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EFFECTS OF GREYWATER DISCHARGES ON SHALLOW SOIL PROPERTIES

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ABSTRACT

Discharge of detergent-containing wastewater (greywater) into soils is common in rural areas in Yucatan, Mexico since the majority of soils are shallow and bedrock makes the building of drainage systems a challenge. The aim of this study was to evaluate the effect of greywater discharges on shallow soil properties. Physical and chemical properties of soil samples collected from 100 household home gardens in the municipality of Hunucmá, Yucatan were analysed. Two soil samples were taken in each home garden, one in a soil affected by greywater discharges and one in unaffected soil. Average powdered detergent used was 7 kg / year / home garden. Our calculations indicated that 23 tons of sodium and 19 tons of phosphorus are verted annually in the Hunucmá municipality. Compared to unaffected soils, samples of greywater-affected soils contained significantly higher pH and electrical conductivity values and higher phosphorous and sodium contents, as well as lower REDOX potential and sand and silt contents. Greywater discharges modify the physical and chemical properties of shallow soils. Further research is needed to better understand the dynamics of the elements contained in the detergent-containing greywaters, systematically verted on soils, as well as their impacts on vegetation development and aquifer contamination.

Keywords: laundry greywaters; surfactants; home gardens; soil quality; soil degradation; soil contamination.

1. INTRODUCTION

Detergents, from the Latin *detergeré* - "to clean", are natural or synthetic products in liquid or solid form used in domestic and industrial cleaning applications [1]. Surfactants are the principal active components of detergents, representing 10-15% of most formulations [2]. Based on their chemical properties, surfactants are classified as anionic, cationic, non-ionic or amphoteric, each providing a different function in cleaning [3]. Detergents contain different concentrations of active chemical components that can alter physicochemical properties in the environment where they are discharged. For example, high detergent concentrations increase pH and electrical conductivity of the soils into which they are discharged [4].

Rural households in the state of Yucatan, Mexico, perform multiple productive (fruit, vegetable, livestock, among others) and domestic activities (laundry) in their home garden. It is common for rural home gardens to have a wash basin (*batea* in the Spanish) in the back for washing clothes and dishes. The greywaters produced from washing contain diluted detergents. The shallow soils (< 30 cm) and porous limestone bedrock of the northern Yucatan Peninsula make drainage system installation a challenge [5]. Greywater from home garden wash basins is consequently discharged directly into the surrounding soil, rarely having received a second use.

Eutrophication is a known effect of the detergent-containing greywaters addition to water bodies [6, 7, 8, 9, 10], but little is known about the effects of detergent addition on soil properties [11, 4, 12]. Physical properties may be affected by water saturation, leaching of fine particles and dispersion due to the sodium contained in detergents, while chemical properties can be altered due to the alkaline nature of detergents as well as the nutrients added (specially sodium and phosphorous).

Soils in rural home gardens in Yucatan are richer in phosphorous than soils under other circumstances [13], quite possibly due to the high phosphorous content in the detergents commonly used for washing. We hypothesized that detergent-containing wastewater (greywaters) added to soil in a regular basis will affect negatively soil physicochemical properties (sand, silt and clay contents, field capacity, pH, REDOX potential and, Sodium and Phosphorous contents). The present study objective was to identify the effects of greywaters discharge on the physicochemical properties of shallow soils subjected to daily discharges of detergent-containing wastewater.

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2. MATERIALS AND METHODS

2.1 Study area

Hunucmá municipality is in the northwest of the state of Yucatan, Mexico (20° 54'-21° 16' N; 89°48'-90°16' W). It covers an area of 840.52 km^2 and altitude ranges from 7 to 10 masl. Climate is very warm and semi-dry with annual average temperatures of 24 to 28 °C and annual average precipitation of 600 to 700 mm [14]. Soils are shallow and dominated by Lithic Leptosols.

2.2 Detergents: brand identification and use habits

Study units were home gardens located within the municipality's urban area. Semi-structured interviews were applied to housewives in 100 randomly-selected households with home gardens (Figure 1). Data collected included the main types of detergents used, detergent brands, amount used, frequency of use and secondary uses/discard habits. The detergents cited by the housewives were analysed to identify each brand's active ingredients and estimate the amount of different compounds discharged into home garden soils.

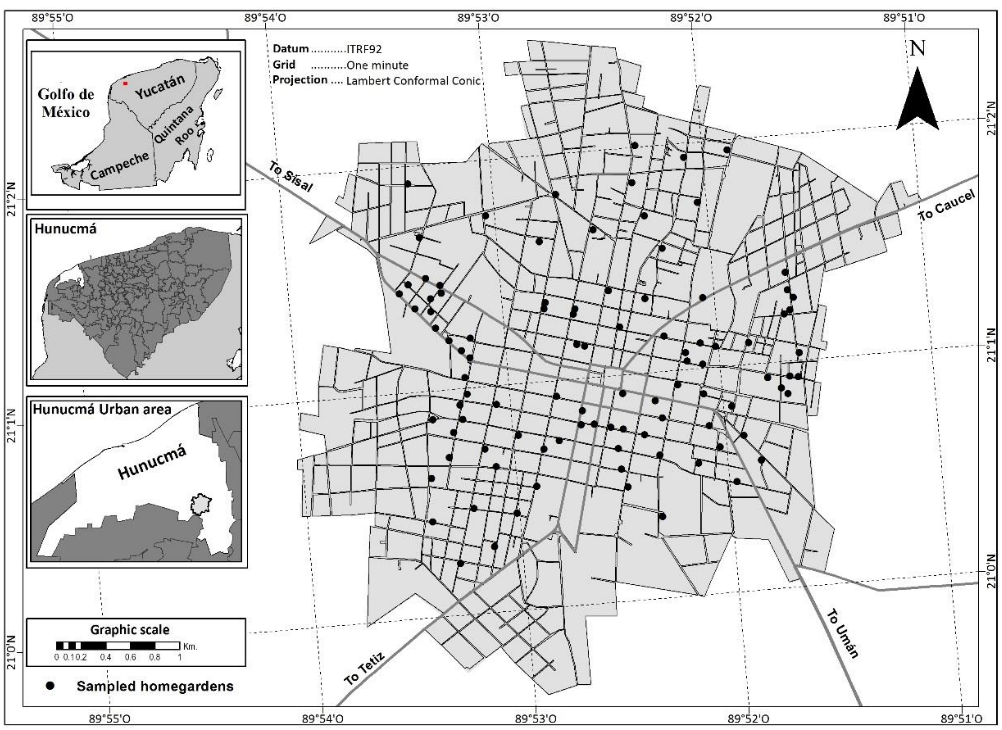

Figure 1: Location of sampling sites in the urban area of the municipality of Hunucmá, Yucatán.

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2.3 Soil sampling

During the dry season, two soil samples were collected from each home garden at 0-30 cm depth (or at bedrock). One sample was collected within a 2 m radius of the greywater discharge zone (WD: with detergent), and a second was collected from soils which, according to interviewees, had no contact with greywaters (WOD: without detergent). A total of 200 soil samples (100 WD and 100 WOD) were taken. Time of soil exposure to greywater at the WD sampling sites ranged from 1 to 60 years. After transport to the laboratory, soil samples where oven-dried (24 hours, 105 °C) and stored until analysis.

2.4 Soil analyses

Seven analyses were run on the soil samples: particle size analysis (Bouyocus or densimeter method) [15]; field capacity (gravimetric) [16]; pH 1:2 soil:water suspension (potentiometric) [17]; Electric conductivity (EC) 1:5 soil:water [18]; REDOX potential 1:2 ratio (potentiometric) [19]; phosphorus content (Olsen method) [20]; and sodium content (flame photometry) [21]. Analyses were done at the Soil, Plant and Water Analysis Laboratory (Laboratorio de Análisis de Suelos, Plantas y Aguas - LASPA), Biological and Agricultural Sciences Campus (Campus de Ciencias Biológicas y Agropecuarias), Autonomous University of Yucatan (Universidad Autónoma de Yucatán - UADY).

2.5 Statistical analysis

A principal components analysis (PCA) was done of soil properties in the WD and WOD samples. The components were extracted from the correlation matrix and the centroids (multivariate vectors of the means) for the two soil groups compared using a multivariate analysis with one-factor permutations (PERMANOVA). Bray-Curtis dissimilarity was used as a measure of distance [22, 23], since multivariate variances were non-normal and non-homogeneous. For the same reasons, univariate comparisons were run with a permutation test for two samples. Univariate and multivariate calculations were done using the PAST ver. 2.174 software [24]. For the univariate comparisons, a Bonferroni adjustment was applied for hypothesis testing ($\alpha = 0.0056$).

3. RESULTS AND DISCUSSION

3.1 Detergent brand identification and use habits

A total of 15 brands of powdered detergents were used among the housewives for washing clothes and dishes; the five most popular brands were "Foca" (La Corona®), "Ariel", (Procter & Gamble®), "Axion" (Colgate-Palmolive®), "Ace" (Procter & Gamble®) and "Blancanieves" (La

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Corona®). All contain the anionic surfactant sodium tripolyphosphate, which can account for 15-40% of total detergent weight [25]. The only liquid dishwashing detergent reported was "Axion" (Colgate-Palmolive®), which is labelled as not containing phosphorus; instead, it may contain a combination of sodium dodecyl sulphate and sodium lauryl ether sulphate [26]. In most cases (78%) clothes were washed in a washing machine, and in the remainder (22%) in a wash basin. Powdered detergents were used in both cases. Many of the housewives that used a washing machine frequently rinsed the clothes in the wash basin. Dishes were often washed in the wash basin, but only 18% of the housewives used liquid detergents. After washing clothes or dishes, 53% of housewives did not reuse the residual water for other activities, 25% reused it to wash the floor of the house and the remaining 22% used it to water plants in the home garden. No matter the case, the wastewater ended up in the home garden soil. The average amount of powdered detergent used was 5.22 kg / month / home garden for clothes washing, and 2.6 kg / month / home garden for dish washing (Table 1).

Table 1: Amount of detergents used by homegarden in Hunucmá, Yucatán

Cloth washing	Average
Clothes washing in "batea"/ homegarden / month (Kg)	2.33 ±1.5
Clothes washing by washing machine/homegarden / mes (Kg)	2.89 ± 1.8
Dish washing	
Powdered detergent/homegarden/month (Kg)	1.75 ±1.28
Liquid detergent/homegarden/month (l)	0.85 ± 0.52

3.2 Soil properties

The pH, EC, sodium and phosphorus contents were higher (P <0.05) in WD soils, while REDOX potential (RP), and sand and silt contents were lower (P <0.05) (Table 2).

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Table 2: Physical and chemical properties of soils with and without detergents in Hunucmá, Yucatán.

Soil property		FC (%)	pH	EC (µS/cm)	RP (mV)	P (mg/Kg)	Na (mg/Kg)	Clay (%)	Silt (%)	Sand (%)
WD	Mean	84.65	7.84	520.42	135.77	106.39	6.67	34.07	22.31	43.62
	SD	24.10	0.36	365.55	30.41	87.06	2.92	11.46	6.99	13.99
WOD	Mean	89.78	8.08	757.69	126.17	142.89	10.71	31.99	20.92	47.09
	SD	32.15	0.44	484.99	34.56	89.20	5.05	10.72	7.63	14.38
P value		0.208	<0.0001	<0.0003	<0.0364	<0.0365	<0.0001	>0.1804	>0.1784	<0.0847

WD= With detergent; WOD= Without detergent; FC= Field capacity; EC= Electric conductivity; RP= REDOX Potential; P= Phosphorous content; Na= sodium content; SD= standard deviation.

Water content at field capacity exhibited no differences between the soils, probably due to heterogeneity in the shallow soils, stoniness, porosity and fissures in the bedrock (field observations), all of which can alter water filtration rate and water retention capacity. This contrasts with reported reductions in hydraulic conductivity and possible hydrophobic properties in soils containing detergent surfactants [27, 28].

Soil pH is vital because it determines the availability of soil nutrients [4]. Mean pH in the WOD soil samples was 0.2 units higher ($p < 0.05$) than in the WD samples. This is similar to a 0.1 unit difference in pH between loam soils irrigated with detergent-containing greywater for 60 days and untreated soils [8]. In the studied soils the observed increase in pH is important because it may decrease the availability of phosphorus and other micronutrients [29], especially since soils in the study area are alkaline.

Electrical conductivity (EC) was 45% higher ($p < 0.05$) in the WD soils than in the WOD soils. This agrees with a reported 26% increase in EC in soils irrigated with greywater compared to soils irrigated with potable water [4]. In contrast, [30] found that the EC of soil decrease after two years of greywater irrigation, this was correlated with a decrease of the calcium content in soil which is not likely to occur in Yucatán where limestone is abundant. In another study, one year of applying detergent-containing greywater to a clay-silty soil collected in Jordan home gardens raised soil EC and lowered soil organic matter content [11]. In this same study, soil salinity gradually increased with wastewater exposure. Indeed, higher EC may be linked to higher soil sodium content, an abundant element in the sodium tripolyphosphate of detergents [25]. In this study sodium content was significantly greater in soils WD compared to those WOD. [31] found that use of greywaters predispose soil to salinization.

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Mean phosphorus (P) content was 34% higher ($p < 0.05$) in the WD soils than the WOD soils. This agrees with the five-fold increase in P concentration reported in soils irrigated with detergent-containing wastewater over those irrigated with potable water [32], and increased P content in Cambisols irrigated for 18 months with greywaters from baths and kitchens [33].

REDOX potential did not differ between the WD and WOD soils, probably because soils in the study are very shallow and allow water to rapidly filter through, preventing anaerobic conditions from developing.

Particle size analysis showed the WD soils to have decreased clay and silt contents, and increased sand content, indicating that finer soil particles were washed away in the areas exposed to greywater [34].

Results from the PCA showed the first two principal components to explain 43.2% of variation in the data (Table 3).

Table 3: Relationship between the original variables and the first two main components

Soil property	Component 1	Component 2
Field capacity	0.3405	0.5028
pH	0.2914	-0.02193
Electric conductivity	0.3626	0.6307
REDOX potential	-0.4961	-0.1152
Phosphorus	0.2681	0.5303
Sodium	0.3591	0.6099
Clay content	-0.7514	0.3723
Silt content	-0.5686	0.2716
Sand content	0.8784	-0.43
Eigenvalue	2.44	1.71
Explained variance (%)	27.10	19.05

The variables correlated most closely with the first component were soil sand and clay contents, while those most correlated with the second component were electrical conductivity and sodium concentration. No clear difference was observed between WD and WOD soils for the first two principal components (Figure 2).

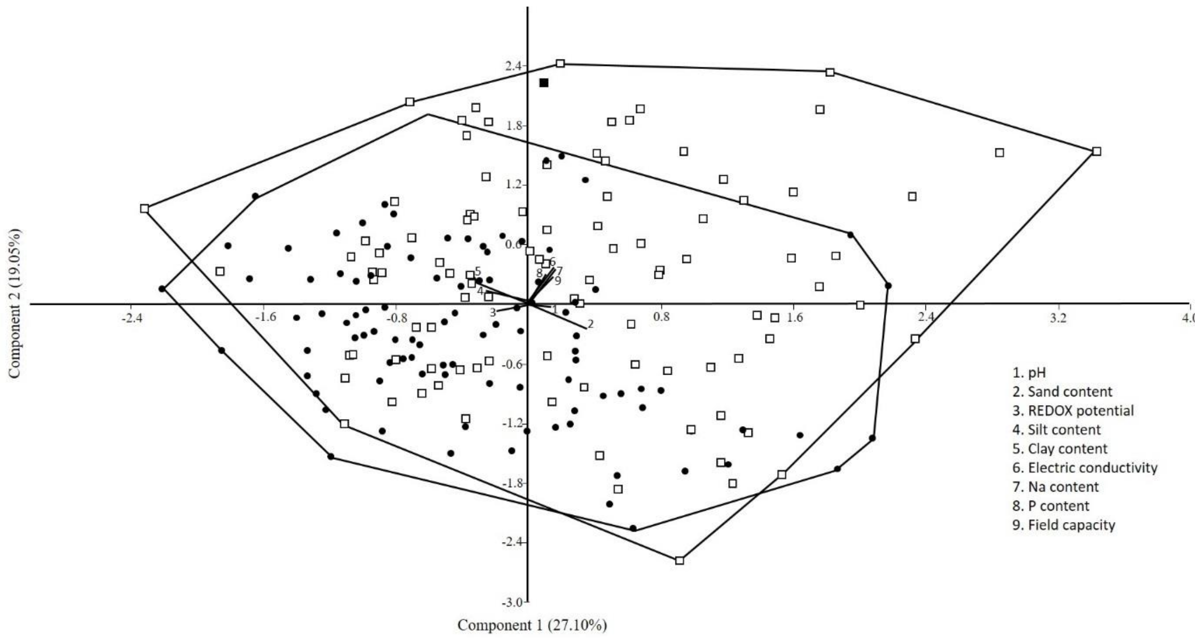

Figure 2: Principal component analysis. Squares represent soil samples with detergents and circles represents samples without detergents.

The PERMANOVA identified differences between the centroids of WD and WOD soils (F = 13.82, P = 0.0001, 9999 permutations). In univariate terms, soil groups differed in pH, electrical conductivity (EC), phosphorus concentration and sodium concentration (Table 4).

Table 4. Confidence intervals of the analyzed variables in the soils with detergent (WD) and without detergent (WOD)

Soil property	WD	WOD
Field capacity	83.40 – 96.16 A	79.87 – 89.42 A
pH	7.99 – 8.16 A	7.77 – 7.91 B
Electric conductivity	661.46 – 853.92 A	447.89 – 592.96 B
REDOX potential	119.31 – 133.03 A	129.74 – 141.81 A
Phosphorus	125.19 – 160.59 A	89.11 – 123.66 B
Sodium	9.71 – 11.72 A	6.09 – 7.25 B
Clays	29.87 – 34.12 A	31.80 – 36.35 A
Silts	19.41 – 22.44 A	20.92 – 23.70 A
Sands	44.23 – 49.94 A	40.84 – 46.40 A

Different letters between rows indicate significant differences according to the Bonferroni adjustment ($\alpha = 0.0056$)

Greywater discharge did not have a cumulative effect over time (data not shown), suggesting that the shallow soils in the study area have minimal holding capacity for the elements contained in greywaters. This means most of these elements probably quickly filter down into the aquifer due to the karstic nature of the area [5]. [35] found that the long-term application of greywater had a moderate impact on a sandy soil of New Zealand, authors attributed their findings to the texture of soil along with the high precipitation of the study site.

3.3 Impact of detergent discharge on soil in home gardens

To scale the problem of greywater discharge use in Hunucmá municipality, calculations were done of the total amount of detergents used for laundry and dish washing in the area (Table 5). Since each kilogram of laundry detergent contains approximately 200 g sodium tripolyphosphate ($Na_5P_3O_{10}$), an estimated 62.5 g sodium and 50.5 g phosphorus are added to the soil per kg of detergent used.

Table 5: Estimated amounts of detergents used in Hunucmá, Yucatán

Amound of detergent used	Average
Clothes washing by “batea”	
municipality* / month (tons)	3.71
municipality* / year (tons)	44.52
Clothes washing by washing machine	
municipality* / month (tons)	16.30
municipality* / year (tons)	195.56
Dish washing (powdered detergent)	
municipality* / month (tons)	10.37
municipality* / year (tons)	124.44
Dish washing (liquid detergent)	
municipality* / month (l)	1105.85
municipality* / year (l)	13270.20

Calculated data for the 7230 homegardens throughout the municipality [36], assuming that 78% of the homegardens (5639) use washing machine and 18% (1591) “batea”, and 82% of the homegardens (5929) use powdered detergents and 18% (1301) liquid detergents.

Given the number of households (n = 7230) and habitants (24910) in Hunucmá, this represents annual discharges of 23 tons of sodium and 19 tons of phosphorus for the municipality (Table 6) and 0.92 g of phosphorus / per capita and 0.76 g of sodium / per capita. Use patterns are likely to be similar in other rural locations, in the state of Yucatán there are approximately 679351 habitants living in 2486 rural localities [36], these means that the discharge of phosphorous and sodium for the whole state would be 625.00 and 516.30 tons respectively. These are very conservative numbers as many peri-urban areas also contribute with greywater discharges.

Table 6: Estimated amounts of phosphorus and sodium added to the soil through the laundry detergents used to wash clothes and dishes in Hunucmá, Yucatán.

	P	Na
Clothes washing in "batea"		
municipality* / month (tons)	0.23	0.19
municipality* / year (tons)	2.78	2.25
Clothes washing by washing machine		
municipality* / month (tons)	1.02	0.82
municipality* / year (tons)	12.22	9.8
Dishes washing (powdered detergent)		
municipality* / month (tons)	0.65	0.52
municipality* / year (tons)	7.78	6.28
TOTAL		
Municipality total / month (tons)	1.90	1.53
Municipality total / year (tons)	22.8	18.4

Calculated data for the 7230 homegardens in the municipality [36]. Liquid detergents were not included because they did not contain phosphorus.

In 1984, [37] concluded that anion surfactants were not an environmental hazard because their fast biodegradability; however, we demonstrated here that soil properties are clearly affected. Further research is needed to better understand the dynamics of the elements contained in the detergent-containing greywaters, systematically verted on soils, as well as their impacts on vegetation development and aquifer contamination. Adequate public policies also need to be developed to reduce direct greywater discharges into soils, and to reduce surfactants use in detergents. One example is the Resolution No. 359 of the National Environmental Council (CONAMA) of Brazil updated in 2005 which made mandatory the reduction of 15% total phosphorous by weight of laundry cleaning products [38]. Recently, Colombia also published the Resolution 0689 which stablishes the maximum limits of phosphorous in detergents [39]. Unfortunately there are no resolutions like those in México.

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4. CONCLUSIONS

Discharge of detergent-containing greywaters into soils increased phosphorus and sodium contents, and raised pH and electrical conductivity, while reducing REDOX potential and sand and silt content. Continued discharge will degrade soil quality, particularly in the shallow soils in rural areas where greywaters are poured into soil in a daily basis. Mitigation measures will need to address the practice of direct greywater discharge, detergent surfactant content in laundry products and, use of new alternative detergents with no phosphate surfactants.

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