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Soil hydrophobicity and crop evapotranspiration of two indigenous vegetables under different wastewater irrigations in southwest Nigeria

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The increased demand for irrigation to boost food supply has placed emphasis on the use of wastewaters. However, the indiscriminate use of wastewaters could impair soil functions and influence other hydrologic processes. The objective of this study was to evaluate soil hydrophobicity and evapotranspiration of two indigenous vegetables under wastewater irrigation in southwest Nigeria. The study was a factorial experiment, laid out in randomized complete block design (RBCD) with three replications. The vegetable factor consisted of SM - Eggplant (*Solanum macrocarpon*) and CA – Lagos spinach (*Celosia angentea*), while the wastewaters were abattoir wastewater (AW), bathroom and laundry wastewater (BW) and cassava effluent (CE), with rainwater (RW) as control. Soil hydrophobicity was determined before the experiment and after harvest using water-droplet penetration time (WDPT) method while the crop evapotranspiration was determined using soil water balance technique. Wastewater irrigation significantly (p<0.05) influenced soil hydrophobicity, as the initially wettable soil became slightly hydrophobic, with the highest degree from CE wastewater. The evapotranspiration of both vegetables was significantly (p<0.05) affected, with none of the wastewater treatments dominating the temporal distribution of crop evapotranspiration. Continuous application of wastewater for irrigation could increase the level of water repellency, affect soil water dynamics and availability.

Key words: Soil water repellency, wastewater effluent, evapotranspiration.

INTRODUCTION

The increased competition for water among urban and semi-urban centers, industries and agriculture has put agriculture particularly irrigated agriculture under severe pressure as irrigation has been the largest user of water (Van der Hoek et al., 2002). Therefore, the problem of water shortage due to demand for increased irrigation (Yao et al., 2013) to boost food supply has placed emphasis on the use of treated, partially-treated and untreated wastewater. Kauser (2007) reported that at least one-tenth of the world's population are now

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consuming food produced by wastewater and it is estimated that about 200 million hectares in 50 countries are irrigated with raw or partially-treated wastewater (United Nations, 2003). As populations continue to increase and more freshwater is diverted to cities for domestic use, 70% of which later returns as wastewater (Ashraf et al., 2013). Khalil and Kakar (2011) reported that 80% of the inhabitants in Pakistan are using untreated wastewater for irrigation because of the relatively high levels of essential nutrients, such as phosphorus, nitrogen and potassium.

Untreated wastewater has become a preferred source of water for irrigation (Ensink et al., 2002) since there is no need for conventional fertilizers which are beyond the reach of most farmers. Rijsberman (2004) highlighted some direct benefits of wastewater collection and reuse, including double cropping and lower input costs for agricultural crop productions. Despite these advantages, the use of untreated wastewaters poses threat to the environment, such as impairment of certain soil functions, pollution of water bodies, interference with crop performance and so on.

Soil physical processes such as water movement and retention is affected by soil water repellency or hydrophobicity (Mataix-Solera et al., 2007). Hydrophobicity is a phenomenon of difficulty in wetting the soil, associated with coating of soil particles by hydrophobic organic substances, which reduces soil sorptivity (Vogelmann et al., 2013). According to these authors, the organic substances responsible for repellency can be of various origins, such as type of vegetation, bush burning, and microbial activities. Soil water repellency has become a subject of global concern with substantial effects on crop production, soil use and management (Müller and Deurer, 2011).

As a primary effect, Cerdà and Doerr (2007) cited a reduction in water infiltration and hence the amount of plant available water, thereby affecting seed germination, crop growth and development. Kawamoto et al. (2007) asserted that increased hydrophobicity has serious implications for soil management, affecting the water dynamics and consequently crop growing conditions. Tabatabaei et al (2007) observed that continuous use of wastewater for irrigation could alter water entry. Madsen et al. (2011) mentioned that due to reduced infiltration rate; surface runoff may be increased, accelerating the risk of erosion. Wastewater effluents, especially household wastewater, in untreated state, contain appreciable amount of organic substances among others, thus could contribute to coating of soil particles and cause soil hydrophobicity (Wallach et al., 2005). Because the plant available water is altered due to reduced water entry by wastewater irrigation, therefore different soil water status could result when wastewater is sourced from different sources as they contain different levels of hydrophobic organic compounds. In this context, the differences in plant available water will also influence plant water uptake.

We hypothesized that wastewater irrigation significantly affected soil hydrophobic character and water use pattern of two contrasting vegetables. Therefore, the objective of this study was to evaluate soil hydrophobicity and water use pattern of two indigenous vegetables under different wastewater irrigations in southwest Nigeria.

MATERIALS AND METHODS

Experimental site

The experiment was conducted in the screen house of the Department of Agricultural Engineering, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso (latitude 8° 10°N and longitude 4° 10°E, about 342 m above the mean sea level) in southwest Nigeria during the 2013 growing season. The study site is characterized by bimodal rainfall pattern, with peaks in June and September and phenomena break in the month of August. The mean annual rainfall is about 1200 mm while the mean 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 dry wind (harmattan) blows from the north (Olaniyi, 2006). The soil of the area is classified as Hapludalf (SSS, 2010), sandy loam texture and the particle size distribution analysis showed that the 0 to15 cm layer of the soil is composed of 78% sand, 11% silt and 11% clay.

Wastewater sampling and analysis

Three types of raw untreated wastewaters were collected and rainwater (RW) was used as the control. The waste waters are abattoir wastewater (AW), bathroom and laundry wastewater (BW) and cassava effluent (CE). AW was collected from the outlet of the drain of the slaughtering slab at Atenda abattoir in Ogbomoso. This was done immediately after the animals were slaughtered and the slab flushed. BW was collected from bathrooms and laundries in some student hostels of LAUTECH, while the CE was collected from a garri processing factory at A*arada* market in Ogbomoso. RW was collected through a clean roof gutter attached to the roof of the screen house. The raw wastewater samples were kept in bottles that have been soaked for 24 h in HNO_3 solution to kill any microbes. The bottles were labeled accordingly, sealed, refrigerated and taken to the laboratory within 24 h of collection for analysis. The chemical properties analyzed include HCO_3^-, Na^+, Ca^{2+}, Mg^{2+}, Total suspended solid (TSS), Total Dissolved Solid (TDS), Biochemical Oxygen Demand (BOD_5), pH, Electrical Conductivity (EC) and CN^-, using standard laboratory procedures.

Experimental design and preparation of mini-lysimeters

The study was a two factor (wastewater versus type of vegetable) experiment, laid out in a randomized complete block design (RBCD) with three replications. The vegetable factor consisted of SM - Eggplant (*Solanum macrocarpon*) known as Igbagba or Igbo in Yoruba (Ojo et al., 2011) and CA - Cockscomb (USDA, 2013) or Lagos Spinach (*Celosia angentea*) while the wastewater factor were: abattoir wastewater (AW), bathroom and laundry wastewater (BW), cassava effluent (CE) and rainwater (RW) as control. Thus, twenty-four buckets (22 cm high and 25.5 cm diameter), perforated at the bottom (for drainage) were used. The buckets were filled with soil sample from the same area (used for soil physico-chemical analysis), after air dried and passed through a 2 mm sieve.

To obtain soil condition in the mini-lysimeter similar to the natural state (field), subsample was weighed from the sieved soil sample based on the volume of the mini-lysimeters and determined field bulk density. The subsample was re-wetted using determined field moisture content and packed in the marked lysimeters using fabricated circular wood (with the same diameter as the lysimeter) and soft-head hammer. A gap of about 5 cm was left between the tip of the lysimeter and soil surface to prevent surface runoff. The lysimeters were placed on planks and arranged in such a way that drained water was easy to collect.

Planting, irrigation application and crop management

The vegetables were nursed and transplanted into the mini-lysimeters. The transplanted vegetables were adequately irrigated with rainwater until they are established. After a week, the plants were subjected to wastewater irrigation treatment. Because there was no established water requirement for the two vegetables, a preliminary investigation was carried out based on the surface area of the lysimeters and which will not cause overflow and saturation, thus four hundred cubic centimeters (400 cm^3) of each of the wastewater treatments and rainwater was arrived at. The water treatments were added at intervals based on visual observation when the soil surface becomes relatively dry. There was no fertilizer application and unwanted plants were removed manually. Other management procedures for the two indigenous vegetables were followed according to cultural practices.

Determination of soil hydrophobicity

The hydrophobicity test was performed using water droplet penetration time (WDPT) method on disturbed soil samples, after air-dried, crushed and passed through a 2 mm sieve. The soil samples were later placed in Petri dishes (volume of 25 cm^3) for the test. The WDPT method consisted of applying a drop of water using a precision pipette, and then recording the time taken for the drop to penetrate the soil sample (King, 1981). Each drop was released from a height of 10 mm above the soil surface to minimize the impact on the soil surface, the test was replicated 9 times for each treatment and the mean values were used to characterize the hydrophobic level. Five classes of water repellency were distinguished: wettable (WDPT < 5s); slightly repellent (5s < WDPT < 60s); strongly repellent (60s < WDPT < 600s); severely repellent (600s < WDPT < 3600s); and extremely repellent (WDPT > 3600s) (Dekker and Jungerius, 1990).

Determination of reference crop evapotranspiration and water use

Reference crop evapotranspiration ET_o was calculated using Penman-Montieth equation (Allen et al., 1998; Valipour, 2014) using FAO reference crop evapotranspiration calculator (FAO EToCalc, version 3.1) from daily meteorological data recorded in the screen house. The crop water use (crop evapotranspiration, ET_C) of each vegetable during the growth period was calculated using soil water balance equation proposed by Martin and Gilley (1993):

$$ET_C = \frac{(I - Q - \Delta S + R_Q)}{A} \times 10$$

Where: ET_C = crop evapotranspiration or consumptive water use (mm); I = irrigation water added, (cm^3); Q = deep percolation (cm^3), measured from the base of the mini-lysimeter as drainage water collected; ΔS = soil water storage (cm^3), the difference between mini-lysimeter weights between two consecutive days during the growing period; R_Q = runoff (cm^3), (= 0 in this study because there was no runoff from the mini-lysimeters); and A = cross sectional area of the mini-lysimeter (cm^2); 10 is a conversion factor from cm/d to mm/d.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) of the General Linear Model (GLM) and where the F-value of the effect of wastewater and interaction between wastewater and type of vegetable was significant, Fisher's Least Significant Difference (LSD) was used to separate means. All statistical analyses were performed using the statistical package, SPSS (*SPSS, IBM version 20.0*).

RESULTS AND DISCUSSION

Physical and chemical properties of wastewater and rainwater samples

The results of the physico-chemical characteristics of the various wastewaters and rainwater used for the experiments are presented in Table 1. The concentrations of Na, Ca, Mg, EC, CN^- and HCO_3^- were below the limits recommended by Food and Agricultural Organization standards (FAO; Pescod, 1992) for the reuse of wastewater for irrigation. The TDS values were within the 450-2000 mg/L standard. However, all the wastewater samples had SAR values above the FAO standard limit (FAO; Pescod, 1992) of 9, with abattoir (AW) and domestic (BW) wastewaters having higher SAR, 25.5 and 24.5, respectively while that of RW was below the limit. Likewise, the total suspended solids (TSS) concentration was also higher than the FAO limit of 20 mg/L, with the highest value (1875 mg/L) from AW sample and the lowest value (26 mg/L) from rainwater (RW) sample.

The biochemical oxygen demand (BOD_5) was below the FAO limit in RW; however, other wastewaters had values above the limit. Valipour et al. (2013) developed an environmental flow diagram (EFD) for the determination of sources of pollutants from wastewater irrigation and division sources based on acceptor environment (soil) found the concentration of BOD_5 from wastewater higher than that of irrigation standard, indicating as warming for irrigation purpose. The pH values from RW and cassava effluent (CE) samples were within the FAO limit of 6.5-8.4, whereas those of AW and BW were below the minimum threshold.

The pH determines the availability of nutrients, the potency of harmful substances as well as the physical properties of the soil (Osakwe, 2012) and the implication is that the soil pH can either be elevated or decreased. Osakwe (2012) and Abegunrin et al. (2013) found decreased soil pH due to wastewater application.

Table 1. Physico-chemical characteristics of rain and waste waters used for the experiment

Parameter	Standard*	Wastewater type			Control
		BW	CE	AW	RW
Ca (mg/L)	230	198	151	212	101
Mg (mg/L)	100	23	32	22	21
Na (mg/L)	69	50	28	48	20
Co (ppm)	0.05	nd	nd	nd	nd
Cr (ppm)	0.1	nd	nd	nd	nd
Cd (ppm)	0.01	nd	nd	nd	nd
Pb (ppm)	5.0	nd	nd	nd	nd
Ni (ppm)	0.2	nd	nd	nd	nd
EC (µS/cm)	2700	836	408	281	54
SAR	9	25.5	13.2	24.5	1.2
TDS (mg/L)	450-2000	589	309	229	35
TSS (mg/L)	20	104	312	1875	26
BOD_5 (mg/L)	20	67	73.4	455	6.8
pH	6.5-8.4	5.7	4.0	6.7	7.5
CN^- (mg/L)	0.10	0.04	0.08	0.016	0.001
HCO_3^- (mg/L)	1.5-8.5	0.25	0.96	0.48	0.19

Ca: Calcium; Mg: Magnesium; K: potassium; Na: Sodium; Co: Cobalt; Cr: Chromium; Cd: Cadmium; Pb: Lead; Ni: Nickel; EC: electrical conductivity; TDS: total dissolved solids; TSS: total soluble solids; BOD_5: biologically oxygen demand; O&G: oil and grease; CN^-: cyanide; HCO_3^-: carbonate AW: abattoir wastewater; BW: bathroom and laundry wastewater; CE: cassava effluent; RW: rainwater; nd: not detected. *Wastewater reuse standards for irrigation. Source: (FAO; Pescod, 1992).

According to Mojiri (2011), the soil pH decreases initially with wastewater application but subsequently increases.

Interestingly, none of the trace elements and heavy metals, Co, Cr, Cd, Pb and Ni, was detected in all the wastewater and rainwater samples analyzed. Also, Valipour et al. (2013) did not detect the presence of heavy metals (Fe, Al, Mn, Zn, Li), thus posing no threat to the environment.

Degree of soil hydrophobicity

The level of soil water repellency depends on the proportion of soil particles with a hydrophobic surface coating (Doerr et al., 2006), which is strongly influenced by the surface area of the soil. The descriptive statistics of maximum, minimum, median and quartile values of water droplet penetration time (WDPT) of the soil under different wastewater irrigation and control, rainwater are shown by the Box-whisker plot in Figure 1. Table 2 shows the classification of the degree of soil hydrophobicity under different wastewater treatments and vegetables. Irrespective of vegetables, wastewater had significant ($p<0.05$) effect on WDPT.

The CE treatment had the maximum WDPT while the lowest value was obtained from RW. However, the median value was highest in CE treatment and also lowest in RW treatment. In general, the descriptive statistics from AW and CE treatments were in the high range while that of RW were low (Figure 1). The initial hydrophobicity test showed that the pre-wastewater irrigated soil was wettable, with an average WDPT of 5.4 s. At the end of wastewater application, there was varying degree of WDPT values under the different wastewater treatments and vegetables, with average values ranging between 8.5 and 12.3 s.

The highest and lowest values from CE and RW treatments, respectively, with all values greater than the initial value (Table 2). The classification of the degree of soil hydrophobicity showed that the soils changed to slightly hydrophobic. This confirms that increased use of wastewater effluent for irrigation could increase the level

of water repellency and adversely affect soil hydraulic properties and water dynamics. The low degree of hydrophobicity in this study is attributed to the relatively short period of evaluation. Wallach et al. (2005) working on soil water repellency under prolonged irrigation withtreated sewage effluent in a semiarid environment found extreme to severe soil water repellency. The significant difference in the occurrence of hydrophobicity may be attributed to different organic matter load from these wastewaters, although further research is needed to ascertain this. Keizer et al. (2007) and González-Peñaloza et al. (2012) reported that soil hydrophobicity results from the input of hydrophobic organic compounds as a result of the addition of organic materials. Although, there was no significant difference ($p<0.05$) in the degree of repellency between the vegetables, however

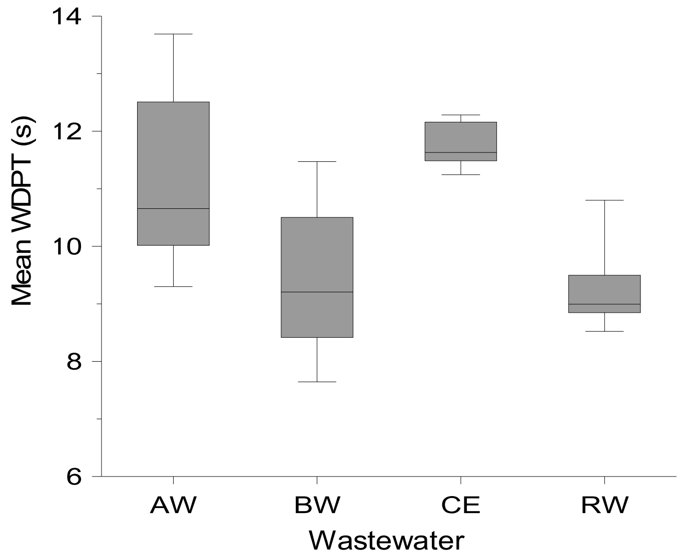

Figure 1. Box-whisker plot showing the maximum, minimum, median, and quartile values of water droplet penetration time (WDPT) of the soil under different wastewater irrigation and control, rainwater.AW: abattoir wastewater; BW: bathroom and laundry wastewater; CE: cassava effluent; RW: rainwater.

Table 2. Classification of the degree of water repellency of the soil under different wastewater irrigation and vegetables.

Treatment	WDPT, s		WDPT, s		WDPT, s	
	Initial	Classification	CA	Classification	SM	Classification
AW	5.4	WT	12.3	SR	10.0	SR
BW	5.4	WT	10.5	SR	10.3	SR
CE	5.4	WT	11.7	SR	13.7	SR
RW	5.4	WT	7.2	SR	9.4	SR
Average	5.4	WT	10.4	SR	10.3	SR
WW				9.92*		
Veg				0.02ns		
WW x Veg				4.53*		

SM: Eggplant (*S. macrocarpon*); CA: Lagos spinach (*C. argentea*); AW: abattoir wastewater; BW: bathroom and laundry wastewater; CE: cassava effluent; RW: rainwater; WW: wastewater effect; Veg: vegetable effect; WW x Veg: wastewater x vegetable interaction. WDPT: water droplet penetration time, seconds. WT: wettable; SR: slightly repellence. *: significant; ns: not significant at 5% level of probability by Fisher`s Least Significant Difference (LSD) test.

significant interaction on water repellency was obtained between the wastewaters and vegetables (Table 2).

Effect of wastewater irrigation on crop evapotranspiration

Crop evapotranspiration is a combined result of evaporation from the soil surface as well as transpiration from the plant. The evaporation from the soil surface is a function of the soil moisture condition, crop growth stage, the fraction of the soil surface covered by plant canopy etc., while transpiration depends on leaf area index, evaporative demand of the atmosphere and soil moisture condition.

The temporal variability of average values of crop evapotranspiration (ETc) of both vegetables and evaporative demand of the screen house microclimate (ETo) during the growing period are presented in Figure 2 while Table 3 shows the statistical comparison of the temporal distribution of consumptive water use and total water use (ETcTot) of both vegetables under different wastewater irrigation. Based on the limited weather data (maximum and minimum as well as wet- and dry-bulb

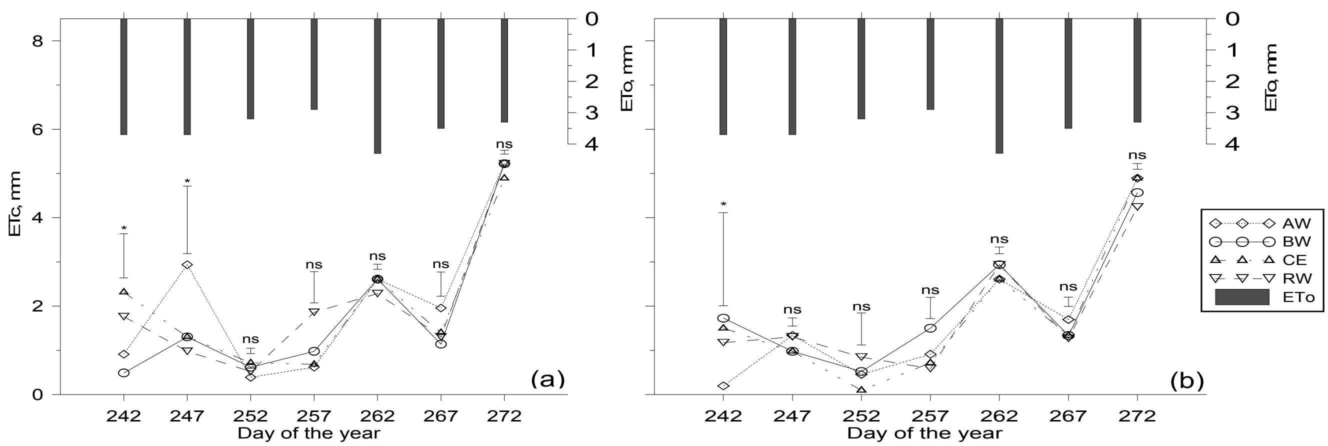

Figure 2. Temporal variability of average values of crop evapotranspiration (ETc), mm, of (a) Eggplant (*S. macrocarpon*), and (b) Lagos spinach (*C. argentea*) vegetables and evaporative demand of the screen house microclimate (ETo), mm, during the growing period between August and September 2013.AW: abattoir wastewater; BW: bathroom and laundry wastewater; CE: cassava effluent; RW: rainwater*significant and ns: not significant at 5% probability level by Fisher`s LSD test.

temperatures) of the screen house, the evaporative demand of the screen house climate (ETo) was not more than about 4 mm/day (Figure 2). The reliability of the ETo values was compared with Valipour (2014) who evaluated the potential evapotranspiration in Iran provinces using combinations of limited weather data of temperature only; temperature and relative humidity only; and temperature, relative humidity and wind speed. The author found the coefficient of determination, R^2, greater than 0.93 when compared with full weather data set.

There was significant effect of wastewater on ETc during the first two weeks of monitoring (Table 3), however, there was no discernible trend as regards the daily ETc with respect to crop growth stage as the average ETc values either rise or fall throughout the growing period (Figure 2). For the SM vegetable, the average ETc at the onset of the monitoring period (a week after transplanting) ranged between 0.49 and 2.32 mm/day, with the significantly ($p<0.05$) highest value from CE treatment. At the middle of the evaluation period, the ETc was low in some cases, with the average ETc values ranging between 0.62 and 1.86 mm/day, and no significant difference among the wastewater treatments. At the end of the evaluation period, the ETc was high, ranging between 4.90 and 5.22 mm/day, also with no significant difference among the wastewater treatments (Figure 2a). For the CA vegetable, similar trend was observed on the temporal distribution of ETc but different results were obtained from the wastewater treatments (Figure 2b).

At the initial period of evaluation, the average values of ETc ranged between 0.20 and 1.73 mm/day, with the significantly highest value from BW. At the middle of the evaluation period, the ETc was also low, with values between 0.59 and 1.50 mm/day, with no significant effect from the wastewaters. At the end of the evaluation period, the ETc was not more than 4.90 mm/day, with no wastewater treatment superior over one another (Figure 2b).

A comparison of both vegetables showed no significant difference in the values of ETc throughout the growing period, however there was significant interaction between the wastewater treatments and vegetables only at the first week of evaluation (Table 3). The trend in the ETc values agrees with the findings of Igbadun (2012) who used mini-lysimeters to estimate the crop water use of maize and groundnut in northern Nigeria. Shukla et al. (2007) in their study on water use and crop coefficient(Kc) for watermelon in southwest Florida reported that the Kc of watermelon determined from the lysimeter study was comparable to the Kc by FAO-Penman Monteith (Allen et al., 1998). The ETc trend is a function of the evaporative demand of the screen house microclimate which is also influenced by that of the outside air. Comparing the two vegetables, there was differences in the trend of ETc. Igbadun (2012) also found different ETc values for maize and groundnut crops, respectively. The differences in the response of the two vegetables to wastewater treatments were not unexpected because crop response to different management practices is not always the same as a result of differences in crop specie and physiology.

Table 4 shows the results of the soil water balance of the wastewater irrigated vegetables. For the entire evaluation period, the total amount of waste- and rainwater applied was 109.64 mm, the total deep percolation (Dp) ranged from 39.84 to 50.00 mm while the change in soil water storage (ΔS) had values between 4.89 and 12.07 mm (Table 3).

The total crop evapotranspiration (ETc) of the SM vegetable under the different wastewater treatments ranged between 52.96 and 57.72 mm while that of CA

Table 3. Statistical comparison of the temporal distribution of consumptive water use and total water use (ETcTot) of both vegetables under different wastewater irrigation.

Statistical parameter	Day of the year during the growing period							
LSD(p<0.05)	242	247	252	257	262	267	272	ETcTot
WW	5.16*	3.88*	0.78^{ns}	1.38^{ns}	0.07^{ns}	2.34^{ns}	0.16^{ns}	1.48^{ns}
Veg	0.76^{ns}	3.62^{ns}	0.30^{ns}	0.18^{ns}	0.60^{ns}	0.05^{ns}	2.12^{ns}	2.26^{ns}
WW x Veg	3.76*	2.54^{ns}	1.80^{ns}	2.66^{ns}	0.24^{ns}	0.28^{ns}	0.39^{ns}	1.52^{ns}

WW: wastewater effect; Veg: vegetable effect; WW x Veg: wastewater x vegetable interaction; ETcTot: total crop evapotranspiration.
*: significant; ns: not significant at 5% level of probability by Fisher`s Least Significant Difference (LSD) test.

Table 4. Soil water balance of the wastewater irrigated vegetables showing total irrigation applied, I; deep percolation, Dp; change in soil water storage, ∆S and crop evapotranspiration, ETc.

Vegetable	Wastewater	I (mm)	Dp (mm)	∆S (mm)	ETc (mm)
SM	AW	109.64	39.84	12.07	57.72
	BW	109.64	50.00	4.89	54.75
	CE	109.64	49.83	6.85	52.96
	RW	109.64	47.02	6.20	56.42
CA	AW	109.64	43.07	11.75	54.82
	BW	109.64	40.82	9.79	59.03
	CE	109.64	44.41	11.09	54.13
	RW	109.64	43.17	5.22	61.25

SM: Eggplant (*S. macrocarpon*) CA: Lagos spinach (*C. argentea*)AW: abattoir wastewater; BW: bathroom and laundry wastewater; CE: cassava effluent; RW: rainwater.

vegetable was between 54.13 and 61.25 mm, with SM vegetable having slightly higher ETc. The differences in soil water storage were attributed to the effect of the wastewater treatments on soil hydraulic properties and water dynamics. Cerdà and Doerr (2007) said a reduction in water infiltration due to wastewater irrigation could reduce amount of plant available water, with negative effect on crop growth and development. Although, the soil samples were packed into the mini- lysimeters using field bulk density and moisture content, however such natural condition is rarely attainable because of the rearrangement of soil particles due to alternate drying and wetting cycles caused by irrigation. During the reconsolidation process the effective stress in the soil approaches zero, causing the soil matrix to collapse under its own weight, thus decreasing the size and number of macropores at varying degree. Also the dynamic forces (adsorption and momentum) of the wastewater moving through the pores tend to compress the soil matrix. Thus, the marked differences in deep drainage and soil water storage among the treatments.

Conclusion

The occurrence of soil hydrophobicity and water use pattern of two indigenous vegetables under different wastewater irrigations was investigated. Wastewater irrigation significantly (p<0.05) influenced the occurrence of soil hydrophobicity, as the initially wettable soil changed to slightly hydrophobic, with the highest degree from cassava effluent wastewater treatment. The ETc of both vegetables was significantly (p<0.05) affected, although not more than two weeks after sowing while none of the wastewater treatments was dominant as regards the temporal distribution of the ETc. The continuous application of wastewater for irrigation will tend to increase the level of water repellency, adversely affect soil hydraulic properties and water dynamics and influence soil water retention.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Abegunrin TP, Awe GO, Idowu DO, Onigbogi OO, Onofua OE (2013). Effect of wastewater irrigation on soil properties and growth of cucumber (*Cucumis sativa*). J. Soc. Sci. Environ. Manage. 4(7):139-145.

Allen RG, Pereira LS, Raes D, Smith M (1998). Crop evapotranspiration: guidelines for computing crop water requirements. FAO. Irrigation and Drainage Rome: Italy. 56:328.

Ashraf E, Shah F, Luqman M, Younis M, Aziz I, Farooq U (2013). Use of untreated wastewater for vegetable farming: a threat to food safety. Int. J. Agric. Appl. Sci. 5(1):27-33.

Cerdà A, Doerr SH (2007). Soil wettability, runoff and erodibility of major dry-Mediterranean land use types on calcareous soils. Hydrolog. Proc. 21:2325-2336. Available online: <http://onlinelibrary.wiley.com/doi/10.1002/hyp.6755/pdf>.

Accessed: 20th June, 2014. doi: 10.1002/hyp.6755.

Dekker LW, Jungerius PD (1990). Water repellency in the dunes with special reference to The Netherlands. Catena 18:173–183.

Doerr SH, Shakesby RA, Dekker LW, Ritsema CJ (2006). Occurrence prediction and hydrological effects of water repellency amongst major soil and land-use types in ahumid temperate climate. Euriron. J. Soil Sci. 57:741-754.

Ensink JHJ, van der Hoek W, Matsuno Y, Munir S, Aslam MR (2002). Use of untreated wastewater in peri-urban agriculture in Pakistan: Risks and opportunities. Research Report 64. Colombo, Sri Lanka: Int. Water Manage. Institute, P. 32.

González-Peñaloza FA, Cerdà A, Zavala LM, Jordán A, Giménez-Morera AG, Arcenegui V (2012). Do conservative agriculture practices increase soil water repellency? A case study in citrus-cropped soils. Soil. Tillage Res, 124:233–239.

Igbadun HE (2012). Estimation of crop water use of rainfed maize and groundnut using mini-lysimeters. Pacific J. Sci. Tech. 13(1):527-535.

Khalil S, Kakar MK (2011). Agricultural Use of Untreated Wastewater in Pakistan, Asian J. Agri. Rural Develop. 1: 21-26.

Kauser S (2007). Water use in vegetable production in district Faisalabad. MSc Thesis, Department of Environmental and Resource Economics, University of Agriculture, Faisalabad, Pakistan.

Kawamoto K, Moldrup P, Komatsu T, de Jonge LW, Oda M (2007). Water repellency of aggregate size fractions of a volcanic ash soil. Soc. Sci. Soc. Am. J. 71:1658-1666. Available online: <https://www.soils.org/publications/sssaj/pdfs/71/6/1658>. Accessed on: 20th June, 2014. doi: 10.2136/sssaj2006.0284.

Keizer JJ, Doerr SH, Malvar MC, Ferreira AJD, Pereira VMFG (2007). Temporal and spatial variations in topsoil water repellency throughout a crop-rotation cycle on sandy soil in north-central Portugal. Hydrol. Proc. 21:2317–2324.

King PM (1981). Comparison of methods for measuring severity of water repellence of sandy soils and assessment of some factors that affect its measurements. Austr. J. Soil Res. 19:275–285.

Madsen MD, Zvirzdin DL, Petersen SL, Hopkins BG, Roundy BA, Chandler DG (2011). Soil water repellency within a burned pinon–juniper woodland: sparial distribution, severity, and eco-hydrologic implications. Soc. Sci. Soc. Am. J. 75:1543–1553.

Martin DL, Gilley GP (1993). Irrigation water requirements. In: National Engineering Handbook, Chapter 2, Part 623, USDA/SCS, P. 284.

Mataix-Solera J, Arcenegui V, Guerrero C, Mayora AM, Morales J, González J, García-Orenes F, Gómez I (2007). Water repellency under different plant species in a calcareous forest soil in a semiarid Mediterranean environment. Hydrol. Proc. 21:2300–2309.

Müller K, Deurer M (2011). Review of the remediation strategies for soil water repellency. Agric. Ecosyst. Environ. 144:208-221. Available online: <http://www.sciencedirect.com/science/article/pii/S0167880911002878>. Accessed: 20th June, 2014. doi: 10.1016/j.agee.2011.08.008.

Ojo DO, Olaleye O, Alabi OO, Atobatele JT, Chianu JN (2011). Integrated Harvesting Techniques for African Egg Plant (*Solanum macrocarpon* L. cv. Igbagba). Am. J. Exper. Agric. 1(4):458-465.

Olaniyi JO (2006). Influence of Nitrogen and Phosphorus fertilizers on seed yield and quality of Wgusi melon (*Citrullus lanatus* (Thumb) Mansf) in Ogbomoso, Southwest Nigeria. Ph.D Thesis, University of Ibadan, pp. *57-155.*

Osakwe SA (2012). Effect of cassava processing efluente on physical and chemical properties of soils in Abraka and Environs, Delta State, Nigeria. Chem. Mat. Res. 2(7):27-39.

Pescod MB (1992). Wastewater treatment and use in agriculture, FAO Irrigate. Drain. P. 47. FAO, Rome.

Rijsberman F (2004). Sanitation and access to clean water. In: Lomborg B (ed) Global crises, global solutions. Cambridge University Press, London.

Soil Survey Staff (2010). Keys to Soil Taxonomy, 11th ed. USDA - Natural Resources Conservation Service, Washington, DC.

Shukla S, Jaber F, Srivastava S, Knowles J (2007). Water use and crop coeficiente for watermelon in southwest Florida. Final Report, Report No. WRP-LY-0009, Deliverable 9. Institute of Food and Agricultural Sciences (IFAS), University of Florida, Immokalee, 70pp.

Tabatabaei SH, Najafi P, Amini H (2007). Assessment of Change in Soil Water Content Properties Irrigated with Industrial Sugar Beet Wastewater. Pak. J. Biol. Sci. 10:1649-1654.

United Nations (2003). Water for people, water for life. The United Nations world water development report. Barcelona: UNESCO.

USDA (2013). Cockscombs or Silver cock's comb (*Celosia argentea*). US Department of Agriculture. Accessed on 13 December, 2013.

Valipour M, Mousavi SM, Valipour R, Rezaei E (2013). Deal with environmental challenges in Civil Engineering projects using a new technology. J. Civil Environ. Eng. 3:126. Doi.10.4172/2165-784X.1000126.

Valipour M (2014). Analysis of potential evapotranspiration using limited weather data. Appl. Water Sci. Doi. 10.10071S1320-014-0234-2.

van der Hoek W, Ul Hassan M, Ensink JHJ, Feenstra S, Raschid-Sally L, Munir S, Aslam R, Ali N, Hussain R, Matsuno Y (2002). Urban wastewater in Pakistan: A valuable resource for agriculture. Research Report 63. Colombo, Sri Lanka: IWMI.

Vogelmann ES, Reichert JM, Prevedello J, Awe GO (2013). Hydro-physical processes and soil properties correlated with origin of hydrophobicity. Ciência Rural 43(9):1582-1589.

Wallach R, Ben-Arie O, Graber ER (2005). Soil water repellency induced by long-term irrigation with treated sewage effluent. J. Environ. Qual. 34:1910-1920.

Yao H, Zhang S, Xue X, Yang J, Hu K, Yu X (2013). Influence of the sewage irrigation on the agricultural soil properties in Tongliao City, China. Front. Environ. Sci. Eng. 7(2):273-280.