Treated wastewater irrigation effects on aggregate stability of Sandy loam soils in Semi-arid Tropical Zone of Nigeria

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ABSTRACT: *Irrigation with treated wastewater (TWW) for agricultural production is gradually becoming very important recycling option that substitutes fresh water (FW) particularly in water stressed regions like the Semi-arid Tropical zone of Nigeria. However, owing to high salt concentrations, dissolved organic matter and organic compounds found in the TWW occasionally, its application can have potential adversative impacts such as reduction of soil aggregate stability (SAS), which in turn affects soil quality. To assess the impact of TWW irrigation in comparison to FW irrigation on soils aggregation and SAS, wet sieving technique and the relationship of coefficient of variation (KV) and Mean Weight Diameter (MWD) were applied, while normal standard procedure was used for determination of some selected soil chemical and physical characteristics. The results indicated that the application of TWW increased the soil aggregate stability, and significantly highest (P<0.05) in phase III soils compared to other phases and control treated soils possibly due to relatively high organic matter content in the TWW sites compared to FW sites. Furthermore, the TWW is characterized by low concentration of salinity and sodicity parameters such as EC and Na, and comparatively high microbial glue like adhesive substances from the OC of the TWW soils. This in turn improve the aggregation, structural stability of the topsoil on one hand, and reduce the soils vulnerability to erosion on the other hand by binding micro-aggregates together to form macro-aggregates and larger pore spaces between micro-aggregates. Consequently, leading to improved water infiltration and permeability. Overall, the results indicated that the use of TWW for irrigation is a viable option, but care should be taken on the type and composition of the TWW particularly with regards to soluble salts concentration, organic and inorganic substances, as they can influence soils aggregate stability with other soil physical and chemical properties. This will consequently affect general soil quality and crop yield.*

KEYWORDS: Salinity; soil aggregate stability; irrigation; treated wastewater; Nigeria.

INTRODUCTION

Due to fresh water (FW) scarcity as a result of high pressure demand, treated wastewaters (TWWs) are now becoming the state of the art wastewater recycling options for irrigation agriculture particularly in arid and semi-arid tropical regions (Ghareibeh et al., 2016; Almuktar et al., 2018). This is owing to their prospective features of reducing pressure demand on the natural fresh water reserves coupled with provision of rich essential nutrients for soil fertility and quality improvement, crop growth and development when effectively and accurately treated. Moreover, due to provision of the nutrients, the TWWs help farmers save their money from buying organic and inorganic fertilizers, with simultaneous environmental protection from direct wastewater pollution (FAO, 2012; Sani et al., 2020). In addition, high temperatures of the tropical region that lead to fast organic matter (OM) decomposition and depletion, scarce rainfall with sparse vegetation leading to little inputs of OM turnover in to the soil warrant the need for the lost organic matter replenishment via the wastewater application on one hand. On the other hand, the need for disposal of TWW, water scarcity and low soil fertility in the regions have justified that large amounts of the TWWs be used for irrigation and fertility purposes in these countries (Mahmoud et al., 2012).

Substitution of FW by TWW application in agricultural irrigation has been reported as an imperative soil and water conservation strategy because of its positive contribution in improving soil physical properties such as aggregate stability (AS) (Ghareibeh et al., 2016; Sani et al., 2020) via indirect increase of OM content. Subsequently, the OM increases soil fertility and quality improvement depending on the sources, constituents and types of the wastewater applied. For example, Mahmoud et al (2012) expounded that Olive mill untreated wastewater have increased AS and OM concentration in their research conducted in Mediterranean countries while the reverse was the case in the experiment conducted in Spain soils (Morugan-Coronado et al., 2011) using TWW from textile industry compared to fresh water (FW). Furthermore, the authors demonstrated that there was an increase in electrical conductivity (EC) and sodium ion concentration in the soil because of the high former parameter concentration in the wastewater indicating positive correlation between increase in salt concentration and decrease in soils AS (Schacht and Marschner, 2015). However, some studies revealed no differences in AS between TWW and FW irrigation on their experimental soils (Bhardwaj et al., 2007).

Previous studies have demonstarted that application of TWW as irrigation amendment can effectively increase OM concentration and soil fertility in a shorter term (Morugan-Coronado et al., 2011) and longer term (Ghareibeh et al., 2016). The increase in OM enhances aggregate stability and carbon sequestration (Whalen and Chang, 2002) leading to decrease in global warming because of the carbon entrapment in the soil's aggregates. In addition, the TWW can improve soil physical, chemical and hydrological parameters (Mohawesh et al., 2013; Ghareibeh et al., 2016) when adequately treated and properly applied. AS is an important indicator used in evaluating soil structure and texture, erosion resistance, soil infiltration and permeability, ease of seedling emergence and prediction of soil's capability to sustain long-term crop production (Letey et al., 1985; Mahmoud et al., 2012). Furthermore, it is now an index of carbon sequestration capability of agricultural soils because of its role in entrapping carbon in both micro and macro aggregates and subsequent reduction in global warming which makes it to be an important topic of research recently in soil science globally (Whalen and Chang, 2002; Halima et al., 2009; Villasica et al., 2018).

Aggregate stability is defined as the ability of bound soil particles by cohesive forces to withstand the applied disruptive forces by either wind or water which will otherwise disintegrate the soil particles into different aggregates leading to their erosion (Kemper and Rosenau, 1986; Sani et al., 2009) and influences soil quality.

In arid and semi-arid countries like Nigeria, soil degradation is one of the main environmental problem as a result of insufficient agricultural management of irrigation with low-quality treated wastewaters (Anderson, 2003; Sani et al., 2020). In addition, the soils in the region are prone to losing OM via oxidation as a result of high temperatures in the climate. Hence, the application of TWW rich in OM could be a potential alternative for fresh water use in irrigation and additional source of nutrients which when applied appropriately, will improve soil properties and increase the storage of organic carbon in the soil and enhance its aggregate stability (Whalen and Chang, 2002; ;Ghosh et al., 2018; Sani et al., 2020).

However, if the TWW contains high concentration of salinity parameters such as EC and Na, many studies (Bhardwaj et al., 2007; Morugan-Coronado et al., 2011) have shown that irrigation with the wastewater could rupture the soil aggregates. Subsequently, reducing the soil stability, hydraulic conductivity, increase in surface sealing, increase in water runoff and erosion problems leading to soil compaction and a decrease in soil aeration with negative impact to crop production and soil environment. Hence, aggregate stability improvement could lead to enhancement of soil structure leading to soil carbon sequestration by the binding aggregates which in turn will decrease global warming effect and increase resistance of the soil against erosion by either wind or water. Moreover, the benefits of aggregate stability is not only restricted to erosion control and soil quality relationship (Whalen and Chang, 2002), it also has the ability to reduce nutrient (particularly phosphorus) transport from agricultural soils to water bodies through leaching and runoff processes (Whalen and Chang, 2001).

This research will be useful to environmental and agricultural authorities with provision of established interpreted data and information on the role of TWWs and their potential effect when applied as irrigation amendments particularly on soils aggregate stability for sustainable agricultural production and development with concomitant environmental protection.

Although, concerted efforts were made on assessing AS in Semi-arid Tropical regions of Nigeria like Ogunwole (2008), Sani (2009) and Lawal et al.(2009) who assessed the correlation between aggregate stability and carbon concentration after long term application of manure and inorganic fertilizers, and changes in aggregate stability and carbon sequestration mediated by land use practices on Savanna alfisols respectively, data on the effect of industrial TWWs irrigation on aggregate stability of the soils in the regions are scarce.

The overall aim of this study was to assess the AS of the sandy loam soils irrigated with discharged TWW in Sharada industrial estate, Kano state, semi-arid tropical zone of Nigeria with the following objectives;

1- The impact of applied TWW on soils aggregate;
2- Assess the stability of the soil aggregates after log-term irrigation with the TWW

MATERIALS AND METHODS

Experimental site

This experiment was conducted on the soils of Sharada industrial area in Kano, Northern Sudan Savannah ecology of Nigeria, located between longitude 8^{o} and 9^{o}E and latitude 10^{o} and 12^{o}N in the Semi-arid ecological Savannah zone of the country. The area is tropical wet and dry type with seasonal variation in between June to October and November to May respectively and a stable temperature of 26^{o}C with highest value of 39^{o}C occurring in the month of April/May and the lowest of 14^{o}C in December (Sani et al., 2021). The experimental soils are located in three phases; phase I, II and III respectively. Each phase has a concentration of many industries in no order ranging from battery production factories, sacks and nylon manufacturing companies, oil and gas, textiles and tanneries, plastic industries etc. The TWW released from these industries admix and drain into gutters through the industries discharge outlets and combine with domestic waste water released from the municipal houses in the area. The mixture subsequently empties into a concrete open sink, where the farmers in the area use it for their soil irrigation (Sani et al., 2020). The type of irrigation practiced by the farmers in the area was surface irrigation.

Field sampling

Soil samples were collected from three different locations (Sharada phases I, II and III) using auger. In each phase, ten representative soil samples were collected and bulked from the surrounding farms at a depth of (0-30cm) using simple random technique to make three composite samples beside control. All samples were kept in a well label polythene bags for laboratory analysis.

Routine laboratory analyses

Soil pH and EC were determined using pH and conductivity meters respectively, Cation Exchange Capacity (CEC) was determined using neutral pH_7 in NH_4OAC saturation method as described by Anderson and Ingram (1993). Organic Carbon (OC) was estimatd by the dichromate oxidation method as detailed by Nelson and Sommers (1982) while Mechanical analysis was done by standard hydrometer method as outlined by Gee and Bauder (1986). Total Phosphorus (P) was determined by acid digestion as outlined by Murphy and Relay (1962), Total Nitrogen (TN) content was evaluated using the micro-Kjeldhal technique as described by Bremmer (1982) while The exchangeable bases of Na and K were determined using the flame photometer; Mg and Ca were determined using atomic absorption spectrophotometer.

Aggregate stability and sizes determination

Composite soil samples previously sieved through 5-mm mesh was used to determine aggregate stability (Kemper and Rosenau, 1986; Zhang and Horn, 2001) using wet sieving method. 200g of soil was transferred into the upper sieve (>2.0 mm) and immersed in water 50 times or strokes, others; 1 mm, 0.6 mm, 0.25 mm, 0.15 mm were immersed 45, 40, 35 and 30 strokes respectively. Soil remaining in the sieve was collected separately in a metallic container and oven dried for 24 hrs at 105 ^{0}C then weighed and recorded against the sieve size. Water soil mixture that passes through the 2 mm sieve was stirred and made to pass through the second sieve (1.0 mm) into the second bucket, by immersing 45 times or strokes. The fraction that finally remained on the 1.0 mm sieve was also collected separately and oven dried for 24 hrs at 105 ^{0}C and recorded against the sieve.

The procedure was repeated for all the sieves up to the 0.05 mm sized sieve and the aggregate stability was calculated using the relationship of KV (Co) = I/MWD, where KV is an index of aggregate stability evaluation (Valle et al., 2000), I= upper sieve mean diameter, and MWD is the mean weight diameter of the >2mm sieve size particles. The soil aggregates were analysed after being air-dried and gently sieved to separate macro-aggregates (>2mm in size) usually between 3-5mm from the micro-aggregates (<2mm in size). The macro-aggregates were then dried at 40^{0}C for 24h before subsequent analyses (Mahmoud et al., 2012).

Irrigation Water Quality

The TWW used for irrigation of the soil of the area was generated from wastewater treatment outlets of the Sharada industries. The released TWW from the three phases empty into a concrete open furrow, where the farmers in the area use it for their surface soil irrigation. The use of the industrial TWW as irrigation water has been in practice by the farmers for over thirty years (Abdu et al., 2011). The soils that receive no TWW are designated as FW treated soils and as control. The key characteristics of the TWW are depicted in table 1 below:

Table 1 Overall Mean Values of Treated Wastewater Parameters Used for Irrigating the Sandy loam soils in Sharada Industrial area in different phases

	Treated wastewater			Fresh water
Parameters	Phase I	Phase II	Phase III	Control
COD (mg/l)	329.30	341.70	378.30	2.61
EC(ds/m)	0.62	0.58	0.45	0.020
Mg (mg/l)	58.07	53.02	52.27	0.92
Ca (mg/l)	131.15	155.74	122.95	0.49
HCO_3 (me/l)	488.00	305.00	305.00	12.27
K (mg/l)	18.99	17.72	13.50	0.21
Na (mg/l)	12.77	12.27	11.11	0.09
Cl (me/l)	177.50	159.75	124.25	5.12
TDS (mg/l)	337.00	353.00	275.00	27.00
NO_3-N (mg/l)	119.09	59.54	31.53	3.13

Statistical analysis

To assess the effects of the treated wastewater on aggregate stability and other selected soil parameters in different phases and their corresponding differences, data mean values of the parameters in each phase were subjected to analysis of variance (ANOVA) using SPSS Statistical package. The treatment means were separated using Duncan Multiple Range Test (DMRT) at 5% level of probability

RESULTS AND DISCUSSION

Effect of TWW and FW on aggregate characteristics

Comparison of >2mm macro-aggregates

As a result of long-term irrigation with TWW, the proportion of >2mm macro-aggregates recorded the highest values in phase III irrigated soils followed by phase II and control while phase I amended soils recorded the least values (Table 2). Although, no statistical significant differences (P>0.05) recorded, the highest proportion of macro-aggregates fractions observed in phase III amended soils could be attributed to the relatively high OC concentration in the soils compared to other phases and control amended plot. This high OC helps in binding individual soil particles together to form macro-aggregates (Mahmoud et al., 2012) and could help control water erosion. Several studies have indicated no clear significant trends and difference in soils macro-aggregates concentration in soils irrigated with TWW and FW (Levy et al., 2003; Bhardwaj et al., 2007) which is in agreement with the current study data. However, some studies reported increase of macro-aggregates as a result of TWW irrigation compared with FW (Morugan-Conarado et al.,2011; Ghareibeh et al., 2016) while others indicated decrease in the aggregates concentration (Levy and Mamedov, 2002; Schacht and Marschner, 2015). The plausible reason for these contradicting differences in results mentioned in the literature compared to our study data could be ascribed to types, composition, dose and frequency of the wastewater used for the irrigation (Wegner et al., 2007; Morugan-Conarado et al., 2011) in addition to the nature and type of the irrigated soil (Valla et al., 2000; Boruvka et al., 2002). Moreover, high or low concentration of salinity, sodicity and OC concentration could be another reason (Bhardwaj et al., 2007; Morugan-Coronado et al., 2011).

Comparison of <2mm micro-aggregates

The <2mm micro-aggregate proportion in the study irrigated soils showed a clear trend in increasing concentration from phase III to phase I and control irrigated soils (Table 2). Findings indicated that phase III recorded the highest values followed by phase II, phase I and control. Micro-aggregates are the basis for formation of macro-aggregates (Tisdal and Oades, 1982). They also help in trapping organic carbon in them due to presence of silt and clay that bind the organic matter with colloids. The differences in micro-aggregates concentration is not statistically different (P>0.05) as depicted in Table 2. The high concentration observed in < 2mm under phase III amended soils could be attributed to the bonding between binding agents produced by the release of soil organic matter in the applied TWW and silt + clay particles of the irrigated soils. Hence, could physically and chemically limit its decomposition leading to soil structure improvement with larger pore space between the micro-aggregates (Chaofu Weiet al., 2006), leading to water permeability and infiltration enhancement, and soil resistance to water erosion impact (Mahmoud e al., 2012). Sani (2009) reported that soil micro aggregates trap soil organic carbon in them due to the presence of clay and silt particles that bind the organic matter with colloids, and subsequent formation of macro-aggregates (Tisdall and Oades, 1982; Emerson, 2008), increasing aggregate stability and resistance to mechanical disruption of soil aggregates by tillage.

Effect of TWW and FW on aggregate stability
Comparison of Mean Weight Diameter (MWD)
MWD is an expression used in assessing AS of a soil structure, a very important soil property that directly or indirectly influences other physical and chemical properties of the soil and can be used as an index of soil degradation (Cerda 2000) because it is an indicator of soils resistance to erosion and structural damage.

The MWD of soil AS observations revealed that there was a significant difference ($P<0.05$) between the irrigated soils with FW and TWW (Table 2) in different phases. Phase III recorded the highest values of MWD followed by phase II, phase I and control treated with FW, though phase I and the control were statistically at par ($P>0.05$).

COD in a wastewater used for soil irrigation, is a source of the soil organic carbon (Sani et al., 2021). Considering the COD and OC concentrations of the TWW and FW (Table 1), and irrigated soils (Table 4a) respectively in different phases, findings indicated that there was a positive correlation between MWD, COD and the OC concentrations, and the MWD concentration was significantly higher in phase III soils in comparison to other phases and control or FW treated soils probably due to the high concentration of the organic carbon in the phase III soils which might have increased the MWD concentration and the AS.

Table 2: Aggregate fractions and mean weight diameter (MWD) with Coefficient of variation (KV) at the depth of 30cm after irrigation with industrial TWW and FW

Locations	MWD (mm)	Macro-aggregates (>2mm)	Micro-aggregates (<2mm)	KV (Coefficient of variation)
Control	0.1721^{b}	0.1725	0.1421	65.5^{a}
Phase I	0.1742^{b}	0.1523	0.1589	64.5^{a}
Phase II	0.2276^{ab}	0.1976	0.2167	38.5^{b}
Phase III	0.2740^{a}	0.2112	0.2211	30.5^{c}

Means having the same letters in the same column are statistically the same, NS = Not significantly different and Means are separated using DMRT at 5% level

The MWD as an index of AS confirmed that aggregate stability increased due to the long-term application of the industrial TWW (Mahmoud et al., 2012) in phase III soils compared to other phases and FW irrigated soils because of the high OC contents in the industrial wastewater. Many publications expounded that OC is one of the most important binding agent that improves AS (Tisdal and Oades, 1982;Pollakova, 2012; Simansky and Bajcan, 2014), and the stability increases the soil's resistance to differential slaking and swelling of clays by increasing the cohesion of the soil's aggregates through the binding of mineral particles by means of organic polymers or by the physical capture of the aggregates by roots or fungi (Chenu et al., 2000;Mahmoud et al., 2012) subsequently protecting the soil from the impact of erosion either by wind or water.

Though, some findings in literature showed high MWD values (Table 3) with corresponding AS classification (Le Bissonnais, 1996; Mahmoud et al., 2012) as very stable, medium stable, stable and unstable. According to the table, the AS of the current study fell within the unstable class. However, the reason behind this could be attributed to differences in the irrigation wastewater composition and the nature of the irrigated soils. For example, based on table, the MWD values in all TWW and FW irrigated soils were all below 0.62mm (unstable stability class) with corresponding values of 0.72% OC concentration. Nevertheless, the authors of the research used untreated olive mill wastewater (OMW) very high in OC contents (30.57g/l) compared to an average of 4.0g/l OC in the TWW used for irrigation in the current study (Table 1). Moreover, the soil of the reported research was silt loam and has high amount of clay in comparison to the current study sandy loam with low amount of clay concentration. In addition, the indices used to assess the stability classes were OC and MWD concentration under three AS tests; slow and fast wetting, and wet stirring. However, these tests were only applicable on saline and anthropogenic reclaimed dumpsite soils (Boruvka et al., 2002) which is different from the soils of the current study

Comparison of Coefficient of Vulnerability (KV)

Coefficient of vulnerability is an indirect measure of soil's AS expressed as KV, a proposed index of assessing soil structural stability by Valla et al. (2000), which is the number of times the initial size of soil aggregate will reduce due to any disaggregation mechanism, exposing the soil vulnerability to erosion by wind or water, hence, the higher the coefficient, the less stable the soil aggregates and vice-versa. The values of KV recorded in Sharada phases I, II, III and control soils irrigated with industrial TWW and FW ranged from 64.50, 38.50, 30.50 and 65.5 (Table 2) respectively.

Generally, structural vulnerability values were higher in control and phase I (65.50 and 64.50) compared with phase II and III (38.50 and 30.50) indicating the less stability of the soils aggregates in this order; control< phase I< phase II<phase III. This implies that control and phase I soils are more vulnerable to erosion indicating the less stability of the soils aggregates in comparison to other phases while phase III is less vulnerable and more stable to withstand disruptive forces of either wind or water erosion.

Considering the assertion of Valla et al.(2000), applied TWW in phase III soils have improved and increased the soils AS and decreased its vulnerability to mechanisms of disaggregation such as erosion, followed by phase II in comparison to phase I and FW treated soils probably due to relatively high MWD and OC contents (Tables 2 and 4a) recorded under the former phase compared to the latter phases and FW treated soils. Many studies have indicated that high amount of OC leads to high MWD concentration and high AS (Lopez-Pineiro et al., 2007; Mahmoud et al.,2012; Schacht and Marschner, 2015) leading to increases resistance of the soil against external forces of mechanical disruption such as tillage operations, resistance of aggregates to slaking and swelling, ploughing frequency (Zaher et al., 2005), protection against rainfall and irrigation water dislodge and rearrange of soil particles through forming surface sealing, retards in infiltration, runoff and erosion (Sani, 2009).

Effect of TWW and FW on some selected soil properties in the soil aggregates
Comparison of Soil Texture
The result of soil texture was depicted in Table 4b. It indicated that the soil texture in phase I, II, III and control soils treated with TWW and FW respectively recorded sand 88%, silt 4% and clay 8%; sand 78%, silt 8% and clay 14% and sand 62%, silt 20% and clay 18% for TWW. That of FW recorded values of sand 92%, Silt 2% and clay 8% in that order. However, no statistical significant ($P>0.05$) difference was recorded in all TWW and FW irrigated soils. Even though, no significant difference recorded, sand fraction dominated silt and clay particles, and the plausible reason for that could be attributed to high amount of particles from the TWW (Almuktar et al., 2018; Sani et al., 2020) and lack of any organic and inorganic amendments in the FW treated soils leading to the observed high sand particles compared to silt and clay, making the clay and silt fractions very low confirming the study of Pantami (2019) who reported similar trend of the soil texture sand, silt and clay fractions.

Table 3: Stability classification using OC concentration and MWD of Aggregate fractions for three aggregate stability tests; Slow and fast wetting, and wet stirring

Treatments	OC% conc.	MWD (mm)	Stability Class
Slow wetting	0.88	1.23	Medium
	3.67	2.72	Very stable
	3.50	3.39	Very stable
Fast wetting	0.72	0.62	Unstable
	2.52	1.82	Stable
	3.16	2.67	Very stable
Wet stirring	0.77	0.91	Medium
	3.42	2.47	Very stable
	3.19	3.05	Very stable

Modified from Le Bissonnais (1996) and Mahmoud et al. (2012)

Comparison of Soil pH

Soil pH is one of the most important soil parameter as it affects the movement of soil trace elements and their distribution. In a decreased soil pH condition, most essential plant nutrients are not much available compared to non-essential that, become more available and can reach toxic levels (Sani et al., 2020).

The result of soil pH in the soils irrigated with TWW and FW was presented in Table 4a. The soil pH range was between 6.8 and 7.1 in all the three phases and control soils. The result indicated no statistical significant difference recorded (P>0.05) between the irrigated soils and H^+ concentrations. pH values recorded in the current study could be considered neutral (Msanya, 2012) possibly due to low amount of dissolved salts in both TWW and FW since high pH means higher amount of dissolved salts (Pantami, 2019) in the irrigation water. This indicates no effect and threat to increase in aggregation and aggregate stability of the irrigated soils because high amount of dissolve salts leads to soil disaggregation and reduce aggregate stability with resultant negative effect to the soil structure and texture (Schacht and Marschner, 2015). The pH result obtained in this study was in agreement with the data reported elsewhere (Sani et al, 2020, 2021).

Comparison of Electrical Conductivity

Electrical conductivity (EC) is a soil salinity indicator (Bauder et al., 2011). The EC findings of both TWW and FW irrigated soils were presented in Table 4a. The results indicated that the mean EC values recorded were highest in phase III followed by Phase II, phase I and FW irrigated soils, and were statistically (P>0.05) similar (Table 4a). The possible reason behind this high EC values in phase III compared to other phases and FW treated soils could be attributed to high amount of solid particles in the TWW of phase III industries likely due to the intrusion of domestic or agricultural waste water that contain high amount of solids (Maradi et al., 2013). However, all the EC values complied with recommended threshold values of 0-4dS/m in soils (FAO, 1993) indicating no threat of salinity and decrease in aggregation and aggregate stability in the soils that could hinder infiltration, water permeability, resistance to soil and water erosion (Schacht and Marschner, 2015), and overall growth and productivity of grown crops (Bauder at al., 2011; Sani et al., 2021). The EC results of this study was in agreement with the data reported elsewhere (Sani et al., 2021)

Comparison of the Exchangeable Bases (Ca, Mg, K and Na)

The result of exchangeable bases was shown in Table 4b. Findings indicated that the concentration of Ca and Mg was stable and in increasing order. FW soils recorded lowest values in comparison to other phases with phase III recording the highest values. The difference in Ca and Mg concentration was statistically (P<0.05) significant in all phases and FW treated soils. In contrast, the concentrations of K and Na were unstable and variable with no pattern of either increasing or decreasing order and recorded no statistical significant difference between (P>0.05) TWW and FW treated soils.

According to the literature rating (Esu, 1991), the concentration of all the exchangeable bases in the soils is low, as a result, this will not cause soil water permeability and infiltration difficulty

(Bauder et al., 2011; Sani et al., 2020), hence, a threat free to crop growth and development. Moreover, their concentration in the soil is not high enough to cause soil disaggregation, reduction in aggregate stability and vulnerability of the soil to danger of erosion (Valla et al., 2000).

Comparison of Organic Carbon

Soil organic carbon (SOC) concentration was highest in phase III followed by Phases II, I and FW treated soils but low in concentration according to the rating reported in literature (Esu, 1991). However, no significant statistical (P>0.05) difference was observed between the wastewater and the irrigated soils (Table 4a). Even though, no significant difference recorded, phase III soils accumulated higher OC in comparison to other soils likely attributed to high COD concentration from the TWW (Table 1). This OC in turn will enhance and improve aggregation and aggregate stability of the soils making them more resistant and less vulnerable to erosion when compared to other soils in the other phases and FW treated soils. Many publications indicated positive correlation between high OC and increase in both micro and macro-aggregates, aggregate stability and soils quality improvement (Bhardwaj et al., 2007; Morugan-Coranado et al., 2011; Mahmoud et al., 2012; Ghareibeh et al., 2016).

The data of OC concentration of the current study was in agreement with the result reported previously elsewhere (Sani et al., 2021).

Table 4a; Mean values of some Selected properties of >2mm Soil Aggregates at the depth of 30cm Treated with FW and Industrial TWW in different phases and their corresponding Statistical Significant Differences

Treatments	pH (H_2O)	pH ($CaCl_2$)	EC (dS/m)	O.C. (%)	N (%)	P (mg/kg)	CEC (Cmol/kg)	MWD
Control	7.100^{NS}	7.120^{NS}	0.7950^{NS}	0.595^{NS}	0.315^{c}	10.11^{b}	3.145^{b}	0.1721^{b}
Phase I	6.810^{NS}	6.803^{NS}	0.8800^{NS}	0.610^{NS}	0.470^{a}	11.91^{ab}	3.160^{b}	0.1742^{b}
Phase II	6.840^{NS}	7.003^{NS}	0.8067^{NS}	0.646^{NS}	0.350^{b}	13.12^{a}	6.283^{a}	0.2276^{ab}
Phase III	7.057^{NS}	6.933^{NS}	0.9833^{NS}	0.666^{NS}	0.503^{a}	10.32^{b}	6.600^{a}	0.2740^{a}

Means having the same letters in the same column are statistically the same, NS = Not significantly different and Means are separated using DMRT at 5% level

Comparison of Total Nitrogen

Table 4a indicated that both TWW and FW treated soils recorded low concentration of nitrogen (Esu, 1991), though phase III recorded highest values in comparison to other phases and FW treated soils probably due to confluence of human and animal faces (Nuruddeen et al., 2016), and excess nitrogenous compounds in the TWW from domestic and agricultural sources (Sani et al., 2020). Moreover, statistically significant differences were recorded (P<0.05) between the nitrogen concentration in the FW and TWW treated soils in different phases (Table 4a). Ammonium and nitrate nitrogen are the major sources of nitrogen in irrigation wastewater and when applied inform of irrigation amendment to soil in appropriate concentration, increase nitrogen content within the crops requirement. Furthermore, this high N contents in the soil serves as a source of energy to microorganisms that produce glue like microbial binding agents that bind soil aggregates leading to high aggregate stability (Annabi et al., 2017; Liu et al., 2019), increasing the soil structural stability and decreasing its vulnerability to soil erosion. However, in contrast, excessive N concentration above permissible limit, leads to soil nitrogen toxicity, soil acidification and exert harmful effects to the crops grown in the affected soils (Sani et al., 2020). A relevant research conducted in the region regarding the concentration of TN reported different data in comparison with the TN data obtained in the current study (Dawaki et al., 2013). Nevertheless, type and differences in the chemical compositions of the industrial wastes applied in the reported literature and that of the TWW used in the current study (Sani et al., 2020) could be the rationale.

Comparison of Cation Exchange Capacity

Table 4a showed the variability in Cation Exchange Capacity (CEC) concentration of the soils irrigated with FW and TWW. However, the CEC concentration is low based on literature ranking (Esu, 1991). Despite this, the result indicated that highest CEC values were recorded in phase III compared to other phases and FW treated soils with a significant difference (P<0.05) statistically. This could possibly be due to high percentage of clay particles, OC, TN and P in phase III TWW soils because they are responsible for retaining the exchangeable cations (Lickaz and Penny, 2001). Hence, if they are much in the wastewater, they rise the CEC concentration and vice-versa in the soils. Moreover, the increase in the CEC concentration of the soil increases SOC concentration that acts like glue which bonds micro-aggregates together to form macro-aggregates with resultant improvement in aggregate stability and reduction in aggregates vulnerability to erosion (Valla et al., 2004).

Table 4b; Mean values of some Selected properties of >2mm Soil Aggregates at the depth of 30cm Treated with FW and Industrial TWW in different phases and their corresponding Statistical Significant Differences

Treatments	Na (Cmol/kg)	Ca (Cmol/kg)	Mg (Cmol/kg)	K (Cmol/kg)	Sand (%)	Silt (%)	Clay (%)	Texture
Control	**0.09^{NS}**	**0.49^{c}**	**0.92^{b}**	**0.21^{NS}**	**90**	**2**	**8**	**SL**
Phase I	0.46 ^{NS}	1.62^{b}	1.01^{b}	0.63 ^{NS}	88	4	8	LS
Phase II	0.30 ^{NS}	2.52^{ab}	1.73 ^{a}	0.67 ^{NS}	78	8	14	SL
Phase III	0.12 ^{NS}	3.69^{a}	1.91 ^{a}	0.61 ^{NS}	62	20	18	SL

Means having the same letters in the same column are statistically the same, NS = Not significantly different and Means are separated using DMRT at 5% level
of confidence

Comparison of Phosphorus

The concentration of phosphorus (P) in soils irrigated with FW and TWW was presented in Table 4a.The result indicated that P concentration was higher in TWW phase II compared to other phases and FW treated soils with statistically significant (P<0.05) difference. Even though, P concentration recorded significant statistical difference across the TWW phases and FW soils, all the concentrations were not high according to the rating of Esu (1991). However, the reason for the high concentration of P in TWW phase II soils could be attributed to high P in the phase II industrial TWW (Sani et al., 2020), confirming the data previously reported by Toze (2006) and (Dawaki et al., 2013) who found very high levels of N and P association between domestic and industrial wastewaters. This indicates positive correlation between N and P concentrations in the soil with indirect promotion in the diversity of microorganisms in the soil and production of organic binding agents by the microbes that cement the soil aggregates and improve their stability, reduce their vulnerability to erosion and enhance soil quality (Annabi et al., 2017; Liu et al., 2019).

CONCLUSIONS

The irrigation of industrial TWW has been shown to have distinct effects on the properties of soil aggregates. Both micro and macro-aggregates and their stability increased with TWW application. This is a consequence of low salts concentration and relatively enhanced organic C content found in the wastewater, which binds the soil particles together. By that, on the one hand, larger interspaces are created, aggregation increases and on the other hand, stability improved. Overall, the results of this study indicates that irrigation with TWW relatively increased soil aggregate stability and other associated soil quality indices of Semi-arid sandy loam soils, and is accredited to the TWW induced decreases in soil sodicity and salinity parameters that are important indicators for soil quality. More studies on this are suggested to improve site-specific irrigation water and leaching management, which appears to be essential in order to prevent soil quality degradation as a consequence of irrigation with TWW.

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