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RESEARCH ARTICLE

Effect of Cereal Gruel Supernatant on Physical-chemical and Geotechnical Properties of Greywater contaminated Soils

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Abstract

Greywater comes in contact with natural topsoils of some houses within rural and peri-urban settings, leading to changes in their inherent features. This micro study assessed the impact of Cereal Gruel Supernatant (CGS) amendment on selected physical, chemical, and geo-environmental characteristics of greywater contaminated Soils (GCSs). The GCSs and Control Soils (CS) were collected from two different sample sites in Basement Complex environment at depths 50, 100, and 150 cm from the surface. The test comprised of four sets: CS without greywater, GCS, CS with 50 ml of CGS, and GCS with 50 ml of CGS. The results revealed that the modification of most tested properties on GCSs hinged on sample depth whereas impact of CGS amendment on properties of GCS was location dependent. There is no significant effect of CGS on both maximum dry density and moisture content of contaminated soils at the two locations. Analysis of variance (ANOVA) showed that according to sampling depths criterion, there are significant differences at 5% level for most analyzed soil properties except shear strength, organic matter and soil resistivity whereas no substantial difference at 5% level occurred with respect to soil amendment with CGS. More analysis is required to study the variations of soil parameters with specimen depths by various cereal based starchy fermented gruel on GCS at varying volumes.

Keywords: Basement Complex, Greywater, Physical-chemical, Geotechnical, Cereal gruel supernatant

Introduction

Wastewaters are usually produced as end products of certain regular humanoid activities. The volume of wastewater produced by a society as a result of anthropogenic activities depends to some extent on the standard of living, domestic water consumption, pattern of development in a geographical setting, and cultural beliefs of the residents of a particular society (Baharvand and Mansouri Daneshvar, 2019; Schilling and Tr□nckner, 2020; Ganiyu *et al.*, 2020). According to Greywatersafer.com (2004) and Ghrair *et al.* (2018), Greywater is defined as wastewater that is generated as water outflows from the bathrooms, kitchens, and laundry without the wastewater from toilets. The issue of management of greywater for alternative uses has not been given proper attention by environmentalists in developing countries of African continent, where improper disposal of wastewater is more rampant (Morel, 2005). The reuse of greywater attempts to preserve the nearby freshwater source thereby reducing the impact of environmental pollution of shallow aquifers (Al-Hamaeideh and Bino, 2010). Though, the use of greywater for agricultural purposes is well reported (Travis *et al.*, 2008; Al-Hamaiedeh and Bino, 2010; Anwar, 2011; Mohamed *et al.*, 2018) there is insufficient information/data on the geotechnical and physical-chemical characteristics of greywater contaminated soils. Ganiyu *et al.*, 2020 previously studied the impacts of greywater on soil properties.

Surfactants, (being major components of detergents and bathing soaps used in laundry and bathtubs) are compounds (deliquescent and hydrophobic) that have potentials of altering physical-chemical and geo-environmental characteristics of near surface soil (Mohamed *et al.*, 2018; Ganiyu *et al.*, 2020). For instance, Mohamed *et al.* (2018) investigated the alterations in soil characteristics after the irrigation process with laundry wastewater. Calabar and Karabash (2015) evaluated the changes in California bearing ratio of sub-base material modified with tire buffings and cement addition. Several researchers have also investigated the use of treated wastewater as mixing water for concrete production

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(Cebeci and Saatci, 1989; Shekarachi *et al.*, 2012; Kucche *et al.*, 2015)) while Ghrair *et al.*, (2018) evaluated the potential of reused greywater (treated and raw greywaters) in concrete and mortar. However, non-ionic surfactants have also been reported to promote the solubilization of heavy metals while the anionic and cationic surfactants hindered the removal of dissolved heavy metals (Kosobucki *et al.*, 2008; Ren *et al.*, 2014). Surfactants are reported to be useful in bio-acidification process as they assist in increasing the dissolution of substrates by reducing interfacial tension (Ren *et al.*, 2014). The application of organic materials for soil amendment as a means of improving physical properties of degraded soil was reported by Are *et al.* (2018). However; treatment of porous media such as soil with fermented liquids and its associated effects has not been reported.

Fermented cereal gruels and beverages serve as source of Lactic Acid Bacteria (LAB) and yeasts (Olukoya *et al.*, 1994; Steinkraus, 1996). The major microorganism found in *Ogi* fermentation is *L.plantarum,* responsible for the production of lactic acid (Banigo and Muller, 1972; Ohenhen and Ikenebomeh, 2007). Studies conducted by Afolayan *et al.* (2017) revealed that *Omidun* (cereal gruel supernatant (CGS)) obtained from popular acid fermented cereal gruel sediment called *Ogi* in Nigeria had the highest LAB count compared to the cooked Ogi. However, published works on effects of soil microbial isolates dwell more on how to improve increased grain crop yields (Khosravi *et al.*, 1998; Abd El-Ghaniy *et al.*, 2010). In addition, priobiotic strains have been reported to have potential for the deletion of metalloids from water and soil (Bhakta *et al.*, 2012; Ameen *et al.*, 2020; Hasr Moradi Kargar and Hadizadeh Shirazi, 2020). It has also been reported by Osungbaro (2009) that different varieties of maize exhibit various pasting viscosities and consistencies on the amylograph while the swelling characteristics (thickening) of *Ogi* have been found to be predisposed by fermentation period. For instance, Aminigo and Akingbala (2004) reported that lowering of viscosities in the process of supplementation of fermented cereal foods has effects on the consistency of the gruels prepared there from. Furthermore, Klang *et al.* (2019) reported that reduction of the swelling capacity on maize-based formulations could be due to its richness in amylase and fermentation process.

In this study, we lengthen the work of Ganiyu *et al.* (2020) by considering the potential of cereal gruel supernatant (CGS), a readily available cereal based starchy fermented gruel as treatment on improving physiohemical and geoenvironmental characteristics of greywater polluted soils. The explicit objectives were to assess the effect of fermented cereal gruel treatment on physicochemical and hydrogeological features of sullage polluted soils at changing sampling depths, the potential of greywater contaminated soil as suitable aggregate for pavement sub base and base materials and the use of analysis of variance to study the interdependence amongst the mean values of analyzed soil properties under different sampling locations and fermented gruel treatment.

Material and Methods

Description of the Study Area and its Geology

The research study took place at two different sampling locations (Mapo and Isolu within Ibadan and Abeokuta cities, respectively) southwest, Nigeria. The location map showing the two sampling sites is shown in Fig.1. The two study sites fall within the humid environment of southwest Nigeria (Akintola, 1986; Badmus and Olatinsu, 2010; Akinyemi *et al.*, 2011). Residential houses in the two sampling locations are characterized by worst environmental conditions, overcrowded buildings, derelict and makeshift wooden houses with little or no compliance to urban development and planning regulations. Furthermore, houses in the studied locations discharge household wastewaters/sewages into pit latrines while greywater (sullage) has been in interaction with untilled soils for more than twenty epochs in the two sites.

Geological Setting

The sampling sites is within the basement complex formation in southwest Nigeria (Key, 1992; Akinse and Gbadebo, 2016). The basement complex rock consists of crystalline igneous and metamorphic rocks, and are lightly classified into three key units specifically the migmatite-gneiss, undifferentiated schist belt, and older granite series (Elueze, 2000; Okunlola *et al.*, 2009; Ganiyu *et al.*, 2020). The predominant basement rocks underlie Isolu and Mapo sites are migmatite and quartzite, respectively (Ganiyu *et al.*, 2020).

Soil Sampling, Analysis and Treatment

Twenty four (24) soil samples were obtained at changing soil depths of 0-0.5 m, 0.5-1.0 m, and 1.0-1.5 m from the two sample sites. At each study site, two sample points were formed: discharge region of greywater in direct contact with natural soil and a control (unpolluted) site. From the discharge point of greywater, a 2 m by 2 m was identified with the use of a tape measure, with soil samples taken at the center of the plot. Sullage polluted soil (SPS) was obtained in the confines of sullage release region whereas control (unpolluted) sample was taken

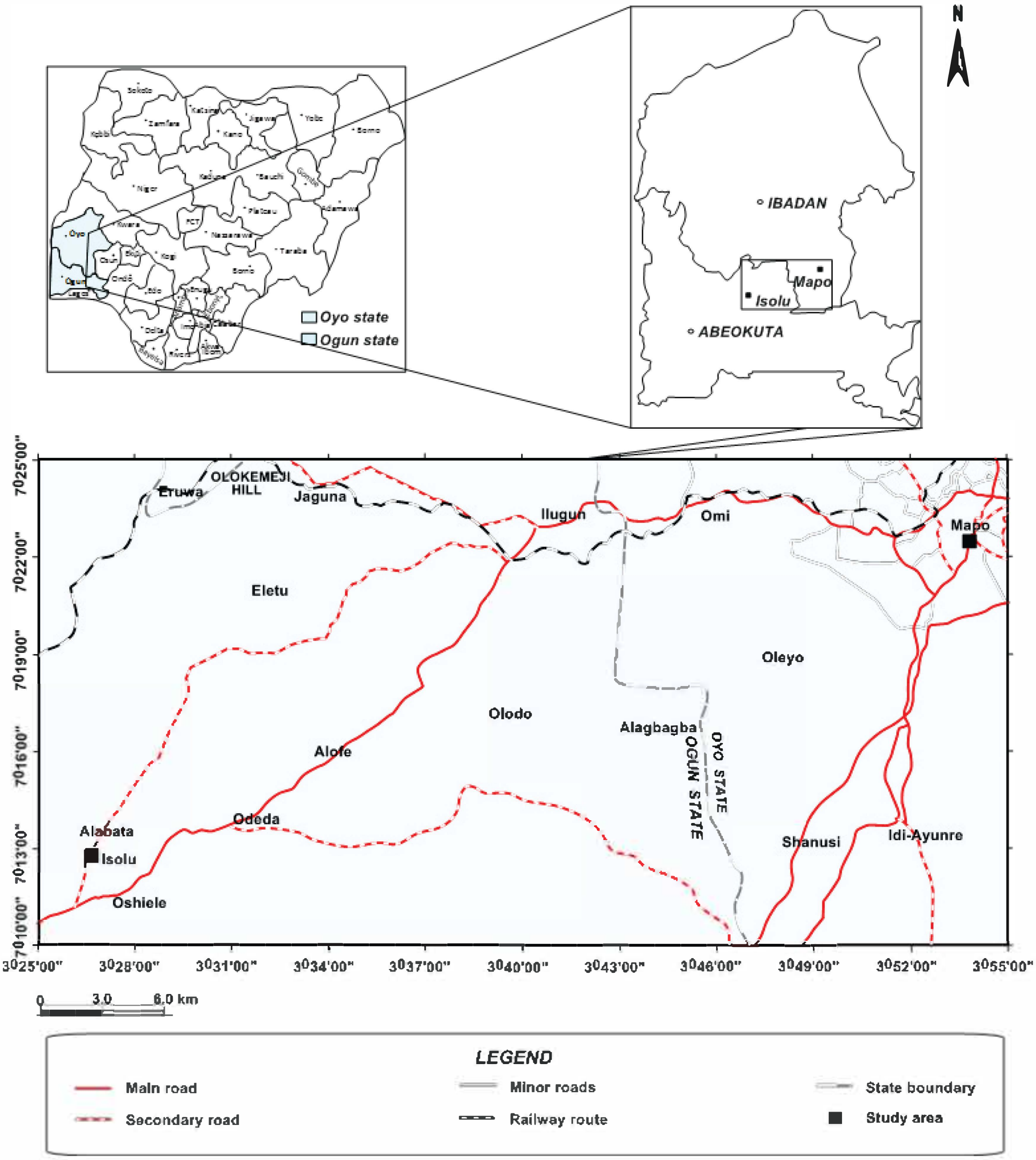

Fig. 1. Site Map of the Study area (source: Ganiyu *et al.*, 2020)

out of unpolluted spot at separate sample site. The disrupted soil samples were collected with the help of soil auger and suitably packed inside polythene bags and labeled properly for easy identification. Disturbed soil samples collected were used for physical-chemical and geotechnics qualities. The soil samples were dehumidified, mildly crushed and separated with a 2 mm sieve before commencement of analyses. Metallic cylindrical cores (5 cm diameter and 5 cm in height) were also used to take placid soil samples at variable depths for the ascertainment of saturated hydraulic conductivity, porosity, and moisture content. Samples were obtained at different depths in order to assess the trend of variation of analyzed parameters with sampling depth. The collected samples were evaluated in the soil physics laboratory at the Institute of Agricultural Research & Training (IAR&T), Moor Plantation, Ibadan, Oyo State, Nigeria

Another set of GCSs and CSs from the two locations were further treated with 50 ml of Cereal Gruel Supernatant

(CGS) and left for a week for chemical reactions to take place between the soil particles and CGS. The soil physical-chemical factors considered were soil pH, OM, CEC, particle size distribution (PSD), as well as soil resistivity (SR) while geotechnics characteristics are plastic limit (PL), liquid limit (LL), plasticity index (PI), bearing ratio (BR), SS, porosity, MC and K_{sat} respectively. A digital pH meter was used to measure pH in water of each soil sample based on ASTM G51-95 (ASTM, 2012) standard while soil MC was determined using weight loss method in conformity with ASTM D4959-07 (ASTM, 2007). PSD was evaluated by revised Boyoucous gravimeter as defined by Gee and Or (2002) with soil textural sorting done with the use of USDA textural triangle. The SR was measured with the use of miller soil boxes in conformity with the ASTM G57-05 (ASTM, 2005) standard, K_{sat} of core (undisturbed) samples was determined by constant head method after Reynolds and Elrick (2002). Both PL and LL were evaluated based on ASTM D4318-17E1 (ASTM, 2017) standard whereas SS was quantified using ASTM D2850-15 (ASTM, 2015) standard. The BR was measured according to ASTM D1883-16 (ASTM, 2016) standard.

Soil permeability was estimated as the quotient of pore capacity of the test sample to the total volume of specimen. The cation exchange capacity was measured by ammonium acetate (NH_4OAC) displacement techniques of Jackson (1958) whereas organic matter (OM) was measured in the laboratory by $K_2Cr_2O_7$-H_2SO_4 method as improved by Nelson and Somners (1982). The dry density was estimated according to ASTM D7263-09 (ASTM, 2018) utilizing the expression:

$$\rho_d = \frac{Ms(\mathrm{g})}{V_b\ (cm^3)}$$

Where ρ_d stands for earth dry density (in g cm^{-3}); M_s denotes the mass of oven parched soil (in gram) and V_b stands for the volume of the soil (in cm^3). The capacity of the soil is approximately equals to the volume of the cylindrical core, and $V_b = \pi r^2 h$; with r and h referring to the internal radius and the height of the cylindrical core, respectively.

Statistical Analysis

Analysis of variance (ANOVA) was used on the obtained soil data in order to evaluate the implication of all tested soil factors based on sampling depths and amendments. Univariate ANOVA was done to examine if the chosen soil physical-chemical and geotechnical/hydrogeological properties altered considerably regarding changing depths and soil treatment.

Results and Discussion

Physical-chemical and Hydromechanical Properties of test soils

The outcomes of physical-chemical qualities of the collected control soils, GCSs, treated CSs and treated GCSs at the two sampling locations are shown in Table 1, whereas the results of soil hydro-geotechnical characteristics are shown in Table 2. As shown in Table 1, addition of CGS treatment to CS and GCS for each sampling depth at Ibadan location resulted in slight reduction in percent sand content but slight increase in percent silt. However, for soil samples collected at Isolu location, treatment with CGS leads to slight rise in % sand of control soil (CS) at all selection depths, but only at soil depths 50 and 100 cm for Isolu GCS. The addition of CGS to CS and GCS samples at Ibadan resulted in slight increase in % clay at each soil depth. However, at Isolu sampling location, the percent clay in GCS reduced following the application of CGS at 0.5 and 1.0 m sampling depths. Treatment of collected soil samples at Ibadan (Vertic Cambisol) with CGS did not alter the pH status of either CS or GCS. However, addition of CGS to Isolu GCS leads to alteration in soil pH status at sampling depths 0.5 and 1.0 m (see Table 1).According to pH permissible limit set for mixing water for concrete, the pHs of Isolu GCS at all sampling depths fall within the pH limit of 6 – 9 (CCCA, 2007; EPA, 2012). We observed trivial rise in OM under the CGS treatment of control (unpolluted) soil as well as GCS at Ibadan location. Nevertheless, the alteration in OM due to the addition of CGS to CS and GCSs at Isolu location did not follow clear trends. There is no noticeable effect on CEC values of both GCSs and CSs at Ibadan location following the application of CGS at all sampling depths. However, addition of CGS treatment to Isolu CSs resulted in slight reduction of their CEC values at depths 0-50 cm and 50-100 cm relative to CEC values of untreated CS. The CEC value of treated GCS at depth 0.5 m increased significantly over that of untreated GCS but slightly increased at 1.0 m depth at Eutric Luvisols location. Compared to the initial porosity values of untreated control and GCS at Ibadan, the addition of CGS treatment to both CS and GCS did not result in any alteration of porosity values at all sampling depths. However, there is reduction in porosity values for treated Isolu GCS at depths 0- 0.5 and 0.5-1.0 m. The obtained SR values for soil samples from Isolu and Ibadan varied from 3.56 to 7.45 ohmcm and from 4.31 to 7.77 ohmcm, respectively. The soil resistivity values for GCSs and CSs at both locations fall below 10.00 ohmcm.

Soil resistivity values at 0.5 and 1.0 m depths remain constant for untreated and treated CSs at Ibadan while addition of CGS to Ibadan GCS results in slight increment of soil resistivity values at all sampling depths. However, addition of 50 ml CGS to Isolu CS resulted in reduction of soil resistivity values at 0.5 and 1.0 m depths while the reduction of SR occurred at soil piths100 cm and 150 cm for treated Isolu GCS.

Table 2 shows that K_{sat} value of Ibadan GCS at depth 0.5 m clearly reduced following the addition of CGS treatment. Addition of CGS to Ibadan CS revealed no noticeable effect on K_{sat} values while there is fluctuation in K_{sat} values for treated Ibadan GCSs. When compared with the initial values of K_{sat} in untreated CS at Isolu location, addition of CGS treatment leads to reduction of K_{sat} at both 0.5 and 1.0 m depths. However, addition of CGS to Isolu GCS resulted in significant increase of K_{sat} at 0.5 m depth. It must be noted that the lowest K_{sat} value (0.13 cm/hr) was noticed in treated Isolu GCS (with highest value of MC (0.110 m^3 m^{-3}) at depth 1.0 -1.5 m whereas the maximum value of K_{sat} (lowest MC value (0.082m^3 m^{-3}) was also observed in treated Isolu GCS at soil depth 0.5 m.

Hydro- geotechnical Properties

The results of hydro-geotechnical analyses carried out on the collected and treated soils from the two sampling sites are presented in Table 2. The collected raw CS, GCS, treated CS and treated GCS at 0.5 and 1.0 m sampling

Table 1. Physicochemical characteristics of untreated and treated soils at the two sites

Description	sand	silt	Clay	pH in H_2O	OM (g/kg)	CEC (cmol/kg)	Soil resistivity (ohm cm)
0.5 m Control Mapo I	74.22	12.86	12.92	9.32	0.81	2.87	6.25
1.0 m Control Mapo I	66.22	12.86	20.92	8.31	0.81	0.99	6.25
1.5 m Control Mapo I	60.22	8.86	30.92	5.21	0.56	0.37	4.31
0.5 m Control Mapo 2	73.29	13.26	13.45	9.49	0.84	2.85	6.45
1.0 m Control Mapo 2	65.29	13.26	21.45	8.45	0.84	0.99	6.45
1.5 m Control Mapo 2	59.29	9.26	31.45	5.36	0.59	0.37	4.50
0.5 m GCSMapo Ib	74.68	12.86	12.46	9.38	0.81	3.35	6.25
1.0m GCSMapo Ib	67.68	13.86	18.46	9.16	0.88	1.25	6.74
1.5 m GCS Mapo Ib	60.68	10.86	28.46	6.43	0.69	0.48	5.28
0.5 m GCS Mapo 2	73.56	12.99	13.45	9.33	0.82	2.87	6.31
1.0 m GCS Mapo 2	66.56	15.99	21.45	10.39	1.01	1.42	7.77
1.5 m GCS Mapo 2	59.56	11.99	31.45	6.97	0.76	0.44	5.83
0.5 m Control Isolu	71.68	8.86	19.46	6.20	0.56	1.23	4.31
1.0 m Control Isolu	59.68	14.86	25.46	8.66	0.94	0.66	7.22
1.5 m Control Isolu	53.68	12.86	33.46	6.74	0.81	0.35	6.25
0.5 m Control Isolu 2	72.03	7.52	20.45	5.29	0.48	1.10	3.66
1.0 m Control Isolu 2	60.03	14.52	25.45	8.51	0.92	0.59	7.06
1.5 m Control Isolu 2	54.03	13.52	32.45	7.13	0.86	0.37	6.57
0.5 m GCS Isolu	72.22	9.86	17.92	6.95	0.62	1.40	4.79
1.0 m GCS Isolu	58.22	14.86	26.92	8.45	0.94	0.55	7.22
1.5 m GCS Isolu	52.22	12.86	34.92	6.56	0.81	0.31	6.25
0.5 m GCS Isolu 2	73.22	15.33	11.45	10.96	0.97	3.86	7.45
1.0 m GCS Isolu 2	66.22	7.33	26.45	4.74	0.46	0.57	3.56
1.5 m GCS Isolu 2	52.22	12.33	35.45	6.29	0.78	0.28	5.99

*Note: Description with 2 at the front denotes soil treated with CGS depths in Ibadan sampling location had LL values within the permissible limit of <25% for suitable aggregates for base and sub-base courses. At Isolu location, raw CS, raw GCS, and treated CS collected at 0.5 m depth had LL values within the specification set by ASTM D1241-00 (2000) and AASHTO M147 (2008). However, addition of CGS to Isolu GCS allowed LL values at 0.5 and 1.0 m depths to be within the specification limit for sub-base materials. It must however be emphasized that state like Colorado allows LL values up to 35% (Colorado, 2010; Osouli *et al.*, 2017). All the collected raw soil samples (CS and GCS) as well as treated soil samples at the two locations had PL values that lie within the safe recommended values of 50% maximum for sub-base and base materials. From Table 2, the level of plasticity of all the tested soil samples (raw and treated CS, raw and treated GCS) from the two sampling sites belong to low plastic soil with PI less than 7.0 (Mohamed *et al.*, 2018). According to the standard specification of PI values for aggregates used in base and sub- base courses, the CS, GCS, treated CS, and treated GCS for each sampling depth at Ibadan had PI values < 6% and thus suitable as aggregates for base and sub-base materials (ASTM D1241-00, 2000). However, at Isolu location, CS, GCS, treated control soil, and treated GCS at 0.5 and 1.0 m depths pass the specification limit of PI< 6%. The values of DD fluctuated from 1.38 to 1.60 Mg/m^3 in collected samples at Isolu whereas it varied starting 1.43 to 1.59 Mg/m^3 in Ibadan soil samples. The minimum values of DD for collected GCS, CS, treated GCS, and treated CS for the two study sites were observed at depth 1.5 m. Application of CGS treatment elevates the DD values of Isolu GCS. However, the DD values almost remain unchanged for amended GCS at Ibadan. Highest value of dry density was discovered in treated Isolu GCS (of sandy loam texture and minimum MC) at depth 0.5 m.

Table 2. Hydro-geotechnical properties of collected and treated soils at the two sites

Description	DD (Mg m^{-3})	Porosity (%)	MC m^3 m^{-3}	Ksat (cm/hr)	Liquid Limit	Plastic Limit	Plasticity Index	Shear Strength KN/m^2	Bearing Ratio (%)
0.5 m Control Mapo Ib	1.58	40.38	0.087	1.31	17.2	13.7	3.5	151.61	3.82
1.0 m Control Mapo Ib	1.49	43.77	0.093	0.45	22..5	17.9	4.6	150.82	6.18
1.5 m Control Mapo Ib	1.42	46.42	0.98	0.17	26.5	21.1	5.4	104.46	6.30
0.5 m Control Mapo 2	1.58	40.38	0.088	1.30	17.8	14.2	3.6	156.18	4.10
1.0 m Control Mapo 2	1.49	43.77	0.94	0.45	23.1	18.4	4.7	156.19	6.54
1.5 m Control Mapo 2	1.42	46.42	0.099	0.17	27.1	21.6	5.5	109.17	6.70
0.5 m GCS Mapo Ib	1.59	40.00	0.083	1.53	16.9	13.4	3.4	151.70	3.68
1.0 m GCS Mapo Ib	1.51	43.02	0.089	0.57	21.5	17.2	4.4	163.50	5.88
1.5 m GCS Mapo Ib	1.44	45.66	0.097	0.22	26.2	20.9	5.3	128.04	7.11
0.5 m GCS Mapo 2	1.58	40.38	0.083	1.31	17.6	14.0	3.6	153.15	4.02
1.0 m GCS Mapo 2	1.51	43.02	0.091	0.65	22.3	17.8	4.5	188.52	6.41
1.5 m GS Mapo 2	1.43	46.04	0.098	0.20	27.0	21.5	5.5	141.36	7.84
0.5 m Control Isolu	1.52	42.64	0.084	0.56	18.9	15.0	3.8	105.43	3.96
1.0 m ControlIsolu	1.45	45.28	0.096	0.30	26.9	21.4	5.5	175.19	8.70
1.5 m Control Isolu	1.40	47.17	0.107	0.16	30.9	24.6	6.3	151.70	9.89
0.5 m Control Isolu 2	1.51	43.02	0.090	0.50	18.6	14.8	3.8	88.66	3.54
1.0 m Control Isolu 2	1.44	45.66	0.096	0.27	26.6	21.2	5.7	171.19	8.50
1.5 m Control Isolu 2	1.40	47.17	0.109	0.17	30.6	24.4	6.5	159.40	10.09
0.5 m GCS Isolu	1.52	42.64	0.083	0.64	18.5	14.7	3.8	116.25	4.06
1.0 m GCS Isolu	1.43	46.04	0.094	0.25	27.9	22.2	5.4	175.19	9.20
1.5 m GCS Isolu	1.38	47.92	0.109	0.14	31.9	25.4	6.2	151.58	10.32
0.5 m GCS Isolu 2	1.60	39.62	0.082	1.76	17.9	14.2	3.6	180.74	4.04
1.0 m GCS Isolu 2	1.46	44.91	0.086	0.26	22.5	17.9	4.6	86.42	4.46
1.5 m GCS Isolu 2	1.38	47.92	0.110	0.13	31.9	25.4	6.5	145.37	10.05

*Note: Description with 2 at the front denotes treated soil with CGS

Fig. 2a. Soil physical-chemical properties as affected by amended and un-amended control and greywater contaminated soils

Fig. 2b. Soil hydro-geotechnical properties as affected by amended and un-amended control and greywater-polluted soils

Table 3. ANOVA result for the analyzed soil parameters

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Depth	Sand	1111.583	2	555.792	36.038	.000
	Silt	17.583	2	8.792	1.151	.349
	Clay	1125.250	2	562.625	32.699	.000
	dry density	.092	2	.046	32.852	.000
	Porosity	131.370	2	65.685	32.886	.000
	MC	.001	2	.001	30.068	.000
	hydraulic conductivity	3.875	2	1.937	18.466	.000
	Liquid Limit	494.298	2	247.149	35.540	.000
	Plastic Limit	315.901	2	157.950	36.300	.000
	Plasticity index	20.606	2	10.303	35.174	.000
	Soil resistivity	4.151	2	2.076	1.151	.349
	pH	21.618	2	10.809	3.485	.064
	Organic matter	.070	2	.035	1.149	.349
	Shear strength	2409.137	2	1204.568	1.138	.353
	Bearing ratio	89.044	2	44.522	16.423	.000
	CEC	18.631	2	9.315	18.521	.000
Soil Type	Sand	5.172	3	1.724	.112	.952
	Silt	3.152	3	1.051	.138	.936
	Clay	14.326	3	4.775	.278	.841
	dry density	.001	3	.000	.335	.800
	Porosity	2.010	3	.670	.335	.800
	MC	6.617E-005	3	2.206E-005	.969	.439
	hydraulic conductivity	.220	3	.073	.699	.570
	Liquid Limit	2.090	3	.697	.100	.958
	Plastic Limit	1.388	3	.463	.106	.955
	Plasticity index	.088	3	.029	.100	.958
	Soil resistivity	.734	3	.245	.136	.937
	pH	2.266	3	.755	.243	.864
	Organic matter	.012	3	.004	.132	.939
	Shear strength	438.695	3	146.232	.138	.935
	Bearing ratio	1.078	3	.359	.132	.939
	CEC	1.051	3	.350	.696	.572
Depth * Soil Type	Sand	15.750	6	2.625	.170	.980
	Silt	24.750	6	4.125	.540	.768
	Clay	11.750	6	1.958	.114	.993
	dry density	.002	6	.000	.187	.975
	Porosity	2.239	6	.373	.187	.975
	MC	4.458E-005	6	7.431E-006	.327	.910
	hydraulic conductivity	.303	6	.050	.481	.810
	Liquid Limit	7.203	6	1.200	.173	.979

	Plastic Limit	4.526	6	.754	.173	.979
	Plasticity index	.331	6	.055	.188	.974
	Soil resistivity	5.841	6	.973	.540	.769
	pH	9.000	6	1.500	.484	.808
	Organic matter	.101	6	.017	.552	.760
	Shear strength	3415.615	6	569.269	.538	.770
	Bearing ratio	6.206	6	1.034	.382	.877
	CEC	1.457	6	.243	.483	.809
Error	Sand	185.070	12	15.422		
	Silt	91.635	12	7.636		
	Clay	206.475	12	17.206		
	dry density	.017	12	.001		
	Porosity	23.968	12	1.997		
	MC	.000	12	2.275E-005		
	hydraulic conductivity	1.259	12	.105		
	Liquid Limit	83.450	12	6.954		
	Plastic Limit	52.215	12	4.351		
	Plasticity index	3.515	12	.293		
	Soil resistivity	21.631	12	1.803		
	pH	37.221	12	3.102		
	Organic matter	.365	12	.030		
	Shear strength	12704.800	12	1058.733		
	Bearing ratio	32.532	12	2.711		
	CEC	6.036	12	.503		
	CEC	63.483	24			
Total	Sand	1317.575	23			
	Silt	137.120	23			
	Clay	1357.800	23			
	dry density	.112	23			
	Porosity	159.588	23			
	MC	.002	23			
	hydraulic conductivity	5.656	23			
	Liquid Limit	587.040	23			
	Plastic Limit	374.030	23			
	Plasticity index	24.540	23			
	Soil resistivity	32.357	23			
	pH	70.105	23			
	Organic matter	.548	23			
	Shear strength	18968.247	23			
	Bearing ratio	128.859	23			
	CEC	27.174	23			

This is in agreement with reported result of Shifa and Thomas (2017) that maximum dry density occurred at lowest MC. The addition of CGS treatment did not affect the DD values of both GCS and CS at Ibadan sampling location. The values of shear strength (SS) for Eutric Luvisols soils ranged from 86.4 to 180.7 KN/m^2 and 104.5 to 188.5 KN/m^2 for Vertic Cambisol soils. The minimum shear strength value was obtained in treated Isolu GCS at depth 1.0 m whereas maximum shear strength value was observed in treated Ibadan GCS at soil depth 1.0 m. Addition of CGS to both CSs and GCSs collected from Ibadan location led to increase in SS values at all the sampling depths when compared with SS values of untreated CS and GCS. There is reduction in SS values at 0.5 m and 1.0 m sampling depths for CS treated with CGS at Isolu sampling location. However, addition of CGS to Isolu GCS resulted in higher SS value at depth 0.5 m. The bearing ratio (BR) results for sullage polluted soil and unpolluted soil at the two study sites rise with increase in soil depths (Table 2). Compared to initial BRs of CS and GCS at Ibadan, addition of CGS treatment resulted in slight increase of BR value for each sampling depth. However, application of CGS treatment led to reduction in BR values of treated Isolu CS at 0.5 and 1.0 m depths. There is significant reduction in BR value of treated Isolu GCS at 1.0 m sampling depth. The moisture content (MC) of Isolu soils in m^{3}m-^{3} fluctuated between 0.082 and 0.110 whereas it varied from 0.083 to 0.099 in collected Ibadan soils. It should be noted that addition of CGS to control soils and GCSs at the two study sites resulted in little or no change in MC. Fig. 2a and 2b show the impact of CGS treatment on values of analyzed properties in collected soil samples (CS and GCS).

Results of Statistical Analyses

Table 3 presented the ANOVA results according to sampling depths and cereal gruel treatment. From the ANOVA Table 3, the variations in clay particles, sand particles, soil pH, CEC, porosity, MC, saturated hydraulic conductivity (K_{sat}), PI, ALs, and bearing ratio (BR) were substantial at 5% level according to soil depth. However, the differences in all analyzed parameters upon treatment with CGS were not significant at 5% level ($p<0.05$). For the two study locations, the mean % clay, porosity, MC, PL, LL, PI, and BR increased from 0.5 m to 1.5 m depth. However, the mean values of soil properties such as % sand, DD, K_{sat}, pH, and CEC decreased from 0.5 m depth to 1.5 m depth. Similar significant changes in % sand and % clay with soil depth were also reported by Gul *et al.* (2011). They discovered that sand particles decreased while clay content increased with increasing soil depth. A similar increase in soil MC with depth was also obtained by Okiotor *et al.* (2019) in their analysis of geotechnical properties of Ajali sandstone in southeastern part of Nigeria. The reduction of CEC with increase in depth obtained in this study concurs with similar observation by Alhaji *et al.* (2020). However, the reduction in DD with increase in sampling depth obtained in this study is in contrast with increase in DD with increase in depth reported by Alhaji *et al.* (2020) for soils under gneiss basement complex in north-central part of Nigeria. It should be noted that highest mean values of ALs and PI were recorded at depth 1.5 m for treated Isolu GCS while the minimum values of ALs and PI were observed at soil depth 0.5 m for Ibadan sullage polluted soils. However, highest values of porosity, % clay, and MC at depth 1.5 m were observed in Isolu GCS while least values of % clay, porosity, and MC were observed in treated Isolu greywater contaminated soil (GCS) at soil depth 50 cm. The recorded results for DD, K_{sat}, soil pH and CEC for treated Isolu GCS were significantly higher at 0.5 m depth than at other sampling depths. However, untreated Ibadan GCS had significantly higher value of % sand at 0.5 m depth.

Conclusion

The study assessed the impact of fermented CGS treatment on observed soil properties of GCSs at various sampling depths in two locations within Basement Complex formation. Laboratory soil analyses were performed on GCS, CS, treated GCS and treated CS to assess alteration of selected soil properties. The results showed that alteration of chosen soil geotechnics/hydraulic and physical-chemical qualities on both CS and GCS depends greatly on depth. The effect of CGS treatment on analyzed samples altered soil properties on different scales. For example, the CGS treatment had no significant effects on DD and MC at both locations while other analyzed properties are site specific. According to pH permissible limit set for mixing water for concrete, the pHs of Isolu GCSs at all sampling depths fall within the pH limit of 6 – 9. The maximum and minimum values of K_{sat} and CEC were observed in treated Isolu greywater polluted soil at 0.5 and 1.5 m depths, correspondingly. All the collected raw soil samples (CS and GCS) as well as treated/amended soils samples at both sites had PL values that lie within the safe recommended values of 50% maximum for sub-base and base materials. Furthermore, the degree of plasticity of all the collected soil samples (raw and treated CS, raw and treated GCS) at the two study sites indicates their low plastic nature. ANOVA result revealed no significant differences in the mean values of all analyzed parameters based on soil treatment while most of the analyzed soil qualities with the exception of shear strength, SR, and OM content varied considerably at 5% level based on soil depths. There should be a further study to evaluate the effects of other starchy fermented gruels treatments at varying concentrations on soil properties at various sampling depths.

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