Irrigation Science
https://doi.org/10.1007/s00271-024-00927-5

ORIGINAL PAPER

Fertility and heavy metal pollution in silage maize soil irrigated with different levels of recycled wastewater under conventional and no-tillage practices

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Received: 15 October 2023 / Accepted: 10 March 2024

Abstract

Irrigation with recycled domestic wastewater has been known to obtain positive effects on improving soil fertility, but it may also become a risk factor in case of causing an increase in soil salinity and/or heavy metal concentration of soil. No-tillage can retain soil moisture, helping to reduce irrigation water necessity, and thus lower amounts of heavy metals and salts are added to soil under wastewater irrigation conditions. The objective of this study was to analyze the effects of wastewater irrigation at different levels of on silage maize cultivation under conventional tillage and no-tillage conditions by comparing to full irrigation with fresh water. The two-year experiment was planned according to the split-plots design in the random blocks with three replications. The results indicated that full irrigation with wastewater increased soil salinity, organic matter content, total nitrogen, plant available phosphous, exchangeable cations, exchangeable sodium percentage and soil essential and non-essential heavy metal contents, but decreased soil pH and lime content. Increasing rates in organic matter content, total nitrogen, plant available phosphorus and exchangeable potassium were higher, but in electrical conductivity, and heavy metal accumulation were lower in soil under no-tillage as compared to conventional tillage. Contamination and enrichment factors and geographic accumulation index showed that non-essential heavy metal contamination due to cadmium and nickel, increased in full irrigation with wastewater. Irrigation with wastewater also increased heavy metal accumulation in silage maize. No-tillage can be a recommendable water management practice considering that the risks of soil salinity and heavy metal accumulation can be reduced and that soil fertility can be increased. Also, in reducing the risk of accumulation of cadmium and nickel in soil, 33% deficit irrigation with wastewater can make no-tillage more available.

Introduction

Fresh water scarcity is an increasing problem worldwide, with the impact of rapidly increasing demand and climate change. Hanjra and Qureshi (2010) reported that approximately 3 billion people will experience water and food poverty in 2025. Burak and Margat (2016) stated that global water demand will increase by 23–42% in 2050 compared to 2010. The amount of water available should be increased by 53% and agricultural areas by 38% to meet the food needs of the increasing population in 2050 (Mancosu et al. 2015).

Agricultural activities consume fresh water resources the most compared to other sectors. FAO (2020) has stated that the amount of water used for agricultural activities on a

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global scale is 69% of the total amount of water. This ratio differs depending on the development level of the countries, nevertheless, it is still a concern for the future of fresh water resources. Therefore, using marginal water resources such as wastewater in agricultural irrigation and saving water are considered an option.

A very large part of the wastewater, such as 99%, is water, and the remaining part is colloidal and dissolved solid particles (UN 2014). Wastewater is a potential source of nutrients with its high organic and inorganic contents, improves soil structure and makes positive contributions for increasing yield and crop quality (Tunc and Sahin 2016; Dogan Demir and Sahin 2017; Cakmakci and Sahin 2021b). Qin and Horvath (2020) reported that crude wastewater can contain more macro and micronutrients than chemical fertilizer, even under treated conditions. With use of wastewater in irrigation, structural properties of soil and microorganism activities can be improved, as well as discharge problems of wastewater can be solved (Cakmakci and Sahin 2021a). Thus, wastewater use reduces the need for chemical fertilizers and offers a more economical and environmental production alternative through its disposal. However, under conditions with greater nutrient input to soil, synergism or antagonism nutrient interactions can increase or decrease yield (René et al. 2017). In addition, continious use of wastewaters in irrigation cannot improve soil structure if its high sodium adsorption ratio (>4) and pH (>8) value and can also be detrimental the dissolved organic carbon contribution (Suarez and Gonzalez-Rubio 2017). Thus, high concentrations of Na and the resulting increased SAR can cause severe decreases in soil permeability.

Recycled wastewater may also contain serious risk factors such as soil salinity and heavy metal pollution. High EC value of wastewater may increase salinity level of soils, reducing the yield and quality, and the soils become barren in the following processes (Wen et al. 2018).

The heavy metal content of wastewater mostly originates from industry and industrial wastes. In general, domestic wastewater does not contain high heavy metal content since not including industrial wastes (Agyei and Ensink 2016). Heavy metals present in domestic wastewater originate from chemicals such as detergents, softeners and other cleaning materials (Jenkins and Russell 1994). Heavy metals in soils in diverse dissolved (free cations and complexed species of positive, neutral, negative charges), particulate (sorbed, structural, coprecipitated), and colloidal (micro and nano sized particles) species may be found (Uchimiya et al. 2020).

Heavy metals have a toxic effect on crop, preventing or limiting the functions of crop physiology (Yerli et al. 2020). In fact, some heavy metals such as Fe, Cu, Mn, Mo and Zn are micronutrients. However, while small amounts of these microelements are needed by plants, higher concentrations have toxic effects.

The extent of heavy metal contamination in soil under wastewater irrigation conditions varies depending on source of wastewater and the length of application period. Therefore, numerous studies have reported that there were no significant increases in heavy metals in soils irrigated with recycled domestic wastewater due to the short-term application effect, and the values were below the allowable threshold heavy metal contents in soil (Kiziloglu et al. 2008; Tunc and Sahin 2016; Dogan Demir and Sahin 2017; Cakmakci and Sahin 2021a). However, serious heavy metal pollution and salinity problems can be seen in soils irrigated with wastewater for long periods (Al-Omron et al. 2012). These risks can be reduced and also water savings can be achieved by deficit irrigation approach where irrigation is carried out with less water than the amount of water needed by crops. Therefore, deficit irrigation approach can be considered as a good practice to decrease excessive accumulation of heavy metals in agricultural soils through wastewater irrigation. Additionally, as a result of reducing the amount of irrigation water by preserving soil moisture for longer periods in no-tillage practice (Gozubuyuk et al. 2020), less heavy metals contamination and salt accumulation can be achieved with wastewater irrigation.

Maize, one of the most grown product groups in the world with more than 1.1 million tonnes production on an area of 194 million hectares (FAO 2020), is an accumulator crop with high resistance to heavy metal pollution with its ability to accumulate heavy metal (Aladesanmi et al. 2019). In irrigation with wastewater, available soil moisture can be accompanied by increased heavy metals in soil can increase transfer from soil to crops (Wei et al. 2020). Cakmakci and Sahin (2021a) reported that heavy metal accumulation in maize irrigated with wastewater was due to the heavy metal content of soil. However, metal speciation and spatial considerations generally control plant uptake rather than total metal concentration (Uchimiya et al. 2010). The specification controls toxicokinetics (uptake and transport of metals by crop) while toxicodynamics (interaction between the crop and absorbed species) drives the toxicity outcome (Uchimiya et al. 2020).

Therefore, it is important to limit heavy metal accumulation in areas irrigated with recycled wastewater to ensure food chain safety by preventing heavy metal accumulation in the crop in the use of recycled wastewater in irrigation for the sustainability of fresh water resources. Previous studies focused on the efficiency and soil quality of silage maize grown with recycled wastewater (Asgari et al. 2007; Mousavi and Shahsavari 2014; Tabatabaei et al. 2017; Bashir et al. 2021; Cakmakci and Sahin 2021b) but did not focus on potential risks and management of these risks. Practical approaches for reducing the risks of heavy metal pollution and soil salinity, and improving soil fertility in soil irrigated with recycled wastewater showed that the issue can be regulated with deficit irrigation and tillage-sowing approaches. This study examined the hypotheses that no-tillage practice under irrigation conditions with recycled domestic wastewater could reduce wastewater-induced heavy metal pollution of silage maize field soil as well as soil salinity compared to conventional tillage, and that no-tillage could save irrigation water and improve soil fertility.

Materials and methods

The location, climate and soil properties of the study area

Field studies were carried out in the vegetation period between May and September 2020 and 2021 in the experimental field of Van Yuzuncu Yil University, Faculty of Agriculture, located in the eastern part of Turkiye, at 38°34’35” North latitude and 43°17’26” East longitude and 1670 m altitude.

Table 1 Soil properties of the study field prior to the experiment

Property	0–30 cm	30–60 cm	60–90cm
Sand (%)	45.6	44.5	46.7
Silt (%)	24.6	23.8	24.7
Clay (%)	29.8	31.8	28.6
Soil texture class	Sandy clay loam		
EC (dS m^{-1})	0.335	0.363	0.390
pH	8.17	8.20	8.50
$CaCO_3$ (%)	10.7	12.0	15.2
Organic matter (%)	1.36	1.23	1.03
Total Kjeldahl N (%)	0.081	0.078	0.079
P_2O_5 (kg ha^{-1})	89	86	78
K_2O (kg ha^{-1})	878	890	910
Exchangeable Ca (cmol kg^{-1})	14.91	15.23	14.99
Exchangeable Mg (cmol kg^{-1})	5.11	5.21	5.21
Exchangeable Na (cmol kg^{-1})	0.32	0.35	0.33
Exchangeable K (cmol kg^{-1})	1.14	0.97	1.09
CEC (cmol kg^{-1})	21.49	21.77	21.62
ESP (%)	1.48	1.62	1.53
B (mg kg^{-1})	0.193	0.189	0.190
Fe (mg kg^{-1})	4.25	3.96	3.25
Cu (mg kg^{-1})	2.10	1.98	1.63
Mn (mg kg^{-1})	7.45	6.93	5.11
Zn (mg kg^{-1})	50.7	45.9	34.2
Pb (mg kg^{-1})	3.35	3.20	2.86
Cd (mg kg^{-1})	0.022	0.023	0.019
Cr (mg kg^{-1})	0.165	0.145	0.131
Ni (mg kg^{-1})	0.112	0.088	0.073

EC: Electrical conductivity, CEC: cation exchange capacity, ESP: exchangeable sodium percentage

The long-term data of the Van Meteorology Station (1976–2021) showed that the region has a semi-arid climate with a mean annual precipitation of 391.9 mm (GDM 2021). The data measured with the climate station (Imetos 2) installed right next to the experimental area, the mean temperature and total precipitation values in the production period of 2020 (15 May – 13 September) – 2021 (11 May – 4 September) were 22.4 °C and 37.0 mm, and 22.8 °C and 52.1 mm, respectively.

The initial soil properties showed that the texture of the experimental soil was sandy clay loam (USDA classification) with medium alkalinity and medium lime content, and having low organic matter content without salinity problem (Table 1).

Irrigation system, irrigation water resources and analysis

Irrigation water was applied by surface drip irrigation system using dripelines with an in-line dripper 2.3 L h^{-1} flow rate at 0.1 MPa operation pressure with 33 cm spacing. The volume of applied irrigation water was controlled using a water meter placed on each plot.

The tap water was used as the fresh water source. The recycled wastewater was taken from the discharge point of the Biological Waste Water Treatment Plant, which contains only domestic pollution elements of approximately 125 000 inhabitants in the central Edremit district of Van. It was transported to the experimental area with a water tanker before each irrigation, transferred to polyethylene water tank and used in irrigation.

Water samples were taken to represent each month during the irrigation periods. The results of quality analysis of irrigation water as the mean of the sampling periods and the two years are presented in Table 2. The methods and procedures used in analysis were described in Yerli and Sahin (2022).

It was concluded that the heavy metal contents of recycled wastewater were below the maximum concentrations and there was no harm in using them in irrigation in terms of other quality criteria (Yerli and Sahin 2022), based upon the “Water Pollution Control Regulation” inland water resources classification (Anonymous 2008), “Waste Water Treatment Plants Technical Procedures Communique” (Anonymous 2010), and also according to other international criteria (Ayers and Westcot 1994; EPA 2004).

Experimental design, tillage-sowing and irrigation practices

The experiment was carried out according to the split-plots experimental design in random blocks and with three

Table 2 Quality analysis results of irrigation waters

Property	Fresh water	Recycled wastewater
pH	8.14 ± 0.05	7.55 ± 0.08
EC (dS m^{-1})	0.35 ± 0.01	1.12 ± 0.03
Ca (me l^{-1})	0.98 ± 003	2.28 ± 0.09
Mg (me l^{-1})	1.34 ± 0.06	3.06 ± 0.08
Na (me l^{-1})	0.88 ± 0.03	4.13 ± 0.04
K (me l^{-1})	0.14 ± 0.01	1.10 ± 0.09
CO_3 (me l^{-1})	-	-
HCO_3 (me l^{-1})	2.12 ± 0.06	5.10 ± 0.06
Cl (me l^{-1})	0.38 ± 0.02	2.02 ± 0.06
SO_4 (me l^{-1})	0.81 ± 0.04	1.65 ± 0.08
NO_3 (me l^{-1})	-	1.57 ± 0.05
B (mg l^{-1})	-	0.51 ± 0.03
Fe (mg l^{-1})	0.05 ± 0.01	0.41 ± 0.01
Cu (mg l^{-1})	-	0.011 ± 0.001
Mn (mg l^{-1})	-	0.081 ± 0.007
Zn (mg l^{-1})	-	0.015 ± 0.001
Pb (mg l^{-1})	-	0.001 ± 0.001
Cd (mg l^{-1})	-	0.001 ± 0.001
Cr (mg l^{-1})	-	0.001 ± 0.001
Ni (mg l^{-1})	-	0.042 ± 0.002
Total Kjeldahl N (mg l^{-1})	-	10.89 ± 0.49
Total P (mg l^{-1})	-	1.49 ± 0.14
SSM (mg l^{-1})	-	25.06 ± 2.16
COD (mg l^{-1})	-	37.24 ± 1.21
BOD_5 (mg l^{-1})	-	22.94 ± 0.877
SAR	0.83 ± 0.03	2.53 ± 0.04
Fecal coliform (EMS 100 ml^{-1})	-	144.2 ± 7.5

- : not detected, EC: electrical conductivity, SSM: suspended solid material, COD: chemical oxygen demand, BOD_5: biological oxygen demand, SAR: sodium adsorption ratio

replications. In the experiment, the main treatments were set as two different tillage-sowing practices; conventional tillage (CT) and no-tillage (NT), and the sub-treatments were at 100% (full) (WW100), 67% (WW67) and 33% (WW33) levels irrigations (100%) with recycled wastewater, and a control group constituting at 100% (full) level irrigation with fresh water (FW100). Thus, the total number of plots was 24 (3 replications × 2 tillages-sowing practices × 4 irrigation treatments), and each plot was planned in 3.5 m × 7.2 m (25.2 m^2) dimensions, with 5 rows (70 cm interrow and 15 cm row spacing).

In the CT, the soil was first plowed with a plow, then the clods formed in the soil were broken down by using a cultivator-rotary harrow and the field surface was leveled. Subsequently, silage maize seeds (cv. OSSK-644) were sowed via a pneumatic seeder. Sowing was carried out with a direct sowing machine on the same day as CT, without any tillage application in the NT plots.

Until the crop reaches 40–50 cm height, all plots were equally irrigated using only fresh water, with a 30% wetting percentage so that the decreased moisture content at a depth of 30 cm was completed to the field capacity. In determining the irrigation time in this period, it has been taken into account that Σ [ETc – precipitation] reached 40% of the available water at 30 cm depth (≈ 19.1 mm). After this period, irrigation practices with wastewater were initiated, separately for tillage-sowing practices. Thus, by determining the decrease in the moisture in the fresh water plots according to the field capacity, 100%, 67%, and 33% irrigation applications with wastewater and also 100% irrigation applications with fresh water were carried out with a 65% wetting percentage. In order to determine irrigation time in this period, the fact that Σ [ETc – precipitation] reaches 40% of the available water at a depth of 90 cm (≈ 59.5 mm) was taken into account. To calculate the ETc used to determine the irrigation time (ETc = kc × ETo), kc was provided from the "Crop Water Consumption Guide for Irrigated Crops in Turkey", and ETo was calculated daily in the Cropwat software using the data obtained from the climate station (Imetos 2) installed in the experimental area. The amounts and volumes of irrigation water applied for each plot were determined by basic equations (Kanber and Unlu 2010), the controls of irrigation water volumes were made with water meter readings. The amount of seasonal irrigation water applied to the subjects as a result of the study is given in Fig. 1.

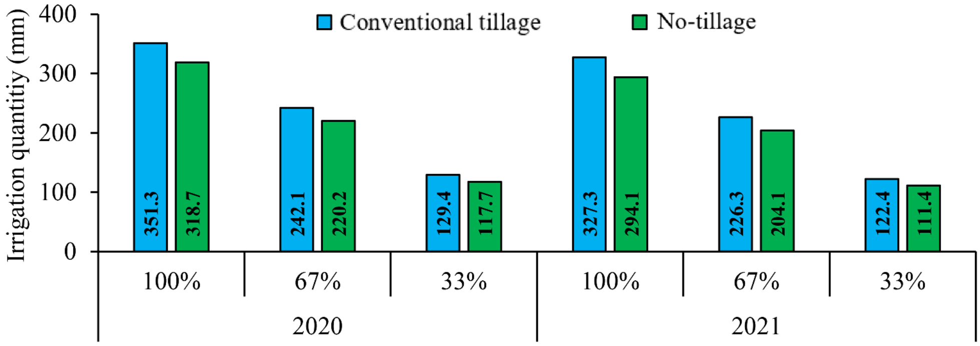


Fig. 1 Seasonal irrigation quantities in experimental years (100%, 67% and 33% represent irrigation water levels)

Cultural practices

For weed control in the CT, the first hoeing and the second hoeing was carried out when the crop height was 15–20 cm and 40–50 cm, respectively. Hoeing was not carried out in the NT, the weed characteristics of the field were determined and herbicide containing Linuron and 2.4-D Fluorosulan active substance was applied.

In the first year, urea (45–46% N) and triple superphosphate (43–46% P_2O_5) fertilizers were applied to all plots at doses of 100 kg ha^{-1} and 150 kg ha^{-1}, respectively, with seed sowing. The second urea fertilization was carried out by fertigation program equal to the first dose when the crop height was 40–50 cm (Celebi et al. 2010). However, the fertilization in the second year was applied to only FW100 plots considering residual fertilizer effect form previous year in wastewater plots, and missing doses were completed based upon the result of total N and P_2O_5 analyzes before sowing. Thus 67 kg ha^{-1} and 56 kg ha^{-1} urea, 65 kg ha^{-1} and 60 kg ha^{-1} triple super phosphate fertilizers were applied to the FW100 plots of CT and NT, respectively, in the seed sowing. The second urea fertilization was carried out by fertigation equal to the first dose when the height was 40–50 cm as in the first year.

Soil analysis

At the end of both years of the experiment, soil samples were taken from the midpoint of the middle row of all parcels, from three different layers, to a depth of 90 cm (0–30 cm, 30–60 cm, 60–90 cm), within the wet front. In soil samples, EC (Corwin and Rhoades 19824) and pH (McLean 1982) were determined by direct reading in the saturation extract. The principles of Calcimeter, Walkley-Black, and Kjeldahl methods were applied for $CaCO_3$ (Nelson 1982), organic matter (Nelson and Sommers 1982), and total N (Bremner and Mulvaney 1982) analyses, respectively. Plant available P (Olsen et al. 1982) and exchangeable K (Knudsen et al. 1982) were determined using Atomic Absorption Spectrophotometer and fleymphotometer, respectively. By shaking the samples with 1 N ammonium acetate, the displacement of cations was ensured and the quantifying exchangeable cations (K^+, Ca^{++}, $+ Mg^{++}$ and $+ Na^+$) were determined by reading in Atomic Absorption Spectrophotometer (Thomas 1982). CEC was calculated by the sum of four exchangeable cations determined in soil. Exchangeable Sodium Percentage (ESP) was obtained as a percentage Exchangeable Na/CEC (Kanber and Unlu 2010). The microelements (B, Fe, Cu, Mn, Zn) and and non-essential heavy metals (Pb, Cd, Cr and Ni) were analyzed according to DTPA extraction in available form. After air-dry soil samples sieved through a 0.15 mm sieve were placed in the wet combustion device tubes, 9 ml HNO_3 and 3 ml H_2O_2 were added and subjected to wet combustion at high pressure, and then the samples filtered through filter paper were determined by readings on the Inductively Coupled Plasma-Optical Emission Spectrometer device (Anonymous 2007).

Soil contamination indicators by heavy metals

The contamination factor (CF), enrichment factor (EF), geographic accumulation index (GAI), and the pollution load index (PLI) were calculated using the Eqs. 1, 2, 3, and 4 (Weissmannová and Pavlovský 2017; El-Anwar and Ahmed 2019) and used for determining the degree of pollution caused by heavy metals in soils.

$$\mathrm{CF} = \frac{\mathrm{C}}{\mathrm{Cr}} \tag{1}$$

$$\mathrm{EF} = \frac{\left(\frac{\mathrm{C}}{\mathrm{CFe}}\right)}{\left(\frac{\mathrm{C}}{\mathrm{CFe}}\right)\mathrm{r}} \tag{2}$$

$$\mathrm{GAI} = \log 2\left(\frac{\mathrm{C}}{1.5 \times \mathrm{Cr}}\right) \tag{3}$$

$$\mathrm{PLI} = \sqrt[\mathrm{n}]{\mathrm{CF1} \times \mathrm{CF2} \times \ldots \times \mathrm{CFn}} \tag{4}$$

Where the CF is the contamination factor, the C is the metal concentration of the soil sample, the Cr is the value of the same element in the reference environment, the EF is the enrichment factor, the (C/C_{Fe}) is the ratio of heavy metal content to Fe content in the soil sample, the $(C/C_{Fe})r$ is the same ratio of heavy metal content in the reference environment, the GAI is geographic accumulation index, 1.5 is a constant factor depending on the formulation to improve the reference environment conditions, the PLI is pollution load index, the n is the number of heavy metals in the study. The contents of all heavy metals used in the calculation of the CF, EF, GAI, and the PLI were evaluated as mg kg^{-1}.

The metals that are generally referenced in the calculation of soil pollution indicators are Mn, Al, and Fe (Weissmannová and Pavlovský 2017). However, since the trace elements of the soils may differ depending on the climate, environmental or other external conditions of the regions, the use of the same reference metals in different regions prevents the appropriate calculation of soil pollution indicators. Therefore, calculating soil pollution indicators using a reference metal to represent the region is a more valuable approach (Santos-Francés et al. 2017). Accordingly, based on different studies carried out in the same region (Cakmakci and Sahin 2021a), Fe was considered as the reference metal in the calculations. Also, since the surface soil layer is more critical in crop production (Dogan Demir and Sahin

2017), the 0–30 cm soil layer was accepted as the reference environment layer for the present study. The evaluation of soil pollution indicators by heavy metals was carried out according to Zhao et al. (2014) and Weissmannová and Pavlovský (2017).

Heavy metal content of silage maize crops

At the end of both years, the harvested silage maizes were kept for a certain period of time until they became air-dry. Then, dried-milled-sieved crop samples were subjected to wet burning in wet burning device tubes, and the essential heavy metal (Fe, Cu, Mn, Zn) and non-essential heavy metal (Pb, Cd, Cr, Ni) contents of the samples filtered on filter paper were determined by reading in an Inductively Coupled Plasma-Optical Emission Spectrometer (Anonymous 2007).

Evaluation of the dataset

The ANOVA analysis was performed for all parameters to determine the differences in the experimental years (2020 and 2021) and soil layers (0–30 cm, 30–60 cm, and 60–90 cm), and the results showed that there was a general similarity for all parameters in the experimental years and soil layers. Also, considering that the surface soil layer is more critical in crop production, the evaluations were carried out on 0–30 cm soil layer and in the mean of the experimental years (Cakmakci and Sahin 2021a). Thus, by accepting the variables of tillage-sowing and irrigation practices as constant, the importance and interactions of the variables were analyzed in the SPSS package program adopting the General Linear Model approach and the mean values were compared at 5% probability level by the Duncan multiple comparison test. Correlograms with a scatterplot, correlation coefficient, and variable distribution were built using the RStudio package to determine the correlation relationships among parameters.

Results and discussion

Soil chemical properties (EC, pH, $CaCO_3$ organic matter, total Kjeldahl N, plant available P and K)

The effects of both irrigation and tillage-sowing practices on EC, organic matter, total Kjeldahl N, and plant available P and K (as P_2O_5 and K_2O) values were significant, and the effect of only irrigation treatments on pH and $CaCO_3$ values was significant (Table 3). The EC values increased compared to the pre-experimental values (Table 1); however, a higher increase was determined by 2.2 times in full irrigation with wastewater. A positive correlation was determined between the EC and the amount of irrigation water

Table 3 The chemical properties of the soil in different irrigation and tillage-sowing treatments

Treatment		EC (dS m^{-1})	pH	$CaCO_3$ (%)	Organic matter (%)	Total Kjeldahl N (%)	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
CT	FW100	0.542 ± 0.006	8.13 ± 0.01	10.3 ± 0.01	1.75 ± 0.01	0.088 ± 0.001	110 ± 1.8	905 ± 1
	WW100	0.735 ± 0.004	7.92 ± 0.01	9.1 ± 0.02	2.04 ± 0.01	0.127 ± 0.003	131 ± 0.6	1007 ± 7
	WW67	0.587 ± 0.003	8.10 ± 0.02	9.4 ± 0.02	1.81 ± 0.01	0.111 ± 0.001	126 ± 0.2	967 ± 3
	WW33	0.442 ± 0.006	8.12 ± 0.01	10.5 ± 0.01	1.52 ± 0.02	0.082 ± 0.001	124 ± 0.4	883 ± 2
NT	FW100	0.520 ± 0.004	8.13 ± 0.01	10.3 ± 0.02	1.77 ± 0.02	0.096 ± 0.001	115 ± 0.5	917 ± 3
	WW100	0.710 ± 0.004	7.94 ± 0.01	9.1 ± 0.03	2.08 ± 0.01	0.137 ± 0.003	134 ± 0.4	1015 ± 3
	WW67	0.561 ± 0.005	8.10 ± 0.02	9.4 ± 0.02	1.83 ± 0.02	0.120 ± 0.001	127 ± 0.3	972 ± 1
	WW33	0.423 ± 0.004	8.13 ± 0.01	10.6 ± 0.02	1.55 ± 0.01	0.087 ± 0.001	125 ± 0.8	882 ± 4
Irrigation	FW100	0.531 ± 0.006 C	8.13 ± 0.01 A	10.3 ± 0.01 B	1.76 ± 0.01 C	0.092 ± 0.002 C	112 ± 1.3 D	911 ± 3 C
	WW100	0.723 ± 0.006 A	7.93 ± 0.01 C	9.1 ± 0.02 D	2.06 ± 0.01 A	0.132 ± 0.003 A	133 ± 0.7 A	1011 ± 4 A
	WW67	0.574 ± 0.006 B	8.10 ± 0.01 B	9.4 ± 0.02 C	1.82 ± 0.01 B	0.116 ± 0.002 B	126 ± 0.3 B	970 ± 2 B
	WW33	0.433 ± 0.005 D	8.13 ± 0.01 A	10.6 ± 0.01 A	1.54 ± 0.01 D	0.085 ± 0.001 D	125 ± 0.5 C	883 ± 2 D
Tillage-sowing	CT	0.577 ± 0.032 A	8.07 ± 0.03	9.8 ± 0.18	1.78 ± 0.06 B	0.102 ± 0.005 B	123 ± 2.4 B	941 ± 2 B
	NT	0.554 ± 0.031 B	8.08 ± 0.02	9.9 ± 0.19	1.81 ± 0.06 A	0.110 ± 0.006 A	125 ± 2.1 A	947 ± 2 A
P value	Interaction	0.866	0.903	0.0725	0.602	0.317	0.088	0.315
	Irrigation	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Tillage-sowing	0.000	0.245	0.732	0.008	0.000	0.000	0.031
Mean square	Interaction	0.241	0.189	0.444	0.637	1.272	2.597	1.280
	Irrigation	1 497.082	129.859	2 439.663	585.404	310.514	255.793	5.558
	Tillage-sowing	55.680	1.455	0.121	9.062	43.854	22.028	528.645

CT: Conventional tillage, NT: No-tillage, FW100: Full irrigation with fresh water, WW100: Full irrigation with recycled wastewater, WW67: Irrigation at 67% level with recycled wastewater, WW33: Irrigation at 33% level with recycled wastewater, ±: Standard error of the mean, Significant differences at 5% probability level between treatments are indicated by different letters

(Fig. 2). The higher EC values in WW100 can be considered a result of wastewater containing more salt than fresh water (Table 2). In various studies, the EC values increased due to irrigation with wastewater (Singh et al. 2012; Cicek et al. 2013; Bedbabis et al. 2014) and it was reported that this increase was limited by the deficit irrigation with wastewater (Tunc and Sahin 2016; Dogan Demir and Sahin 2017; Cakmakci and Sahin 2021a). Also, with a similar approach, due to less irrigation water amount of the NT (Fig. 1), soil EC value was lower than the CT.

The pH values decreased in all irrigation treatments compared to the pre-experimental values (Table 1); however, this decrease was substantially higher in WW100. The wastewater has a significantly lower pH value than freshwater (Table 2) and likely has a greater buffering capacity. The fact that the soil pH was found to be lower in WW100 compared to FW100 can be related to the high N content of the wastewater (Table 2). The soil pH decreases as a result of the release of three protons (H+) for each mole of NO_2 formed by the nitrification of NH_3 with the introduction of N into the soil (Silva et al. 2016). Also, soil acidity may increase as a result of the decomposition of organic acids and organic substances in the soil under irrigation with wastewater conditions (Vaseghi et al. 2005). Many studies reported that soil pH values decrease due to irrigation with wastewater (Singh et al. 2012; Cicek et al. 2013; Bedbabis et al. 2014; Tunc and Sahin 2016; Dogan Demir and Sahin 2017). Less N contribution of wastewater to the soil under deficit irrigation conditions (Table 3) explains the limitation in pH reduction (Cakmakci and Sahin 2021a). The negative correlation relations of pH with irrigation water amount and total N ($P < 0.01$) also support this result (Fig. 2).

The $CaCO_3$ values in WW33 and FW100 were close to the pre-experimental values (Table 1); whereas $CaCO_3$ decreased significantly in WW100 and WW67. This decrease was associated with a decrease in pH due to the positive correlation between $CaCO_3$ and pH (Fig. 2). This can be explained by low pH values in the soil increase $CaCO_3$ solubility. Kiziloglu et al. (2008), Tunc and Sahin (2016), and Dogan Demir and Sahin (2017) have reported that irrigation with wastewater leads to a decrease in pH, resulting in a decrease in the $CaCO_3$ content.

Organic matter increased in all irrigation and tillage-sowing treatments compared to the pre-experimental values (Table 1), and the increase was significant in WW100. The higher increase in irrigation conditions with wastewater compared to fresh water can be evaluated in relation to the higher COD and BOD_5 content of wastewater (Table 2). In a similar with, Bedbabis et al. (2015) have reported increases in soil organic matter due to the high COD and BOD_5 content of wastewater under wastewater irrigation conditions. In previous studies, it has been reported that soil organic

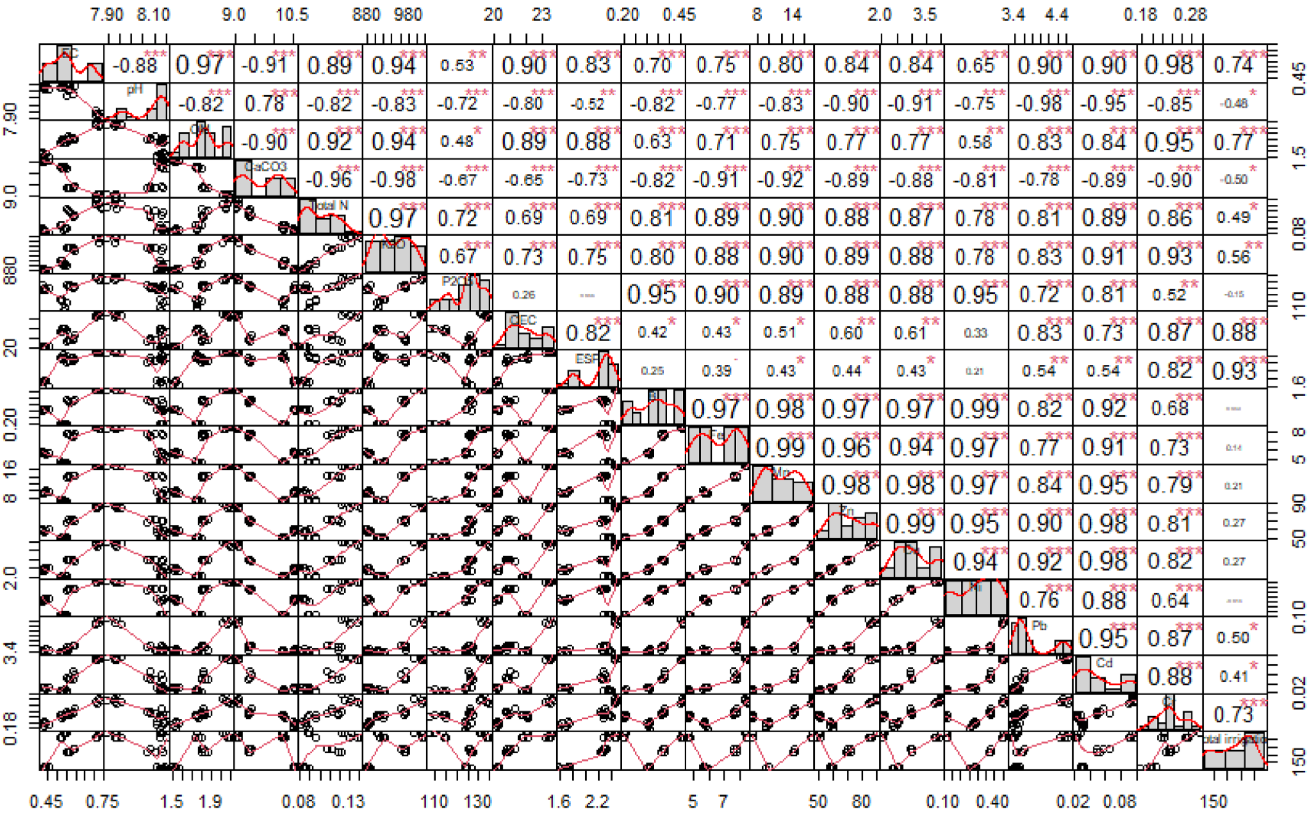


Fig. 2 Correlation matrix among parameters (***: $P < 0.001$, **: $P < 0.01$, *: $P < 0.05$)

matter content was enriched due to irrigation with wastewater (Dogan Demir and Sahin 2020; Liu et al. 2021). Also, it was thought that crop residues contribute to the increase of organic matter in the soil as a result of the better development of crops irrigated with wastewater (Cakmakci and Sahin 2021a). Similarly, the increase under freshwater irrigation relative to pre-experimental values was evaluated to be because of the decomposition of plant residues remaining in the soil due to crop production. Organic matter values, which increased at lower levels in WW33, can also be explained by the limitation of organic matter accumulation due to less water application to the soil as mentioned by Dogan Demir and Sahin (2017).

It is thought that the increase in mineralization and decomposition as a result of increased aeration due to tillage may have caused the CT to have lower organic matter than the NT. Malhi et al. (2018) reported that the increase in mineralization and decomposition as a result of increased aeration due to tillage caused the NT to have lower organic matter than the NT. Crop residues also left on the soil surface in the NT enrich the soil with organic matter (Tabaglio et al. 2009). In numerous studies, it has been reported that organic matter increased in the NT compared to that in intensive tillage (Yang et al. 2019; Gozubuyuk et al. 2020; Kan et al. 2020).

The total Kjeldahl N, P_2O_5, and K_2O increased in all irrigation and tillage-sowing treatments compared to the pre-experimental values (Table 1). This increase was the highest in WW100 with the rich N, P, and K content of the wastewater, and decreased by less nutrient inputs due to less water application to the soil. In many studies, total N, P_2O_5, and K_2O increased due to irrigation with wastewater (Galavi et al. 2010; Tunc and Sahin 2017; Erel et al. 2019; Xi et al. 2021) and limited by the deficit wastewater irrigation application (Tunc and Sahin 2016; Dogan Demir and Sahin 2017; Cakmakci and Sahin 2021a).

The higher total N, P_2O_5, and K_2O content in the NT compared to the CT can be explained by the contribution of crop residues to the increase in the N, P, and K content of the soil. Also, increased decomposition in the soil as a result of intensive tillage with the CT application may have reduced the total N, P_2O_5, and K_2O content. Malhi et al. (2018) have reported that intensive tillage causes a decrease in the N content of the soil by increasing the incorporation of crop residues into the soil. Schmer et al. (2014) have stated that the NT application increased N accumulation on the soil surface. Dalal et al. (2011) have stated that crop residues have positive contributions to increasing the amount of macro and secondary elements in minimum tillage.

The exchangeable cations, cation exchange capacity and exchangeable sodium percentage of the soil

The effects of irrigation treatments on CEC, ESP, and all exchangeable cations and the effects of tillage-sowing practices on CEC and exchangeable Ca and Na values were significant (Table 4). Except for WW33, the Ca, Na and K values increased in all irrigation and tillage-sowing applications compared to the pre-experimental values (Table 1). The highest increase was determined in WW100, whereas Mg decreased in all treatments (Table 1). While the increasing exchangeable cation content of soil in the WW100 treatment can be explained depending on the cation content of the wastewater (Table 2), the decreasing content in the deficit irrigation can be evaluated due to less cation entry into the soil with wastewater. Similarly, Cakmakci and Sahin (2021a) also stated that cations in the soil increased by irrigation with wastewater, but the increasing rate decreased in deficit irrigation with wastewater. In addition, in many studies, the exchangeable cation content of soils increased due to irrigation with wastewater (Singh et al. 2009, 2012; Silva et al. 2016; Feder 2021) and it has been reported that exchangeable cations decreased with increase in deficit irrigation level (Cicek et al. 2013; Tunc and Sahin 2016; Dogan Demir and Sahin 2020).

The fact that the exchangeable Ca and Na contents in the NT were also lower than in the CT was thought to be related to the decrease in Ca and Na passage to the soil due to less irrigation quantity in the NT (Fig. 1). Furthermore, the fact that the exchangeable Mg was below the soil's initial content (Table 1) can be regarded as an indication that Mg plays an active role in the nutrition of silage maize. Rehm et al. (2002) have reported that Mg is an essential nutrient for maize. Additionally, competition between exchangeable Mg and Ca can be mentioned (Rufyikiri et al. 2002). Unlukara et al. (2008) stated that increasing the amount of exchangeable Ca in the soil by using water with high salt content in irrigation may increase Mg uptake from crop.

The CEC increased significantly in WW100 compared to pre-experimental values (Table 1), and it was partially close to the pre-experimental values in FW100, the CT, and the NT, whereas decreased in WW67 and WW33 applications. Lower CEC values in the NT were found due to less Ca, Mg, Na, and K contents in the soil (Table 4). The increase in CEC in WW100 can be associated with the cation content of the wastewater and also the high organic matter contribution of the wastewater to the soils (Tables 2 and 3). Wastewater treatment increased organic matter content in soil and then CEC. Thus, it was believed that our findings reliably reflect organic matter affects CEC. The positive correlation between CEC and organic matter also supported this result (Fig. 2). The organic matter increased in soil supports the

Table 4 The exchangeable cations, cation exchange capacity and exchangeable sodium percentage of the soil in different irrigation and tillage-sowing treatments

Treatment		Exchangeable Ca (cmol kg^{-1})	Exchangeable Mg (cmol kg^{-1})	Exchangeable Na (cmol kg^{-1})	Exchangeable K (cmol kg^{-1})	CEC (cmol kg^{-1})	ESP (%)
CT	FW100	16.13 ± 0.03	4.15 ± 0.02	0.52 ± 0.004	1.21 ± 0.01	22.02 ± 0.04	2.38 ± 0.02
	WW100	17.24 ± 0.01	4.37 ± 0.02	0.59 ± 0.003	1.40 ± 0.04	23.59 ± 0.06	2.48 ± 0.02
	WW67	15.23 ± 0.12	4.08 ± 0.03	0.48 ± 0.005	1.23 ± 0.02	21.01 ± 0.15	2.30 ± 0.02
	WW33	14.83 ± 0.04	3.86 ± 0.05	0.34 ± 0.010	1.12 ± 0.02	20.16 ± 0.03	1.69 ± 0.05
NT	FW100	16.02 ± 0.07	4.12 ± 0.06	0.51 ± 0.003	1.20 ± 0.02	21.84 ± 0.10	2.33 ± 0.02
	WW100	17.03 ± 0.06	4.34 ± 0.01	0.58 ± 0.004	1.38 ± 0.03	23.32 ± 0.07	2.46 ± 0.01
	WW67	15.04 ± 0.05	4.06 ± 0.01	0.47 ± 0.004	1.23 ± 0.01	20.80 ± 0.06	2.25 ± 0.01
	WW33	14.74 ± 0.05	3.93 ± 0.02	0.34 ± 0.003	1.10 ± 0.02	20.12 ± 0.08	1.67 ± 0.02
Irrigation	FW100	16.08 ± 0.04 B	4.14 ± 0.03 B	0.52 ± 0.004 B	1.21 ± 0.01 B	21.93 ± 0.06 B	2.36 ± 0.02 B
	WW100	17.14 ± 0.05 A	4.36 ± 0.01 A	0.59 ± 0.003 A	1.39 ± 0.02 A	23.46 ± 0.07 A	2.47 ± 0.01 A
	WW67	15.14 ± 0.07 C	4.07 ± 0.01 B	0.48 ± 0.005 C	1.23 ± 0.01 B	20.91 ± 0.09 C	2.28 ± 0.02 C
	WW33	14.79 ± 0.03 D	3.90 ± 0.03 C	0.34 ± 0.004 D	1.11 ± 0.01 C	20.14 ± 0.04 D	1.68 ± 0.03 D
Tillage-sowing	CT	15.86 ± 0.28 A	4.12 ± 0.06	0.48 ± 0.027 A	1.24 ± 0.03	21.70 ± 0.39 A	2.21 ± 0.09
	NT	15.71 ± 0.27 B	4.11 ± 0.03	0.47 ± 0.026 B	1.23 ± 0.03	21.52 ± 0.37 B	2.18 ± 0.09
P value	Interaction	0.773	0.390	0.652	0.979	0.604	0.810
	Irrigation	0.000	0.000	0.000	0.000	0.000	0.000
	Tillage-sowing	0.005	1.000	0.004	0.475	0.011	0.059
Mean square	Interaction	0.374	1.069	0.555	0.062	0.634	0.321
	Irrigation	558.611	74.890	841.636	50.925	576.283	395.406
	Tillage-sowing	10.749	0.000	11.271	0.534	8.247	4.135

CT: Conventional tillage, NT: No-tillage, FW100: Full irrigation with fresh water, WW100: Full irrigation with recycled wastewater, WW67: Irrigation at 67% level with recycled wastewater, WW33: Irrigation at 33% level with recycled wastewater, CEC: Cation exchange capacity, ESP: Exchangeable sodium percentage, ±: Standard error of the mean, Significant differences at 5% probability level between treatments are indicated by different letters

development of CEC of the soil by providing a larger CEC volume, thanks to the negatively charged surfaces of the organic matter (Villa et al. 2021). In addition, the presence of sufficient organic matter in soil also reduces loss of CEC of the soil (Curtin et al. 2015). Similarly, many studies have reported that the exchangeable cation contents of the surface soil increase due to irrigation with wastewater (Khurana and Singh 2012; Cicek et al. 2013; Silva et al. 2016). Dogan Demir and Sahin (2020) have stated that the CEC decreased due to the increase in deficit level in wastewater irrigation.

The ESP increased in all irrigation treatments compared to the pre-experimental values (Table 1), and the highest and the lowest increases were in WW100 and WW33, respectively. The change of ESP is directly related to the trends of exchangeable Na and CEC, which are the formulaic calculation components of the ESP. Therefore, the higher and lower ESP values in WW100 and WW33 can be explained by exchangeable Na content and CEC (Table 4). Sou et al. (2013); Cakmakci and Sahin (2021a) have reported that increased ESP values in wastewater irrigation conditions were due to the Na content increasing more than the CEC.

The DTPA extractable microelement and heavy metal contents of soil samples

The effects of irrigation treatments and tillage-sowing practices on all microelement and heavy metal contents were significant (Table 5). The microelement and heavy metal contents increased compared to the pre-experimental values in wastewater irrigation and tillage-sowing applications, the increases were limited in FW100 and the values were found close to the initial contents (Table 1). The higher microelement and heavy metal content in wastewater irrigation conditions compared to fresh water irrigation was associated with the microelement and metal content of the wastewater (Table 2). However, due to the decrease in the level of irrigation with wastewater, the passage of heavy metals to the soil was limited. Various studies have reported that microelement and heavy metal accumulation in the soil increased as a result of irrigation with wastewater (Galavi et al. 2010; Avci and Deveci 2013; Tunc and Sahin 2017; Cakmakci and Sahin 2021a; Nawaz et al. 2021). The higher amount of microelements and heavy metal accumulation in the CT compared to the NT application was associated with the more amount of irrigation water in the CT (Fig. 1). However, unlike other microelements and heavy metals, Fe

Table 5 The DTPA extractable microelement (B, Fe, Cu, Mn, Zn) and non-essential heavy metal (Pb, Cd, Cr, Ni) contents of the soil in different irrigation and tillage-sowing treatments

Treatment		B (mg kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Pb (mg kg^{-1})	Cd (mg kg^{-1})	Cr (mg kg^{-1})	Ni (mg kg^{-1})
CT	FW100	0.201 ± 0.001	4.60 ± 0.01	2.03 ± 0.02 f	7.15 ± 0.03 f	51.1 ± 0.3 e	3.43 ± 0.02	0.026 ± 0.001	0.224 ± 0.001	0.117 ± 0.002 f
	WW100	0.463 ± 0.002	8.37 ± 0.04	3.99 ± 0.01 a	17.19 ± 0.01 a	89.7 ± 0.2 a	4.62 ± 0.05	0.095 ± 0.001	0.284 ± 0.006	0.465 ± 0.003 a
	WW67	0.376 ± 0.004	7.65 ± 0.07	2.96 ± 0.02 c	14.22 ± 0.02 b	71.6 ± 0.7 c	3.62 ± 0.01	0.057 ± 0.004	0.239 ± 0.004	0.381 ± 0.001 c
	WW33	0.312 ± 0.003	5.66 ± 0.04	2.54 ± 0.01 d	9.90 ± 0.07 d	58.9 ± 0.9 d	3.45 ± 0.03	0.031 ± 0.001	0.200 ± 0.004	0.287 ± 0.002 d
NT	FW100	0.196 ± 0.002	4.68 ± 0.04	2.01 ± 0.01 f	7.15 ± 0.02 f	49.7 ± 0.6 e	3.34 ± 0.02	0.023 ± 0.001	0.222 ± 0.003	0.117 ± 0.001 f
	WW100	0.462 ± 0.003	8.51 ± 0.01	3.83 ± 0.06 b	17.17 ± 0.05 a	85.7 ± 0.7 b	4.54 ± 0.06	0.092 ± 0.002	0.269 ± 0.002	0.448 ± 0.003 b
	WW67	0.370 ± 0.005	7.74 ± 0.05	3.01 ± 0.01 c	14.05 ± 0.05 c	70.3 ± 1.0 c	3.51 ± 0.05	0.050 ± 0.002	0.233 ± 0.003	0.376 ± 0.002 c
	WW33	0.308 ± 0.004	5.81 ± 0.06	2.39 ± 0.02 e	9.38 ± 0.03 e	59.1 ± 0.7 d	3.39 ± 0.03	0.031 ± 0.001	0.187 ± 0.007	0.265 ± 0.006 e
Irrigation	FW100	0.199 ± 0.001 D	4.64 ± 0.03 D	2.02 ± 0.01 D	7.15 ± 0.02 D	50.4 ± 0.4 D	3.39 ± 0.02 C	0.025 ± 0.001 D	0.223 ± 0.001 C	0.117 ± 0.001 D
	WW100	0.463 ± 0.001 A	8.44 ± 0.04 A	3.91 ± 0.04 A	17.18 ± 0.02 A	87.7 ± 0.9 A	4.58 ± 0.04 A	0.094 ± 0.001 A	0.277 ± 0.004 A	0.457 ± 0.004 A
	WW67	0.373 ± 0.003 B	7.70 ± 0.04 B	2.99 ± 0.01 B	14.14 ± 0.05 B	71.0 ± 0.6 B	3.57 ± 0.03 B	0.054 ± 0.003 B	0.236 ± 0.003 B	0.379 ± 0.002 B
	WW33	0.310 ± 0.002 C	5.74 ± 0.05 C	2.47 ± 0.03 C	9.64 ± 0.12 C	59.0 ± 0.5 C	3.42 ± 0.02 C	0.031 ± 0.001 C	0.194 ± 0.004 D	0.276 ± 0.006 C
Tillage-sowing	CT	0.338 ± 0.029	6.57 ± 0.46 B	2.88 ± 0.22 A	12.12 ± 1.16 A	67.8 ± 4.4 A	3.78 ± 0.15 A	0.055 ± 0.009 A	0.237 ± 0.009 A	0.313 ± 0.039 A
	NT	0.334 ± 0.029	6.69 ± 0.46 A	2.81 ± 0.21 B	11.94 ± 1.18 B	66.2 ± 4.1 B	3.70 ± 0.15 B	0.052 ± 0.009 B	0.228 ± 0.009 B	0.302 ± 0.038 B
P value	Interaction	0.849	0.776	0.003	0.000	0.044	0.926	0.304	0.364	0.010
	Irrigation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Tillage-sowing	0.085	0.002	0.002	0.000	0.003	0.004	0.022	0.004	0.000
Mean square	Interaction	0.266	0.370	7.399	18.132	3.400	0.154	1.314	1.136	5.305
	Irrigation	2 698.656	3 155.747	1 992.594	24 767.864	1 207.138	469.466	517.526	155.506	5 003.335
	Tillage-sowing	3.367	13.642	14.564	37.302	11.831	11.103	6.462	10.911	27.679

CT: Conventional tillage, NT: No-tillage, FW100: Full irrigation with fresh water, WW100: Full irrigation with recycled wastewater, WW67: Irrigation at 67% level with recycled wastewater, WW33: Irrigation at 33% level with recycled wastewater, ±: Standard error of the mean, Significant differences at 5% probability level between treatments are indicated by different letters was higher in the NT. This may be due to the antagonistic or synergistic effects of Fe with B, Mg, Ca, P, and N elements (Sonmez et al. 2006). Also, the differentiation of the accumulation of some heavy metals in the soil by organic matter, clay, Fe, and Al oxides (Montiel-Rozas et al. 2016) may explain this result. In general, it has been reported that lower amounts of microelements and heavy metal contents are obtained in the NT or reduced soil tillage applications in many studies (García-Marco et al. 2014; Gómez-Rey et al. 2014; Kumar and Kumari 2020).

Soil pH, $CaCO_3$, EC, organic matter, total N, P_2O_5, K_2O, and CEC play an important role in the accumulation of heavy metals in the soil. In the present study, heavy metals were in a negative correlation with pH and $CaCO_3$, whereas a positive correlation with EC, organic matter, total N, P_2O_5, K_2O and CEC (Fig. 2). Wei et al. (2020) determined a negative correlation relationship between heavy metal content in the soil and soil pH. In soils irrigated with wastewater, increases in heavy metal contents can be observed since hydrogen ions, which occur due to the decrease in pH, create a higher attraction power than metal ions (Singh et al. 2009). In general, pH values lower than 6.5 to 7.0 favor the availability and mobility of heavy metals (Khaskhoussy et al. 2015).

The effect of $CaCO_3$ on heavy metals can be indirectly evaluated by pH effect. Decreased pH increases $CaCO_3$ solubility, causing a decrease in $CaCO_3$ in soil (Table 3), thus increasing the availability of heavy metals (Table 5) (Cakmakci and Sahin 2021a). Similarly, Mico et al. (2006) have reported that a significant negative correlation was determined between $CaCO_3$ and heavy metals.

High soil water salinity causes osmotic stress in crops growth. In these conditions, even if there is water in the soil, the plant cannot benefit from water sufficiently, therefore, with the decrease in water intake, the intake of nutrient and metals is also limited. Nutrients and metals that the crop cannot absorb tend to accumulate in soil, and the behavior of metals in soil changes significantly (Bartkowiak et al. 2020). Bolan et al. (2014) pointed out that the mobility of heavy metals increased due to the increase in salinity in the soil. Similarly, Acosta et al. (2011) stated that increasing soil EC increased the mobilization of heavy metals. Cakmakci and Sahin (2021a) also determined a positive correlation between soil EC and heavy metals.

The increasing amount of organic matter in soil reduces heavy metal uptake of crops and causes soil contamination. Soil organic matter content directly or indirectly affects the distribution of heavy metals in soil (Bolan et al. 2014). Low molecular weight organic acids in the structure of organic matter increase the accumulation of heavy metals in soil and control their distribution (Park et al. 2016). These organic acids act as chelators, limiting the uptake of heavy metals by crops and increasing the mobilization of heavy metals away from the rhizosphere region (Cakmakci and Sahin 2021a). Singh et al. (2009) and Navarro-Pedreño et al. (2018) have reported a strong positive correlation between heavy metals in soil with organic matter. In another, it has been stated that the contribution of organic matter to soil decreased the heavy metal uptake of crops and increased the accumulation of heavy metals in the soil (Fijałkowski et al. 2012).

High N input to the soil significantly increases the heavy metal content (Bolan et al. 2014). This increase was explained by the indirect effect of N on pH (Cakmakci and Sahin 2021a). Ammonium, a formation of N, increases the effectiveness of heavy metals by decreasing soil pH (Fijałkowski et al. 2012). Similarly, phosphate compounds can directly trigger the mobility of heavy metals (Bolan et al. 2014). The relationship between heavy metals and CEC can be explained by the relationship of CEC with organic matter and clay minerals. The increase in organic matter in the soil can increase heavy metal mobility as well as support the increase of CEC and cause heavy metal accumulation in the soil (Kizilkaya et al. 2004). Xiao et al. (2022) pointed out that CEC and heavy metal concentration in the soil may show a positive correlation.

Although heavy metals increased in wastewater irrigation treatments after the study, Zn, Cu, Cd, Ni, Pb and Cr contents were below the limit values (Zn: 300 mg kg^{-1}, Cu: 140 mg kg^{-1}, Cd: 3 mg kg^{-1}, Ni: 75 mg kg^{-1} and Pb: 300 mg kg^{-1}) specified by the World Health Organization (Khan et al. 2013). Considering the National Regulation also, that the Zn, Cu, Cd, Ni, Pb and Cr contents were below the limit values (Zn: 200 mg kg^{-1}, Cu: 100 mg kg^{-1}, Cd: 1.5 mg kg^{-1}, Ni: 70 mg kg^{-1}, Pb: 100 mg kg^{-1} and Cr: 100 mg kg^{-1} for $pH \geq 7$) (Anonymous 2010).

Soil contamination indicators by heavy metals

The CF values showed moderate enrichment for B, Fe, Cu, Mn, Zn micronutritions and contamination for non-essential heavy metals Pb and Cr in two tillage-sowing practices also, whereas they showed considerable pollution for Ni in WW100 and WW67 treatments, for Cd in WW100 treatment (Fig. 3).

Examining the EF values, minimal enrichment was observed in all applications for B, Cu, Mn, Zn, Pb, and Cr, while the pollution degree was determined at moderate enrichment level for Cd and Ni in WW100 in CT and Cd in WW100 in the NT practice. However, in WW100, the pollution level was at the limit for Ni (Fig. 4).

Considering the GAI values, the B, Fe, Cu, Mn, Zn, and Cr heavy metals were found at unpolluted and unpolluted to moderately polluted levels in all treatments, whereas Pb was found at the lowest pollution level (unpolluted) in

Fig. 3 Contamination factor (CF) for soil heavy metals in different irrigation and tillage-sowing treatments (FW100: Full irrigation with fresh water, WW100: Full irrigation with recycled wastewater, WW67: Irrigation at 67% level with recycled wastewater, WW33: Irrigation at 33% level with recycled wastewater)

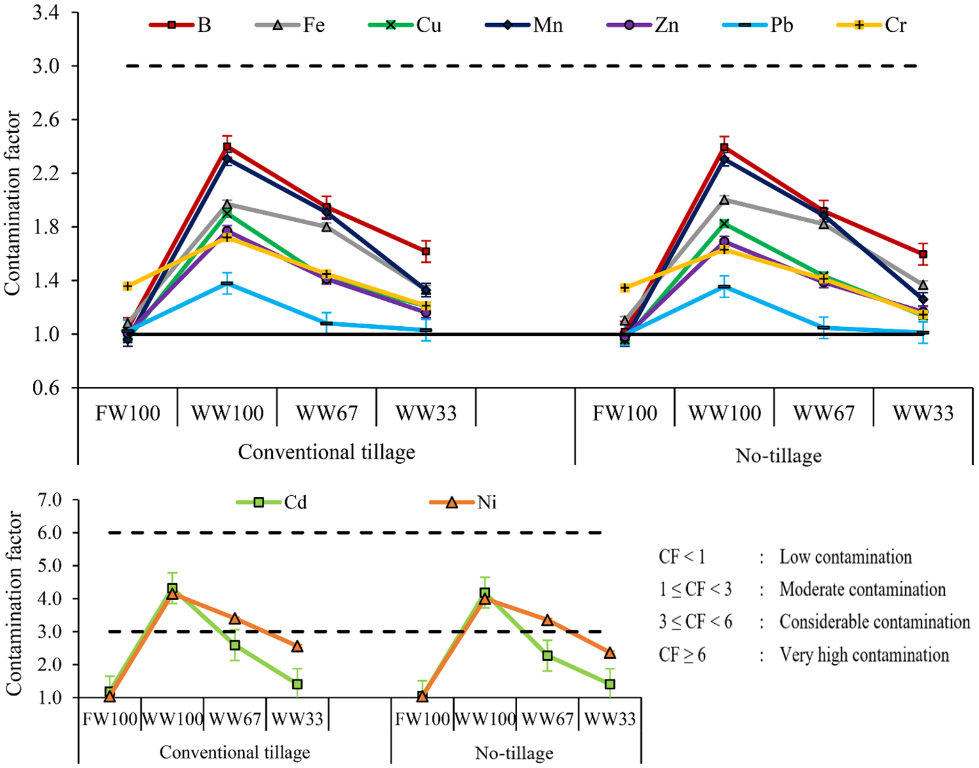
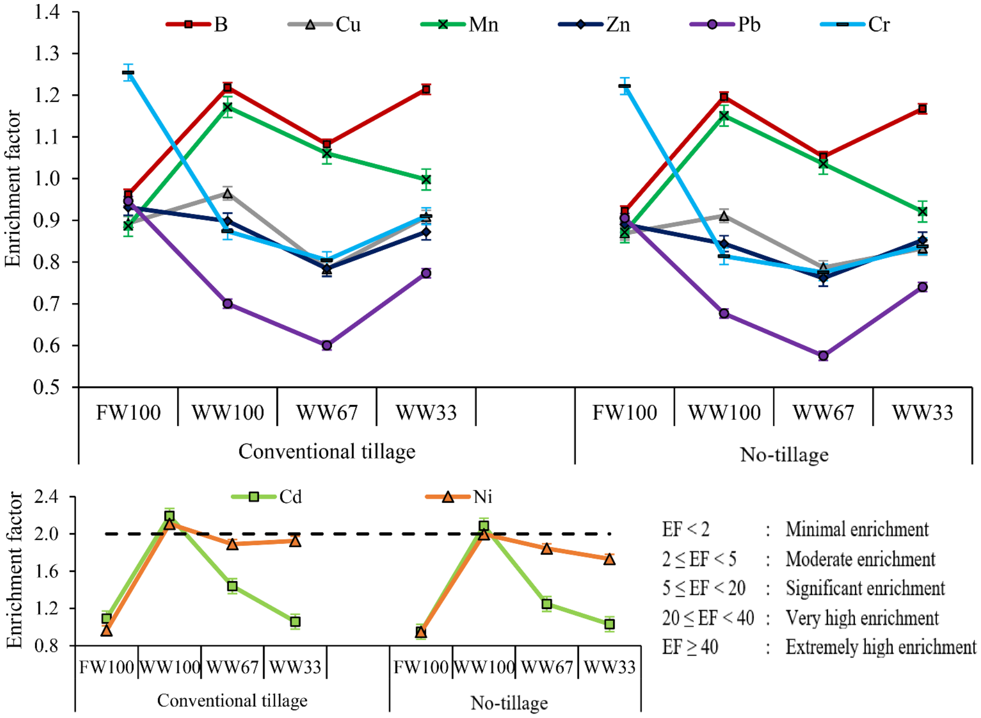


Fig. 4 Enrichment factor (EF) for soil heavy metals in different irrigation and tillage-sowing treatments (FW100: Full irrigation with fresh water, WW100: Full irrigation with recycled wastewater, WW67: Irrigation at 67% level with recycled wastewater, WW33: Irrigation at 33% level with recycled wastewater)



all treatments (Fig. 5). Ni was at the moderately polluted level in WW100 and WW67 for both tillage-sowing practices, while Cd was at the moderately polluted level only in WW100. In WW67, Cd was determined from unpolluted to moderately polluted level, while in WW33 it was determined just below this level.

The PLI values showing the total pollution load of heavy metals in the soil resulted in the moderately polluted level in WW100 (Fig. 6). The WW67 and WW33 treatments listed after WW100 in terms of pollution load showed an unpolluted to the moderate pollute level of pollution load. The FW100 treatment at the same pollution class; however,

Fig. 5 Geographic accumulation index (GAI) for soil heavy metals in different irrigation and tillage-sowing treatments (FW100: Full irrigation with fresh water, WW100: Full irrigation with recycled wastewater, WW67: Irrigation at 67% level with recycled wastewater, WW33: Irrigation at 33% level with recycled wastewater)

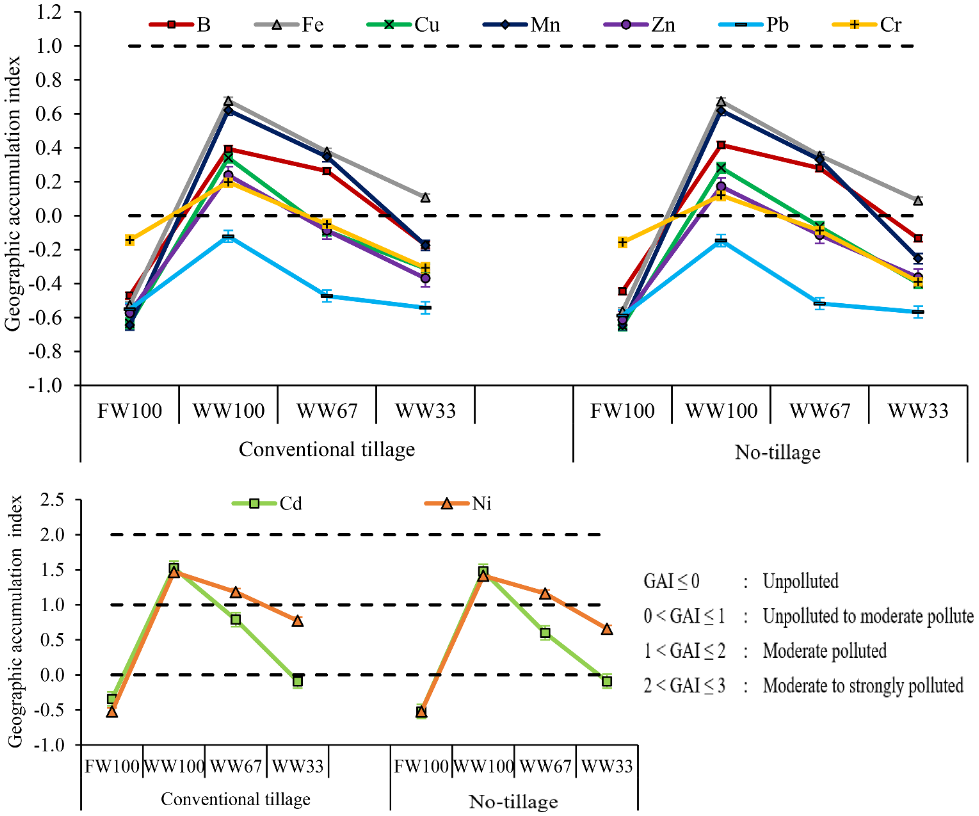
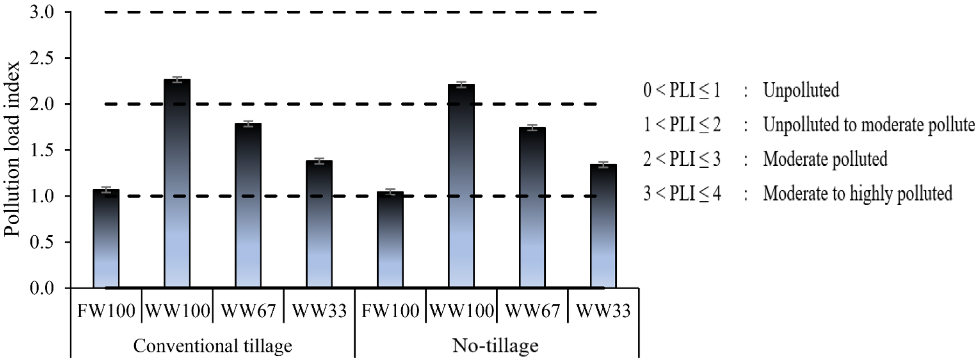


Fig. 6 Pollution load index (PLI) for soil heavy metals in different irrigation and tillage-sowing treatments (FW100: Full irrigation with fresh water, WW100: Full irrigation with recycled wastewater, WW67: Irrigation at 67% level with recycled wastewater, WW33: Irrigation at 33% level with recycled wastewater)



exceeded the unpolluted to moderate pollute pollution level by a very low amount and remained at the limit.

As a result, although the level of heavy metals in wastewater irrigation conditions did not pose a significant problem (Figs. 3, 4, 5 and 6) in terms of essential and non-essential heavy metal pollution indices, it was seen that heavy metal tend to accumulate in the soil in wastewater irrigation. Especially in terms of non-essential heavy metals Cd and Ni, the effect of this risk increases even more. Considering the high harmful impact of Cd and Ni among heavy metals (Yerli et al. 2020), this may affect forage quality in silage maize under the irrigation conditions with wastewater. SimilarlyCakmakci and Sahin (2021a) have stated that the pollution indicators in the silage maize field irrigated with recycled wastewater are at risky levels, especially for Cd and Ni. Khaskhoussy et al. (2015) have stated that the Cd and Ni concentrations in the soil exceeded the threshold values in irrigation with wastewater.

Microelement and heavy metal content of silage maize crop

The effect of irrigation treatments on all microelement and heavy metal contents of silage maize was significant, whereas the effect of tillage-sowing practices was significant for only Cd (Table 6). Microelement and non-essential heavy metal content of silage maize increased under wastewater irrigation and resulted in an accumulation in the form of Fe > Mn > Zn > Cu > Cr > Ni > Pb > Cd.

Table 6 The essential heavy metal (Fe, Cu, Mn, Zn) and non-essential heavy metal (Pb, Cd, Cr, Ni) contents of the silage maize crop in different irrigation and tillage-sowing treatments

Treatment		Fe (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Pb (mg kg^{-1})	Cd (mg kg^{-1})	Cr (mg kg^{-1})	Ni (mg kg^{-1})
CT	FW100	147.7 ± 2.2	3.88 ± 0.15	24.1 ± 0.4	24.3 ± 0.1	0.055 ± 0.001	0.060 ± 0.002	0.20 ± 0.01	0.039 ± 0.001
	WW100	182.8 ± 1.8	7.32 ± 0.14	61.9 ± 0.8	42.9 ± 0.4	0.308 ± 0.004	0.201 ± 0.001	0.98 ± 0.04	0.209 ± 0.004
	WW67	152.3 ± 2.6	5.90 ± 0.15	47.9 ± 0.7	37.2 ± 0.7	0.242 ± 0.003	0.139 ± 0.002	0.72 ± 0.06	0.164 ± 0.001
	WW33	114.7 ± 1.6	2.32 ± 0.11	13.7 ± 0.2	20.0 ± 0.6	0.162 ± 0.004	0.068 ± 0.001	0.48 ± 0.02	0.088 ± 0.002
NT	FW100	148.9 ± 2.4	4.00 ± 0.12	24.4 ± 0.4	24.0 ± 0.4	0.053 ± 0.001	0.048 ± 0.003	0.19 ± 0.01	0.038 ± 0.002
	WW100	182.5 ± 1.3	7.29 ± 0.11	62.4 ± 0.4	42.8 ± 0.4	0.304 ± 0.003	0.193 ± 0.003	0.85 ± 0.02	0.206 ± 0.002
	WW67	156.9 ± 4.0	5.82 ± 0.17	49.5 ± 0.6	39.7 ± 0.8	0.239 ± 0.003	0.129 ± 0.004	0.72 ± 0.02	0.164 ± 0.002
	WW33	111.7 ± 2.0	2.49 ± 0.05	13.7 ± 0.2	19.8 ± 0.4	0.165 ± 0.007	0.058 ± 0.001	0.44 ± 0.01	0.089 ± 0.002
Irrigation	FW100	148.3 ± 1.5 C	3.94 ± 0.09 C	24.3 ± 0.3 C	24.2 ± 0.2 C	0.054 ± 0.001 D	0.054 ± 0.003 D	0.20 ± 0.01 D	0.039 ± 0.001 D
	WW100	182.7 ± 1.0 A	7.31 ± 0.08 A	62.2 ± 0.4 A	42.9 ± 0.3 A	0.306 ± 0.003 A	0.197 ± 0.002 A	0.92 ± 0.03 A	0.208 ± 0.002 A
	WW67	154.6 ± 2.4 B	5.86 ± 0.01 B	48.7 ± 0.6 B	37.0 ± 0.5 B	0.241 ± 0.002 B	0.134 ± 0.003 B	0.72 ± 0.03 B	0.164 ± 0.001 B
	WW33	113.2 ± 1.4 D	2.41 ± 0.06 D	13.7 ± 0.1 D	19.9 ± 0.3 D	0.164 ± 0.004 C	0.063 ± 0.002 C	0.46 ± 0.01 C	0.089 ± 0.001 C
Tillage-sowing	CT	149.4 ± 7.3	4.86 ± 0.58	36.9 ± 5.7	31.1 ± 2.8	0.192 ± 0.029	0.117 ± 0.017 A	0.60 ± 0.09	0.125 ± 0.020
	NT	150.0 ± 7.7	4.90 ± 0.55	37.5 ± 5.8	30.8 ± 2.8	0.190 ± 0.028	0.107 ± 0.018 B	0.55 ± 0.08	0.124 ± 0.020
P value	Interaction	0.466	0.732	0.453	0.969	0.778	0.838	0.109	0.877
	Irrigation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Tillage-sowing	0.724	0.637	0.104	0.503	0.682	0.000	0.052	0.822
Mean square	Interaction	15.282	0.021	0.727	0.065	1.482E-005	4.819E-006	0.006	2.889E-006
	Irrigation	4 884.434	27.693	2 952.705	691.396	0.070	0.027	0.585	0.034
	Tillage-sowing	2.220	0.011	2.344	0.375	7.042E-006	0.001	0.010	6.667E-007

CT: Conventional tillage, NT: No-tillage, FW100: Full irrigation with fresh water, WW100: Full irrigation with recycled wastewater, WW67: Irrigation at 67% level with recycled wastewater, WW33: Irrigation at 33% level with recycled wastewater, ±: Standard error of the mean, Significant differences at 5% probability level between treatments are indicated by different letters

Considering that maize is a potential accumulator crop (Aladesanmi et al. 2019), increased heavy metal contents in soil under wastewater irrigation conditions (Table 5) caused more heavy metal accumulation in the organs of maize. As parallel to the results of this study, the results of many studies have also revealed that due to the high element content of wastewater, heavy metal accumulation in the crop increases with accumulation in soil (Kiziloglu et al. 2008; Avci and Deveci 2013; Erel et al. 2019; Cakmakci and Sahin 2021a; Nawaz et al. 2021). In addition, it has been determined in many studies that the heavy metal contents of the crop decrease due to the deficit irrigation (Simsek et al. 2011; Dogan Demir and Sahin 2017; Tunc and Sahin 2017).

Kobaissi et al. (2014) stated that Cd was the most accumulated heavy metal in the leaf of maize irrigated with wastewater. It has been stated that Cd contents in the tissues of the crops are highly correlated with Cd concentrations in the solution (Grant et al. 1998). In this case, the higher Cd content in crops grown under the CT conditions can be evaluated as related to the higher Cd accumulation in the soil of the CT compared to NT (Table 5) and the contribution of higher irrigation water amount (Fig. 5) to Cd uptake in this treatment. In addition, it is thought that the element uptake differences between tillage-sowing practices may occur with the changing root development depending on the change in the tillage-sowing practice or may be caused by the differentiation of the interactions between the elements as a result of the possible effects of the tillage-sowing practice on the soil properties. Sungur et al. (2014) stated that element uptake into the crop is closely related to many soil properties, especially soil pH, $CaCO_3$, organic matter and CEC. Kobaissi et al. (2014) stated that Fe content in soil reduced the uptake of heavy metals, especially Cd. Therefore, the fact that Fe content in soil was determined higher under the NT conditions compared to the CT application (Table 5) may also support this situation.

Conclusion

Although soil nutrient content was improved under full irrigation conditions with recycled domestic wastewater, soil salinity and the heavy metal content of soil and silage maize were also increased. The evaluations with the contamination factor, enrichment factor, geographic accumulation index, and the pollution load index also showed that, full irrigation with wastewater increased heavy metal pollution compared to the deficit irrigation practice. The pollution caused by Cd and Ni metals was found at levels that may pose a risk in full irrigation with wastewater. No-tillage practice was more effective in improving the nutrient content of the soil compared to conventional tillage, and provided better results in reducing soil salinity and heavy metal accumulation in different irrigation levels with wastewater.

It was concluded that no-tillage is a recommendable production practice in silage maize irrigated with wastewater that can reduce soil salinity and heavy metal pollution and improve soil fertility. However, there is a need for further studies on the wastewater management to reduce the possible pollution risks of Cd and Ni metals.

Acknowledgements We would like to thank the Scientific and Technological Research Council of Turkey (TÜBİTAK) for financially supporting this study with project number 119O528.

Author contributions All authors contributed to the study conception and design. C. Yerli: Methodology, Resources, Investigation, Statistical analysis. U. Sahin: Project administration, Conceptualization, Methodology, Resources, Formal analysis, Statistical analysis, Writing - review & editing. T. Oztas: Methodology, Writing - review & editing. S. Ors: Methodology, Writing - review & editing. All authors read and approved the final manuscript.

Funding Open access funding provided by the Scientific and Technological Research Council of Türkiye (TÜBİTAK).

Declarations

Competing interests The authors declare no competing interests.

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