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Article

Effect of treated wastewater use on soil and forage crops of *Chenopodium quinoa* Willd and *Zea mays* L.

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Abstract:

Given the scarcity of water resources for agricultural use, it is necessary to promote the use of wastewater for agriculture. The towns of Capulálpam de Méndez and Ixtlán de Juárez in the State of Oaxaca have anaerobic wastewater treatment plants (WWTP). The morphological growth, biomass production and N and P content were evaluated in two forage species —*Chenopodium quinoa* Willd and *Zea mays*— irrigated with treated wastewater (TWW). A complete randomized design (CRD) was established in each municipality, given the homogeneity of the soil, using a 2 x 2 factorial arrangement, i.e., two forage crops (Quinoa and corn) and two types of irrigation (fresh water and treated wastewater), with 4 replicates per treatment. Analyses of variance and Tukey mean tests ($P \leq 0.05$) were performed for the studied variables. In the soils, the pH level was "moderately acid" to "neutral" (5.1 to 7.3); the EC indicated "negligible effects of salinity"; organic matter was found at intervals of "medium to high", and the texture was sandy clay loam in Ixtlán and clay loam in Capulálpam. Growth variables (plant height, stem diameter, and number of leaves) and biomass were significantly higher in plants irrigated with treated wastewater in both forage crops. Nitrogen and phosphorus contents were significantly higher in quinoa and corn plants receiving TWW. TWW could be an alternative that would help reduce the use of chemical fertilizers, as it is an important source of nutrients in forage crops.

Keywords: Biomass, Fresh weight, Dry weight, Water treatment.

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Introduction

In the world, more than 70 % of fresh or potable water withdrawals are related to the agricultural sector[1], and in Mexico, 76 %. Part of this, approximately 29 %, is used for growing fodder crops[2]. One of the most widely cultivated species is fodder corn, due to the high energy value it provides to livestock[3], whose function is to generate proteins for human consumption. Protein content can be considered a valuable unit of measurement for comparing foods[4]. The Food and Agriculture Organization of the United Nations (FAO) has estimated that, in order to overcome the problem of water scarcity or lack of water, at least 20 million hectares of agricultural land are irrigated with untreated or partially treated wastewater[5]. Thus, land irrigated with wastewater amounts to 10 % of the total distributed in fifty countries around the world. The World Health Organization (WHO) and FAO attach importance to the use of treated wastewater (TWW) in agricultural irrigation, as well as to the switch from freshwater to treated or reused wastewater. TWW contains essential nutrients for crops and, for irrigation purposes, counteracts environmental and health risks[5,6,7]. Forages are highly water-demanding and are an indirect human consumption product. The use of TWW is a way of guaranteeing water for the future; it is a process of sustainability and a small step towards the productivity of local agroecosystems. For this reason, it is advisable to establish fodder crops close to the sites where the wastewater treatment plants are located. Quinoa (*Chenopodium quinoa* Willd) as forage has the advantage of being cultivated at altitudes ranging from sea level to 4,000 m asl; it tolerates frost and drought and adapts to different regions with acidic and alkaline soils (pH 4 to 9), and its nutritional value lies in the ideal balance of amino acids in its protein, which makes it an ideal component in diets[8].

Corn is the world's most widely grown agricultural product[9]. By 2025, it is estimated that 60 % of the global corn consumption will be destined for animal feed, and that this percentage will grow at an average annual rate of 1.8 %, driven by the expansion of livestock in developing countries[10]. In Mexico, corn is utilized as fodder, grain, stubble, silage, and for industrial uses (tamale leaves), and it is one of the main irrigated crops with untreated wastewater[11].

In order to ensure that TWW does not pose a risk to soil, crops, and human health, it is recommended to use wastewater that has passed through a treatment plant[12,13]. The use of TWW in crops will save costs, protect the aquifers, and make fresh water available to the population. Therefore, the purpose of this study was to evaluate the morphological growth, biomass production and N and P content in two forage species —*Chenopodium quinoa* Willd and *Zea Mays*— irrigated with treated wastewater (TWW) in Ixtlán de Juárez and Capulálpam de Méndez, Oaxaca, Mexico.

Material and methods

Study area

The study was conducted in the "Sierra Norte" of Oaxaca, Mexico, located in the sub-province of the Southern Sierra Madre of Mexico, and in the hydrological region RH28, "Papaloapan", the second largest watershed in the country[14]. The research was carried out in the towns of Ixtlán de Juárez and Capulálpam de Méndez. The municipality of Ixtlán de Juárez (17° 20' N, 96° 29' W), is located at an altitude of 2,030 m asl; the climate is C (w) temperate sub-humid, and the area has a rugged orography; the average rainfall is 900 to 1,100 mm per year; the average annual temperature is 20 ºC[15], and the soil type is humic Acrisol (HA). The municipality of Capulálpam de Méndez (17° 18' N, 96° 27' W) is located at an altitude of 2,040 m asl; the climate is classified as C (w2) (w) b (i ') g temperate sub-humid; the average precipitation is 1,115 mm per year and occurs between June and October; the average annual temperature is 15.2 ºC[16]; the soil type is cambisol.

Experimental design and sowing

A complete randomized design (CRD) was used in each municipality (Ixtlán de Juárez and Capulálpam de Méndez). The treatments consisted of a 2 x 2 factorial, i.e. the two forage crops (*Chenopodium quinoa* Willd and *Zea Mays* L) and two types of irrigation: fresh water (DW) and treated wastewater (TWW), with four replicates per treatment. The study was established in March 2017. The cultivated plot in Ixtlán was established in an area of 300 m^2 (20 x 15 m) divided into four sections of 60 m^2 each (15 x 4 m), with a slope of 3 %. The cultivated area in Capulálpam was 400 m^2 (20 x 20 m) divided into four subplots of 80 m^2, with a slope of 1 %. The cultivated area of both Ixtlán and Calpulálpam was subdivided into two parts: in the first subplot, sown with quinoa, was irrigated with freshwater and treated wastewater; in the second section, corn was grown and also irrigated with treated wastewater and freshwater (FW). The subplots were divided by five unsown furrows for the application of the types of irrigation. The soil was prepared with a tractor, the distance between furrows of both crops was 80 cm, drawn parallel to the slope. The quinoa variety Ontifor was sown by hand continuously in the bottom of the furrow, at a depth of less than 3.0 cm approximately, with an approximate density of 450,000 plants ha^{-1}[8,17]. Corn (creole *Zea mays*) was planted by hand continuously at the bottom of the furrow for forage, at a depth of approximately 4.0 cm, with a density of 60,000 plants ha^{-1}.

Obtainment of treated wastewater (TWW)

The wastewater treatment plants (WWTPs) receive all the domestic water from the same localities; Ixtlán receives a flow rate of 3.3 L s^{-1} and Capulálpam receives a flow rate of 1.0 L s^{-1}. The WWTPs have a pretreatment system based on grids of different diameters, which are located at the inlet of the reception channel to retain solid wastes, such as soda caps, hair, wood, PET, etc. The water passes through the sand trap (3.0 m long channel), where the first process of sedimentation of solids takes place. The wastewater enters the biodigesters by gravity; each drop has a free fall of 3.10 m (this is where most of the sludge settles) and, by laminar flow, the water reaches the tubular sedimentation area (inner tank) and gradually rises until it overflows into the biodigester area (outer tank). The biodigester area is composed of polyethylene fabrics to facilitate the accommodation of anaerobic bacteria, which is why they are called hosts. Bacteria generally form granules at the apexes of the hosts, and they take care of the biodigestion of the wastewater, transforming it into treated (biodigested) wastewater. The process takes 14 h.

Obtainment of fresh water (FW)

In Capulálpam, fresh or clean water was extracted directly from a well and piped to the plot. In Ixtlán de Juárez, fresh water was obtained from the potable water system. Neither synthetic fertilizers nor pest or disease control substances were applied. Crops were established during the dry season following the World Health Organization's Guidelines and Recommendations for the Safe Use of Wastewater in Agriculture[6]. Irrigations with fresh water and with treated wastewater were carried out at the same time, for five days, using 2" diameter hoses to flood the furrows.

Soil analysis

Soil samples were collected from each study site for analysis[18]. Four soil samples were obtained at the beginning stage, four at the intermediate stage, and four at the end of the cultivation process, adding up to a total of 12 samples in the cultivated area of Ixtlán. Likewise, a total of 12 soil samples were extracted from the cultivated area of Capulálpam. The initial samples were taken before planting and irrigation, and the intermediate and final samples, 45 and 90 d later, respectively. Two kg of each sample were collected at a depth of 30 cm from each site. The pH and electrical conductivity (EC) were determined with a potentiometer (Conductronic PC45), organic matter (Walkley and Black method), texture (Bouyoucos method), nitrogen (by micro Kjeldahl), and phosphorus (Bray and Kurtz 1 method), the latter using a UV-Vis spectrophotometer (GBC CITRA10).

Measurement of plant growth variables

For each treatment, ten Quinoa plants and six corn plants of an easy-to-handle size were randomly selected from each crop, discarding the plants on the edges. Their height was measured with a flexometer from ground level to the last main leaf; their stem diameter was measured with a vernier at 3.0 cm from the ground, and the number of leaves on each plant was counted. Variables were read at 60 and 90 d in quinoa and corn, respectively. The plants were harvested after 90 d to obtain forage because more than 50 % of the plants no longer showed increased growth in height and stem diameter. To account for biomass, four plants in each treatment were destructively sampled and leaves, stems and roots were separated 90 d after planting. The fresh material was placed in forced air circulation ovens at 65 ºC until a constant weight was reached. The fresh and dry weight of each plant was obtained. The nitrogen content was measured with an organic elemental analyzer (PerkinElmer, series II, model 2400), and the phosphorus content, by the vanadomolybdic method in a UV-Vis spectrophotometer (GBC, model CITRA10)[19].

Statistical analysis

Analyses of variance and Tukey's mean tests ($P \leq 0.05$) were performed on the data obtained in the field for the variables studied in the quinoa and corn crops. The effect of the factors and treatments, i.e., the type of irrigation on both crops established at each site, was evaluated.

Results and discussion

Physical and chemical properties of soil

The pH of the soils before crop establishment was "moderately acidic", i.e. pH 5.1 - 6.5[19]; at 45 and 90 d after planting. In some cases, the pH increased to a "neutral" level (pH 6.6 - 7.3); such pH increase could be due to nitrates being transformed to atmospheric nitrogen (N2)[20]. This condition is contrary to that of other studies where soils irrigated with secondary treatment water show decreases in pH of 8.2 to 7.6[21] and 8.0 to 7.7[22]. The electrical conductivity (EC) in the soils before planting was 0.31 to 0.44 dS m^{-1}, which, according to the norm NOM-021-2000, is considered as "negligible salinity effects" (< 1.0 dS m^{-1}) in both the Ixtlán and Capulálpam soils[23,24]. 45 and 90 d after planting, the EC increased mainly when irrigated with TWW, still within the "negligible effects of salinity"; only two soil samples increased to 1.05 and 1.27 dS m^{-1}, the latter value being categorized as "very slightly saline" (1.1 – 2.0 dS m^{-1}). The cause of this could be the fact that soils retain cations, expressed as cation exchange capacity (CEC), due to the increase in clay and organic matter[25]. For the same reason, an increase of a few tenths was observed in soils irrigated with TWW. This confirmed the findings of other researchers in the sense that soil EC increased when TWW irrigation was applied: 0.34 – 0.42 dS m^{-1}(21) and 2.73 – 4.70 dS m^{-1}[22].

A similar trend was obtained with soil organic matter. In the initial sampling, the values indicated a "medium" (1.6 - 3.5 %) to "high" (3.6 - 6.0 %) content; after sowing and irrigation (45 d) the percentages increased in both crops and remained in the same "medium" and "high" ranges. In this regard, some researchers indicate that wastewater contributes organic matter to the soil, helping to maintain soil fertility[24,26,27]. However, in the final stage (90 d), the organic matter content decreased. In general, TWW improves soil fertility by providing nutrients and other benefits to crops, thereby reducing the use of chemical fertilizers[28]. The soils have average fertility, average erosion capacity, and average organic matter mineralization capacity, all easy to manage for the farmer. The region where these localities are located has a rugged orography.

Table 1: Quantification of pH, electrical conductivity, and organic matter in soils as a function of locality, crop, irrigation water type, and sampling time

		Soils of Ixtlán				**Soils of Capulálpam**			
		Quinoa		**Corn**		**Quinoa**		**Corn**	
Parameter	**Sampling time**	**FW**	**TWW**	**FW**	**TWW**	**FW**	**TWW**	**FW**	**TWW**
pH	Initial	5.39	5.38	5.33	5.43	5.40	5.65	5.23	5.35
	Intermediate	6.62	6.26	6.92	6.08	5.93	5.57	5.47	5.73
	Final	6.75	6.25	6.57	6.65	6.21	5.31	5.69	5.78
EC, dS m^{-1}	Initial	0.31	0.32	0.33	0.31	0.39	0.36	0.44	0.37
	Intermediate	0.57	0.71	0.68	0.74	0.49	1.05	0.47	0.58
	Final	0.56	0.77	0.84	0.7	0.46	1.27	0.39	0.51
Organic	Initial	2.44	1.89	2.99	2.68	4.23	3.40	5.23	4.07
matter, %	Intermediate	2.79	2.85	4.31	4.52	3.65	2.94	4.70	3.59
	Final	2.22	3.52	2.41	3.00	3.42	1.90	3.30	3.93
Texture		Loamy clayey sandy				Loamy clayey			

FW= fresh water; TWW= treated wastewater; EC= electrical conductivity; Initial=samples before planting; Intermediate= 45 d after planting; Final= 90 d after planting.

Plant growth

Quinoa, a domesticated Andean crop, belongs to the Amaranthaceae family and is also considered a forage crop[29]. Corn belongs to the Poaceae family, a crop with different uses such as fodder for livestock[30]. The type of growth and vegetative development differs between the two forage species. An analysis of variance showed significant differences ($P\leq0.01$) in the factor "type of water" for the variables height, stem diameter, and number of leaves in quinoa plants, at 60 and 90 d after planting; the same occurred in corn plants except for the variable number of leaves.

Plant height, stem diameter, and number of quinoa leaves were significantly higher ($P\leq0.05$) when irrigation was with treated wastewater at 60 and 90 days after planting (Table 2). The results for corn were similar (Table 3), except for the number of leaves, which showed no significant difference, which means that the number of leaves was similar when the plants were irrigated with treated wastewater and with freshwater. Plant height was significantly greater ($P\leq0.05$) in plants that received treated wastewater. The results show that treated wastewater should no longer be seen as a waste product, but as a water resource that can be treated and reused productively(12).

Table 2: Quinoa growth at 60 and 90 days after planting in two locations irrigated with freshwater and treated wastewater

Site	Water type	Height (cm)	SD (cm)	No. of leaves	Height (cm)	SD (cm)	No. of leaves
		----------- 60 days ---------			---------- 90 days ------------		
Ixtlán	FW	73.52^{b}	0.44^{b}	59^{b}	136.92^{b}	0.60^{b}	80^{b}
	TWW	125.73^{a}	0.75^{a}	92^{a}	175.5^{a}	0.94^{a}	113^{a}
Capulálpam	FW	29.15^{c}	0.35^{b}	48^{b}	57.61^{c}	0.44 c	62^{b}
	TWW	117.42^{a}	0.87^{a}	113^{a}	143.75^{b}	0.95^{a}	123^{a}
$\bar{x}$ FW		51.34^{b}	0.40^{b}	54^{b}	97.27^{b}	0.77^{b}	71^{b}
$\bar{x}$ TWW		121.58^{a}	0.81^{a}	103^{a}	159.63^{a}	0.95^{a}	118^{a}

FW= fresh water; TWW=treated wastewater. SD= stem diameter.

^{acb} Values with the same letter within each column and within each crop are not different ($P\leq0.05$).

Table 3: Corn growth at 60 and 90 days after planting in two locations irrigated with freshwater and treated wastewater

Site	Water type	Height (cm)	SD (cm)	No. of leaves	Height (cm)	SD (cm)	No. of leaves
		---------- 60 days --------			--------- 90 days ----------		
Ixtlán	FW	111.70^{b}	2.11^{b}	11^{b}	255.91^{b}	2.31^{b}	14^{a}
	TWW	174.08^{a}	2.40^{a}	13^{a}	340.22^{a}	2.57^{a}	14^{a}
Capulálpam	FW	74.37^{c}	1.91^{b}	9^{c}	157.72^{c}	1.92 c	11^{b}
	TWW	124.29^{b}	2.58^{a}	11^{b}	248.91^{b}	2.66^{a}	12^{b}
$\bar{x}$ FW		93.04^{b}	2.01^{b}	10^{b}	206.81^{b}	2.12^{b}	13^{a}
$\bar{x}$ TWW		149.19^{a}	2.49^{a}	12^{a}	294.57^{a}	2.62^{a}	13^{a}

FW= fresh water; TWW=treated wastewater. SD= stem diameter;

^{abc} Values with the same letter within each column and within each crop are not different ($P\leq0.05$).

Biomass

An analysis of variance showed significant differences ($P\leq0.05$) in root, leaf, and stem fresh and dry weight of the studied quinoa and corn plants when irrigated with fresh water versus treated wastewater. The fresh and dry weights of the quinoa and forage corn crops were significantly higher ($P\leq0.05$) in plants irrigated with treated wastewater (Tables 4 and 5). The fresh and dry weight of the organs of both crops was root < leaves < stems. In quinoa plants irrigated with treated wastewater, the total fresh weight of the leaves + stems were 3.4

times higher, and the dry weight was 3.2 higher. Likewise, the fresh weight of corn was 2.3 higher, and the dry weight 2.6 times higher, when irrigated with treated wastewater. This may be due to the higher nutrient content provided by the TWW, as other research has shown(26,31,32). In a similar study to the present one, the N content in the leaves of corn irrigated with TWW was shown to increase from 1 to 3 % with respect to the crops irrigated with aquifer water(33), and the corn plot irrigated with TWW had a yield of 2.58 t ha^{-1}, while the yield of the control plot was 1.61 t ha^{-1}(34).

Table 4: Fresh and dry weight of Quinoa irrigated with fresh water and treated wastewater in two locations

Site-Water type	Root Fresh	Root Dry	Leaves Fresh	Leaves Dry	Stem Fresh	Stem Dry
	g					
I-FW	4.60 ^{b}	0.58 ^{b}	15.77 ^{c}	2.10 ^{b}	25.80 ^{c}	6.35 ^{b}
I-TWW	6.98 ^{a}	1.91 ^{a}	52.91 ^{a}	6.05 ^{a}	106.91^{a}	18.74 ^{a}
C-FW	1.77 ^{c}	0.73 ^{b}	12.80 ^{c}	1.92 ^{b}	15.30 ^{c}	3.04 ^{b}
C-TWW	6.05 ^{a}	1.93 ^{a}	28.15 ^{b}	5.52 ^{a}	53.25 ^{b}	13.19 ^{a}
$\bar{x}$ FW	3.19 ^{b}	0.66 ^{b}	14.29 ^{b}	2.01 ^{b}	20.55 ^{b}	4.70 ^{b}
$\bar{x}$ TWW	6.52 ^{a}	1.92 ^{a}	40.53 ^{a}	5.79 ^{a}	80.08 ^{a}	15.97 ^{a}

I=Ixtlán, C=Capulálpam, FW= fresh water, TWW=treated wastewater. $\bar{x}$ = average.
abc Values with the same letter within each column are not significantly different ($P\leq0.05$).

Table 5: Fresh and dry weight of corn irrigated with fresh water and treated wastewater in two locations

Site –Water type	Root Fresh	Root Dry	Leaves Fresh	Leaves Dry	Stem Fresh	Stem Dry
	g					
I-FW	28.92 ^{a}	4.25 ^{b}	133.75 ^{b}	25.75 ^{b}	406.30 ^{b}	42.25 ^{b}
I-TWW	73.25 ^{a}	11.56 ^{a}	266.00 ^{a}	56.00 ^{a}	895.50 ^{a}	99.00 ^{a}
C-FW	32.85 ^{a}	6.82 ^{b}	119.00 ^{b}	22.75 ^{b}	381.50 ^{b}	29.75 ^{b}
C-TWW	83.50 ^{a}	15.50 ^{a}	261.50 ^{a}	54.25 ^{a}	1056.30 ^{a}	111.00 ^{a}
$\bar{x}$ FW	30.89 ^{b}	5.54 ^{b}	126.38 ^{b}	24.25 ^{b}	393.90 ^{b}	36.00 ^{b}
	79.31%	82.06%	85.95%	80.81%	77.17%	90.86%
$\bar{x}$ TWW	78.38 ^{a}	13.53 ^{a}	263.75 ^{a}	55.13 ^{a}	975.90 ^{a}	105.00 ^{a}
	70.55%	82.73%	78.33%	79.10%	80.06%	89.24%

I=Ixtlán, C=Capulálpam, FW= Fresh water, TWW=Treated wastewater. $\bar{x}$ = average.
ab Values with the same letter within each column are not different ($P\leq0.05$).

The water content was significantly higher in quinoa and forage corn plants that were irrigated with TWW than in plants that were irrigated with fresh water (Table 6); the leaves showed lower percentage values of water and a significantly higher water content. In corn plants, the water content ranged between 80 and 90 %; in quinoa, it was 70 to 85 %, depending on the organ concerned. These results express the influence of TWW on the water content.

Table 6: Water content in quinoa and corn plants irrigated with freshwater and treated wastewater in two locations

Site – Water type	Root Quinoa	Root Corn	Leaves Quinoa	Leaves Corn	Stem Quinoa	Stem Corn
	g					
I-FW	4.02 ^{b}	24.67 ^{b}	13.67 ^{c}	108.00 ^{b}	19.45 ^{c}	364.05 ^{b}
I -TWW	5.07 ^{a}	61.69 ^{a}	46.86 ^{a}	210.00 ^{a}	88.17 ^{a}	796.50 ^{a}
C-FW	1.07 ^{c}	26.03 ^{b}	10.88 ^{c}	96.25 ^{b}	12.26 ^{c}	451.75 ^{b}
C-TWW	4.12 ^{b}	68.00 ^{a}	22.63 ^{b}	207.25 ^{a}	40.06 ^{b}	945.30 ^{a}
$\bar{x}$ FW	2.53 ^{b}	25.35 ^{b}	12.28 ^{b}	102.13 ^{b}	15.86 ^{b}	357.90 ^{b}
$\bar{x}$ TWW	4.60 ^{a}	64.85 ^{a}	31.75 ^{a}	208.63 ^{a}	64.12 ^{a}	870.90 ^{a}

I=Ixtlán, C=Capulálpam, FW= fresh water, TWW=treated wastewater. $\bar{x}$ = average.
^{abc} Values with the same letter within each column are not different ($P \leq 0.05$).

Plant nitrogen and phosphorus content

In general, the nitrogen and phosphorus content were significantly higher in the organs of quinoa and feed corn plants irrigated with TWW, with the exception of some organs in both crops (Table 7). Research on citrus fruit trees[35] and vegetables[36] reports a higher N concentration in leaves and a higher crop growth, due to the higher amount of nutrients and organic matter in wastewater[12]. The concentration of N and P in the organs of the plants irrigated with TWW does not represent a danger for the plants themselves, and, therefore, neither for the human or animal that consumes it[12]. In Almeria, Spain, wastewater is reused because of its moderate salt content and its high content of nutrients for plants, particularly of N, P, and K[37]. These results indicate that the plants were able to grow more easily when they obtained more N and P. The highest N and P content in quinoa plants was found in the leaves, followed by the stem and nutrient the root, respectively. In forage corn plants, P content was second to that of quinoa, and the N content was higher in the stem, followed by the leaves and the root (Table 7). Khaskhoussy *et al*[22], found higher N content in corn irrigated with TWW: leaves 1.2 % and root 0.6 %, as compared to corn irrigated with FW: leaves 1.0 % and root 0.45 %, Munir *et al*[38] showed that the N content of TWW-irrigated corn plants was significantly higher than that of TWW-irrigated corn plants —of 1.08 %—, compared to plants irrigated with FW (0.66 %). A similar tendency was reflected in the P content of TWW-irrigated plants: 0.19 %, and FW-irrigated plants: 18 %. Therefore, the use of treated wastewater could be considered as an alternative that will help reduce the use of chemical fertilizers on forage crops in the region and replicate them in another site.

Table 7: Nitrogen and phosphorus content in organs of quinoa and forage corn plants when irrigated with freshwater and with treated wastewater

Site – Water type	**Root**	**Leaves**	**Stem**	**Root**	**Leaves**	**Stem**
	-------- Quinoa --------			**-------- Corn --------**		
	Nitrogen (%)					
I-FW	2.15 ^{a}	1.70 ^{ab}	4.07 ^{b}	0.67 ^{c}	1.64 ^{c}	0.76 ^{a}
I- TWW	2.07 ^{a}	2.48 ^{a}	6.03 ^{a}	1.35 ^{b}	2.97 ^{ab}	3.32 ^{a}
C- FW	1.32 ^{a}	0.09 ^{b}	2.36 ^{c}	1.33 ^{b}	2.73 ^{b}	1.57 ^{a}
C-TWW	1.91 ^{a}	1.95 ^{ab}	5.30 ^{a}	2.18 ^{a}	3.52 ^{a}	2.30 ^{a}
$\bar{x}$ FW	1.73 ^{a}	3.21^{b}	1.33 ^{b}	1.00 ^{b}	1.16 ^{b}	2.18 ^{a}
$\bar{x}$ TWW	1.99 ^{a}	5.66 ^{a}	2.21 ^{a}	1.76 ^{a}	2.81 ^{a}	3.24 ^{a}
	Phosphorus (mg kg^{-1})					
I- FW	0.12 ^{b}	0.17 ^{b}	0.25 ^{b}	0.10 ^{b}	0.28 ^{c}	0.24 ^{b}
I- TWW	0.22 ^{a}	0.20 ^{a}	0.34 ^{a}	0.16 ^{a}	0.45 ^{a}	0.43 ^{a}
C- FW	0.08 ^{b}	0.13 ^{c}	0.24 ^{b}	0.17 ^{a}	0.38 ^{b}	0.27 ^{b}
C-TWW	0.10 ^{b}	0.11 ^{c}	0.39 ^{a}	0.08 ^{b}	0.30 ^{c}	0.10 ^{c}
$\bar{x}$ FW	0.10 ^{b}	0.24 ^{b}	0.15 ^{a}	0.13 ^{a}	0.33 ^{b}	0.25 ^{a}
$\bar{x}$ TWW	0.16 ^{a}	0.37 ^{a}	0.16 ^{a}	0.14 ^{a}	0.38 ^{a}	0.27 ^{a}

I=Ixtlán, C=Capulálpam, FW= fresh water, TWW=treated wastewater. $\bar{x}$ = average.
^{acb} Values with the same letter within each column, crop, and element are not different ($P \leq 0.05$).

Conclusions and implications

In the soil pH, neither the electrical conductivity nor the organic matter content represented any risk when irrigation with treated wastewater was applied. The plant height, stem diameter, and number of leaves of quinoa plants were significantly higher when these were irrigated with treated wastewater; the same applies for corn, except for the variable number of leaves, which did not show a significant difference. The biomass of both forage crops was significantly higher in those plots where treated wastewater was utilized, compared to irrigation with freshwater. The nitrogen and phosphorus content were significantly higher in both quinoa and corn plants that were irrigated with treated wastewater. Treated wastewater is an important source of nutrients for forage crops and represents an alternative for significantly reducing the use of chemical fertilizers.

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