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Impact of Mixing Biogas Liquid Manure with Soil on Water Infiltration under Flood Irrigation System

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Authors' contributions

This work was carried out in collaboration between all authors. Author MHEB executed field experiments, managed the experimental work and reviewed the measurements and the final manuscript. Author AMA made data analysis, managed the literature review and wrote the first draft of the manuscript. Author SGH participated in the field experiments and provided the electronic device for measuring infiltration time. All authors read and approved the final manuscript.

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ABSTRACT

Biogas liquid manure is byproduct from biogas production projects. It is free from insects, flies, mosquitoes. Since the biogas projects are currently deployed in Egypt and the trend towards increased use, so the mixing such manure with soil can affect the water infiltration into the soil. The study assessed the contributions of biogas liquid manure on water infiltration of a sandy clay loam soil when using three water qualities. The biogas liquid manure was applied at rates of 0, 2, 4 and 6 lit/m^2.The double-ring infiltrometer was used to get infiltration data. An electronic device was utilized to note the time the water begins to infiltrate. The results showed that the rate of biogas liquid manure and water quality had a significant effect on cumulative infiltration. The range of cumulative infiltration after 180 min was varied from 128 mm to 490 mm. The cumulative infiltration significantly decreases with the increasing of biogas liquid manure rate at any of water quality. The constants of the Kostiakov infiltration equation were influenced by biogas liquid manure and water quality. The

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highest constant (κ) of 14.6832 $mm/\min^{\alpha}$ was observed for application rate of 0 lit/m^2 biogas liquid manure to the soil and the lowest constant (κ) of 7.5895 $mm/\min^{\alpha}$ was observed for application rate of 6 lit/m^2.The highest constant (α) of 0.7217 was observed for application rate of 0 lit/m^2 of biogas liquid manure to the soil and the lowest constant (α) of 0.4728 was observed for application rate of 6 lit/m^2 biogas liquid manure to the soil. A multiple linear regression was employed to estimate final cumulative infiltration after 180 min based on the rate of biogas liquid manure and sodium adsorption ratio of used water with coefficient of determination of 0.9183. Moreover, a regression model was developed to estimate the cumulative infiltration at any time up to 180 min based on biogas liquid manure application rate and sodium adsorption ratio of water.

Keywords: Biogas liquid manure; water infiltration; Kostiakov; regression.

1. INTRODUCTION

Egyptian researchers have developed different techniques to produce biogas from animal wastes and also from different agricultural wastes to be an energy source for farmer houses applications [1-2]. However, 40% of the amounts of agricultural residues and animal wastes which were utilized in biogas production could produce energy and the rest percentage is biogas by-products [3]. Such biogas byproducts called manure or slurry. Generally, manure can be handled as a solid, semi-solid, slurry, or liquid. Manure of less than 4-5% solids can be handled as a liquid, manure of 5-10% solids can be handled as a slurry, manure of 10-15% solids can be handled as a semi-solid, and manure above 20% solids can be handled as a solid [4].

Soil irrigation using wastewaters is a promising practice in areas facing water scarcity and pollution of water resources by wastes. Depending on the composition, irrigation with wastewater might require the addition of greater quantities of gypsum to prevent physical degradation of the soil [5], may cause electrochemical changes and increase the nutrient content in the soil solution [6], or even the block or reduce the size of the pores when supplying sediments and do not improve soil permeability [7].

The biogas liquid manure is a valuable source of nutrients and organic matter for crop production and may be applied by a variety of methods, including irrigation, surface spreading and shallow subsurface injection [8]. Moreover, it improves the soil physical environment [9].

The speed at which soil is able to absorb rainfall or irrigation water is called infiltration rate [10]. It is a movement of water vertically downwards, lateral and upward in the soil [11] and is used in planning water conservation technique [12].

Infiltration rate is affected by several variables such as the amount of organic matter in the soil [13] and by quality of the irrigation water [14]. The two most common water quality factors which influence the normal infiltration rate are the salinity of the water and its sodium content relative to the calcium and magnesium content. Infiltration generally decreases with either decreasing salinity or increasing sodium content relative to calcium and magnesium. However, Emdad et al. [15] noticed that the infiltration under field conditions was inversely related to the sodium adsorption ratio of the applied water.

In literature, different studies have been conducted to show the effect of adding manure or similar materials on infiltration. Talebnezhad and Sepaskhah [16] showed that application of soil conditioners such as Bentonite reduced the infiltration rate. However the effects of Bentonite application rates of 0, 2, 4 and 6 g/L on infiltration of a loamy sand soil were determined in a soil column in the laboratory. The exponent of the Kostiakov infiltration equation was not influenced by Bentonite application rates. The maximum reduction in infiltration rate of Kostiakov equation coefficient and final infiltration rate occurred with 2 g/L Bentonite.

The research efforts must be undertake to decrease the environmental effects of byproducts from biogas projects. Furthermore, limited research has been done to quantify the beneficial effect of applying biogas byproducts such as biogas liquid manure to the soil. So, the main objective of the present work was to study the effect of levels of additive biogas liquid manure on a soil on water infiltration under different water qualities.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experimental work was conducted during April 2016 at Tractors and Farm Machinery Testing & Research Station at Sabahia, Alexandria Governorate, Egypt. This location lies between latitude 30.76° north and longitude 29.696° east.The soil in this location was represented condition of a broad area in the region.

Prior infiltration run, 5 soil samples were collected from the top soil layer (0-20 cm) of the tested soil. These samples were transferred to the laboratory located in Soils, Water and Environment Research Institute, Alexandria Branch for analysis. Air dry soil samples were ground to pass through a 2 sieve and soluble cations and anions were determined [17]. Analyses were done on soil extracts. Mechanical analysis was made by the hydrometer method and organic matter was calculated according to Black et al. [18] method.

The bulk density of the soil was determined by means of soil core, constant volume technique, with the use of a metal cylinder of 8 cm inside diameter and 10 cm high. The obtained samples were dried at 105℃ for 24 hours and the oven-dry weight was determined. Soil bulk volume was taken as the net inside volume of the metal cylinder also, soil moisture contents were determined.

The soil moisture content (MC,%db) was calculated according to Black et al. [18] as following:

$$MC = \frac{SW - SD}{SD} \times 100 \tag{1}$$

Where SW is wet soil mass, (g) and SD is dry soil mass (g). Soil bulk density (ρd , g/cm^3) was determined according to Black et al. [18] by using the following formula:

$$\rho d = \frac{SD}{V} \tag{2}$$

Where V is net inside volume of the metal cylinder (cm^3). Averages of initial soil moisture content and soil bulk density were 10.56% (dry base) and 1.48 g/cm^3, respectively. The soil at the site has a uniform sandy clay loam texture (47.11% sand, 30.14% silt and 22.75% clay). Moreover, the organic matter percentage in the soil was 1.2%.

Sodium adsorption ratio (SAR) is utilized to describe the soil and water quality. SAR is a measure of the suitability of water for use in agricultural irrigation, as determined by the concentrations of solids dissolved in the water. The formula for calculating sodium adsorption ratio is as follows [19]:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{1}{2}\left(Ca^{++} + Mg^{++}\right)}} \tag{3}$$

Where Na$^+$, Ca^{++}, and Mg^{++} represent concentrations expressed in milliequivalents per liter (meq/l). Chemical characteristics and SAR value of the studied soil are shown in Table 1.

Table 1. Chemical characteristics and SAR value of the studied soil

Parameter	Unit	Value
Na$^+$	(mg/L)	24
K+	(mg/L)	26
Ca^{++}	(mg/L)	0.6
Mg^{++}	(mg/L)	1.3
HCO$_3$	(mg/L)	0.4
Cl$^-$	(mg/L)	10
SAR	(----)	3.99

2.2 Provenance of the Used Water

The provenance of the W1 (water 1) was surface Nile water however, River Nile is always an important fresh water resource and plays an important role in Egyptian activities since it is a natural potential source of drinking, irrigation and industry [20]. The provenance of the W2 (water 2) was ground water. However, ground water is also an important water resource in Egypt and the provenance of the W3 (water 3) was from canal of agricultural drainage water. Water samples were subjected to analysis to get electric conductivity (EC) and soluble cations and anions and sodium adsorption ratio of the water was calculated by the help of Eq. (3). Table 2 illustrates chemical characteristics, EC and SAR value of the studied waters.

2.3 Biogas Liquid Manure Application Rates

The biogas liquid manure was brought from the biogas project located at Tractors and Farm

Machinery Testing & Research Station, Sabahia, Alexandria Governorate, Egypt. The justification of the choice of the particular liquid manure was due to it was available in huge quantities and there was no local study indicating the effect of mixing such manure with soil on the water infiltration into the soil. The components of the biogas liquid manure were analyzed in the laboratories of the services unit of soil analysis, Soil Department, Faculty of Agriculture, Alexandria University, Egypt. Table 3 shows characteristics of the investigated biogas liquid manure.

Table 2. Chemical characteristics, EC and SAR value of the studied waters

Parameter	Unit	Values		
		W1	**W2**	**W3**
EC	(dS/m)	0.83	1.19	11.91
Na^+	(mg/L)	15	20	28
K+	(mg/L)	8	19	46
Ca^{++}	(mg/L)	0.4	0.4	0.5
Mg^{++}	(mg/L)	0.5	0.9	1.3
HCO_3	(mg/L)	0.3	0.2	0.2
Cl^-	(mg/L)	0.8	0.9	10.1
SAR	(----)	3.73	4.10	4.74

Table 3. Characteristics of the investigated biogas liquid manure

Variable	Unit	Value
Density	Kg/m^3	1013
Solid percentage	%	5
Organic matter	%	51

The biogas liquid manure was spread on the soil with different application rates. However, the application rates were 2, 4 and 6 lit/m^2 (AR1, AR2 and AR3). The plot area was 0.7 m* 0.7m. In addition, the control treatment was considered, i.e. no biogas liquid manure was spread on the soil (AR0). Complete randomized block design with three replicates was applied for each of the following treatments:

- Treatment 1: 0 lit/m^2 + Water 1 (AR0+W1).
- Treatment 2: 0 lit/m^2 + Water 2(AR0+W2).
- Treatment 3: 0 lit/m^2 + Water 3 (AR0+W3).
- Treatment 4: 2 lit/m^2 + Water 1(AR1+W1).
- Treatment 5: 2 lit/m^2 + Water 2 (AR1+W2).
- Treatment 6: 2 lit/m^2 + Water 3(AR1+W3).
- Treatment 7: 4 lit/m^2 + Water 1 (AR2+W1).
- Treatment 8: 4 lit/m^2 + Water 2 (AR2+W2).
- Treatment 9: 4 lit/m^2 + Water 3 (AR2+W3).
- Treatment 10: 6 lit/m^2 + Water 1 (AR3+W1).
- Treatment 11: 6 lit/m^2 + Water 2 (AR3+W2).
- Treatment 12: 6 lit/m^2 + Water 3 (AR3+W3).

2.4 Water Infiltration

Cumulative infiltration is the total quantity of water that enters the soil in a given time. Thus, cumulative infiltration is a parameter commonly used in evaluating the infiltration characteristics of soil. Infiltration is a dynamic process, variable in time and space and plays a vital role in the replenishment of soil water, which is responsible for the growth and development of crops [10].

Double-ring infiltrometer was concentrically placed at three different points. Three water qualities were transported to the site in plastic containers. The used double-ring infiltrometer was 40 cm high and having inner and outer iron rings with thickness of 1 cm. The diameters of inner and outer rings were 32 cm and 47 cm, respectively. The rings were driven at about 10 cm deep in soil by using falling weight type hammer striking on a wooden plank placed on top of ring uniformly without or undue disturbance to soil surface. Water was poured slowly into the inner cylinder. The outer cylinder, which acts as a buffer, was also filled with water to the same height in order to minimize the lateral seepage from the inner cylinder. A graduated steel rule (length =100 cm) was placed in the inner ring. The rule was adjusted to the desired level to which water is to be added. An electronic device [21] was utilized to note the time the water begins to infiltrate. The device consisted of three main items, namely oscillator, converter and operational amplifier besides the sensor as shown in Fig. 1. The device sensor was put inside the inner ring as depicted in Fig. 2. Calibration was achieved and the signals were measured using voltmeter. The experiments were carried out for a period of 180 minutes as indicated by Uloma et al. [22]. This was based on the fact that infiltration usually takes 120-360 minutes for the soil infiltration process to reach steady state as reported in Lili et al. [23]. The observations for infiltration rate were carried out on the inner ring. Three infiltration measurements were conducted using each water quality and average was taken later.

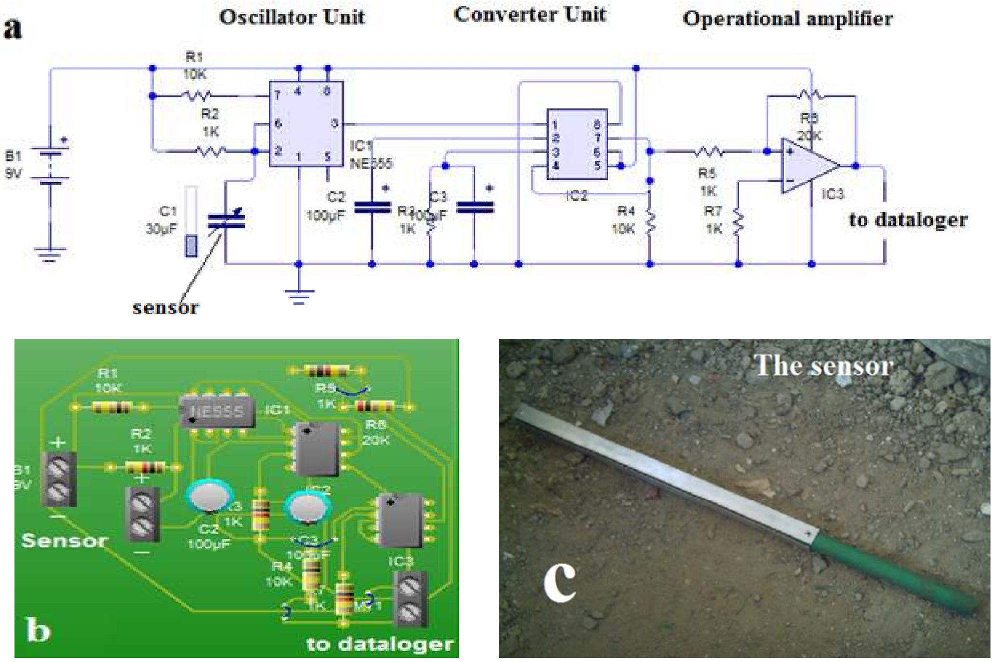

Fig. 1. Components of an electronic device [21] to note the time the water begins to infiltrate into the soil a) circuit diagram b) circuit components c) sensor

2.5 Kostiakov's Infiltration Model

Despite the availability of a large number of infiltration models, some of the available empirical models have been quite popular and frequently used in various water resource applications world over, owing to their simplicity and yielding reasonably satisfactory results in most applications [22]. One of such models is Kostiakov's infiltration model [24] which is derived using the observed data. This model suggested a formula which assumes that at time T = 0, the infiltration rate is infinite and at time T = ∞, the rate approaches zero. The equation is given by:

$$Z = \kappa T^{\alpha} \tag{4}$$

Where T is the time elapsed for the experiment. Z is the cumulative infiltration, α and κ are empirical constants that are site specific and depend on soil conditions such as soil texture, moisture content, bulk density and other soil properties [22]. As a Kostiakov infiltration equation is an empirical one, no physical meanings are attached to its associated constants [25]. The parameter α is accepted by most authors to be less than 1 [26,27].

To determine the parameters α and κ, the logs of both sides of Eq. (4) were taken. This gives:

$$\log Z = \log \kappa + \alpha \log(T) \tag{5}$$

A plot of log Z against log T gives a straight line whose slope gives the value of α, while log κ gives the intercept. The value of κ was obtained from the anti-log κ. i.e.

$$\kappa = 10^{\log \kappa} \tag{6}$$

Fig. 2. Utilizing electronic sensor to note the time the water begins to infiltrate into the soil

2.6 Statistical Analysis

The collected data were compiled and tabulated in proper form and were subjected to statistical analysis [28] to examine the treatment effects. The data were subjected to analysis of variance using ANOVA procedure. The model tested the main effects for application rates of biogas liquid manure and water quality. Differences between group means were determined using LSD at the P <0.05 level.

2.7 Regression Analysis

Multiple Linear Regression (MLR) models are used to study the linear relationship between a dependent variable and several independent variables by fitting a linear equation to observed data samples [29]. The general form of the regression equation is as follows:

$$Y = b_0 + b_1 X_1 + ... + b_3 X_3 + ... + b_n X_n \tag{7}$$

Where Y is the dependent variable representing final cumulative infiltration after 180 min also Y is the dependent variable representing constants α and κ of Kostiakov equation (Eq.4), b_0 is a constant, where the regression line intercepts the y-axis, $b_1 .... b_n$ are regression coefficients, representing the amount of the dependent variable Y changes when the corresponding independent changes 1 unit and $X_1 - X_n$ are independent variables. MLR analysis was carried out using Excel spreadsheets.

3. RESULTS AND DISCUSSION

3.1 Soil and Water Characteristics

The amount of sodium (Na^+) in the soil is an important factor in determining its suitability for supporting trees and shrubs because Na^+ strongly influences water infiltration. Soil Na^+ is best described by the SAR, an indication of the amount of extractable Na^+ relative to calcium (Ca^{++}) and magnesium (Mg^{++}) [30]. The SAR of the soil is considered as one of the important chemical characteristics of the soil in terms of distribution soil particles [31]. Soil SAR indicates the likelihood of reduced soil permeability (water infiltration) especially on heavy-textured soils. However, soils with a high percentage of small clay particles are called “heavy-textured” and are characterized by slow water infiltration into the soil. Soils with a high percentage of large sand particles are called “light-textured” and are characterized by rapid water infiltration. Medium-textured soils (sandy loams, loams, sandy clay loam, clay loam, silt, silt loam, silty clay loam) fall somewhere between light- and heavy-textured soils. However, a soil SAR >13 suggests a likelihood of reduced soil permeability [30]. The SAR value in the present study was 3.99, however, Elbashier [31] reported range for SAR of 1.8-18 with an average of 7.86 for sandy clay loam soil.

Based on the water characteristics illustrated in Table 2, it is clear that SAR values were 3.73, for W1, 4.10 for W2 and 4.74 for W3. El-Sayed and Salem [20] reported SAR based on the amount of Na^+ relative to Ca^{++} and Mg^{++} for surface Nile water was in the range of 1.414-4.793 and this range was changed based on water pollution. In addition, electric conductivity of the water utilized in this research was 0.83, 1.19 and 11.91 dS/m for W1, W2 and W3, respectively. All the selected water qualities are suitable for irrigation according to water quality assessment of US Salinity Laboratory Staff [32].

3.2 Cumulative Infiltration

Fig. 3 shows an average of the cumulative infiltration as affected by application rates of biogas liquid manure and water quality. These curves were obtained averaging the cumulative infiltration data of the measured points for each treatment. The range of cumulative infiltration after 180 min was varied from 128 mm to 490 mm as illustrated in Table 4. The highest cumulative infiltration after 180 min of 490 mm was observed for application rate of 0 lit/m^2 biogas liquid manure to the soil and W3. The lowest cumulative infiltration after 180 min of 128 mm was observed for application rate of 6 lit/m^2 and W1. As shown in Table 4, the cumulative infiltration was decreased with an increase of application rate of biogas liquid manure. This trend was reviewed by Al-Omran et al. [33], who reported that soil amended with natural deposits improve soil texture and structure, promoted soil aggregates swelling, limited capillary rise and increased water retention, consequently decreasing cumulative infiltration. The implications of the results for the application of biogas liquid manure in irrigation systems may improve water use efficiency by limiting percolation losses while maintaining adequate infiltration rate [34]. Also, the use of biogas liquid manure as a source of nutrients in agricultural production decreases environmental pollution and leads to economic savings for farmers.

Table 4. Averages of final cumulative infiltration and Kostiakov's infiltration (Eq. 4) model constants corresponding to different treatments

Water	Application rate (lit/m^2)	Final cumulative infiltration (mm)	κ ($mm/\min^{\alpha}$)	α (---)
W1	0	332	14.6832	0.6005
W1	2	244	13.8975	0.5520
W1	4	189	12.2696	0.5266
W1	6	128	10.9604	0.4728
W2	0	347	13.2083	0.6294
W2	2	288	12.0672	0.6107
W2	4	212	11.1300	0.5675
W2	6	132	10.3733	0.4897
W3	0	490	11.5494	0.7217
W3	2	356	10.5316	0.6779
W3	4	244	9.0973	0.6337
W3	6	136	7.5895	0.5562

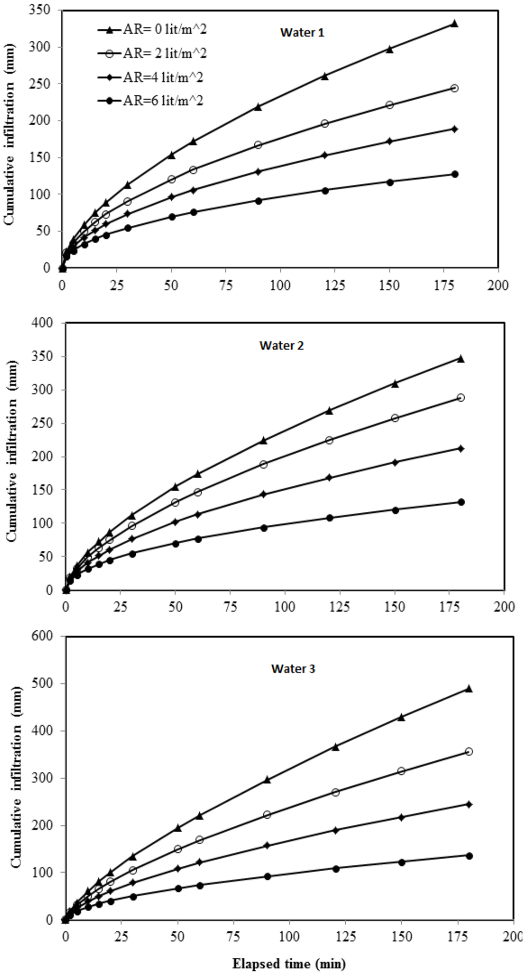

Fig. 3. Change in cumulative infiltration with time among different treatments

3.3 Statistical Analysis

The ANOVA analysis (Table 5) indicated that the application rate of biogas liquid manure added to the soil had significant effect ($P< 0.05$) on final cumulative infiltration and also on both constants α and κ of Kostiakov equation (Eq. 4). Moreover, water quality had significant effect ($P< 0.05$) on final cumulative infiltration and also on both constants α and κ of Kostiakov equation (Eq. 4). Additionally, the interaction between application rate of biogas liquid manure and water quality had significant effect ($P< 0.05$) on final cumulative infiltration and also on both constants α and κ of Kostiakov equation (Eq. 4). Meanwhile, comparison between the mean of final cumulative infiltration and constants (α and κ) (Table 6) by LSD test showed that there was a significant difference between application rate of biogas liquid manure of 0, 2, 4 and 6 lit/m^2 on final cumulative infiltration and also on both constants α and κ of Kostiakov equation (Eq. 4). Also, there was a significant difference between water quality on final cumulative infiltration and also on both constants α and κ of Kostiakov equation (Eq. 4) as shown in Table 6.

3.4 Effect of Application Rate of Biogas Liquid Manure on Constants α and κ of Kostiakov Equation (Eq. 4)

Figs. 4 and 5 indicate effect of application rate of biogas liquid manure on both constants of Kostiakov equation (κ) and (α) for cumulative infiltration, respectively. It is clear that the constants (κ) and (α) decrease with increase of application rate of biogas liquid manure added to the soil at any water quality. This occurrence was observed also by Al-Omran et al. [33], who reported that the empirical constants (κ) and (α) were affected by the type and the concentration of the used soil amended with natural deposits (Aquagel and Bentonite) on sand soils. They indicated that (κ) and (α) values decreased with increasing concentrations of Aquagel and Bentonite. Comparing to untreated soil, the percentage decrease in (κ) values were 12, 27, 43 and 63 when soil was mixed with 1, 2, 3 and 4% Bentonite.

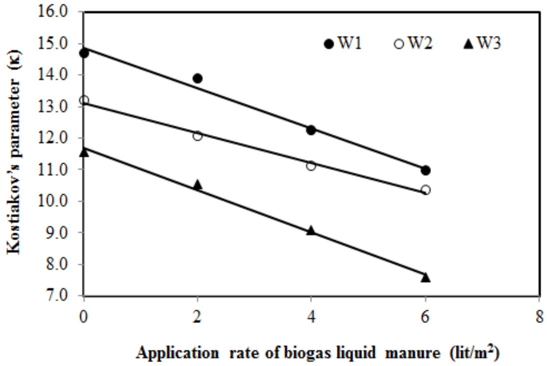

Fig. 4. Effect of application rate of biogas liquid manure on constant of Kostiakov equation (κ) for cumulative infiltration

3.5 Effect of Water Quality on Constants α and κ of Kostiakov Equation (Eq. 4)

Fig. 6 and Fig. 7 indicate effect of the sodium adsorption ratio on both constants of Kostiakov equation (κ) and (α) for cumulative infiltration, respectively. It is clear that the constant (κ) decrease with increase of sodium adsorption ratio of the used water at any application rate of biogas liquid manure added to the soil as shown in Fig. (6). Meanwhile, the constant (α) increase with increase of sodium adsorption ratio of the used water at any application rate of biogas liquid manure added to the soil as shown in Fig. (7). Al-Omran et al. [35] conducted a laboratory study to indicate the effect of soil texture and water quality on infiltration rate, they concluded that effect of soil texture on the infiltration rate was very pronounced while water qualities showed a little effect. Moreover, water quality has a profound influence over the infiltration rate [36].

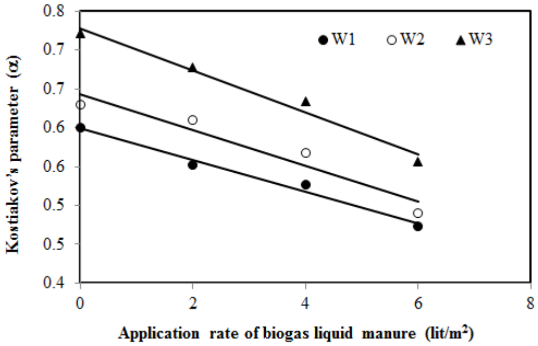

Fig. 5. Effect of application rate of biogas liquid manure on constant of Kostiakov equation (α) for cumulative infiltration

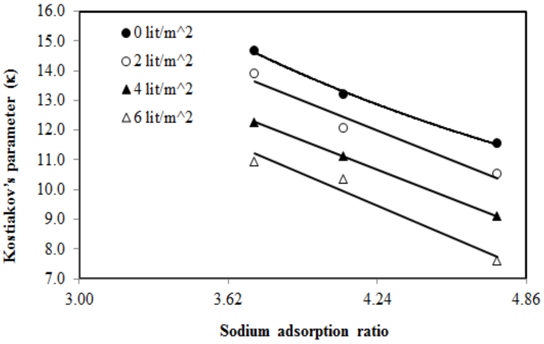

Fig. 6. Effect of sodium adsorption ratio of the used water on constant of Kostiakov equation (κ) for cumulative infiltration

Table 5. Analysis of variance (ANOVA) for final cumulative infiltration and both constants α and κ of Kostiakov equation (Eq. 4)

Source of variation	DF*	Pr > F		
		Final cumulative infiltration	κ	α
Application rate of biogas liquid manure (AR)	3	0.000	0.000	0.000
Water quality (WQ)	2	0.000	0.000	0.000
AR*WQ	6	0.000	0.000	0.015

** Degree of freedom*

Table 6. Mean* final cumulative infiltration and both constants α and κ of Kostiakov equation (Eq.4) as affected by application rate of biogas liquid manure and water quality

	Final cumulative infiltration (mm)	κ ($mm/\min^{\alpha}$)	α (---)
Application rate of biogas liquid manure (lit/m^2)			
0	398.971a	13.1469a	0.6505a
2	296.713b	12.1654b	0.6135b
4	215.409c	10.8323c	0.5759c
6	132.038d	9.6410d	0.5063d
LSD$^+$ (5%)	17.98	0.1318	0.0109
Water quality			
Water 1	223.490c	12.9527a	0.5379c
Water 2	244.965b	11.6947b	0.5743b
Water 3	307.143a	9.6919c	0.6474a
LSD$^+$ (5%)	15.572	0.1141	0.0094

*Means followed by different letters in each column are significantly different at P = 0.05

$^+$LSD = least significant difference

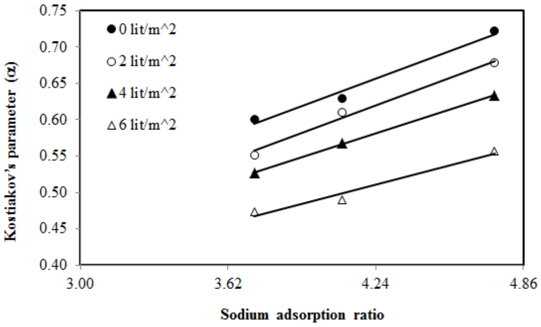

Fig. 7. Effect of sodium adsorption ratio of the used water on constant of Kostiakov equation (α) for cumulative infiltration

3.6 Multiple Linear Regression Analysis

Multiple linear regression (MLR) analysis is one of the modeling techniques that enable us to depict relationships between final cumulative infiltration after 180 minutes and both water sodium adsorption ratio and application rate of biogas liquid manure by fitting a linear equation to the observed data set. In this study, an attempt has been made to establish multiple linear regression equations to provide a prediction of final cumulative infiltration and constants of α and κ of Kostiakov equation (Eq. 4) based on the water sodium adsorption ratio and application rate of biogas liquid manure.

The regression of final cumulative infiltration after 180 minutes on related variables (water sodium adsorption ratio and application rate of biogas biogas liquid manure) was performed and the created MLR model is given as:

$$Z(mm) = 33.1387 + 84.406 \times SAR - 42.755 \times AR$$
$$R^2 = 0.9183 \tag{8}$$

Where Z is final cumulative infiltration after 180 minutes, AR is the application rate of biogas liquid manure to the soil (lit/m^2) and SAR is water sodium adsorption ratio. Due to R^2 indicates the amount of total variability explained by the regression model, thus 91.83% of the total variation in the final cumulative infiltration can be explained by the linear relationship between the application rate of biogas liquid manure and water sodium adsorption ratio and the final cumulative infiltration. The other 8.17% of the total variation in the final cumulative infiltration remains unexplained.

The regression of constant α of the Kostiakov equation (Eq. 4) on related variables (water sodium adsorption ratio and application rate of biogas liquid manure) was performed and the created MLR model is given as:

$$\alpha(\text{—}) = 0.2005 + 0.1089 \times SAR - 0.0235 \times AR$$
$$R^2 = 0.953 \tag{9}$$

The regression of constant κ of the Kostiakov equation (Eq.4) on related variables (water sodium adsorption ratio and application rate of biogas liquid manure) was performed and the created MLR model is given as:

$$\kappa(mm/\min^{\alpha}) = 26.706 - 3.218 \times SAR - 0.593 \times AR$$
$$R^2 = 0.981 \tag{10}$$

A regression model was developed to estimate the cumulative infiltration at any time up to 180 min based on application rate of biogas liquid manure and sodium adsorption ratio of water as follows:

$$Z(mm) = (26.706 - 3.218 \times \mathrm{SAR} - 0.593 \times \mathrm{AR}) \times \mathrm{T}^{(0.2005+0.1089\times\mathrm{SAR}-0.0235\times\mathrm{AR})} \quad (11)$$

The limits of application of the prediction model (Eq. 11) are including time in the range of 0 to 180 min, water sodium adsorption ratio (SAR) is in the range of 3.73-4.74 and application rate of biogas liquid manure (AR) in the range of 0-6 lit/m^2. By applying Eq. (11) by assuming SAR equals to 3.89 and application rate (AR= 5.2 lit/m^2), the cumulative infiltration was obtained until time 180 min as shown in Fig. 8.

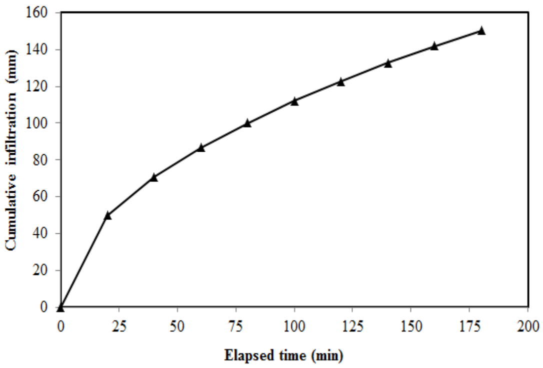

Fig. 8. Change in cumulative infiltration with time when SAR=3.89 and AR = 5.2 lit/m^2 by the help of Eq. (11)

4. CONCLUSION

From the results it can be concluded that the values of cumulative infiltration are directly related to water quality and biogas liquid manure application rate to sandy clay loam soil. Infiltration rates indicated reasonable final cumulative infiltration after 180 minutes to be in the range of 128 mm to 490 mm. The motivation of the present study was to gain information the effect of biogas liquid manure produced locally on infiltration rate. Additionally, the study has only investigated the cumulative infiltration rate of water in a soil; it has not made an assessment of the advance and recession of the water over the field surface. So, it is recommended that field experiments should run to establish the effect of biogas liquid manure application rate on advance and recession of the water over the field surface.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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