resources, such as treated wastewater must be probed in agriculture and industry [6].

Wheat and barley are two of the most important crops worldwide and sustainable agricultural systems for these crops are urgently required. Therefore, the sustainability of wheat and barley production systems based on high use of applied fertilizers needs to be reviewed in the light of their impact on the environment and use of non-renewable resources. For this purpose, the evaluation of supplementary or alternative nutrient sources, and approaches for improving nutrient uptake efficiency is a main aim of wheat production systems. In many areas of developing countries untreated wastewater flows through channels into rivers where it is diverted by subsistence farmers to small plots of crop grown for nearby urban markets. The public risks of using such contaminated streams for irrigation are obvious. The World Health Organization [39] has recommended that crops to be eaten raw should be irrigated only with biologically treated effluent that has been disinfected to achieve a coliform level of not more than 100 coliforms per 100 ml in 80% of the samples. The use of untreated wastewater and water supplies contaminated with sewage for irrigation has been implicated as one of the important sources of pathogenic micro-organisms contaminating vegetables [13, 15, 38]. Application of wastewater to cropland and forested lands is an attractive option for disposal because it can improve physical properties and nutrient contents of soils [28, 33]. Wastewater irrigation provides water, N and P as well as organic matter to the soils [31], but there is a concern about the accumulation of potentially toxic elements such as Cd, Cu, Fe, Mn, Pb and Zn from both domestic and industrial sources. The objectives of this study were to evaluate the fertilizer use efficiency, chemical soil characteristics and possible accumulation of heavy metals in the Entisol, and also to evaluate the yields and nutrient contents of corn in response to irrigation with fish, and municipal wastewater.

Materials and Methods

Pot experiments: Pot experiment was conducted using a randomized complete block design with 5 MWW ratio of 100, 75, 50, 25 and 0% (diluted with irrigation water) and five replicates. The properties of irrigation water (IW) had no restriction use of (C2S1) with 0.28 dS m^{-1} EC, 0.40 SAR and 7.4 pH. The studies were done with an Ustorthents [32] sampled to a depth of 0-15 cm from agricultural fields in Erzurum province (39°55' N, 41º61' E) in Turkey. To support optimum plant growth, ammonium nitrate (100 kg N ha^{-1}), triple superphosphate (80 kg P_2O_5 ha^{-1}), and potassium sulphate (250 mg K_2O kg^{-1} ha^{-1}) were applied before planting. Seeds were placed at the same depth (approximately 2.5 cm below the soil surface) in all pots. Per pot, 24 seeds were sown at twelve points (two seeds at each point) with the same distance apart, and then thinned to twelve uniform plants per pot 10 d after sowing. The wheat seedlings were grown in a greenhouse under a 15 h natural light photoperiod at 25-16°C, and 55% relative humidity. The water content of the soil was maintained at 70% of field capacity (375 g kg^{-1}) throughout the 90 d experiments by daily additions of wastewater. Some chemical properties of the wastewater used for irrigation were determined by the methods described by American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF) [4], and faecal coliforms (FC) were tested by multiple tube fermentation procedure [3] (Table 1). Shoots were harvested 90 d after planting and washed with deionized water to remove soil particles and also soil samples for evaluation of macro and micro elements were taken after plant harvest.

Table 1. Characteristics of the MWW used for irrigation (Mean ±SD, n = 10).

Parameters	Mean ± Sd	Parameters	Mean ± Sd
pH	8.35 ± 0.24	Ni, mg l^{-1}	0.10 ± 0.01
EC, dS m^{-1}	1.79 ± 0.10	Cd, mg l^{-1}	0.13 ± 0.02
TDS, mg l^{-1}	1143 ± 105	Mn, mg l^{-1}	0.29 ± 0.01
SS, mg l^{-1}	128 ± 14	Zn, mg l^{-1}	0.40 + 0.05
Total N, mg l^{-1}	1402 ± 135	Fe, mg l^{-1}	0.30 ± 0.01
P, mg l^{-1}	6.20 ± 0.13	Pb, mg l^{-1}	0.10± 0.01
CO_3, mg l^{-1}	2.00 ± 0.11	Ca, mg l^{-1}	50 ± 1.13
HCO_3, mg l^{-1}	7.00 ± 0.65	Mg, mg l^{-1}	41 ± 0.86
$CaCO_3$, mg l^{-1}	0.11 ± 0.01	Na, mg l^{-1}	196 ± 20
S, mg l^{-1}	3.00 ± 0.04	K, mg l^{-1}	55 ± 0.71
Cl, mg l^{-1}	7.00 ± 0.50	SAR	6.25 ± 0.28
Cu, mg l^{-1}	0.28 ± 0.02	FC, cfu 100 ml^{-1}	3719 ± 14

TDS: Total dissolved salts, SS: Suspended solids, SAR: Sodium adsorption ratio, FC:Faecal coliform.

Soil analysis: Soil samples were air-dried, crushed, and passed through a 2-mm sieve prior to chemical analysis. Cation exchange capacity (CEC) was determined using sodium acetate (buffered at pH 8.2) and ammonium acetate (buffered at pH 7.0) according to Sumner and Miller [35]. The Kjeldahl method [8] was used to determine organic N and plant-available P was determined by using the sodium bicarbonate method of Olsen *et al.* [27]. Electrical conductivity (EC) was measured in saturation extracts according to Rhoades [29]. Soil pH was determined in 1:2 extracts, and calcium carbonate concentration was determined according to McLean[21]. Soil organic matter was determined using the Smith-Weldon method [26]. Ammonium acetate buffered at pH 7 [36] was used to determine exchangeable cations. Micro elements in the soils were determined by diethylene triamine pentaacetic acid (DTPA) extraction methods [18]. Some physical and chemical properties of soil are given in Table 2.

Table 2. Chemical properties of experimental soils before planting (Mean ±SD, n = 10).

Soil properties	0-30 cm
Cation exchangeable capacity (CEC), $cmol_c$ kg^{-1}	24.00 ± 1.85
Total N, %	0.10 ± 0.03
pH (1:2 soil:water)	7.35 ± 0.16
Organic matter, %	1.40 ± 0.09
$CaCO_3$, %	1.30 ± 0.08
Plant available P, mg kg^{-1}	8.00 ± 1.90
Exchangeable Ca, $cmol_c$ kg^{-1}	22.50 ± 2.40
Exchangeable Mg, $cmol_c$ kg^{-1}	8.00 ± 0.50
Exchangeable K, $cmol_c$ kg^{-1}	2.20 ± 0.80
Exchangeable Na, $cmol_c$ kg^{-1}	0.20 ± 0.02
Available Fe, mg kg^{-1}	3.05 ± 0.15
Available Mn, mg kg^{-1}	1.62 ± 0.08
Available Zn, mg kg^{-1}	1.50 ± 0.10
Available Cu, mg kg^{-1}	1.20 ± 0.11
Available B, mg kg^{-1}	0.33 ± 0.07
Available Ni, mg kg^{-1}	0.08 ± 0.01
Available Pb, mg kg^{-1}	0.10 ± 0.02
Available Cd, mg kg^{-1}	0.11 ± 0.04
EC, dS m^{-1}	1.15 ± 0.03

Plant analysis: Plant samples were oven-dried at 68ºC for 48 h and ground to pass 1mm sieve. The Kjeldahl method and a Vapodest 10 Rapid Kjeldahl Distillation Unit (Gerhardt, Konigswinter, Germany) were used to determine total N [8]. Macro- (P, K, S, Ca Mg and Na) and micro-elements (Fe, Mn, Zn, Cu, Pb, Ni and Cd) were determined after wet digestion of dried and ground sub-samples using a HNO_3-H_2O_2 acid mixture (2:3 v/v) with three steps (first step; 145ºC, 75% RF, 5 min; second step; 180ºC, 90% RF, 10 min and third step; 100ºC, 40% RF, 10 min) in microwave (Bergof Speedwave Microwave Digestion Equipment MWS-2) [22]. Tissue P, K, S, Ca, Mg, Fe, Mn, Zn, Cu, Pb, Ni and Cd were determined using an inductively coupled plasma spectrophotometer (Perkin-Elmer, Optima 2100 DV, ICP/OES, Shelton, CT 06484-4794, USA) [23].

Statistical analysis: All data obtained from the effects of different wastewater irrigation on soil and plant chemical properties in contrast to non-wastewater irrigated in the present study were subjected to analysis of variance (ANOVA). The Duncan's multiple range tests were performed for mean comparisons using SAS statistical software [30].

Results and Discussion

Effect of MWW on the soil properties: Municipal wastewater (MWW) irrigated soils (100%) showed lower pH values and higher organic matter, N, P, Mg, Cu, Mn, Zn, Pb, and Cd compared to IW (control). This slight pH change can be attributed to the release of exchangeable cations during the mineralization of organic matter[40]. As this is entisol soil, decrease of pH can increase the solubility of exchangeable cations. Such decrease in the soil pH would enhance solubility and availability of soil nutrients such as phosphorus and micro elements [24, 25]. The salt content of the soils among the treatments increased as a consequence of MWW irrigation. Values represented an increase in salt content in soils cultivated with 65-26 fold at 100% ratio, 18- 20 fold at 75% ratio, 16-13 fold at 50% ratio and 7-6 fold at 25% ratio, compared to the control (0%), respectively (Table 3). Other researchers reported similar increases in the salt contents of soils after MWW irrigation[14, 37]. The organic matter and total N level of the MWW irrigated soils was higher than that of the IW irrigated soils. Organic matter and N levels of the soils decreased sharply with diluted irrigation water. Values represent increases in organic matter of MWW irrigation soil of 86.1-77.2%, 42.3-23.6%, 33.0-22.0%, and 29.2-18.9% in following order 100, 75, 50 and 25% when compared to the control (0%), respectively (Table 3). The N content of the soils showed similarity with organic matter contents. Many investigations, including long- and short-term studies, showed that soil fertility increased as a consequence of the application of wastes such as pig slurry, wastewater, sewage sludge, etc. [7, 10, 20].

The results also show that the cation exchange capacity (CEC) was higher in the MWW soils than in the control soils. When the MWW was treated to the dilution process, CEC values followed the order of 100 > 75 > 50 > 25% in soils. Exchangeable cation contents as Na, K and Ca increased due to MWW irrigation rate, and followed the order of 100 > 75 > 50 > 25% in soils. Available P concentrations were high in the MWW soils cultivated with maize plants when compared with control soils (Table 3), probably due to high organic matter amended with wastewater and increase of the fertilizer use efficiency. Other researches found that application of wastewater irrigation resulted in about 2-, 4- and 4- fold increases in N, P and S, respectively, above the recommended fertilizer rates for forage crops [9]. Plant total heavy metal concentrations, Fe, Mn, Zn, Cu, Ni, Pb and Cd, were less in all soils with treated irrigation water (control) than in MWW treatments. When compared with the control group (0%), results represent a relative increase rate of Fe, Pb, Ni, and Cd were about 2.5-1.5 fold for Fe, 2.0-2.6 fold for Ni, 11-12 fold for Pb, and 7-9 fold for Cd at 100% MWW irrigation treatment. In general, it seems that heavy metals tend to accumulate in the surface layer of soil [11] and their movement is limited by strong binding with clay minerals and organic matter. Our results were in good agreement with Soumare *et al.* [34], Dere *et al.* [12], Abbas *et al.* [1] and Madrid *et al.* [18].

Effect of MWW on the wheat yield: Municipal wastewater irrigation positively affected wheat yields. The highest yield of wheat plant (1.79 g plant^{-1}) was obtained from MWW treatments at 100% ratio (Fig. 1). When compared with the control group (0%), results represent a relative increase rate of dry matter for

Table 3. Chemical properties of the rhizosphere area irrigated with MWW after the harvest of wheat plants.

Parameters	MWW 0	25%	50%	75%	100%
pH, (1:2 soil:water)	7.65 a	7.30 b	6.90 c	6.00 d	5.90 d
Salt content , %	0.01 c	0.05 c	0.14 b	0.17 b	0.60 a
Organic matter, %	1.28 c	1.60 b	1.70 b	1.80 b	2.40 a
$CaCO_3$, %	1.14 a	0.81b	0.50b	0.50b	0.70 b
N,%	0.01 c	0.05 b	0.06 b	0.06 b	0.08a
P, mg kg^{-1}	8.15 c	12.14 b	10.41 b	13.40 b	17.23 a
CEC, cmol$_c$ kg^{-1}	25.00 c	26.00 bc	28.80 b	29.20 b	32.70 a
K, cmol$_c$ kg^{-1}	2.05 b	2.75 b	2.85 b	3.00 ab	3.50 a
Ca, cmol$_c$ kg^{-1}	18.15 b	19.55 b	20.26 ab	23.49 a	24.20 a
Mg, cmol$_c$ kg^{-1}	3.72 c	4.51b	4.65 b	4.88 ab	4.90 a
Na, cmol$_c$ kg^{-1}	0.14 c	0.19 b	0.18 b	0.24 b	0.40 a
Fe, mg kg^{-1}	3.00 a	3.10 a	3.19 a	3.28 a	3.28 a
Cu, mg kg^{-1}	1.30 c	2.00 b	2.12 b	2.31 b	3.55 a
Mn, mg kg^{-1}	1.41 c	1.55 c	1.90 c	2.37 b	3.20 a
Zn, mg kg^{-1}	1.22 b	1.30 b	1.53 b	1.65 b	2.27 a
Pb, mg kg^{-1}	ND	0.07 b	0.07 b	0.09 b	0.15 a
Ni, mg kg^{-1}	ND	0.01 b	0.11 b	0.18 b	0.38 a
Cd, mg kg^{-1}	ND	0.01 b	0.07 b	0.09 b	0.17 a

*Means with different letters within rows are significantly different ($p < 0.05$), ND: Non detectable.

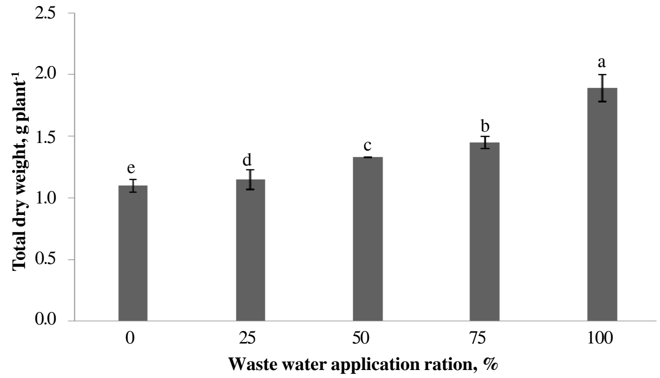

Figure 1. Effect of MWW irrigation treatments on the yield of wheat plants.

MWW at the 100 > 75 > 50 > 25% dilution ratio was about 4.54, 20.9, 31.82 and 62.7%, respectively.

Effect of MWW on the nutrient status of wheat: Wastewater irrigation had significant effects on plant N, P, K, Ca, Mg and S contents of wheat plants (Fig. 2). The 100% ratio treatment had the highest N (105 g 100 g dw^{-1}), P (59 g 100 g dw^{-1}), K (84 g 100 g dw^{-1}), Ca (106 g 100 g dw^{-1}), Mg (25 g 100 g dw^{-1}) and S (35 g100 g dw^{-1}) in MWW irrigation (Fig. 2). Macro element contents of the plants decreased when the MWW ratio irrigation rate was decreased, and followed the order of 100 > 75 > 50 >25%.

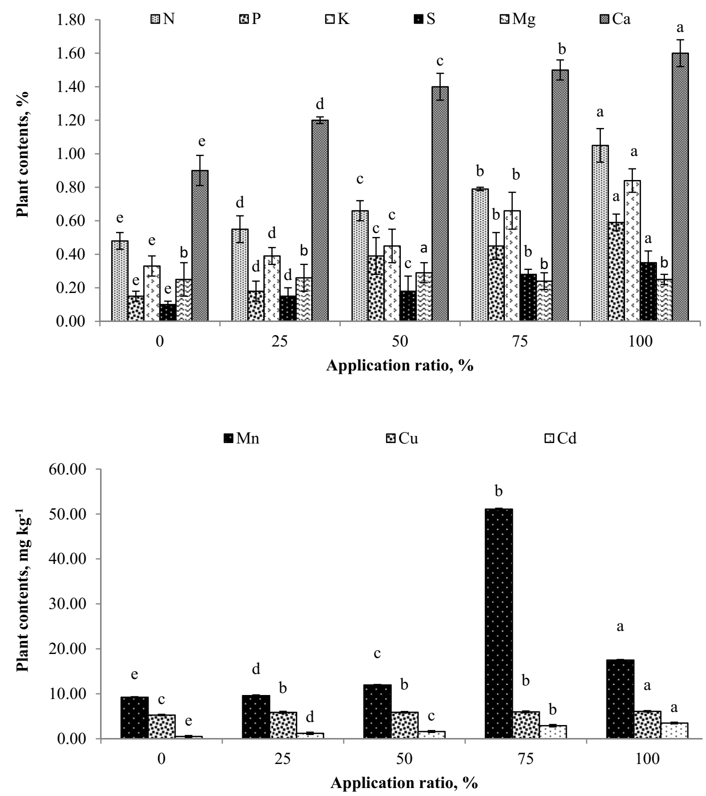

Figure 2. Effect of different MWW treatments on the N, P, K, Ca, Mg, S, Mn, Cu and Cd contents of wheat plants.

Heavy metal contents of plant were also significantly affected by the MWW irrigation. The 100% ratio of MWW treatment had the highest Fe (50.8 mg kg dw^{-1}), Mn (17.5 mg kg dw^{-1}), Zn (65.5 mg kg dw^{-1}), Cu (6.1 mg kg dw^{-1}), Pb (2.2 mg kg dw^{-1}), Ni (0.19 mg kg dw^{-1}), and Cd (3.5 mg kg dw^{-1}) (Fig. 3). Our results were in good agreement with Arroya *et al.* [5] and Kiziloglu *et al.* [16].

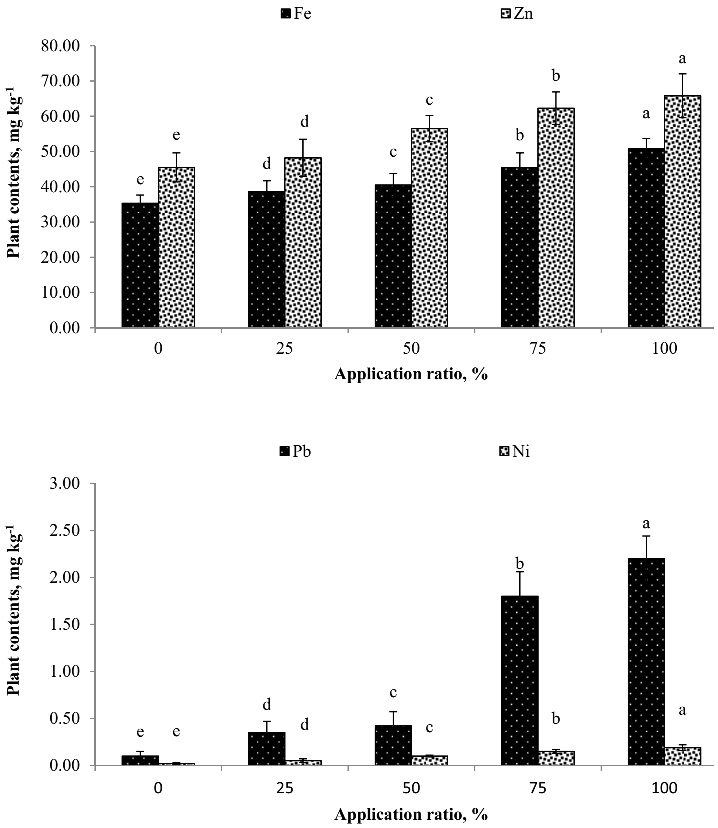

Figure 3. Effect of different MWW irrigation treatments on the Fe, Zn, Pb, and Ni contents of wheat plants.

Conclusions

Municipal wastewater irrigation affects the physical and chemical properties and increase the fertilizer use efficiency of the soils, yields and also mineral contents in the plants. Therefore, characteristics of MWW and soil should be considered in management of wastewater irrigation during the crop production. As compared to control treatment soils, the results revealed that there was a significant decrease in soil pH and there were increases in salt and organic matter contents in soils, CEC and macro and microelement concentrations in leaves. Therefore, MWW had a high nutritive value that may improve plant growth, reduce fertilizer application rates; increase fertilizer use efficiency and increase productivity of poor fertility soils. It is suggested that MWW can be used to irrigate field crops, with a continuous monitoring of the effluent quality to avoid contamination. Soil degradation in semi-arid environments needs alleviation in order to preserve non-renewable resources. MWW irrigation can be used as an organic fertilizer to improve the physical and chemical properties and to increase plant availability of macro and micro nutrients of soils in addition to potential source of nutrients. The major disadvantage of the MWW irrigation is the accumulation of immobile heavy metals in soils. In fact, our results show that the farmer should take a long-term advantage in MWW irrigation and at the same time satisfy consumer demands for food safety. Meanwhile, in the long term, farmers don't have any questions of soil fertility, reduce heavy metal concentration and protection of food chain, MWW should be used as diluted with irrigation water. Field studies are needed to further test and quantify the effectiveness of WW irrigation in enhancing soil fertility and nutrient efficiency.

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