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SHORT RESEARCH COMMUNICATION

Effect of detergents from laundry greywater on soil properties: a preliminary study

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Abstract

Detergent compounds are classes of the organic micro-pollutants in the laundry wastewater. The disposal of these compounds into the soil has several adverse effects on their composition. In the present study, changes in the soil characteristics, which included saturated hydraulic conductivity (K_{sat}), EC, pH, exchangeable sodium percentage, cation exchange capacity (CEC), and sodium adsorption on ratio were examined after the irrigation with laundry wastewater. Ten clothes were washed with one full cap of powder (PLD) and liquid laundry (LLD). Laundry greywater samples were used for the irrigation of soil. The results revealed that the pH of soil increased from 3.85 to 4.42 and 4.09 after irrigation by PLD and LLD greywater, respectively. The EC of the irrigated soil increased from 50.32 to 152.5 and 147.6 µS/cm, respectively. The CEC was raised to 79.93 and 41.39 meq/100 g, while K_{sat} was reduced to 7.38×10^{-10} and 7.11×10^{-10} cm/s, respectively. These findings highlighted the negative effects of laundry greywater discharge on soil properties.

Keywords Laundry greywater · Hydraulic conductivity · CEC · ESP · K_{sat}

Introduction

Greywater is defined as the generated wastewater from household activities, which include bathroom, showers, laundry, and kitchen but not black water from the toilet. The percentage of greywater generated from household activities represents 50–80% of the total water usage; among these wastes, the laundry greywater represents up to 33% (Mohamed et al. 2014a, b). The main composition of laundry greywater are cations such as, Ca, Mg, K, nitrate, sulphate anions, carbonate, and chloride as well as organic micro-pollutants (OMPs) resulting from the detergents (Mohamed et al. 2013a, 2014b; Chan et al. 2014). In order to limit the adverse effects of laundry greywater on the environment, as well as avoiding the occurrence of eutrophication in the water bodies which received these wastes, phosphate-free detergents were introduced in 1986 (Jacob and Wirtschaftsforschung 2005). However, laundry greywater still has many OMPs which have high persistence in the environment. Eriksson et al. (2003) revealed that the greywater in Denmark contained more than 200 types of OMPs which included plasticizers, surfactants, antioxidants, fragrances, and dyes. Ying (2006) reported that the bathing greywater contains high concentration of surfactants.

Surfactants (surface active agents) represent the major OMPs in the greywater because they are used in the generation of detergents and hygiene products, which are utilized extensively in bathing and clothes' washing. The surfactants included the compounds generated from amphoteric, cationic, anionic and nonionic detergents. These classes also encompass anionic and cationic surfactants such as methylestersulphonate, olefinsulphonate, alkyl benzene sulphonates, alkyl ether sulphates, isotridecanolethoxylates, benzalkonium chloride, *n*-hexadecyltrimethy, and ammonium chloride. The utilization of these detergents is dependent on their potential to provide cleaning action, disinfection

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agents, and the low price (Jakobi and Lohr 1987; Lange 1994; Belanger et al. 2002).

In developing countries, the disposal of greywater into soil drainage is a common practice. However, these practices have become unacceptable in many of the developed countries due to the distribution of pollutants such as chemical agents, OMPs, and pathogens into the natural water and soil and then the transmission into the human via food chain. Besides, the high salinity of laundry greywater which is derived from detergents is a major concern. The determination of soil salinity is used to assess the presence or absence of the adverse effects resulting from the utilization of greywater in the irrigation. The level of salinity is quantified based on the sodium adsorption ratio (SAR) index (Lazarova and Asano 2005). The SAR in laundry greywater might reach 12.32 mg L^{-1} which results from the utilization of detergent with concentrations of 3000 mg L^{-1}(Abu-Zreiget al. 2003). It has demonstrated that the increase of SAR causes a decrease in saturated hydraulic conductivity (K_{sat}) in the soil (Gross et al. 2008). The irrigation of soil with greywater contains high levels of sodium (Na), which causes degradation of the soil composition and permeability.

Another negative effect of soil irrigated with the untreated greywater is the elevation in pH values due to the high contents of alkaline detergents (Travis et al. 2010; Sivongxay 2005). The laundry greywater of pH 9 and above acts as a dispersing agent which causes soil particles to split and lead to the increase of soil cation exchange capacity (CEC) (Sivongxay 2005; Anwar 2011).

It was revealed that the properties of sandy soil changed after being irrigated with surfactant-rich laundry greywater (Anwar 2011). Understanding the effect of detergents on the soil properties can potentially assist in designing a proper management for the laundry wastewater disposal or reuse in the irrigations. The local governments in Australia are strongly considering the application of greywater (generated from laundries and bathrooms) as an option for irrigating household lawns and gardens, therefore, reducing the demand for filtered water (Mohamed et al. 2013a).

The present study was performed to assess the negative effects of discharged laundry greywater on the soil characteristics and the impact on the soil chemistry and its infiltration in Batu Pahat, Johor, Malaysia. This study aimed to assess the untreated effluent of detergents from laundry greywater on the soil properties.

Materials and methods

Study area and sampling

Seven soil samples (one sample/week) were collected from Parit Rajazone (coordinate E103′06′14.1″), which is approximately 10 km from Batu Pahat town in Johor, Malaysia. The samples were collected between March and May 2015 (dry season in Malaysia). The study area was selected because the laundry greywater is a direct discharge into the soil (Online Appendix A). The soil sampling point was chosen at an undisturbed land where there is no human activity recorded to avoid effects resulting from human activities. The samples were collected from several mixed subsamples by first eliminating the top 10–15 cm of top soil and the samples were dug for 30 cm depth of soil by using a clean spade in accordance with the procedure described by Misra and Sivongxay (2009) without incorporating any modifications. The samples were transported to a laboratory in firmly sealed polyethylene bags. Thereafter, the samples were subjected to air-drying and were passed through a 2-mm mesh sieve before being stored in polyethylene bags for subsequent tests.

The characteristics of soil samples including pH and electrical conductivity (EC) were tested according to BS 1377: Part 3 (1990). The chemical properties of soil and water which included cation exchange capacity (CEC), exchangeable sodium percentage (ESP), and sodium adsorption ration (SAR) were analysed using X-ray fluorescence (XRF) and atomic absorption spectroscopy (AAS).

Collection of laundry greywater

Two detergents were used in the washing process of clothes and production of laundry greywater. The detergents were powdered laundry detergent (Bio Zip) (PLD) and liquid laundry detergent (Dynamo) (LLD). The detergents were selected because they are the dominant brands used in the study area based on the information gathered from the local community members during the collection of soil samples. The powder and liquid laundry detergents were prepared according to the manufacturers' instructions. A fix of ten clothes was placed in an automatic washing machine (Panasonic, Model NA-F65B2) and one full cap of each detergent was added. The laundry greywater generated after the first, second, and third wash was collected and used to irrigate the examined soil samples.

Experimental set-up of hydraulic conductivity

Hydraulic conductivity experiments were performed according to Darcy's Law calculation as described by Misra and Sivonghay (2009). Three soil cores were carried out in replicates for each laundry greywater. The soil core was constructed with fine cloth, duct tape, filter paper, and PVC pipe (Online Appendix B). In order to prevent mass loss and escape of suspended solids which are less than ≤ 2.0 μm in size, the fine cloth was positioned above the PVC pipe tube. The system was locked tightly to support the soil mass and laundry greywater over it. The soil samples were irrigated with tap water (TW), powdered laundry detergent (Bio Zip) (PLD), and liquid laundry detergent (Dynamo) (LLD) greywater. A measuring cylinder was used to collect drainage water (leachate). The hydraulic conductivity was determined by measuring the total volume of water passing through the soil core within a known time interval (150 min). The saturated hydraulic conductivity was estimated according to Darcy's Law Eq. (1):

$$q = \frac{Q}{At} = \frac{K_{sat}\Delta H}{L}, \quad (1)$$

where, q is the water flux (cm/min); t is time interval (min); A is cross-sectional area of the soil column (cm^2); Q is discharge rate (cm^3/min); K_{sat} is saturated hydraulic conductivity; ΔH is hydrostatic pressure difference from top to bottom of soil column (cm); L is length of the soil column (cm) and $\frac{\Delta H}{L}$ is hydraulic gradient.

$$\text{Hydraulic head difference } (\Delta \text{H}) = \text{Total head at inflow} - \text{Total head at outflow}.$$

Soil leachate chemical analysis

The pH, EC, CEC (the sum of exchangeable cations, Ca, Mg, K and Na), exchangeable sodium percentage (ESP), and SAR properties of the soil solution (leachate) from the hydraulic conductivity experiments were determined after each experiment. The pH and EC were measured using a calibrated pH meter and an EC meter. An amount of 20 g of air-dried soil (< 2 mm) was added to 100 mL of distilled water in a plastic beaker to set up soil water suspensions with a 1:5 soil/water ratio. The determination of CEC, ESP, and SAR was calculated based on Eqs. (2), (3) and (4):

$$\text{EC} = \sum \text{Exchangeable cations in me/100 g oven dry soil}, \quad (2)$$

$$\text{ESP} = \frac{\text{Exchangeable sodium}}{\text{CEC}} \times 100, \quad (3)$$

$$\text{SAR} = \frac{[\text{Na}^+]}{\sqrt{0.5 \times [\text{Ca}^{2+} + \text{Mg}^{2+}]}}. \quad (4)$$

The macro elements which include Ca, Mg, K and Na in the soil powder sample were determined using X-ray fluorescence (Model S4 Pioneer) while their concentrations in the irrigated soil were determined using atomic absorption spectroscopy (AAS) (PerkinElmer, model-analyst 800). The elements were extracted from soil leachate according to AOAC method in which 5 g of soil was mixed with 20 ml of extracting solution and were shaken for 5 min. The samples were then filtered and subjected for AAS analysis.

Table 1 Characteristics of soil collected from Parit Raja, Johor

Parameter	Percentage (%)
Moisture content	10.0
Bulk density	1.36
Liquid limit (LL)	54.2
Plastic limit (PL)	38.4
Plasticity index (I_P)	15.8
Sieve analysis	Co-efficient of uniformity = 5.9 > 4 (well graded) Co-efficient of curvature = 0.74 (clayey gravelly)

Table 2 Classification of soil according to plasticity

Plasticity index (I_P or PI)	Degree of plasticity	Type of soil
0	Non-plastic	Sand
< 7	Low-plastic	Silt
7–17	Medium plastic	Silty clay or clayey silt
> 17	Highly	Plastic clay

Results and discussions

Characteristics of soil samples

The characteristics of the soil collected from the study area are illustrated in Table 1. It can be noted that the soil samples have 10% of moisture. The "plasticity index" (PI) which indicates the collection of moisture substance over which the soil is plastic was 15.8%. The coefficient of curvature (Cc) was 0.74; this value is not in the range 1–3 (AASHTO) standard and indicates that this soil is mostly clayey.

The classification of soil according to plasticity is shown in Table 2 which demonstrates that the soil samples fall into silt clay or clayey silt based on a plasticity index of 15.8%. These findings are in agreement with a previous study conducted by Tjahjanto et al. (2008) which revealed that Parit Rajazone is enclosed by a soft marine clay deposit. The effect of effluent discharge on soil depends on soil properties: for example, silty clay holds water longer than sandy soil, while water is consumed more rapidly by sandy soil (Calkins 2011).

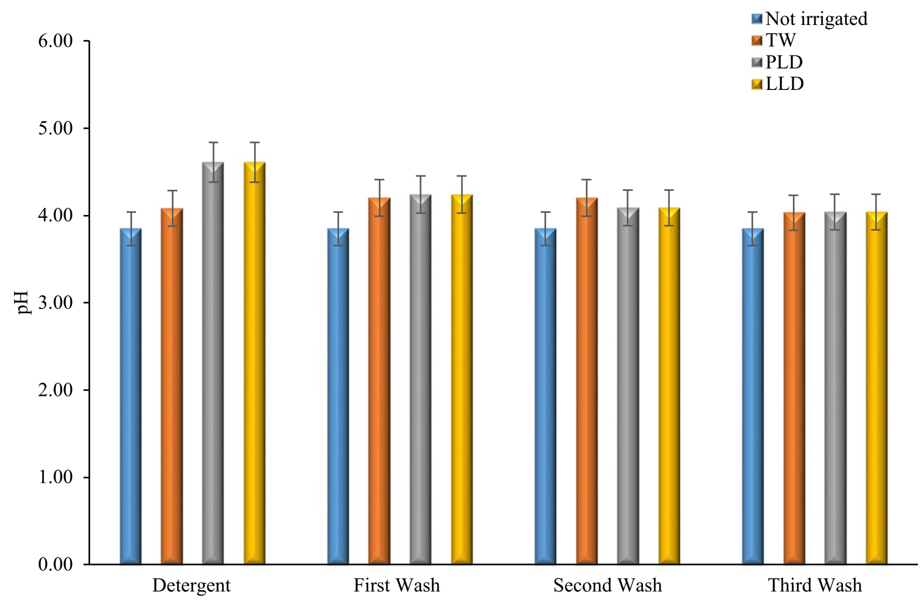

Fig. 1 pH of soil leachate after irrigated with tap water (TW), powder laundry detergent (PLD) and liquid laundry detergent (LLD) greywater; not irrigated (control)

Soil leachate pH and EC after irrigation with laundry greywater

Figure 1 depicts the pH of the soil after being irrigated by TW, PLD, and LLD. It was determined that the pH of soil control (before irrigation with laundry greywater) was pH 3.85, which indicates deficiency of Ca and/or Mg ions in the soil. Calcium survives in soil as transferable Ca associated with negatively-charged sites on clay mineral surfaces and as structural calcium in mineral crystal lattices. The soil pH increased from pH 3.85 to 4.72 and 4.61 after irrigation with PLD and LLD, respectively. However, the soil is still acidic. The presence of Na in PLD and LLD as the main content in laundry detergents can potentially increase the pH level in the irrigated soil. However, the soil pH might reach alkaline levels by frequently receiving the detergents for a long time. These findings are consistent with the findings reported by Waisel (2012), which indicated that the Na increased through the dissociation of adsorbed Na which enhanced the pH of the soil solution.

The electro-conductivity (EC) of soil control and after irrigation by TW, PLD, and LLD is presented in Fig. 2. The maximum EC was recorded in the soil irrigated with PLD (174.5 µS/cm) and was followed by the soil irrigated with LLD (152.5 µS/cm). The minimum EC was noted in the soil irrigated with PLD and LLD for the third wash laundry (56.4 and 53.5 µS/cm, respectively). These results indicate that the EC values decreased with water contain fewer chemicals in detergent. Anwar (2011) studied the effects of reused laundry greywater on local soil in Toowoomba where the EC

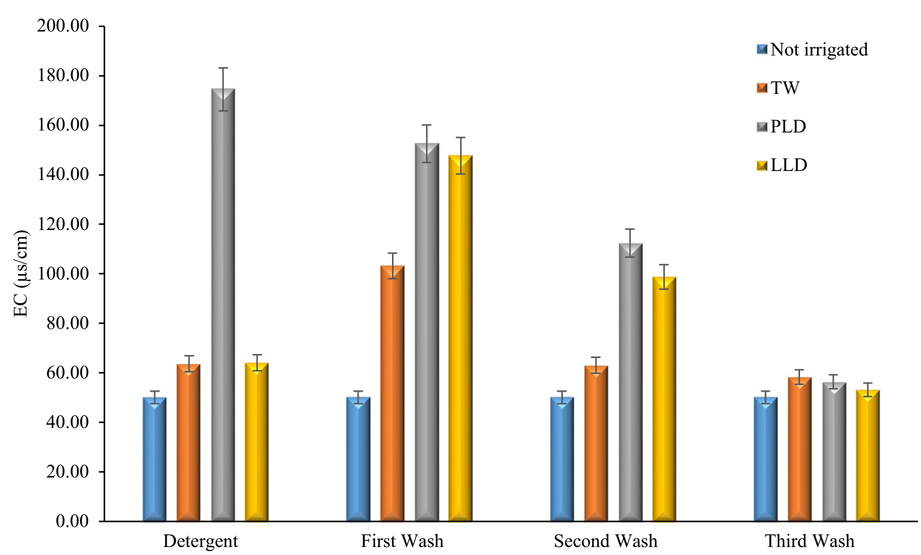

Fig. 2 EC of soil leachate after irrigated with tap water (TW), powder laundry detergent (PLD) and liquid laundry detergent (LLD) greywater

results of soil after irrigation with tap water and laundry greywater were 388 and 752 µS/cm, which indicate that the presence of detergents in the water is associated with the increase of soil EC.

Changes of soil saturated hydraulic conductivity (K_{sat})

The saturated hydraulic conductivity (K_{sat}) for 10 min of soil under the irrigation of TW, PLD, and LLD greywater is presented in Table 3. The results revealed that the K_{sat} reduced after the soil was irrigated with the first wash of PLD and LLD, with K_{sat} of 7.38×10^{-10}cm/s and 7.11 x10^{-10}cm/s, respectively. PLD and LLD irrigation solutions possess high concentrations of salt cations supported by the high EC values, which consequently cause a decrease in the K_{sat}. Soil K_{sat} relies on the type of soil, porosity, and configuration of the soil pores (Anwar 2011). The clayey type of the soil investigated in this study may influence the infiltration rate which makes it slower. The dispersion of clay particles in Ca soil column leached by Na and NaCl aqueous solution led to an irreversible decrease in soil hydraulic conductivity (Yaron et al. 2012). Datnoff et al. (2001) stated that the surface-induced swelling clay is the main mechanism to reduce K_{sat} in the clay. The main cause of K_{sat} reduction can be rationalized as a small pore clogging in the soil due to the adsorption of surfactant. Surfactant effects on water infiltration and on percolation in soils are a function of soil type and surfactant characteristics (Kuhnt 1993). Surfactants decrease the capillary rise of water in soil columns when mixed with sands or clayey soils by decreasing water surface tension (Smith and Gillham 1999). This might be caused by swelling of some clay particles which changes the hydraulic capacity of the soil profile and resulted in reduced retention of soil water and increased depth of infiltration (Karagunduzet al. 2001; Crites et al. 2014).

Table 3 Mean K_{sat} for 10 min of soils irrigated with tap water (TW), powder laundry detergent (PLD) and liquid laundry detergent (LLD) greywater

K_{sat} (10 min)		Change from TW (%)
Detergent		
TW	3.18E−09	0
LLD	7.7E−10	− 75.77
PLD	1.11E−09	− 65.07
First wash		
TW	3.28E−09	0
LLD	7.11E−10	− 78.29
PLD	7.33E−10	− 77.63
Second wash		
TW	3.18E−09	0
LLD	1.68E−09	− 47.13
PLD	1.63E−09	− 48.54
Third wash		
TW	3.23E−09	0
LLD	3.23E−09	0.00
PLD	3.13E−09	− 3.13

CEC, ESP and SAR of soil leachate after irrigation with laundry greywater

The CEC of soil represents the total amount of cations in the soil which can hold on its assimilation complex and replaced under conditions of pH and show the capacity of the soils to provide cations. CEC was determined according to the concentrations of Na, Ca, K and Mg ions. These elements

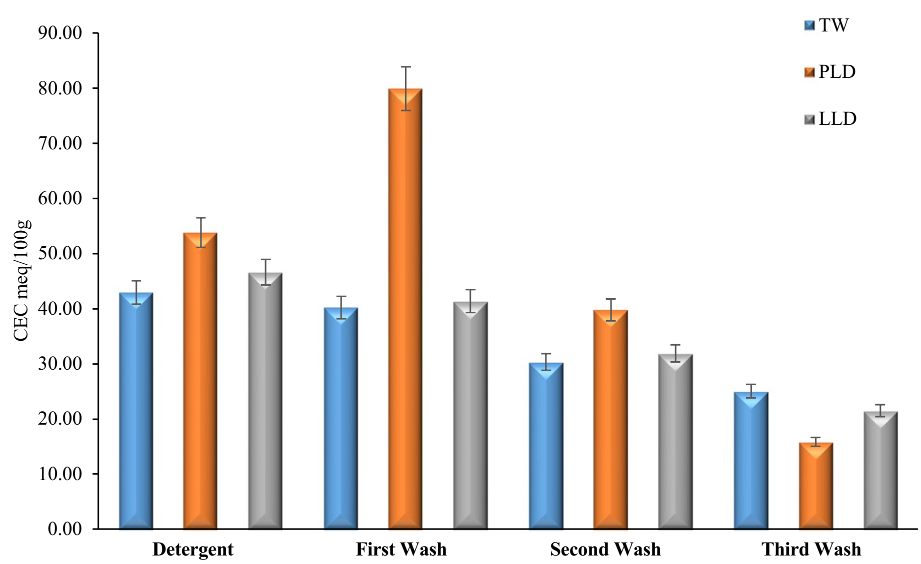

Fig. 3 Cation exchange capacity (CEC) of soil leachate after irrigated with tap water (TW), powder laundry detergent (PLD) and liquid laundry detergent (LLD) greywater

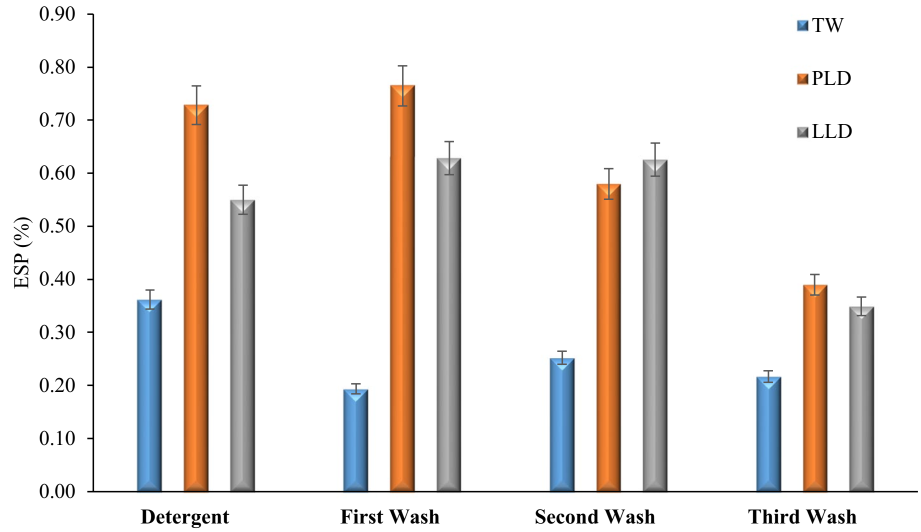

Fig. 4 Exchangeable sodium (ESP) percentage of soil leachate after irrigated with tap water (TW), powder laundry detergent (PLD) and liquid laundry detergent (LLD) greywater

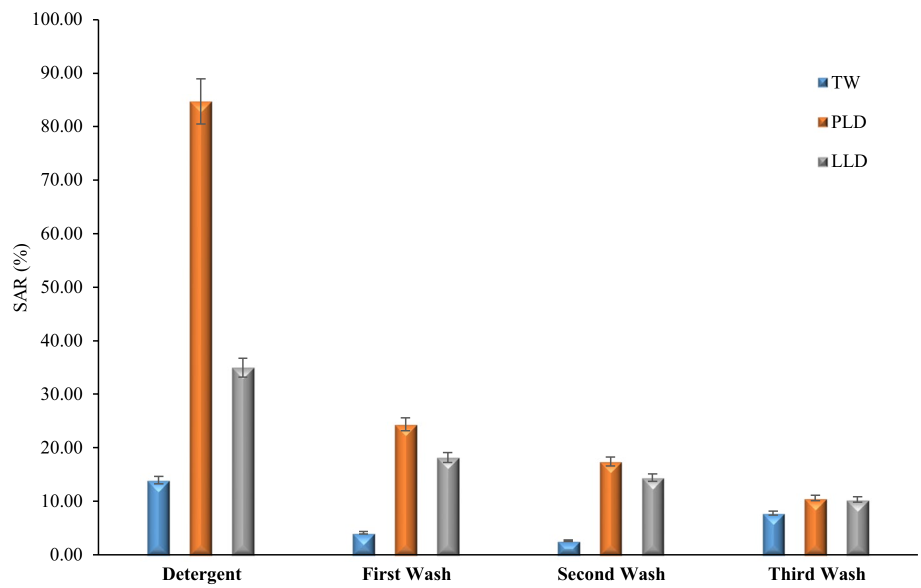

Fig. 5 Sodium adsorption ratio (SAR) of soil leachate after irrigated with tap water (TW), powder laundry detergent (PLD) and liquid laundry detergent (LLD) greywater

indicate the total amount of exchangeable cations which are removed from the soil using a solution contains a neutral salt held within a given mass of soil. Figure 3 shows that the highest of CEC was found when soil irrigated with first wash PLD of 79.93 meq/100 g. Soil CEC after irrigated with PLD and LLD were reduced from first, second and third wash due to the decreases in the concentrations of these cations in the soil with the frequent washing process.

The highest percentage of ESP was recorded in the soil irrigated with first wash PLD 0.76% and PLD detergent 0.73% (Fig. 4). These results indicate that the ESP in the irrigated soil has increased compared with the soil irrigated with TP. The presence of high concentration might increase the possibility of sodium toxicity to plants (Skujins 1991). The increase of ESP to more than 15% which might be caused due to the frequencies irrigation of soil with laundry greywater, the higher levels of exchangeable Na^+ in soil could cause soil aggregates to crumple due to the spread which leads to poor water access and soil (Wu et al. 2009).

Sodium adsorption on the ratio (SAR) of soil after drainage in four different replicates was subjected to every type of irrigation water. Based on the data presented in Fig. 5, SAR soil was mostly higher in the irrigated soil PLD and LLD where the SARs were 84.69 and 34.97 mg/L, respectively. The SAR in this study was found to be higher than the SAR in laundry greywater of 12.32 studied by Misra and Sivongxay (2009). The recommended value of SAR for reuse of greywater is 4 (ANZECC and ARMCANZ 2000). A higher SAR might lead to the degradation of the soil structure and permeability. Irrigation using water with high SAR may involve soil amendments to avoid long-term damage to the soil such as Ca product topdressing, amendments and frequent aeration. Long-term use of raw greywater is estimated to lead to greater negative effects on water penetration into the soil (Travis et al. 2010).

Conclusion

It can be concluded that the direct discharge of laundry greywater into the soil produces negative effects on the soil properties. The soil pH and RC demonstrate a slight increase after irrigation with the first wash PLD and LLD. The infiltration rate and K_{sat} of the first wash became slower after irrigation with PLD and LLD. High levels of CEC, ESP, and SAR were noted in the irrigated soil with PLD in comparison to LLD. A proper management for greywater should be adopted in order to prevent the destruction of soil composition. The detergents in the laundry greywater ought to be reduced to a minimum concentration which would have no adverse effects on the environment. A new regulation standard for the proper disposal of greywater among developing countries needs to be adopted.

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