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Effect of Greywater Irrigation on Soil Characteristics

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Abstract— **In this study, surfactant rich laundry greywater is used to investigate the changes of potential soil properties such as, hydraulic conductivity, porosity, pH, electrical conductivity and pressure-saturation relationship. A series of soil column (composed of several PVC rings) experiment was conducted under unsaturated condition with varying greywater concentration and flow rate. In each experiment, pH, EC and hydraulic conductivity were measured. After greywater flushing in each experiment, the column was kept for 24 hrs to become equilibrium. The column was then dismantled and moisture content in each ring was measured gravimetrically and the soil pressure was taken as the distance of each ring from the reference groundwater level. The Break Through Curves with EC value and the measured value of pH at the column outlet revealed that the greywater with higher concentration reach the column outlet much faster. Soil hydraulic conductivity was found increasing steadily with greywater concentration but soil bulk density was found decreasing with greywater concentration. The porosity was first increasing and then found decreasing with greywater concentration. Pressure saturation curves showed that the capillary rise decreases sharply with greywater concentration due the reduction of surface tension but remain constant after certain concentration which may be referred to the critical micelle concentration (CMC) of surfactants. All the interfaces are saturated with surfactant molecules at this CMC and it does not have any impact on further surface tension reduction. However, greywater irrigation may cause the water-repellent soil but it needs further investigation to confirm this statement.**

Keywords-greywater; soil; irrigation; surfactant ; properties

I. INTRODUCTION

Water is the most precious resource, and Australia is one of the driest continents on the earth facing enormous shortage of potable water. Australians are increasingly becoming aware of the need to preserve water and greywater reuse may be one of the best options to preserve potable water. Greywater reuse has been implemented in many countries but it is relatively new in Australia as guidelines and regulations have been developed recently [1-2]. These guidelines mainly consider the health issues rather than the potential environmental impacts on soil and groundwater. The domestic wastewater may generate effluents with reduced level of nitrogen, solids and organic matter, but often contain higher level of surfactants, oils, boron and salt [3]. These components of greywater may have harmful effects on soil, plants and underground water. Surfactants are the major components of detergents found in domestic wastewater which have hydrophilic head and hydrophobic tail [4]. Surfactant molecules in aqueous solution accumulate onto the different interfaces (such as, liquid/liquid; liquid/air or solid/liquid interfaces) and thus reduce the interfacial tension. Reduction of surface tension in surfactant-rich greywater may change the underlying soil structure and thus the soil-water environments, which are ignored in most of the cases. Recently, interaction between laundry greywater and the saturated soil has been studied to quantify the soil hydraulic conductivity [5] in different soil samples. Shafaran et al. [3] suggested that accumulation of surfactants from greywater may lead to water repellent soil with significant impact on agricultural productivity and environmental sustainability. But still limited information is available regarding the effects of surfactants, commonly present in laundry and household detergents, on hydro-physical properties of soils. The aim of this research is to study the possible changes of soil hydraulic properties during the reuse of laundry greywater in irrigation.

II. MATERIALS AND METHODS

Sandy soil of average grain diameter 0.52mm was chosen for greywater irrigation. The washing powder was chosen carefully based on market popularity, ingredients and the information available in the literatures. Omo Small and mighty 2x concentration top loader is chosen because literatures show its lower environmental impact and it is a popular brand in Australian market [6]. The concentrations of laundry greywater were calculated based on the washing machine size available on Perth market and instructions of Omo washing powder. Normal load wash and three cycles of wash and rinse were assumed and the greywater concentrations used in the experiments were, 0.26g/L, 0.316g/L, 0.368g/L and 0.442g/L. The experiments were conducted in a laboratory soil column composed of several PVC rings of 10 cm diameter and 5 cm length as shown in Fig. 1. The column was filled with water and checked for any leakage. Then the column was packed successively with the soil in small increments under water saturated condition and tapped at the bottom. This procedure ensured the elimination of any trapped air and layer formation during the packing process. The column was kept saturated for 1 hour and the outlet tank was brought down and kept the water level of the outlet at the same level of the bottom of the soil column. The column was kept like this for 24 hours in order to make the system equilibrium. After establishing equilibrium in the system, the greywater of known concentration was flushed through the column and pH and EC at column outlet were measured. When EC value of column effluent became constant, greywater irrigation was stopped. The column was again kept 24 hrs to establish equilibrium in the system and the column was dismantled. The moisture content in each ring was measured gravimetrically and the suction head corresponding to each ring was taken as the distance between the ring's mid-point and the bottom water level. The same experiment was repeated for different greywater concentration and one experiment was done with tap water at the beginning to record the initial soil properties. Separate experiments were done with the same greywater concentration to calculate the soil hydraulic conductivity using constant head method.

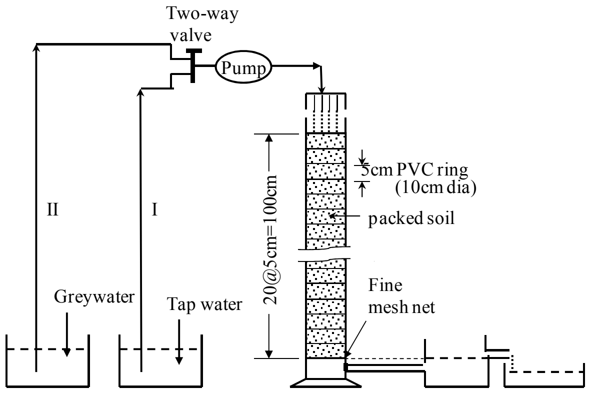

Figure 1. Experimental setup

III. Results and Discussion

A. Soil Electrical Conductivity

Higher concentration of greywater contributes to higher Electrical Conductivity (EC). The EC of aqueous solution indicates the presence of salt and hence the salinity of the soil. Generally the tap water has EC (as EC_0) of 420 µs/cm, but sometimes it may go up to 500 µs/cm plus. The salinity is an issue where laundry water is discharged over the soil in gardens and lawns. A salt is simply a compound that dissociates in water to form cations and anions. Salt in the washing powder is not the common salt that we use to cook. It's made up of cations such as, calcium, magnesium, and potassium and anions of sulphate, phosphate, nitrate, chloride and carbonate. [6]. The breakthrough curves (BTC) of EC measurements are presented in Fig. 2. The BTCs indicate that the higher concentration greywater reach the column outlet faster. The normal electrical conductivity level for irrigation water is about 1ds/m while higher EC values are more likely to induce loss of plant production. The general plant health will be affected by increased salinity in irrigation water due to effects of increased salinity on the physiology of the plant and the effects of soil salts. The normal salinity level in laundry greywater is found between 800 µs/cm to 1050 µs/cm for normal load wash (one scoop of washing powder) and rinse water together [6]. Most of cities discharge greywater into ocean without reuse it; therefore much attention was not paid on the effects of greywater on soil structures. Appropriate regulations are absent in most places to reuse laundry greywater. However, diluting laundry greywater before irrigation may be needed to maintain low levels of soil salinity.

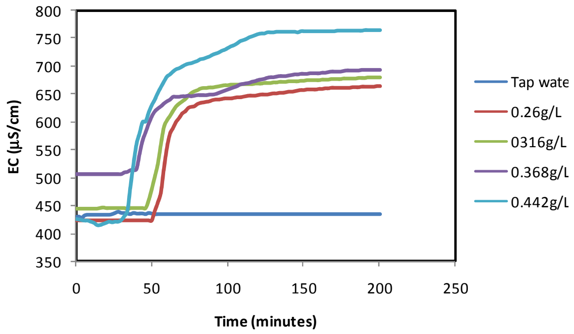

Figure 2. Breakthrough curves with EC

B. Soil pH

The pH values in column effluent were measured with time for each experiment and shown in Fig. 3. Results revealed that the pH value of column effluent starts to increase after 140 minutes for the lower range of greywater concentration but it was obtained much faster in the higher concentration. This was because of the rapid changes of soil hydraulic properties. Higher greywater concentration with high pH value has the ability to dissolve organic matter, such as sweat, blood, food and also has adverse effect on skin [6]. Therefore, one should be careful when handling the wash water where pH value is above 10. The pH value is related with soil structure and health of the plants. High pH value could lead to the dissolution of organic material and induces dispersion in the soil. This is because the detergent in the washing powder supposes to remove soils from clothes. Therefore high pH liquids act as dispersing agents, causing the soil particles to separate and lead to soil structure decline. The normal pH range for biological activity is between 5 and 9. If pH value reached more than 9, biological activity won't be happened in normal way and dissolved organic material can be leached out of soil [6]. The dissolved organic materials degrade in time to become plant nutrients, so a loss of organic material may be detrimental to plant health [6]. Therefore it is recommended to dilute the greywater to reduce pH before using for irrigation.

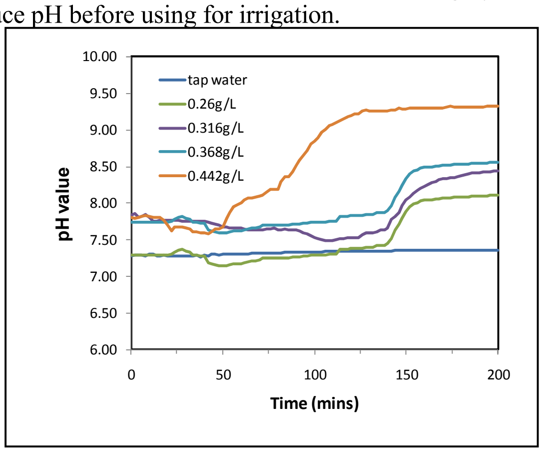

Figure 3. Change of pH during soil irrigation by greywater

C. *Soil Hydraulic Conductivity*

Soil hydraulic conductivity depends on the type of soil, porosity and configuration of the soil pores. Saturated hydraulic conductivity data for sequential leaching of soil with tap water and laundry greywater are shown in Fig. 4. Hydraulic conductivity increases steadily with greywater concentration. This is because of washing the very fine particles and due to the reduction of surface tension. Increasing hydraulic conductivity also indicates that the soil may convert to be water-repellent due to the reuse of greywater in irrigation. As a result, overall water transmitting capacity increases and the water retention capacity decreases. Hydraulic conductivity is a very important soil property when determining the potential risks for widespread groundwater contamination by a contaminating source. Soil with high hydraulic conductivities and large pores for transmit water are likely candidates for far reaching contamination. This means increasing of hydraulic conductivity due to greywater irrigation may enhance the groundwater contamination. Moreover, the presence of phosphorous and nitrogen may act as fertilizer to the plants but high content of laundry detergent can be harmful to the plants, causing phosphorus toxicity and sodium issues.

D. *Bulk density and Porosity*

The bulk density was measured gravimetrically for each ring of the column and the average value of bulk density for the soil media is represented in Table I for different greywater concentration. The results revealed that the bulk density decreases with greywater concentration. This is because the greywater washed out the fine particles, increases the hydraulic conductivity and make the grain size smaller and thus reduce the overall solid mass. The porosity was measured as the saturated moisture content in the lowest ring of the column and also shown in Table I for all the experiments. Porosity was found increasing with greywater concentration at the lower range of greywater concentration but started to increase in the higher range of concentration. This is because of the washing of the fine particles increases the overall void spaces in the soil. But when the concentration increases, the surfactant monomers first saturate different interfaces (i.e. soil/liquid and air/liquid) and then starts to form micelles after certain concentration (i. e., critical micelle concentration) and it reduces the average void spaces for the retention of water content.

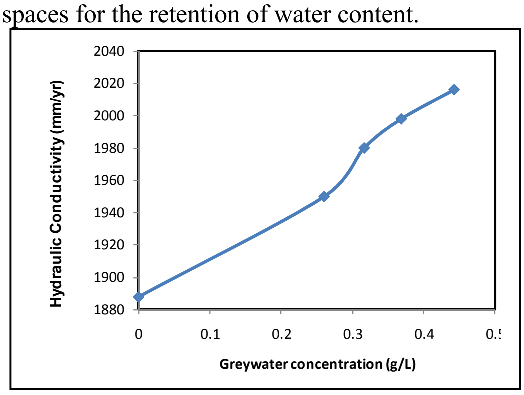

Figure 4. Change of hydraulic conductivity with greywater

TABLE I. CHANGES OF SOIL BULK DENSITY AND POROSITY

Greywater conc. (g/L)	Bulk density (g/cm^3)	Porosity
0 (tap water)	1.392	0.220
0.26	1.387	0.242
0.316	1.376	0.249
0.368	1.369	0.224
0.442	1.355	0.208

E. *Moisture Content and Capillary Rise*

Four column experiments were performed with different greywater concentration and one experiment was done with tap water. The moisture contents in each ring were measureed gravimetrically and the capillary pressure head was taken as the distance between the groundwater table and the mid-point of each ring. The pressure-saturation curves for each experiment are plotted in Fig. 5. Capillary rise is a phenomenon that can have both beneficial and detrimental effects on the soil. It is a main mechanism by which plants can draw water from below the root zone, but it is also a mechanism contributing to the accumulation of salts in the soil [3]. The reduction of capillary pressure with increasing greywater concentration indicates the presence of surfactants in greywater. Considering negligible contact angle, it is expected that the surfactant would reduce the surface tension of the aqueous phase. This is because of the surfactant monomers that have an affinity to accumulate onto the interfaces. This phenomenon consequently changes the migration pattern in the soil pores. Figure 5 revealed that the capillary pressure decrease sharply at the lower concentration of greywater but have a little effect at the higher concentration. This is because the surfactant monomers form micelles when the entire interfaces are saturated with monomers. At this moment, the surfactant concentration is known as critical micelle concentration (CMC). However, CMC value could not be determined as the specific surfactant in the selected detergent is unknown in this study. Though the surfactant in OMO detergent is unknown but several studies show that anionic and non-ionic surfactants are present in detergents. [3, 5]. Shafran et al. [3] reported that it is only the surfactant in laundry detergent has the influence on the reduction of surface tension, not any other ingredients present in it. Another explanation for decrease in capillary pressure is embedded in the mechanism of surfactant adsorption onto the soil surfaces. Shafran et al (2005) performed experiments with the pure surfactants normally present in laundry detergent such as linear alkylbenzene sulfonate (LAS) and found that the electrostatic bonds of negatively charged sulfonate groups interact with the positively charged sand surfaces causing the adsorption of hydrophobic tails of LAS monomers and protruding into the aqueous phase. These actions of surfactants enhance the soil to be water-repellent. A water-repellent soil (or hydrophobic soil) does not wet up spontaneously when a drop of water is placed upon the surface and thus it becomes a problem for future irrigation and enhanced environmental pollution. However, the information about water-repellent soil is inadequate in the literatures and it needs further investigation.

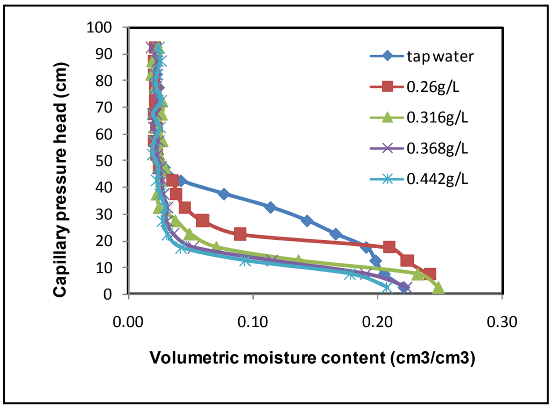

Figure 5. Pressure-saturation curves during the greywater irrigation

IV CONCLUISION

Several soil column experiments were conducted to investigate the possible changes of soil hydraulic properties during the reuse of laundry greywater in irrigation. The results of EC and pH revealed that the greywater reaches much faster at the column outlet with increasing concentration. Soil hydraulic conductivity increases steadily but soil bulk density decreases with greywater concentration. The soil porosity was first increasing but starts to decrease when the surfactant concentration reaches towards CMC value. Capillary rise in the column decreases sharply with greywater concentration but remain constant after CMC. The long-term irrigation of surfactant-rich laundry greywater may lead to water-repellent soil and enhance future environmental pollution. The current knowledge on the causes and characteristics of water-repellent soil is insufficient and further study should be undertaken to understand the accumulation of surfactant in soil due to the reuse of laundry greywater in irrigation.

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REFERENCES

[1] DHWA (Department of Health Western Australia), "Draft guidelines for the reuse of greywater in Western Australia" 2002..

[2] DHWA (Deaprtement of Health Western Australia), "Code of Practice for the reuse of greywater in Western Australia", 2005.

[3] A. W. Shafran, A. Gross, Z. Ronen, N. Weisbrod, and E. Adar, "Effects of surfactants originating from reuse of greywater on capillary rise in the soil", Water Sci. & Technol., 2005, vol. 52 (10-11), pp. 157-166.

[4] M. Abu-Zreig, P. R. Rudra, and T. W. Dickinson, "Effect of application of surfactants on hydraulic properties of soils", Biosystems Engineering, 2003, vol. 84(3), pp. 363–372.

[5] R. K. Misra, and A. Sivongxay, "Reuse of laundry greywater as affected by its interaction with saturated soil", J. of Hydrol. 2009, vol. 366, pp. 55–61.

[6] Lanfax Lab, http://www.lanfaxlabs.com.au/ (accessed April 20, 2009)