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ORIGINAL RESEARCH ARTICLE

INFILTRATION CAPACITY OF COMPACTED LIME TREATED BLACK COTTON SOIL AS HYDRAULIC BARRIER MATERIAL

A. N. Alkali*, I. M. Shettima, B. B. Kurna and N. Y. Okunade

Department of Civil and Water Resources Engineering, University of Maiduguri, Maiduguri, Nigeria

**Corresponding author's email address: abdulhamidalkali.aa@gmail.com*

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ABSTRACT

Studies have shown the effect of hydraulic barriers in the reduction in movement of leachates, that have the potential of contaminating groundwater. Laboratory tests were conducted on black cotton soil treated with up to 5% lime by dry weight to assess its suitability in waste containment facilities. The test samples were subjected to particle size distribution analysis, consistency limit tests, compaction and hydraulic conductivity. The compaction energy of British Standard Light (BSL) was employed. The study showed decrease in liquid limit from 65.20% to 56.30% and plasticity index from 41.50% to 28.58% while plastic limit increased from 23.70% to 27.72% with the increase lime content. Maximum Dry Density (MDD) increases with increased in lime from 1.78 to 1.88 g/cm^3 whereas the Optimum Moisture Content (OMC) decreased from 19.79% to 15.39%. Hydraulic conductivity of black cotton soil treated with percentage of lime content 0%, 1%, 3% and 5% of the soil weight examined for a period of 28days. The hydraulic conductivity value of natural soil was 1.65E-08 and decreased to 3.71 E-09 m/s at 5% lime content. Therefore, it is clear that hydraulic conductivity decreases with percentage increase in lime content. It is recommended that volumetric shrinkage, free swell and unconfined compressive strength should be carried out.

1.0 Introduction

Groundwater constitutes about 0.6% of the total amount of water on earth and about 21.4% of the total freshwater resources on the planet (Mustafa and Yusuf, 2012). Water is regarded as one of the scarcest natural resources on the earth free of pathogens. Despite its quality, shallow groundwater sources in particular are susceptible to contamination from numerous sources notable of which are sanitary landfills. The largest factor influencing the contamination from these sources is due mainly to the level of ease at which the underlying soil beneath landfills allows the movement of these contaminants into the much-needed groundwater. Waste containment facilities mostly called Sanitary landfills are solid waste disposal facilities that operate by compressing the wastes while spreading soil and compacting in layers. These contaminants or leachate from soils with high hydraulic conductivity move vertically and contaminate the underlying groundwater. Hydraulic conductivity is a measure of a porous media to conduct liquid (Chen and Chynoweth, 1995). The minimum requirements recommended in achieving a hydraulic conductivity is less than or equal to 1.0×10^{-9}m/s for most soil lining materials. Various leachates carry physical, chemical or bacteriological contaminants which are detrimental to human health. Consequently, several studies have attempted to prevent the contamination of the underlying soil from leachate by reducing the hydraulic conductivities of the underlying soil of the waste containment facilities. The layer of the containment facility system generally referred to as liners have been developed with other raw materials such as rice husk ash, groundnut shell ash, fly ash, oil palm ash, lime etc. on a variety of soil types. Other materials that have been used includes; geosynthetic materials, processed clay, Cement Kiln Dust (CKD), plastics, glass, and scrap tyres (Moses and Afolayan, 2011). Black cotton soils are expansive soils which are characteristically grey or black in colour and mostly confined to semi-arid regions. The soil is mostly available where annual precipitation is exceeded by evaporation and also derives its name due its suitability for growing cotton (Oriola and Moses, 2011). The cohesive nature of clay soils makes them a suitable integral component of the lining system (Osinubi and Moses, 2011).

Lime has been widely used either as a modifier for these clayey soils or as a binder. When clayey soils with high plasticity such as black cotton soils are treated with lime, the plasticity index is decreased and has less affinity to water (Modak *et al*., 2012). Lime had also been used to stabilize (i.e. impede) the hydraulic conductivity of fly ash. In addition to decreasing the permeability of clay, lime offers resistance against chemical attack by organic solutions, which is one of the vital requirements of waste containment facilities (Moses and Afolayan, 2011). Most of these materials have oxide compositions rich in Calcium, Silicon and Aluminium and are mixed with soils having relatively low hydraulic conductivities such as black cotton soil and laterite which is in relative abundance in the area of study covered by this research.

2. Materials and Methods

2.1 Materials

2.1.1 Black cotton soil and lime: Black cotton soil was obtained from a borrow pit along Yola road at Kumo, Akko Local Government Area, Gombe State, Nigeria. This was achieved using disturbed sampling method which lies on latitude 10^0 2' 43"N and longitude 11^0 12' 47"E. Soil specimens were treated with 0, 1 ,3 and 5% lime by dry weigh of soil. The lime used was purchased in Monday market, Maiduguri, Borno State.

2.2 Methods

2.2.1 Index properties: laboratory tests were carried out to determine the index properties of both natural and lime treated soils. The test was conducted in accordance with British Standard (BS) 1377(1990) for the natural soil and BS 1924 for the lime treated soil.

2.2.2 Compaction: The compactive effort used was BSL. Air dried soil samples passing through BS sieve with 4.76mm aperture mixed with 0%, 1%, 3% and 5% lime by weight of dry soil were used. The tests for both the natural and stabilized soils were conducted according to BS 1377 (1990) Part 4. The British standard light is the effort derived from 2.5kg rammer falling through 30cm onto three layers, each receiving 27 uniformly distributed blows.

2.2.3 Hydraulic conductivity: The specimens were placed into rigid wall permeameters for hydraulic conductivity testing. All tests were conducted using the falling-head method in accordance with procedures described by Head (1992). A relatively short sample was connected to a standpipe, which provided the head of water flowing through the sample. Black cotton soil – lime samples at the different lime contents (0, 1, 3, and 5%) and respective OMCs were compacted using BSL Compactive efforts. Specimens were soaked in a water tank for a minimum period of 24 hours to allow for full saturation and the samples were restrained from swelling vertically during saturation. In the course of the permeation however, the specimens were allowed to swell vertically i.e. no vertical stress was applied. The fully saturated test specimens were then connected to a permeant liquid (tap water). Hydraulic gradient ranged from 5 to 15. Tests were only discontinued when hydraulic conductivity readings were steady.

2.2.4 Oxide composition of lime: Oxide composition of the lime was determined using X-ray fluorescence (XRF) machine (Philips PW1606) at the Chemistry Department of Ahmadu Bello

University Zaria, Kaduna State. The XRF analysis is based on the principle that individual atoms, when excited by external energy source, emit x-ray photons of a characteristic wavelength. By counting the number of photons of each energy emitted from a sample, the elements present is identified and quantified. The system depends on semi-conductor type detectors which receive the entire emitted spectrum from the sample and decode it into histogram of number of counts versus photon energy (Ehi- Eromosele *et al*., 2012). The machine has a very sensitive and accurate power of determining trace and major elements and their oxides in both geologic and biological samples. One gram of well homogenized lime was taken into the machine which was automatically analyzed, and results given.

3. Results and Discussion

3.1 Chemical oxide composition of the lime

The oxide composition of the lime analyzed using **Phillips-PW-1606 X-ray fluorescence (XRF) Spectrometer** is presented in Table 1. The essential oxides of lime comprise of CaO, SiO_2, Al_2O_2 and Fe_2O_2 having 76.42%, 7.33%, 1.99% and 1.07 respectively. CaO has the highest oxide composition which is also the major constituent responsible for the reactions in stabilization process. These reactions include cat-ion exchange, flocculation-agglomeration, carbonation, and pozzolanic reaction (Khan *et al*., 2004).

Table 1: Oxide composition of lime

Oxides	SiO_2	Fe_2O_2	Al_2O_2	CaO	MgO	Na_2O
Composition (%)	7.33	1.07	1.99	76.42	2.12	0.00

3.2 Physical properties of the soil

The physical properties of the black cotton soil used are presented in Table 2 while the particle size distribution curves are presented in Figure 1. The results of preliminary investigations conducted on the natural black cotton soil show that the soil is fine-grained, with a natural moisture content of 6.26%. The soil belongs to the CL group in the Unified Soil Classification System (USCS), (ASTM, 1992) or A-7-6(10) soil group of the American Association of State and Transportation Officials (AASHTO) soil classification system (AASHTO, 1986). The soil has a liquid limit of 65.20%, 23.70% plastic limit and 41.50% plasticity index.

Table 2: Physical properties of the soil

Properties	0%	1%	3%	5%
Natural moisture content (%)	6.28			
Liquid limit	65.20	58.90	57.20	56.30
Plastic limit	23.70	25.93	26.71	27.72
Plasticity index	41.50	32.97	30.49	28.58
Specific gravity	2.66	2.62	2.58	2.56
Percent passing BS no.200 sieve	53.9	64.50	69.05	69.20
ASSHTO soil classification	A-7-6(10)			
Unified soil classification system	CL	CL	CL	CL

CL-Clay Loam

The liquid limit and the plasticity index values decreases with increase in lime contents while the plastic limit increased, possibly due to the exchange reaction which flocculates the soil particles together and reduces the clay size fraction and hence the soil surface area (Osula 1991). This trend is similar to the findings reported by Osinubi and Katte (1997) for black cotton soils.

Corresponding author's e-mail address: abdulhamidalkali.aa@gmail.com

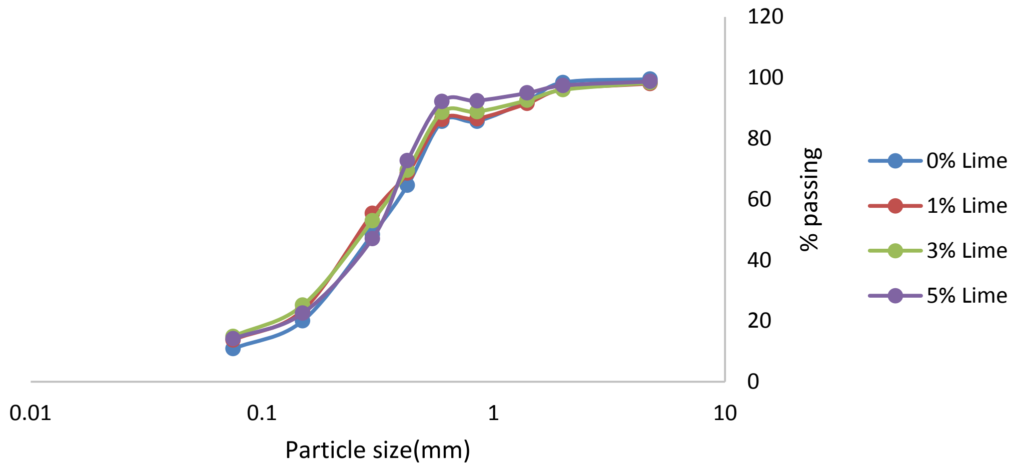

Figure1: Particle size distribution curves for black cotton soil treated with lime

The variation of the specific gravity of black cotton soil-lime mixture is presented in Figure 2. The specific gravity of the natural soil decreased from 2.66 to a least value of 2.56 at 0% to 5% lime. This decrease is due to the low specific gravity value of lime (2.1) which gradually replaced the soil material. The decrease also indicated that mineralogical alteration has not taken place with the MHA (Kumar, 2012; Amadi, 2010).

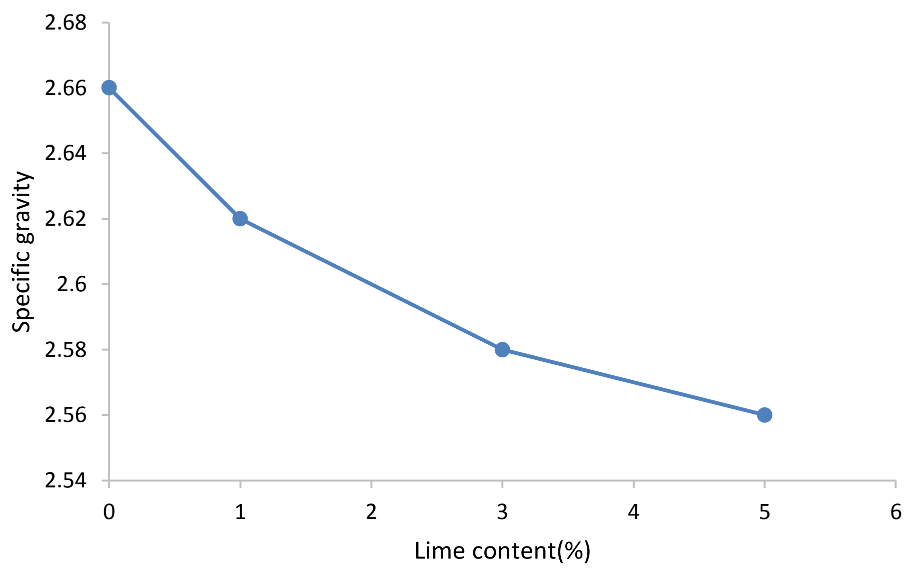

Figure 2: Variation of specific gravity of the black cotton-lime treated soil

3.3 Compaction

3.3.1 Maximum Dry Density

The variation of the Maximum Dry Density (MDD) of the treated soil is shown in Figure 3. The value initially decreased from 1.78 to 1.71 g/cm^3 and later increased. It ranges from 1.78 for the natural soil to 1.88 g/cm^3 for the lime treated soil. This is as a result of the lime occupying the void within the soil matrix and in addition, the flocculation and agglomeration of the clay particle due to exchange of ions (Oriola and Moses, 2010; Moses, 2008).

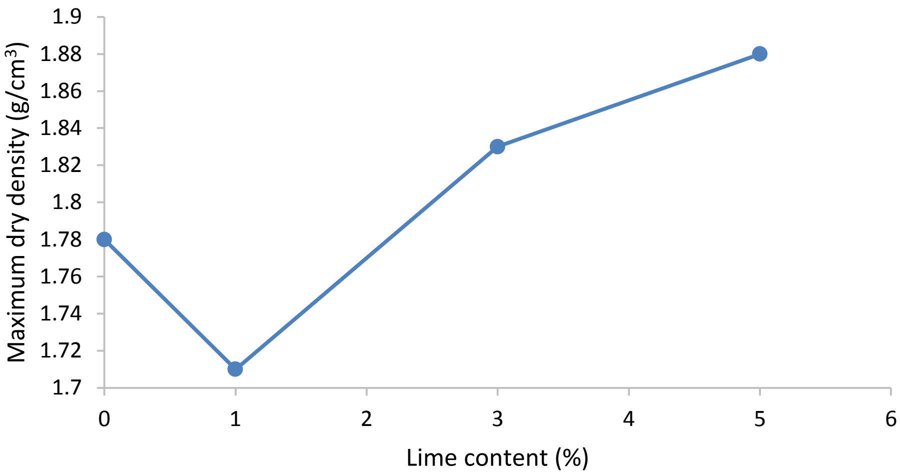

Figure 3: Variation of maximum dry densities for black cotton soil treated with lime

3.3.2 Optimum moisture content

The OMC of the black cotton soil treated with lime reveals a decrease in the OMC values from 19.79 to 15.39% with the addition of lime from 0 to 5%. The trend is depicted in Figure 4. The decrease in the OMC is probably due to self – desiccation in which all the water was used, resulting in low hydration. In a situation where no water movement to or from the lime – paste, the water is exhausted in the hydration reaction, until small amount is left to saturate the solid surfaces which tend to reduce the relative humidity within the paste. This might have affected the reaction mechanism of the lime treated black cotton soil (Moses, 2008; Osinubi and Stephen, 2007).

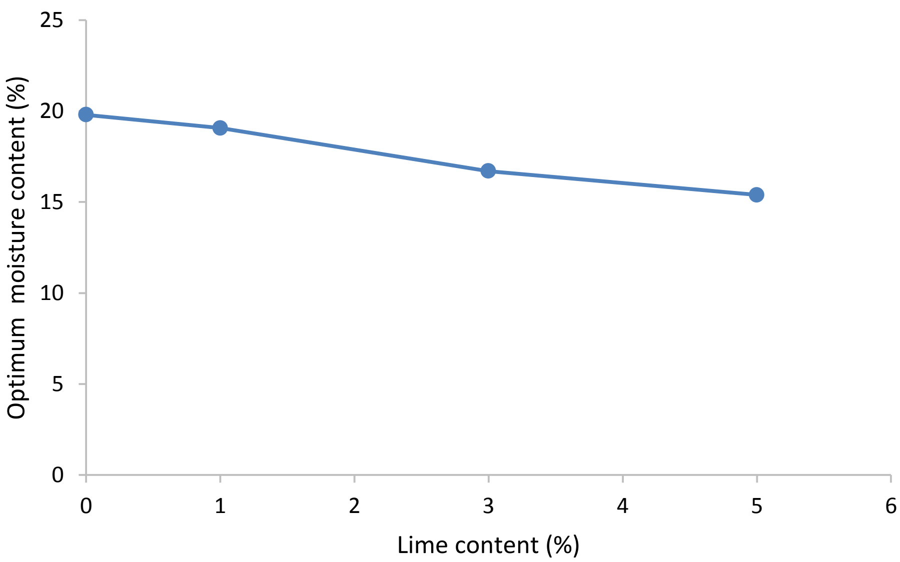

Figure 4: Variation of optimum moisture content for black cotton soil treated with lime

3.4 Hydraulic conductivity

The variation of hydraulic conductivity of the black cotton soil treated with lime at different dosages is shown in Figure 5.

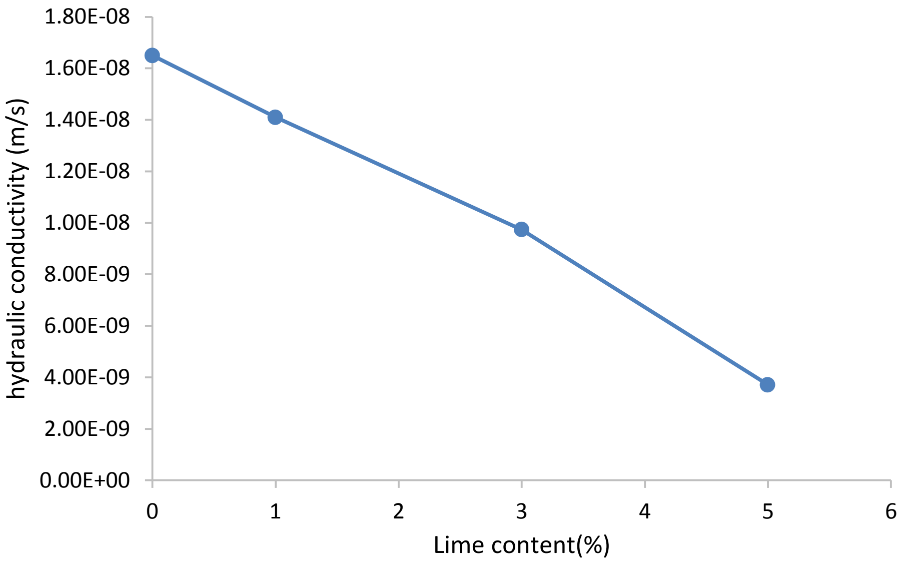

Figure 5: Variation of hydraulic conductivity for black cotton soil treated with lime

The trend is that of decrease in the hydraulic conductivity with the natural soil having a value of 1.65×10^{-8} m/s. The values further decreased to 1.4×10^{-8} m/s, 9.74×10^{-9} m/s and 3.71×10^{-9} m/s for 1%, 3% and 5% lime treatments respectively. Hydraulic conductivity generally decreased with higher molding water content. However, in this study, only the respective optimum water contents were used in preparing the samples and hence the non-rapid decrease in the hydraulic conductivity. The reduction in hydraulic conductivity is due to the arrangement of individual particles influenced by molding water content. It could also be attributed to the soft wet clods of soil that are easily remolded resulting in smaller inter-clod voids and hence lower hydraulic conductivity (Osinubi and Eberemu, 2009).

4.0 Conclusion

The suitability of lime-treated black cotton soil for use as compacted hydraulic barrier in waste containment facilities has exhibited a reduction in infiltration capacity with increase in lime content. Black cotton soil was treated with 0%, 1%, 3% and 5% lime content by weight of the soil. Increase in lime content decreased the liquid limit, shrinkage limit and plasticity index of black cotton soil while the plastic limit increased. The MDD generally increased from 1.78 to 1.88 g/cm^3 while the OMC decreased from 19.79 to 15.39% with increasing lime content. Interestingly, an increase in lime content reduced the hydraulic conductivity of the soil. The least hydraulic conductivity value obtained was 3.71×10^{-9} m/s at 5% lime treatment. This study shows that obtaining hydraulic conductivity lower than 1×10^{-9} m/s with lime treated black cotton soil is possible, provided that the compaction procedure (water content and compaction technique) is well chosen. Finally, it is recommended that the hydraulic conductivity of the soil should be explored using -2, +2, +3 and +4% of the Optimum Moisture Content of the natural soil. Tests such as Unconfined Compressive Strength (UCS) and Volumetric Shrinkage Strain (VSS) should also be conducted to ascertain the accepted range for the established criteria.

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