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Full Length Research Paper

Effect of kitchen wastewater irrigation on soil properties and growth of cucumber (*Cucumis sativus*)

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Scarcity of freshwater is becoming an increasing problem primarily in the arid and semi-arid regions of the world. The study was designed to investigate the effects of wastewater irrigation on soil properties and growth parameters of cucumber (*Cucumis sativus*) in southwestern Nigeria. The irrigation treatments consisted of kitchen wastewater, rainwater and groundwater in a randomized complete block design (RCBD) in three replications. Soil samples were collected in the 0 to 20 cm range, analyzed before irrigation application and after harvest according to USDA standard procedures while crop growth parameters were recorded 3, 5 and 7 weeks after planting. Soil pH decreased in all the soil samples after the different water applications, the lowest pH from kitchen wastewater. Electrical conductivity (EC) increased slightly in all soil samples, the highest EC value of 8.59 × 10^{-4} dS/m from groundwater irrigation. The sodium adsorption ratio (SAR) increased in all the irrigation treatments but was below the critical value of 13. The stem girth and leaf area were not significantly affected by water type (WT) during the three periods of evaluation but leaf numbers and plant length differ significantly at seven week of growth. Soil condition was not significantly impacted by the use of kitchen wastewater, however, appropriate wastewater treatment and water management practices have to be followed to remove the toxic elements which could be hazards to vegetable production and the environment.

Key words: Wastewater, groundwater, electrical conductivity, sodium adsorption ratio.

INTRODUCTION

Scarcity of freshwater is becoming an increasing problem primarily in the arid and semi-arid regions of the world (El Youssfi et al., 2012). This trend is however extending to other regions of the world. The rapid growth of the world's urban population continues to place increased demands on limited fresh water supplies. There is a serious struggle to balance water use among domestic, industrial and agricultural users (Darvishi et al., 2010). This rapid increase in population has not only caused an increase in the demand for the limited available freshwater but has also caused an increase in the volume of wastewater generated year by year (Thapliyal et al., 2011). The untreated water generated can find its way into water systems such as rivers, lakes, groundwater and coastal waters with the potential to cause serious pollution (GOI, 2002). Wastewater may contain undesirable chemical constituents and pathogens that pose negative environmental and health impacts (Papadopoulos, 1995).

On the other hand, large amounts of water are needed for irrigation in agriculture. If the wastewater can be used as an alternative water source for irrigation, the dual problems of negative environmental effects and huge water demand for agricultural irrigation would be solved (Darvishi et al., 2010). The reuse of wastewaters for purposes such as agricultural irrigation can reduce the amount of water that needs to be extracted from environmental water sources (Heidarpour et al., 2007). The reuse of wastewater for irrigation purposes gives it a different fate as agricultural crops can make use of the extra water and nutrients. Groundwater recharge is another positive outcome of wastewater irrigation (Walker and Lin, 2008). Wastewater has a potential to supply carbon nutrients (NPK) and micro nutrients to support crop/plant growth (Singh et al., 2011). It serves as a valuable source of plant nutrients and organic matter needed for maintaining fertility and productivity levels of the soil (Rusan et al., 2007). Wastewater can have a positive effect on soil and eventually plant growth, due to its being rich in organic matter and nutrients (Ghanbari et al., 2007; Mohammad and Ayadi, 2004). When wastewater will be used continuously as the sole source of irrigation water for field crops in arid regions, excessive amounts of nutrients and toxic chemical substances could simultaneously be applied to the soil-plant system. This would cause unfavorable effects on productivity and quality parameters of the crops and the soil (Vazquezmontiel et al., 1996).

In agricultural practices, irrigation water quality is believed to affect the soil characteristics, crops production and management of water (Shainberg and Oster, 1978). For instance, the application of saline/sodic water results in the reduction of crop yield and deterioration of the physical/chemical properties of soil (Singh, 2011). Therefore, it is of

concern to the people/farmers if an irrigant is used, which may contain constituents capable of creating adverse effects on the soil and on agricultural produce. In this context, many studies have been conducted to evaluate the effects of treated and untreated wastewater irrigation on soil physical and chemical properties and crop performance and nutrient status across climates, soils and diverse crops, however results vary between different settings. Tabari et al. (2008) reported that wastewater irrigation could enrich soils with heavy metals to levels that may pose potential risk to the environment and human health while Tabatabaei (2007) observed that continuous wastewater application to the soil could alter soil infiltration characteristics. Mojiri et al. (2013) working on the impact of urban wastewater on soil properties and *Lepidium sativum* in an arid region found increased electrical conductivity (EC), organic matter (OM), total N, Na and heavy metals due to wastewater irrigation. However, they reported an increase in root and shoot length. In contrast, Singh et al. (2012) found that domestic wastewater irrigation had no significant effects on properties of a clay soil apart from slight changes in salt solubility and alkalinity. Despite this volume of studies, there is a dearth of information on the impact of household wastewater irrigation on soil properties and quality of irrigated vegetables applicable to southwestern Nigeria where there is an increased popularity in the application of domestic wastewater for irrigation. Thus, we formulated the hypothesis that irrigation using kitchen wastewater will reduce soil quality and negatively impact cucumber growth and yield. Therefore, the objective of this study was to investigate the effects of wastewater irrigation on soil properties and growth parameters of cucumber (*Cucumis sativus*) in southwestern Nigeria.

MATERIALS AND METHODS

Study area

The study was conducted in a screenhouse in the Department of Agricultural Engineering, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso (8°10^{1}N; 4°10^{1}E); in Southwestern Nigeria. The mean annual rainfall is about 1200 mm while the mean annual maximum and minimum temperatures are 33 and 28°C, respectively. The relative humidity of the area is relatively high (74%) throughout the year except in January when the dry wind blows from the North (Olaniyi et al., 2010) while the soil of the area is classified as Hapludalf (SSS, 2006).

Soil sampling and analyses

Deformed soil samples of the soil to be used were collected from soil depth, 0-20 cm. Samples were bulked and passed through a 2-mm sieve for the analysis of particle size (used to classify the soil), P, pH, exchangeable bases (K^+, Ca^{2+}, Mg^{2+}, Na^{2+}) and electrical conductivity (EC). The Na^+, Ca^{2+} and Mg^{2+} values were used to determine the soil sodium adsorption ratio (SAR) using the equation:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$$

Particle size analysis was done by the Bouyoucos or hydrometer method (Gee and Bauder, 1986), and the corresponding textural class was determined from the USDA textural class triangle. The soil pH was determined with pH-Meter E520 using 1:2.5 soil to water ratio. The EC was determined using a Wilson Grimes conductivity meter. Exchangeable bases were determined by extraction with ammonium acetate, after which potassium (K^+) and sodium (Na^+) were determined by flame photometry while calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined using atomic absorption spectrophotometry (AAS) as detailed by Anderson and Ingram (1993). Sampling and analysis are carried out before planting and after harvesting for each of the different water types used for irrigating the crops during the course of the experiment.

Water sample collection and analysis

Water samples were collected from the three types of water: rainwater, kitchen wastewater and groundwater, using sterilized sampling bottles. The samples were put on ice and transported to the laboratory within 24 h of collection. In the laboratory, they were kept in a refrigerator until they were analyzed. The sample were

Table 1. Properties of the different water types before planting.

Parameter	Groundwater	Rainwater	Wastewater
HCO_3^- (mg/L)	109.8	85.4	244.0
Na^+ (mg/L)	15.0	5.0	10.0
Ca^{2+} (mg/L)	115.2	25.6	35.2
Mg^{2+} (mg/L)	42.0	5.0	15.0
TSS (mg/L)	188.0	140.0	668.0
SAR	1.69	1.28	2.0
pH	6.0	6.4	6.0

TSS, Total suspended solids; SAR, Sodium adsorption ratio; HCO_3^-, hydrogen carbonate, Ca^{2+}, Calcium, Mg^{2+}, magnesium and Na^+, sodium concentration;

analyzed for parameters such as concentrations of bicarbonate (HCO_3^-), Na^+, Mg^{2+}, Ca^{2+}, TSS as well as pH and EC according to APHA (1998) standard methods.

Experimental design, field procedures and management

The experimental design was a one-factor 3 × 8 experiment arranged in a randomized block design (RBD) with three replications consisting twenty four (24) micro-lysimeters. The treatments consisted of water types (WT): Kitchen wastewater, rainwater and groundwater. Three seeds of Cucumber were planted in each micro-lysimeter and were irrigated sufficiently in the first few days to ensure germination and establishment. After crop establishment, equal amount of groundwater, rainwater and wastewater was applied based on cucumber irrigation water requirements, with water applied using surface irrigation method. Apart from the irrigation treatments, soil management such as fertilizer application, weed removal and crop protection were the same for all treatments.

Data collection

The crop was monitored and the growth parameters (plant length, leaf area, stem girth and number of leaves) were measured and recorded under the different irrigation water type. Growth parameters were measured 3, 5 and 7 weeks after planting. Plant length (PL) was determined by measuring the length of the plant from the ground level to the tip of top-most leaf using a flexible tape. The number of leaves (NOL) per plant was made by a visual count of the green leaves while the stem girth (SG) was measured with the aid of a vernier caliper. The green leaf area was estimated as a product of the leaf length (L) and the widest middle portion of the leaf, the width (W) corrected to 0.85, as described by Blanco and Folegatti (2003) according to the equation:

$$LA = 0.85\,(L \times W)$$

Where: L = leaf length, cm; W = width of widest portion of leaf, cm, and LA = leaf area, cm^2.

Statistical analysis

Data was subjected to analysis of variance (ANOVA) procedure and comparison of the soil chemical characteristics before and after the experiment was made using the Tukey Test (DMRT) at 5% level of significance using the ASSISTAT statistical package (ASSISTAT version 7.6 beta).

RESULTS AND DISCUSSION

Water quality

The results of the water (groundwater, rainwater and wastewater) analyses are shown in Table 1. Of the three water samples, rainwater had the lowest values for all the parameters considered except pH with a value of 6.4. Generally the pH values of the three waters fall within the acidic range. Groundwater had the highest values of Na^+, Ca^{2+} and Mg^{2+}. This may be connected with the rock formation of the area where the well was located. Kitchen wastewater however, had the highest value of 668 mg/L and 2.0 for TSS and SAR, respectively. It also had the highest HCO_3^- concentration. The soap chemicals used and suspended particles of food remnants from kitchen waste may have contributed to the highest values of TSS, SAR and HCO_3^-

Soil properties

The soil texture consisted of 80% sand, 16% silt and 4% clay, classified as sandy loam, according to the USDA classification. The soil properties prior to planting are shown in Table 2. The initial value for electrical conductivity (EC) of the soil was 0.0 dS/m while the pH was 7.2, slightly within the basic range. Figure 1a to g shows the values of the different soil parameters before planting and after the application of the three water treatments. The pH of the soil decreased with the three water treatments (Figure 1a). Soil irrigated with kitchen wastewater had the lowest pH value of 6.0 while soil irrigated with rainwater had the highest pH of 6.9. A pH of 6.7 was obtained for soil irrigated with groundwater (Figure 1a). This is likely due to the decomposition of organic matter and production of organic acids in soils which is in line with the findings of Vaseghi et al. (2005) and Khai et al. (2008). Another explanation for this reduction in pH may be as a result of nitrification of N-NH_4^+ from the wastewater as observed by Stamatiadis et al. (1999). Similar result was reported by Hussein (2009). However, other works (Rattan et al., 2005; Rusan et al.,

Table 2. Soil physical and chemical properties before planting.

Soil properties	pH	Na^{+}	Ca^{2+}	Mg^{2+}	K^{+}	SAR	EC	Sand	Silt	Clay	Soil type
		ppm					dS/cm	%			
Value	7.2	110.4	500	380	663	5.26	0	80	16	4	SL

SAR, Sodium adsorption ratio; HCO_3^-, hydrogen carbonate; Ca^{2+}, Calcium; Mg^{2+}, magnesium; Na^+, sodium concentration; EC, electrical conductivity; SL, sandy loam.

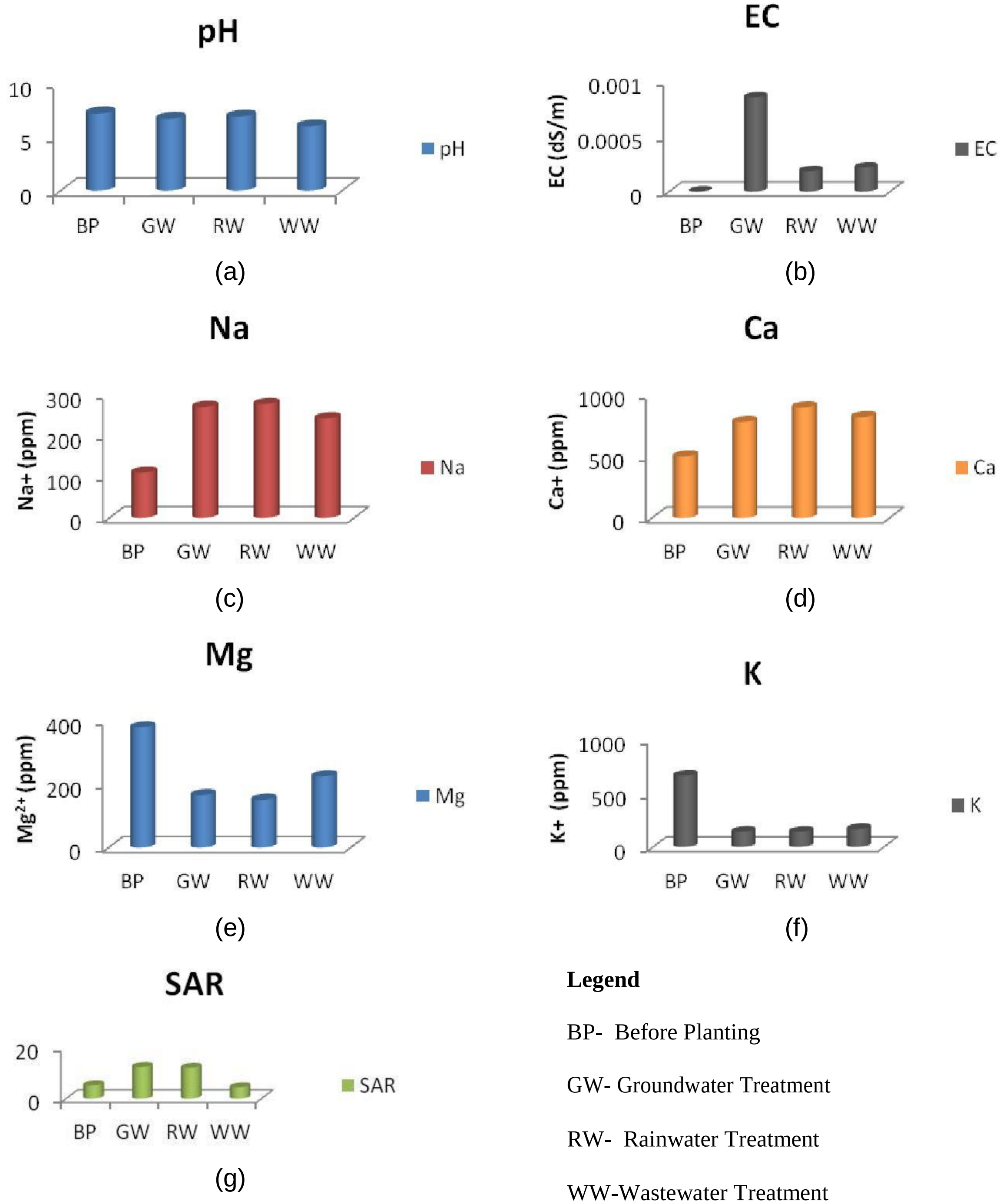

Figure 1. Effects of irrigation water on soil cultivated with cucumber.

Table 3. Soil classification based on electrical conductivity (EC), pH and sodium adsorption ratio.

Soil classification	EC*	pH	SAR
Normal soil	<4	<8.5	<13
Saline soil	>4	<8.5	<13
Sodic soil	<4	8.5-10	>13
Saline-sodic soil	>4	<8.5	>13

*EC, Electrical conductivity; SAR, sodium adsorption ration; pH, level of alkalinity/acidity. Source: Scherer (1996).

2007) have shown that soil pH increased over a long period of irrigation with sewage and wastewater effluents. These investigations described the long term effect while our study was short term and considered kitchen wastewater. According to Mojiri (2011) an initial decrease in pH may be observed in soil irrigated with kitchen wastewater but after a while it may cause an increase of soil pH. SAR increased in soil solution with the three water treatments as maximum value of 12.46 was observed in soil irrigated with groundwater. Soil irrigated with wastewater gave the lowest SAR value of 10.14 while soil irrigated with rainwater gave a value of 12.15 (Figure 1g). Of the treatments, kitchen wastewater was farthest from the critical SAR value of 13 and hence less likely to cause sodicity hazards in the soil. The EC of soil samples treated with groundwater, rainwater and wastewater treatments were 8.59×10^{-4}, 1.85×10^{-4} and 2.17×10^{-4} dS/m, respectively (Figure 1b). At the end of the experiment, the resulted EC value of the treated soil samples remained below the limit of the EC value for agricultural soil, 4 dS/m (Christiansen, 1977). Though EC was not the lowest for wastewater, its value was not far above that for rainwater which contributed the least to soil salinity. The groundwater EC value was the highest. Excess sodium can be detrimental to soil structure and can significantly reduce the soils ability to transmit water (Mace and Amrhein, 2001). The three water treatments added sodium (Na) to the soil (Figure 1c), but Na added by wastewater was not more in comparison to that added by groundwater and rainwater. Therefore, the use of kitchen wastewater is not assessed as leading to an enhanced EC or sodium hazard compared to the other treatments.

Comparing the EC, SAR and pH values of the soils after harvest with threshold values set by Scherer (1996), the soil samples were classified as not posing any threat with respect to salinity and sodicity hazards as well as pH, since EC, SAR and pH values were below 4 dS/m, 13 and 8.5, respectively (Table 3).

Effect of water type irrigation on cucumber growth parameters

For cucumber the number of leaves was not significantly affected by the different water types used for irrigation in the first five weeks of growth, but there was a significant effect at the seventh week of growth (Figure 2a). At 3 weeks after emergence, the average number of leaves for the three water types was about five and there was an increase in the number of leaves between the 3rd and 5th week for all treatments. Plants treated with rainwater had an average of about nine leaves, those with groundwater had about eight, while the kitchen wastewater pots had an average of about seven leaves. Between the 5th and 7 th week, the number of leaves from cucumber treated with rainwater increased significantly to about ten compared with kitchen wastewater plots had about eight while pots under groundwater irrigation treatment had the number reduced to about seven (Figure 2a).

The water-type irrigation systems had no significant effect on cucumber average leaf area (Figure 2b). At 3 WAE, the average leaf area for the three water types was between 60 and 65 cm^2 as shown in Figure 2b. At the 5th week, the average leaf area increased to about 114, 90.2 and 92.1 cm^2 for rainwater, groundwater and wastewater irrigation treatments, respectively. From the 5th week to 7th week, different results were obtained for the average leaf area. While average leaf area from groundwater irrigation slightly increased to about 91 cm^2, that of rainwater and wastewater irrigation reduced to about 112.55 and 78.92 cm^2, respectively (Figure 2b). The plant length of cucumber did not differ significantly in the first five weeks of growth, however significant effect was observed at seventh week of growth as shown in Figure 2c. At 3 weeks of growth (WAE), the average plant length was between 25 and 27 cm for the three water types.

At week 5, there was a significant increase in plant length of cucumber treated with rainwater to about 74 cm. Cucumber treated with groundwater and wastewater has approximately equal plant length of about 50 cm. Between 5 and 7 weeks of growth, rainwater treated cucumber increased in length to about 100 cm while groundwater treated cucumber increased significantly to about 58 cm at a decreasing rate and for the wastewater irrigation, it decreased to about 45 cm.

The water-type irrigation systems had no significant effect on cucumber stem girth. From emergence to the 3rd week of cultivation, the average stem girth of cucumber in

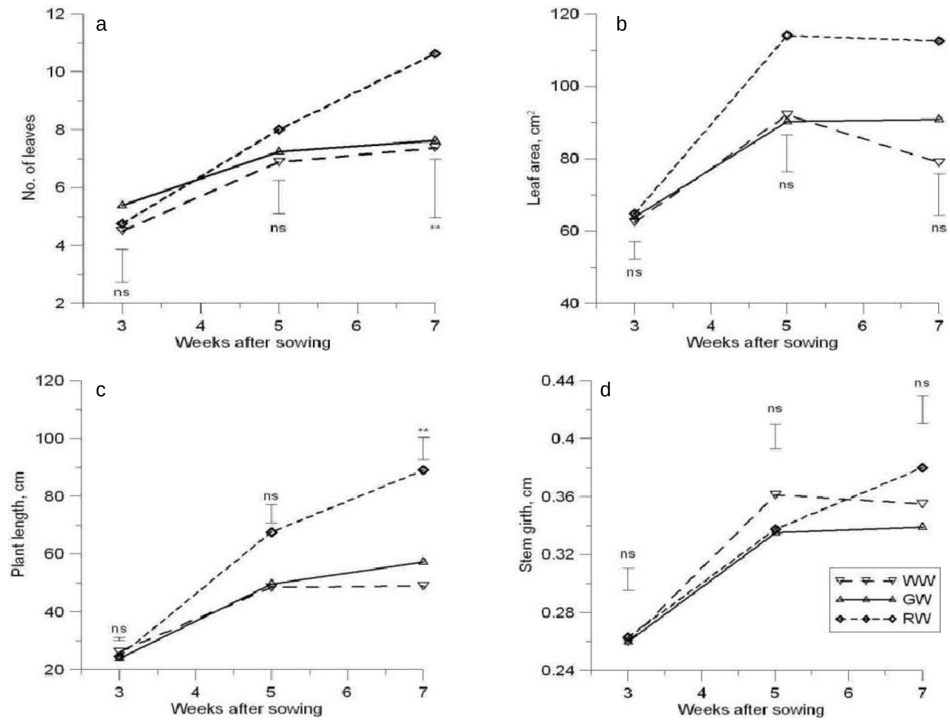

Figure 2. Cucumber growth parameters under theunderifferentdifferentwattypes: (a) number of leaves, leaves; (b) leaf area; (c) plant length, and (d) stem girth.

Figure 2. Cucumber growth parameters the water types: (a) number of (b) leaf area, (c) plant length and (d) stem girth.

Table 4. Summary of the ANOVA for cucumber growth parameters.

Growth parameter	F-values		
	Water-type (WT)	**Duration (D)**	**Interaction**
Leaf area	7.61(3.35)	9(3.35)	1.51(2.73)
Stem thickness	2.13(3.35)	5.37(3.35)	0.37(2.73)
No of leaves	2.83(3.35)	14.05(3.35)	0.97(2.73)
Plant length	17.36(3.35)	44.08(3.35)	5.14(2.73)

The data in brackets are the tabulated F-values at 5% level of significance. A significant effect is indicated by lower tabulated F-values.

the three water-types was about 0.26 cm (Figure 2d). Between 5 and 7 weeks of growth, there was almost no change in stem thickness under groundwater (about 0.34 cm) and kitchen wastewater (about 0.36 cm) irrigation treatments whereas cucumber cultivated with rainwater increased from about 0.34 to 0.38 cm in stem girth. These findings are contrary to the results of Hussein (2009) who recorded increase in cucumber growth and yield with increase in sludge application. Mojiri et al. (2013) also found increase in *Lepidium sativum* root and shoot length when irrigated with wastewater. The authors attributed the increase to increased soil aggregation and contribution of organic matter to chemical properties and nutritional status of the soil, such as decrease in soil pH which enhances solubilization of nutrients and increase their availability and supply for root uptake. The reduction in leaf area and static plant length stem girth with wastewater may be attributed to anti-growth elements which the soil may have absorbed from the wastewater and thus influenced crop growth. The negative effect from the wastewater irrigation as observed is a result of formation of inner-sphere complexes, whereby the toxic elements are strongly adsorbed on soil colloids, form insoluble precipitates easily, thus preventing the exchange of cations necessary for crop growth.

The summary of the ANOVA on the effect of water-type and duration on the growth parameters of cucumber is shown in Table 4. From the table, the main effect of water-type and duration significantly affected the leaf area and plant height of cucumber at 5% level of significance. In each case, the calculated F-value was greater than the tabulated F-value. Water-type had no significant effect on the stem girth and number of leaves while duration had significant effect on both. The interaction between water-type and duration had significant effect only on the plant height.

CONCLUSIONS

The use of kitchen wastewater for irrigation of cucumbers did not adversely affect the soil as compared to rainwater or groundwater. The soil salinity level remained normal and the sodium levels indicated by the sodium adsorption ratio (SAR) were below the critical level of 13, indicating no threat to soil quality and hence could be suitable for crop production. There were some negative effects on plant growth and leaf area and number, not directly related to the inorganic parameters measured during this study, and ascribed to other wastewater components. Appropriate wastewater treatment and water management practices will have to be followed to allow the reuse of untreated kitchen wastewater for irrigation.

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