UNIVERSITY OF CAPE COAST

EVALUATION OF PHYSICAL CHARACTERISTIC OF SANDY SOIL, THE EFFECTS OF AMENDMENTS USING COMSOL MULTIPHYSICS AND LABORATORY EXPERIMENTS

EMMANUEL KOFI AMEWODE

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BY

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Thesis submitted to the Department of Physics of the School of Physical Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Doctor of Philosophy degree in Physics

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this University or elsewhere.

Candidate's Signature …………………………… Date: …………………

Name: Emmanuel Kofi Amewode

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature …………………… Date: ………………

Name: Dr. Alfred Owusu

Co-Supervisor's Signature ………………………… Date: …………….

Name: Dr. Baah Sefa-Ntiri

ABSTRACT

Information on soil water retention and hydraulic properties is paramount for assessing soil properties and modeling movement of water in the soil. This research aims at investigating soil amendments (zeolite, activated charcoal, and rice hush ash) impacts on water retention, physical properties, and hydraulic properties of sandy soil. To assess the changes in water content of sandy soil due to the soil amendments, retention curve of water tests were carried out using both simulation and experimental methods. The results of the water retention tests showed an increase of water content and a decrease in the hydraulic properties (hydraulic conductivity) of sandy soil. Simulation results using the COMSOL Multiphysics model also shows similar trend as water retention increase and a decrease in hydraulic conductivity with rice husk ash, zeolite, and activated charcoal applications respectively. The results confirmed that the COMSOL Multiphysics model gave accurate simulation results in comparison with the experiments. These results suggest there are numerous benefits of adding soil amendments to sandy soil in relation to increasing the retention of water and decreasing hydraulic conductivity. This study also shows that zeolites, rice husk ash and activated charcoal improve the water content level in sandy soils, thus controlling water losses. Therefore, rice husk ash, zeolite, and activated charcoal addition to sandy soil is an effective way to improve plants soil in drought areas.

KEY WORDS

Bulk density

Fourier Transform Infrared Spectroscopy

Hydraulic conductivity

Pressure head

Soil amendments

Water retention

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DEDICATION

To the memory of my late father, Cletus Kodzo Amewode, my Wife, Madam Dora Kudanu, and all my children.

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LIST OF ABBREVIATIONS

ATR	Attenuated Total Reflectance
FTIR	Fourier Transform Infrared
DRIFT	Diffuse Reflectance (infrared) Technique
FEMLAB	Finite Element Method Laboratory
FTIR	Fourier Transform Infrared Spectroscopy
PDEs	Partial Differential Equations
IR	Infrared
DF	Degree of Freedom
MS	Mean of Square Error
MATLAB	MATrix LABoratory
F	F-Statistic
SS	Sum of Squares
ACT 1	Activated Charcoal 1
ACT 2	Activated Charcoal 2
RHA 1	Rice Husk Ash 1
RHA 2	Rice Husk Ash 2
ZEO 1	Zeolite 1
ZEO 2	Zeolite 2
USDA	United State Department of Agriculture

CHAPTER ONE

INTRODUCTION

This chapter deals mostly with the introduction of the topic which includes the use of COMSOL Multiphysics as model tools in the simulation of the flow of water through the sandy soil and detailed study of the effects of zeolite, activated charcoal, and rice husk ash on soil physical properties, water retention, and hydraulic properties. Also, in this chapter, we discuss the water retention curve and hydraulic conductivity as the background of the study. The objectives of this study are spelled out in this chapter and the significance of the study in addition to the scope of the work. Then the statement of the problem that arose the interest to undertake this study is also mentioned. The chapter concluded with the organization of the entire thesis. In this work, the simulation aspect of the work will be done using COMSOL Multiphysics software and amendments with the soils would be performed in the laboratory.

Background of the Study

Soil and water are the two most fundamental natural resources on earth in which people and crops depend on for survival. Because of the growing in the world's population and the advancement of agricultural technologies, it is essential to identify innovative methods of sustainable management of soils and water in a better understanding. The expectations for agricultural soils to maintain, or even improve the quality while, increasing plant yield are challenged by heavy demands of the uncontrolled growth in the world population as stated by United Nations, (2011). Alternatively, producing more food in a growing population area takes higher efficiency in agricultural systems. Nagaraja et al., (2016) suggested that while more proficient farming exercises are expected to fulfill the current food requests, a few issues regarding irrigation and fertilization need to be tackled. Increasingly, irrigation water use efficiency is a major factor to be considered because of competition for water among agricultural, municipal, and industrial users which is likely to increase in the future as reported by Boluwade & Madramootoo, (2011).

In sustainable irrigation practice, the information on water flow in the soil is very significant. Movement of water through the soil has attracted significant interest in recent years because of its importance in agronomic, agricultural, environmental, and geophysical engineering as reported by Vafai, (2000). Movement of water through soil is a very important process in our environment because crops depend on water to grow and produce more food to feed the growing population. As a result of these reasons, it is imperative to understand the processes of simulation of water movement into and through the soil.

Due to the rapid advancement of computer technology, an enormous quantity of numerical model have been built up during the past years to predict the movement of water into and through saturated and unsaturated soils. The application of these numerical models has been restricted due to the knowledge of water retention and soil hydraulic conductivity (Ghanbarian-Alarijeh et al., 2010). The simulation models are, in general, numerical models for computing flow and movement of solute in the soil. The search for analytical solutions to model water movement continues to be of scientific interest due to the soil hydraulic properties which render the governing flow equations non-linear, making it a challenging problem. In both saturated and unsaturated soil, the Richards equation is widely known as the most suitable numerical model for flow. Šimůnek, et al., (2009) stated that among the most normally used models are the Richards equation which is a numerical model for water movement through saturated and unsaturated soil. Damodhara Rao, et al., (2006) further stated that finite element techniques are used to solve the Richards governing equations numerically with a special technique.

Various numerical programming exists for solving Richards' equation when studying the movement of water in the soils. The HYDRUS-2D programming developed by Šimůnek et al., (2008) is one of the numerical modeling environment in the simulation of movement of water and solute in soils. The HYDRUS-2D programming includes finite element technique models aim at mimicking the flow of water through unsaturated soil using Richards' equation. Besides, the RETC (RETention Curve) program which permits the use of hydraulic properties of soil models such as the Mualem-Van Genuchten, (1980) is also used in the modeling flow through unsaturated soils.

The fertility levels of soils in Keta, one of the areas in Ghana are normally extremely poor in plant nutrients and physical properties. Sandy soils that are found in the Keta region are among the broad soils on the planet, covering more than 900 million hectares and are located in the dry and semi-dry districts (Drisesen et al., 2001). Another investigation has discovered that the most well-known farming soils on the planet are the sandy soils (Croker et al., 2004). The sandy soil has been perceived as generally uncultivable, hence restricted ability in holding plant nutrients and water (Noble et al., 2001).

Sandy soil is also often considered as soils with a weak structure, poor water retention properties, high bulk density, high hydraulic conductivity, and high sensitivity to compaction (Drisesen et al., 2001). Therefore, in semi and semi-arid regions such as the Keta, sandy soil have been identified as inherently infertile, having low water content and nutrient retention capacity, poor physical, and hydraulic properties (Noble et al., 2000), therefore required soil amendments. It has been suggested that the water retention and nutrient retention capacity of these sandy soil could increase by the addition of inorganic amendments, subsequently upgrading soil fertility, physical, and hydraulic properties (Panda et al., 2012).

One of the practical ways to deal with water retention is, therefore, to improve physical and hydraulic properties, and keeping a satisfactory degree of plant nutrients in the soil would be applying nanotechnology (e.g., zeolite), and biochar (e.g., activated charcoal, and rice hush ash) amendments to the sandy soil. Unfortunately, farming activities on all types of soil are not suitable. Farming soils can either be sandy or clayey, which releases water during irrigation from the root areas of plants in great amounts or limit water movements. Wang et al., (2016a) stated that amending soil physical properties is a strategy which could influence the water movement in the soil, particularly in coarse-textured soils. Anderson et al., (2009) also established that improvement in retention of water, porosity, and bulk density among the greatest to increase irrigation efficiency. Wang et al., (2016b), further proved that to enhance soil physical properties, soils need some remedy to increase in productivities of both irrigation and fertilization. Henceforth, applying nanotechnology and biochar amendments to sandy soils is a novel approach that sought to increase soil physical, water retention, chemical, and hydraulic conductivity properties (Sarkar & Naidu, 2015).

Nanotechnology is an innovative present-day approach which offers the novel and significant solutions for the limitations of other conventional materials and has various applications (Kim, 2012). An author like Kim, (2012), argued further that nanotechnology often exhibits new and significantly improved biological, chemical, physical, and hydraulic properties due to their large specific area, and structure of the material. Theron et al., (2008) also suggested that nanotechnology uses in the treatment of soil and water, has seen generous development over the decades. Nanotechnology is an innovative modern approach which offers the distinctive and main explanations to the limits of other traditional materials and has many applications (Kim, 2012). LaI, (2008) further argued that applying nanotechnology in farming soil was one of the best ways to deal with increasing agricultural production, tackle natural issues, and feed the developing populace around the world. This nanotechnology material with huge capabilities for soil amendment includes zeolite. Zeolites are considered as a soil amendment because of its highly porous nature, hence having high water retention capacity.

Zeolites are porous minerals with ion-exchange capacity and high absorbance, having group one or group two elements as counter ions (Dyer, 1988). They exist in more than 50 natural and 150 synthetic structures and are considered to improve different soil properties, in which water retention, bulk density, porosity, and hydraulic properties are considered the greatest (Jha & Singh, 2016: Virta, 2002; Gholizadeh-Sepaskhah, 2013). Further prove shows that applying zeolite to sandy soils can improve their water retention capacity (Bernardi et al., 2013). Enamorado-Horrutiner et al., (2016) also proposed that zeolites are one of the commonly used inorganic soil amendments to increase the soil's physical properties. In addition, Xiubin & Zhanbin, (2010) argued that the effects of zeolite additions increased the retention of water, decreased soil bulk density, increased soil porosity, and decreased hydraulic conductivity. A further study proved that applying zeolite to a soil improved the soil hydraulic properties as reported by Ibrahim-Saeedi & Sepaskhah, (2013).

Biochar (e.g., activated charcoal and rice husk ash) is broadly applied to farming soil to enhance soil properties and increased yields of plants (Sohi et al., 2010). It is claimed that biochar improves the quality of the farming lands due to the highly porous nature (Glaser et al., 2000). Numerous investigations have proved that activated charcoal and rice husk ash biochar application reduces hydraulic conductivity and increased retention of water of sandy soil (Arthur & Ameed, 2017; Lim et al., 2016; Sorettenti & Toselli, 2016). A further report stated that the activated charcoal and rice husk ash biochar applications to the soil are measured as the best methodology in improving the soil's physical, hydraulic, and water retention (Kamenyama et al., 2012; Glaser et al., 2015; Dai et al., 2017).

Other scientists have established that biochar amendments improved the diffusion and water flow path of the sandy soil and decreased the pores, which further decreases the hydraulic conductivity properties (Liu et al., 2016; Barnes et al., 2014). A few authors have also demonstrated that activated charcoal and rice husk ash biochar been soil amendments, can increase soil chemical, physical, and plants yields as reported in a few studies (Masulili et al., 2010; Herath et al., 2013; Lu et al., 2014: Van Zwieten et al., 2010. El-

Naggar et al., 2018; Malik et al., 2018) recommended that the activated charcoal and rice husk ash biochar applies to soils may change its chemical properties and influence retention of water. These impacts may upgrade water accessible to plants and decrease erosion. Chan et al., (2008) confirmed that applying biochar to soils enhanced soil physical properties of soil, for example, increased water retention, and reduced soil quality.

Different authors have also argued that the activated charcoal and rice husk ash biochar amendments increased soil pH, potassium, calcium, magnesium, and decreasing bulk density of soils (Chen et al., 2011; Herath et al., 2013; Hardie et al., 2014; Jien & Wang, 2013; Liang & Lehmann, 2006; Rehman et al., 2016; Van Zwieten et al., 2010; Zhang et al., 2010). It is stated further that, rice husk ash biochar's having a porous structure adds to an increasing water retention capacity of soils (Glaser et al., 2002; Gaskin et al., 2007; Ogawa et al., 2006; Pietikainen et al., 2000).

It stated further that activated charcoal and rice husk ash biochar can enormously improve pH of the soil , porosity of the soil, soil bulk density, and hydraulic properties, and additional processes when there is a change in the soil structure (Lehmann & Joseph, 2009); Liang et al., 2006; Major et al., 2010). Duku et al., (2011) established further that activated charcoal application can prompt a decrease in inorganic manure use by farmers. Other research has shown that, the addition of rice husk ash will fundamentally improve soil properties by improving soil pH, by reducing soil bulk density, and increasing available nutrients as reported by Yamato et al., (2006). The application of activated charcoal and rice husk ash is measured as a success win system to increase the soil water retention, porosity, bulk density, hydraulic conductivity, and soil fertility (Dai et al., 2017; Glaser, 2012; Kamenyama et al., 2010).

It is established that water retention and hydraulic properties under dry conditions is significant for modeling water movement in soil (Arthur et al., 2015; Cullotta et al., 2016; Reynolds et al., 2009). Warrick, (2003) also showed that water retention and hydraulic characteristics are important for both saturated and unsaturated soils to mathematically describe the water flow model. Researchers like Al-Jabri et al., (2002) proved further that the information on soil hydraulic conductivity is very significant for proper assessment and understanding the movement of water through soil systems. Ghanbarian-Alarijeh et al., (2010) also expressed that because of the absence of information on the soil hydraulic properties, the applications of numerical simulation models have consistently been limited. This work will provide information on how zeolite, activated charcoal, and rice husk ash could improve the retention ability of water, hydraulic conductivity, and physical properties of the sandy soil in a large scale test.

Statement of the Problem

The climate of the area under study lies in the dry Equatorial climatic district of Ghana and is the driest in the nation with everyday temperatures running from 27–28 °C and mean temperature of about 30°C as reported by (Dickson & Benneh, 1995). The irrigation system is one of a significant aspect of the agricultural basis in the area since the yearly rainfall is under 900 mm, thus, planting of crops on sandy soils during the farming seasons is a problem.

The low water retention capacity and poor nutrient of the sandy soils in both arid and semi-arid regions has become a significant imperative to farmers growing crops in Africa (Smaling & Fresco, 1993). Besides, treatment using fertilizer forms a significant part of the cultivating framework in the area because of the low fertility of the soil (Awadzi et al., 2008). Furthermore, the consistent decrease in food production because of an increase in populace with scanty land resources prompts farmers to use natural and inorganic amendments to improve the growth of the plant and increased the yield of the crop (Reijnties et al., 1992). It is in the light of these research gaps that this study was conducted to contribute to the much-needed information and knowledge necessary for the ongoing application of fertilizers and irrigation to the agricultural system in these areas of study.Therefore, in this work, amendments using zeolite, activated charcoal, and rice husk ash may be seen as a solution to improve on soil physical, water retention, crops nutrient retention, and hydraulic properties. Also using the COMSOL Multiphysics software as a device to simulate the effects of soil amendments on sandy soil would help to mimics the real situation in the field.

Significant of the Study

The use of fertilizer has been the conventional way of amending crops, however, the rising cost of fertilizers has forced the farmers to look for other alternatives to sustain farming in the area. Application of zeolite, activated charcoal, and rice husk ash amendment which is relatively more environmentally friendly, and less costly could be the best options. The use of nanotechnology (zeolite), rice hush ash and activated charcoal as soil amendments is not common in Ghana and some other countries worldwide. It is believed that zeolite, activated charcoal, and rice husk ash biochar amendment may supply adequate water, improved physical properties, hydraulic conductivity, and other nutrients for crops yield.

This study will help to recognize other nanotechnology and biochar amendments available for improving soil fertility, increasing crop production, and reducing over-reliance on only organic fertilizer. In this way, the full potential of zeolite and biochar amendments as modifications to soil fertility will be made known in Ghana and the rest of the world for full exploration for sustainable crop production.

The study may also give information on using the COMSOL Multiphysics software as one of the efficient numerical modeling tools in the simulation of the effects of soil amendments on sandy soils to mimic the real situation on the field. Furthermore, this study may provide the knowledge of using the Earth Science Module of COMSOL Multiphysics to simulate water movement in the soil for scenarios with and without soil amendments incorporation. Also, this research could provide information that will be useful for agriculturalists, ecologists, horticulturists, and environmentalists on the efficiency of zeolite, activated charcoal, and rice husk ash in improving the water retention, physical, and hydraulic properties in the dry, semi-dry, and other areas worldwide. In conclusion, using the knowledge on the Earth Science Module of COMSOL Multiphysics software will help soil physicists, soil scientists, and engineers to predict the rate of water flows and pollutants into the soil and also estimate the effects of the soil amendments on soils in near future.

Objectives of the Work

The objectives of this study are to:

1. Simulate the effects of sandy soil amended with zeolites, activated charcoal, and rice husk ash using the Earth Science Module in COMSOL Multiphysics.
2. Estimate the effects of zeolite, activated charcoal, and rice husk ash amendments on sandy soil physical properties, water retention curve, and hydraulic properties using a laboratory method.

Limitations

Due to time constrain only three (3) of the soil amendments were used to amend the sandy soil under control environmental conditions.

Scope of Work

The thesis was conducted in the Keta District which forms part of the Coastal belt of the Volta Basin of Ghana. The synthetic zeolite, activated charcoal, and rice husk ash used were due to its unique and numerous properties, availability, and cost-effectiveness. The software used for the study was the Earth Science Module of COMSOL Multiphysics (version 5.0) because of its Multiphysics ideas.

Organization of Thesis

The remainder of the thesis document is organized as follows: Key issues, as well as a literature review on soil physical properties, water retention curves, hydraulic properties, soil amendments, and COMSOL Multiphysics software, are provided in Chapter 2. The description of the study area and the simulation and laboratory approaches used are detailed in Chapter 3. Presentation of results, analysis, and discussion are elaborated in Chapter 4 and, finally, Chapter 5 presents a summary of the research conducted, the conclusions reached, and possible areas of future research (recommendations).

Chapter Summary

In summary, the importance of using the COMSOL Multiphysics simulation and the laboratory method on amended sandy soil was stated. The use of zeolite and biochar (activated charcoal, and rice husk ash) amendments on sandy soil was also mentioned in this chapter. Finally, the significance of the study, the scope of the work, objectives, organization of the thesis, and statement of purpose were carried out in this chapter.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This chapter discusses a review of related literature directly linked to the thesis. It discusses the literature on the Earth Science Module of COMSOL Multiphysics used. Pertinent theoretical studies and experimental studies linked with the study are also reviewed. Finally, the chapter concludes with a review of some comparative studies using zeolite, activated charcoal, and rice husk ash in the amendment of sandy soils.

General Background of COMSOL Multiphysics

This chapter offers a brief introduction to the COMSOL Multiphysics program that was used for the simulation of the effects of soil amendments on sandy soil for the study area and a summary of its abilities. The COMSOL Group was established by the Swedish programming engineers COMSOL LAB like Mr. Svante Littmarck & Mr. Farhad (COMSOL LAB, 2009) in 1986. The main variant of COMSOL Multiphysics programming was distributed in 1998 by COMSOL group and it was named a toolbox. The COMSOL Multiphysics (formerly known as FEMLAB) is a fully-featured finite element method modeling package facilitating the solution of many physical problems as implemented in the form of partial differential equations. The COMSOL Multiphysics modeling location simplifies the steps in the simulation process starting from the model geometry, stating the physics, meshing, solving, and finally, post-handling the results (COMSOL LAB, 2009). The COMSOL Multiphysics programming has been far and widely used in different areas of scientific research and designing computation, for instance, it was used in the worldwide global numerical simulation (COMSOL LAB, 2009). The model programming is a solver programming package and a finite element research for different material science and building applications particularly coupled physical phenomena or Multiphysics. It incorporates a total domain for displaying any physical phenomenon that can be portrayed utilizing partial differential equations.

COMSOL Multiphysics programming offers total modeling and simulation solution from characterizing the geometry, meshing, specifying the physics model, and computing the solution. Besides, COMSOL Multiphysics offers advanced post preparing choices for visualizing and analyzing the computed solution. It has become the business standard for multi-physical displaying, plan, research, and advancement. Notwithstanding conventional physics-based user interfaces, COMSOL Multiphysics takes into consideration building coupled frameworks of partial differential equations. COMSOL Multiphysics additionally offers a broad and all-around managed interface to Math Works MATLAB and its tool kits for a huge assortment of programming, pre-handling, and post preparing potential outcomes as reported by Li et al., (2009).

COMSOL Multiphysics programming is a very much recorded, ground-breaking, and stable apparatus containing a lot of utilization formats that reproduces stream and transport of warmth in both soaked and somewhat immersed heterogeneous permeable media. COMSOL Multiphysics can precisely represent complex 3D land media and structures and their consequences for subsurface flow and transport. COMSOL Multiphysics additionally covers a wide scope of utilizations for those inspired by integrated hydrological modeling (Chui & Freyberg, 2007). COMSOL Multiphysics programming additionally permits the clients to perform different kinds of studies, for example, fixed and time-subordinate research, straight and nonlinear studies, and modal and frequency studies. The finite element technique is used when tackling the models, the COMSOL Multiphysics. In the model, a variety of numerical solvers are used to the finite element analysis along with adaptive meshing and error control. The capacity to include client characterized capacities is a positive part of the product. The adaptable idea of the COMSOL Multiphysics condition additionally encourages further research. Notwithstanding being an independent item, COMSOL Multiphysics' Live Link for MATLAB module offers strong capacities for interfacing with MATLAB. The abilities of the Live Link for Math Works MATLAB module allow the user to use the vast usefulness of MATLAB to make as well as control a COMSOL Multiphysics model, take care of a material science issue and post measure the model arrangement from the MATLAB order line interface. COMSOL Multiphysics has built up a module called the Earth Science Module that is useful and significant for liquid flow applications.

Earth Science Module

Earth Science Module is a package of COMSOL Multiphysics programming for simulation of subsurface flow and different applications in earth science (COMSOL, 2009). The Earth Science Module also combines the application modes for simple procedures and connections to the COMSOL and different modules for fluid dynamics and transport analyses. The water movement equations in the earth science application mode represent a wide range of possibilities which includes: (1) Navier-Stokes equations: for surface and other free flows; (2) Darcy's law: for a consistent liquid flow in, saturated soils and (3) Richards' condition: depicts nonlinear fluid movement in both saturated and unsaturated soils.

Water Movement in Saturated and Unsaturated Soil

Water flow through saturated and unsaturated soil is governed by Richards' equations. Richards' equation is the combination of the Darcy-Buckingham equation and mass conservation equation for fluid flow. This equation is useful when dealing with water flow in the soil. From Darcy's law, the total flux across the surface of the soil is given as:

$$u = \frac{-k}{\mu}(\nabla p + \rho g \nabla D) \tag{1}$$

Where u represent Darcy velocity (m/s); k represent permeability of the soil (m^2); μ represent fluid dynamics viscosity (pa.s); p represent fluid's pressure (pa), ρ represent density of water (g/cm^3); g represent gravity (m/s^2); and ∇D represent unit vector. The K can be represented as:

$$\frac{k}{\mu} = \frac{K}{\rho g} \tag{2}$$

Where K, represent the hydraulic conductivity for soil and fluid properties. Redefining the equation, the hydraulic conductivity K, equation (1) becomes

$$u = \frac{-K}{\rho g}(\nabla p + \rho g \nabla D) \tag{3}$$

Combination of continuity equation with Darcy's equation becomes:

$$\frac{\partial}{\partial t}(\rho\varepsilon_{\rho}) + \nabla \cdot (\rho u) = Q_m \quad (4)$$

Where Q_m represent mass source term (kg/m3.s), is ε_{ρ} represent porosity and ρ is the fluid density (kg/m^3). Substitution equation (4) into equation (3) to produces equation (5):

$$\frac{\partial}{\partial t}(\rho\varepsilon_{\rho}) + \nabla \cdot \rho\left[\frac{-k}{\mu}(\nabla p + \rho g \nabla D)\right] = Q_m \quad (5)$$

Expanding the time derivate term in equation **(5)** above yield:

$$\frac{\partial}{\partial t}(\rho\varepsilon_{\rho}) = \varepsilon_{\rho}\frac{\partial p}{\partial t} + \rho\frac{\partial \varepsilon_p}{\partial t} \quad (6)$$

Applying chain rule to define the density and porosity of the fluid as in terms of pressure resulted in equation (7).

$$\frac{\partial}{\partial t}(\rho\varepsilon_{\rho}) = \rho\frac{\partial \rho}{\partial p}\frac{\partial p}{\partial t} + \rho\frac{\partial \varepsilon_p}{\partial p}\frac{\partial p}{\partial t} \quad (7)$$

Inserting the definition of fluid compressibility in equation (7) to the equation on the right side of equation (7) to arrive at equation (8):

$$x_f = \left(\frac{1}{\rho}\right)\frac{\partial \rho}{\partial p} \quad (8)$$

$$\frac{\partial}{\partial t}(\rho\varepsilon_{\rho}) = \rho\left(\epsilon x_f + \frac{\partial \varepsilon_p}{\partial p}\right)\frac{\partial p}{\partial t} = \rho S\frac{\partial p}{\partial t} \quad (9)$$

Using this relation, the generalized governing equation **(**10**)** takes the following form;

$$\rho S\frac{\partial p}{\partial t} + \nabla \cdot \rho\left[\frac{-k}{\mu}(\nabla p + \rho g \nabla D)\right] = Q_m \quad (10)$$

$$H_p = \frac{p}{\rho g}; \qquad H = H_p + D \quad (11)$$

Where ρ represent the fluid density, g is the acceleration due to gravity, S represent a storage coefficient (1/pa), and D is the vertical direction over which g acts.

Richards's Equation

The movement of water into saturated and unsaturated soil is governed by the Richards' equation. The COMSOL Multiphysics mathematically explains Richards' governing equation for the water movement in unsaturated soil. This work substantial under the assumption that the air stage assumes an irrelevant part in the fluid flow (Šimůnek et al., 2012) and that the Richard equation is only applicable to water since the soil is at atmospheric pressure. The partial differential equations describing Richard equation as the governing equation for the model are:

$$(C + S_e S)\frac{\partial h}{\partial_t} + \nabla \cdot \left(-K\nabla(h + D)\right) = 0 \qquad (12)$$

$$S = \varepsilon_p \times_f + (1 - \varepsilon_p)X_p \qquad (13)$$

$$K = K_s\, K_r\, \epsilon_p \qquad (14)$$

$$S_e = \begin{cases} \frac{1}{\left[1+|\alpha H_p|^n\right]^m} & H_p < 0 \\ 1 & H_p \geq 0 \end{cases} \qquad (15)$$

$$K_r = \begin{cases} S_e{}^l\left[1 - \left[1 - S_e{}^{\frac{1}{m}}\right]^m\right]^2 & H_p < 0 \\ a & \\ 1 & H_p \geq 0 \end{cases} \qquad (16)$$

$$C = \begin{cases} \frac{\alpha m}{1 - m}(\theta_s - \theta_r)S_e{}^{\frac{1}{m}}\left[1 - S_e{}^{\frac{1}{m}}\right]^m & H_p < 0 \\ a & \\ 0 & H_p \geq 0 \end{cases} \qquad (17)$$

The soil is considered being unsaturated when the pressure head is less than zero ($H_p < 0$) and saturated when the pressure head is greater or equal to zero ($H_p \geq 0$). Both conditions is applied during the study. The challenge of complexity and a non-linear relationship occurs when C, S_s, and K vary with H_p and θ.

The specific water capacity C is defined as:

$$C = \frac{\partial \theta}{\partial H_p} \tag{18}$$

Where pressure head, H_p [m], C represents specific water capacity, **t** represents time[s], S represents a storage coefficient [m^{-1}], K represents hydraulic conductivity [m/s], Se represents the effective saturation, D is the coordinate (x, y, *z*)[m], and θ is water content (constitutive relation), χ_f represents compressibility of fluid [ms^2kg^{-1}], K_s, represents saturated hydraulic conductivity, Xp is the compressibility of soil particles[ms^2kg^{-1}], ε_p is porosity and Kr is partially-saturated hydraulic conductivity.

Water flow studies involve the use of the water retention curve as the basis. To tackle water flow in the soil, the van Genuchten equation is the most commonly used soil water retention curve equation, and its parameter value accuracy affects the soil-water movement equation computation precision. So van Genuchten equation was chosen for this constitutive model:

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + (\alpha H_p)^n\right]^m} \tag{19}$$

where θ represents water content, θ_r represents residual water content, θ_s represents saturated water content, H_p represents pressure head, l is the pore size distribution index, and α, , *m, n* are soil water retention curve shape parameter obtained empirically during the fitting procedure.

Equation (19) is combine with the Mualem's model, and the final van Genuchten analytical function describing the hydraulic conductivity(K) in terms of pressure head (H_p) and water content (θ) is as shown in equation (20) and (21) respectively (Van Genuchten et al., 1991):

$$K(H_p) = \frac{\left(1-(\alpha H_p)^{n-1}\left(1+(\alpha H_p)^n\right)^{-m}\right)^2}{\left(1+(\alpha H_p)^n\right)^{m/2}} \quad (20)$$

$$K(\theta) = Ks\ \theta^l \left[1-\left(1-\theta^{1/m}\right)^m\right]^2 \quad (21)$$

Where Ks represents hydraulic conductivity at saturation, **α** represents the inverse of air entry value, K represents unsaturated hydraulic conductivity, n represents pore size distribution index and **λ** represent the pore-connectivity parameter.

Physical Properties of the Soil

Physical properties of soil include porosity and bulk density. The physical properties of soil assume an important function in deciding suitability of soil for horticultural and agricultural systems. They are suitably connected with flow, retention, and accessibility of water and supplements to plants and movement of air in the soil (Kay & Angers, 2000). Further research shows that soil physical properties influence a range of system processes and changes in their state because it served as an indicator of soil quality. Also, further study reported that the soil physical properties are an influential factor for properties like porosity, hydraulic conductivity, and water retention which is very vital for irrigation processes (Hawke et al., 2003). Da Silva & Kay, (2004) also reported highlighting the importance of the soil physical environment for crop growth and soil conditions.

Bamberg et al., (2011) conducted a study and reported that soil physical properties changes throughout the crop production season when there are high levels of soil water content after the irrigation process. Kay et al., (2000) further observed that soil physical properties is affected when there is modifications in soil structure. Topp et al., (1997) conducted a study and stated that soil physical properties is defined as the transfer of mass and energy and storage properties that allow dissolved soil nutrient, water, and air contents. Reynolds et al., (2009) further stated that soil physical properties depend on climatic changes, irrigation practices, crop growth and activity involving biological systems. Engelman & LeRoy, (1995) established that as a result of the decrease in worldwide per capita arable land, the physical properties of soils are more significant in recent memory in supporting agricultural efficiency. Hence, saving and re-establishing world soil resources is critical to satisfying the needs of the current populace without jeopardizing the needs of people in the future.

Basic Definitions of Soil Properties

Hydraulic Conductivity

The process in which the soil transmit and retain water and depend upon the pressure head and water content is termed soil hydraulic conductivity

(Dane & Hopmans, 2002). Bagarello et al., (2005) also conducted a further study and found out that hydraulic conductivity is designed to monitor irrigation and drainage systems. Hydraulic conductivity is additionally a significant soil property while assessing the possible use of soil for some agricultural and non-farming users (Chakravorty et al., 1998-99).

Reynolds et al., (2000) expressed that hydraulic conductivity is a significant soil property for some agronomic, environmental, and engineering activities since it is essential in soil-water – solute movement and plant growth models. Thus, information on hydraulic conductivity is significant in taking care of natural issues, and other hydrological measures as announced by (Gulser & Candemir, 2008). Hence, knowing the amount of water measured, sample length, sample area, time taken for water to release, and pressure head difference. The saturated hydraulic conductivity is determined as follows:

$$K_s = \frac{QL}{At\Delta H} \quad (22)$$

Where A, represents the area of the sample, Q, represents the amount of water per unit time, L represents the length of the sample column, ΔH represents the differences in the hydrostatic pressure.

Bulk Density

Soil bulk density is a unique property that changes with the soil structural conditions. McLaren et al., (1996) conducted a study and observed that the soil bulk density is an indicator of porosity and compaction of the soil. Reynolds et al., (2009) also argued that soil bulk density reflect the capability of a soil to provide structural support, adequate water, solute transport and soil aeration. Sparling et al., (2008) further proved that contrast soils having low bulk density can be vulnerable to disintegration and regularly experience the ill effects of inadequate water reserves for good farming practice.

Calhoun et al., (2001) conducted a further study and proved that information on soil bulk density is necessary for the management of soils, which is very crucial in the planning of modern farming methods and soil compaction as well. In all, the bulk density of soil increased with soil profile depth and usually decreases, as mineral soils become improved in texture. Li et al., (2014) further observed that bulk density influenced soil water retention capacity. Blake et al., (1986) demonstrated that soil bulk density standards are essential for calculating the porosity of the soil. Other authors stated that the bulk density values greater than 1.6 g/cm^3 of soil tend to limit plant root development as reported by McKenzie et al., (2004).

Xiliang et al., (1991) established further that zeolite also advances the arrangement of soil that decreases the bulk density, increased soil porosity, and improved crop yield. The sandy soils typically have bulk density ranges from 1.3-1.7 gcm^{-3} which is higher than clay and slits of 1.1-1.6 gcm^{-3}. A soil bulk density (ρ_b) is defined as the oven-dried mass (Ms) per unit total volume (V_t) of soil. The soil bulk density is calculated using the relation:

$$\rho_b = \frac{M_s}{V_t} \qquad (23)$$

Where ρ_b represent bulk density, M_s represent the mass of the soil, and V_t represent the volume of soil.

Porosity

The porosity of soil is characterized as the space between the soil particles. Dominati et al., (2010) expressed that because of the impact of porosity on soil water retention, air permeability, root infiltration, and seepage, soil porosity is a crucial soil physical quality indicator. Kay, (2002) also found that pores of various sizes and shapes influence the retention of water in the soil. McKenzie et al., (2004) exhibited further that porosity gives a decent sign of soil permeability and is critical for the soil plant-climate system.

Cournane, (2010), established further that soil bulk density and porosity are important to soil structure which allows interaction between crops, soil, and water. The porosity of soil is also responsible for the destruction of nutrients. The porosity of soil is greater in organic soils and clayey than in sandy soils. Cameron, (1996) stated that the porosity (ρ_f) of soil is related to particle and bulk densities of the soil and is expressed as:

$$\rho_{f} = \left(1 - \frac{\rho_b}{\rho_s}\right) X\ 100 \qquad (24)$$

Where ρ_s represent the soil's particle density and ρ_b represent the bulk density of the soil.

Water Retention

Soil physical property such as water retention, which is controlled by the macro pores of the soil is essential to life. Further study proved that any accurate determination of soil water retention is important for studies that will help us to understand crop adaption to water stress, which is very important in irrigation processes (Mwale et al., 2005). More also, soil water retention relationship is importantly needed in resolving the Richards equation of flow of water in saturated and partially-saturated soil. Hillel, (1980) also stated that the retention of water is an important property of hydraulic conductivity that affects soil management practices greatly and regulates the functioning of soil in an ecosystem as reported by (Rawls et al., 2003).

More recently, many researchers like Bamberg et al., (2011) established that the rise in water content after irrigation process could bring variations in soil hydraulic, and physical quality throughout the crop production season. Leeper & Uren, (1993) further reported that clayey soil generally retain more water than sandy soils due to the fine particles of a clay. Conversely, sandy soil provides easier transmission of water through the profile. Furthermore, authors like Charman & Murphy, (1989) argued that soil structure together with organic matter and clay soil also influences the retention of soil water.

Particle Size Distribution

Particle size distribution is an essential physical property of soils that influence numerous significant soil qualities, for example, soil structure and texture. Arya et al., (1999) conducted a study and observed that particle size distribution is another material used in determination of the hydraulic properties of a soil indirectly. Anderson et al., (2006) stated further that for estimating the retention curve of water, unsaturated conductivity, and retention of nutrients, particle size distribution is frequently used. Wosten et al., (1995) also conducted research and proved that to predict physical properties, hydraulic properties, and water retention of a soils, a soil particle size distribution is one of the key parameters of soil used.

Many researchers, because of soil physical properties significance have already pointed out damaging effects on particle size distribution (Cook et al., 1994). Li et al., (2006) conducted a research and supported that plant growth and soil salinization depend on the movement and distribution of soil water and salt under agricultural practices, which is further decided by soil particle size distribution as reported further by (Zhao et al., 2006).

Soil Hydraulic Properties

Al-Jabri et al., (2002) noted that the knowledge on hydraulic properties of a soil is needed for the understanding and assessing of soil physical processes in water and solvent flow in soil systems.The characterization of the soil hydraulic properties is significant for some reasons, including water and agricultural management as reported by Schelle et al., (2013).

Water Retention Curve

The knowledge of retention of water is a key tool used in simulation the water movement and pollutant in partially-saturated soils. It is especially crucial for agricultural management, under irrigation practices. Jabro et al., (2009) stated that the retention curve is powerfully affected by the texture and variety of soil mineral.

Tinjum et al., (1997) noted that the water retention curve is necessary for studying plant water stress, ease of use of water for plants, drainage, and infiltration in unsaturated media. Warrick, (2003) also argued that water retention is vital for the numerical account of the model movement of the flow of water, solute movement, and nutrient flow and uptake by plants in both saturated and unsaturated soils.

In addition to that, the hydraulic conductivity function is derived using water retention curves which is an essential tool for soil-water modeling using Richard's governing equation as reported by van Genuchten, (1980). The retention curve shape or pF curve shape depends on the soil type used. Figure 1 shows the general soil water retention curve for various soil types as reported by Larry et al., (2009). The figure illustrates how three different soil types, will influence the behavior of the curve.

In general, the higher the clay content, the higher the water-retaining properties. The clayey soils will be able to hold on much more water at a given potential compared to loamy or sandy soils. This is due to the fine pores and the uniform pore size distribution in clay soils that can hold the water much more resolutely than the relatively large pores in sandy soils. Brady, (2010) further reported that the flat shape of the water retention curve of soil indicates that once the water has been drained from the large pores, only a small amount of water will be present. Figure 1 shows that, on the other hand, the retention curve has a fairly steep form for clay while the retention curve shape has a step form for sand.

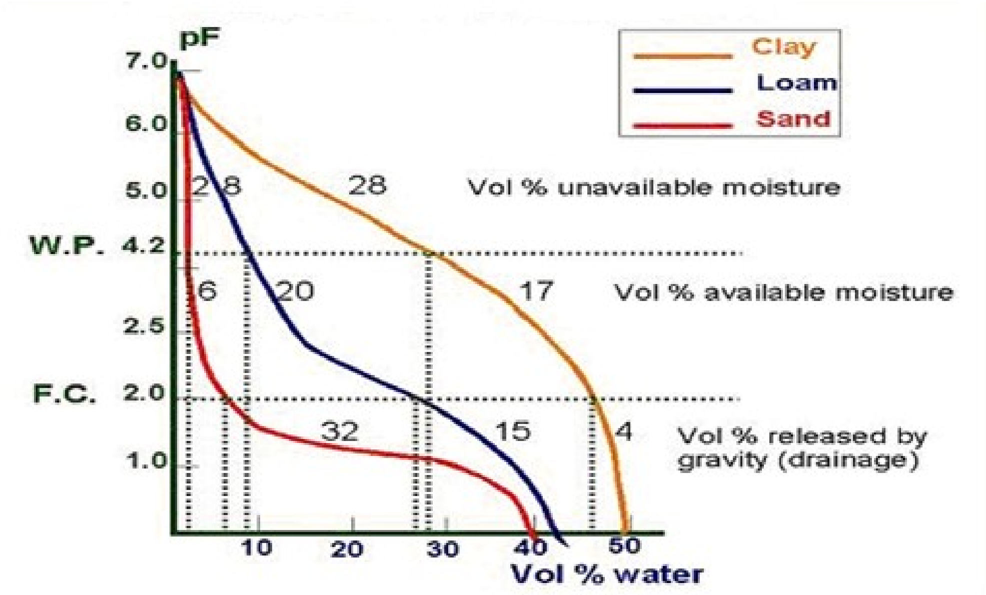

Figure 1: Soil water retention curves for clay, silt loam & sand soil from (Larry et al., (2009)

Water Retention Curves Features

The water retention curve or pF curve is the relation between the pressure head and water content. The pF curve is when the pressure head is stated as the logarithmic value of water.

Water Retention Curve Models

Recently, there are quite many water retention curves models that are used over the years to define the retention of water curves across different types of soils. More of the water retention curves models novel while others are the reform of the current models. Several authors have proposed different functions to define the models. These models use many empirical equations that relate water content and pressure head. Examples of water retention curve models deliberated on are as shown in equation 25-32:

Van Genuchten Model

The model is closed-form analytical expression for the water retention model commonly used. It was developed for computing hydraulic conductivity in terms of information on water retention curve and hydraulic conductivity at saturation. The van Genuchten, (1980) equation is given as:

$$\theta = [(\theta - \theta r)/ (\theta s - \theta r)] = [1 + (\alpha H_p)^n]^{-m} \tag{25}$$

In which θ is the water content, θ_s represents saturated water contents, θ_r represents residual water contents, H_p represents pressure head, α, n and m are empirical shape parameters.

Brooks-Corey Model

Another well-established water retention curve model is Brooks - Corey, (1964). A Brooks and Corey model is also uses experimental data to fit the water retention. The Brooks and Corey model is expressed as:

$$\theta = [(\theta - \theta r)/ (\theta s - \theta r)] = [\, h_b / H_p]^{\lambda} \tag{26}$$

Where λ is pore size distribution index, θ_s represent saturated water content, θ_r, represent the residual water contents, h_b is bubbling pressure, H_p represent pressure head, λ and α are empirical shape parameters.

Fredlund-Xing Model

Fredlund-Xing water retention model (1994) as shown:

$$\theta = \theta_s \left(1 - \frac{\ln\left(1+\frac{\psi}{\psi r}\right)}{\ln\left(1+\frac{1000000}{\psi r}\right)}\right) \left[\frac{1}{\ln\left(e+\frac{\psi}{a}\right)^n}\right]^n \tag{27}$$

where, ψ_r represent pressure head corresponding to the residual water content θ_r, ψ represent pressure head, a is a soil parameter which is related to the air entry values of soil, and α, n are empirical shape parameters.

Gardner Model

The model contains parameters of the water retention model.

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{\left[1+\left(\alpha H_p\right)^n\right]} \quad (28)$$

Where, H_p represent pressure head, θ represent water content, θ_r is the residual water contents, θ_s represent the saturated water contents, α, n and m are empirical shape parameters.

Biexponential Model

Omuto, (2009) developed the Biexponential water retention model which has five parameters contained in a bimodal pore- size distribution.

$$\theta = \theta_r + \theta_1 e^{-\alpha_1 H_p} + \theta_r + \theta_2 e^{-\alpha_2 H_p} \quad (29)$$

where, θ_{b1} is the structural pore-space, θ_r is the sum of residual water contents in the structural pore-space θ_{b1} and textural pore-space θ_{b2}, α_1 represents the inverse of air-entry potential in the structural pore-space, θ_1 represents the difference between saturated water content θ_{s1} and residual water contents, θ_2 represents the difference between saturated water θ_{s2} and residual water contents θ_{b2} in the textural pore-space; α_2 represents the inverse of air-entry potential in the soil textural pore-space.

Campbell Model

Campbell water retention model recommended the equation below:

$$[(\theta- \varphi) = [\ h_b/\mathrm{H}_p]^{1/b} \qquad (30)$$

Where, b represent constant parameter, φ represent porosity, H_p represent pressure head, and θ is the water content.

Tani Model

This is water retention model developed by Tani, (1982):

$$\theta = \theta_r + (\theta_s - \theta_r)\left[1 + (\alpha H_p)e^{-\alpha H_p}\right] \qquad (31)$$

Where H_p represent pressure head, θ_s represent saturated water content, α is the inverse of air-entry potential, and θ_r is the residual water content.

Exponential Model

Exponential water retention model was developed by (Omuto, 2007). The model is shown in equation (32).

$$\theta = (\theta_r + \theta_s)e^{-\alpha \mathrm{H}_p} \qquad (32)$$

Where θ_r represent residual water content, H_p represent pressure head, α represent bubbling pressure, and θ_s represent saturated water content. The Table 1 & 2 summaries the similarity, differences, and advantages of the water retention models used.

Table 1: Role Showing the Similarity and Difference in the Water Retention Curve Models

Water Retention Curve Models	Similarity	Difference
Van Genuchten, model (1980)	The Van Genuchten is used worldwide because it is relatively simple It has four parameters in the equations. Pressure heads is expressed as positive quantities in the parametric expressions. They are used as the reference for comparison with other models.	The air entry point cannot be recognized when using the Van Genuchten model. Because of the inflection point, the model has a continuous character compared to Brooks-Corey. It does not perform well during the high-pressure head values (Lamara & Derriche, 2008)
Brooks-Corey, (1964)	The model is used worldwide because it is relatively simple as in water retention curves (Song et al., 2013). It also has four parameters as the van Genuchten model. Pressure heads is expressed as positive quantities in parametric expressions. Brooks-Corey are used as the reference for comparison with other models	The model recognizes the air entry value. The discontinuous character of the equation is generally considered as a disadvantage, particularly in describing the water retention curve near saturation (van Genuchten and Nielsen, 1985).

Table 1 continued

Fredlund-Xing, (1994)	The model is used for obtaining hysteresis curves of the soils. It also has five parameters	In the model, water content value always tends to be zero at a pressure head equal to 10^6 kPa of the soil. It deals accurately in the pressure head values ranging from zero to 10^6 kPa continuous using the experimental data.
Gardner, (1956)	Two basic parameters like the air entry value and pore size distribution are incorporated. It has four parameters in the equations.	It cannot accurately describe the water retention curve for saturated and near-saturated soils (Song et al., 2013).
Biexponential, (2009)	It has five parameters in the equations.	Bimodal soil pore-size distributions. The model has problem during the fitting (Sillers and Fredlund 2001).
Campbell,(1974)	It has three parameters in the equations.	Below the air entry point, the model does not account well in the water retention curve (Manyame et al., 2007).
Tani,(1982)	It is used widely to model water flow in soils because it is simple (Suzuki, 1984). It has three parameters in the equations.	Less accuracy than when using the other model with parameters of two and three (Kosugi et al., (2002).
Exponential, (2007)	The model was developed by Hutson and Cass (1987) based on the Campbell model. It has three parameters in the equations.	The accuracy of the model is less than when using the other model with parameters of two and three (Kosugi et al., (2002).

Source: Du, 2020; Fredlund-Xing, 1994; Tani, 1982; Campell, (1974)

Table 2: Role Showing the Advantages of Water Retention Curve Models

Water Retention Curve Models	Advantages
Van Genuchten	In the model, the water retention curves give a good account in most situations (Song et al., 2013). Was developed for calculating the hydraulic conductivity from the information on the retention curve and saturated hydraulic conductivity data. Van Genuchten is used during the soil water retention when only a narrow range during the wet period is accessible.
Brooks and Corey	One of the best model widely used by engineers.
Fredlund and Xing	This model describes the water retention curve model more accurately compare with other models such as Gardner, van Genuchten, and Brooks-Corey at a long pressure head range as reported by Leong and Rahardjo (1997).
Gardner	This model applications are very wide and safe to use.
Biexponential	Only model that has bi-modal structure (textural and structural).
Campbell	This model is more precise compared with van Genuchten model under pure sandy soil conditions.
Tani	This model offer a good curve for the soil water retention water retention.
Exponential	This model under a wide range of conditions could precisely describe the retention curve of water.

Source: Du, 2020; Fredlund-Xing, 1994; Omuto, (2007)

The van Genuchten model equation was used in this study because it is widely used in the soil community, and it seems to reflect for most soils the water content and pressure head $\theta(H_p)$ and hydraulic conductivity and water content K (θ) functions. Van Genuchten (1980) is one of the most commonly used models to explain the water retention curve of soils.

Soil Profile

A soil profile is a vertical section or a cross-sectional view of a soil (figure 2). The soil profile helps us to examine the soil structure. It is divided into a number of layers running parallel to the surface called horizons. The main soil horizons are O, A, E, B, C and R.

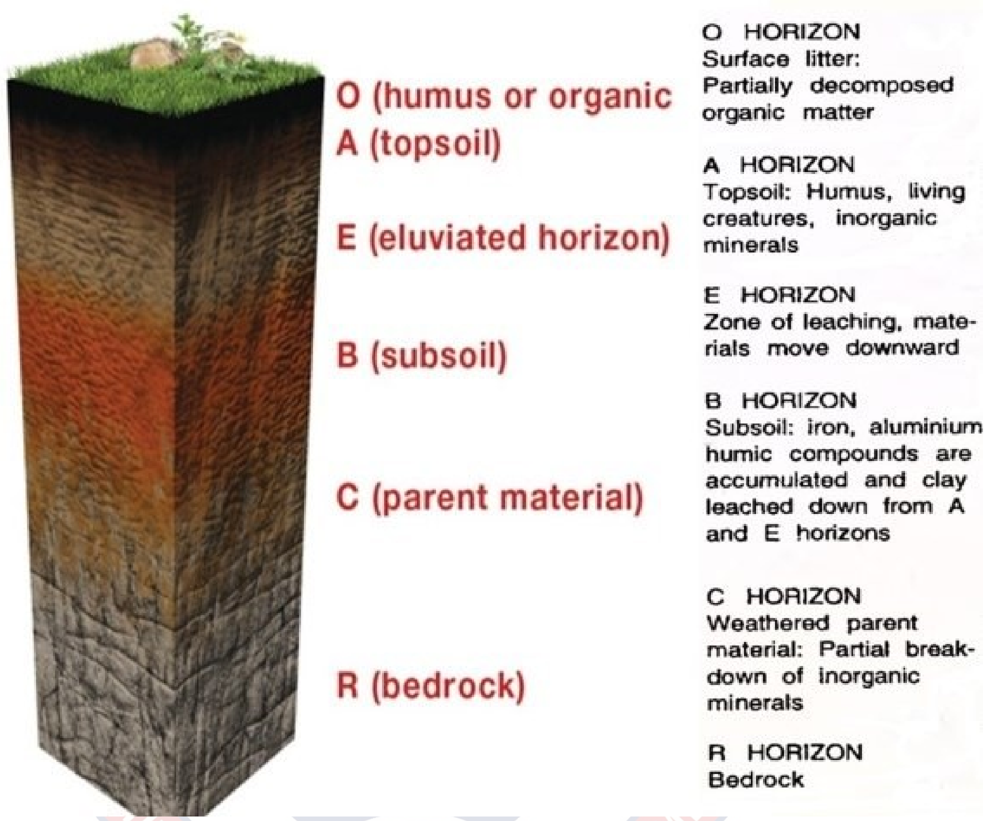

Figure 2: Picture showing the soil profile (https://www.pmfias.com/soil-profile-soil-horizon-soil-types-sandy-clayey-loamy)

Sandy Soils

Sandy soils (sand, loamy sand textured) are among the broad soils on the planet, covering in excess of 900 million hectares which are found in the arid and semi-arid areas (Drisesen et al., 2001). Sandy soil has been well-known as inherently infertile, having low chemical fertility, degraded, poor nutrient, low water retention capacity, high bulk density, and high hydraulic conductivity (Noble et al., 2000). Therefore, they are viewed as minor for crop production because many crops have a difficult time in surviving in them. Sandy soils are characterized as the soil which contains less than 18 % clay and more than 65 % sand (Drisesen et al., 2001). They are often considered as soils with no structure or feeble structure, low water retention capacity, high hydraulic conductivity, high bulk density, low porosity, low organic carbon, highly sensitivity to compaction and high infiltration rate. Bell et al., (2004) argued further that sandy soils found in tropical regions have a wide range of limiting features for farming practice: these include lack of nutrients, acidity nature, low water retention capacity, and poor soil physical qualities. Table 3 shows the values of some of the sandy soil properties in the study area. Thus plants growing on these soils usually suffer drought unless frequently irrigated and fertilized.

Table 3: Soil Bulk Density, Porosity, Organic Matter, Organic Carbon, and Particle Size Distribution of the Soil at the Study Area (Keta District, Ghana)

Soil Sample (cm)	Organic matter (%)	Organic carbon (%)	Porosity (%)	Bulk density (%)	Particle Size Distribution (%)			Soil Texture (USDA)
					Sand Fraction	Silt Fraction	Clay Fraction	
Keta (0-20)	2.5	1.4	40.74	1.57	98.54	0.85	0.61	Sandy
Keta (20-40)	1.9	1.1	41.29	1.55	98.49	0.94	0.57	Sandy
Anloga (0-20)	2.6	1.5	41.74	1.54	99.36	0.33	0.31	Sandy
Anloga (20-40)	2.9	1.7	45.15	1.45	99.43	0.23	0.30	Sandy
Vui (0-20)	1.5	0.9	40.13	1.58	99.61	0.23	0.16	Sandy
Vui (20-40)	0.4	0.2	40.30	1.58	99.66	0.21	0.13	Sandy
Woe (0-20)	1.9	1.1	45.54	1.44	99.61	0.23	0.16	Sandy
Woe (20-40)	1.6	1.0	46.96	1.40	98.72	0.69	0.59	Sandy
Tegbi (0-20)	1.5	0.9	41.40	1.55	99.00	0.57	0.43	Sandy
Tegbi (20-40)	0.5	0.3	45.39	1.44	98.72	0.47	0.81	Sandy

Source; Allotey et al., 2008; Awadzi et al., (2008) Further research have proved that sandy soils also have the lowest organic carbon and organic contents, compared to the different soil types which makes them not good for cultivating different types of crops as reported by Bell et al., (2004). Because of the coarse texture and porous nature of sandy soil, many crop-important nutrients elements can be easily leached. Also, the bulk density of the sandy soils are commonly high, ranges from 1.6-1.8 gcm^{-3} whilst the porosity are low due to the relatively large size of sand particles. The good drainage of the sandy soils is due to the content of large pores present in the soil. Sandy soils retain water less tightly than the finer-textured soils. Thus, they give up water to the crop more readily than the finer-textured soils. The fast infiltration rate of water in sandy soil may be considered advantageous because water penetrates deeper in sandy soil more than fine-textured soils also less water is subject to loss by evaporation in sandy soil. In sandy soils, considerable depth, water, and nutrients may penetrate below the root zone depth and become unavailable to plants.

Bell et al., (1990) stated further that the low nutrient levels in sandy soils, makes crops grown on these soils limit productivity of the crops. Drisesen et al., (2001) further stated that plants growing in sandy soils are short of available water, and practice that increases water in the root zone is recommended. Thus decreasing evaporation of soil moisture through evaporation takes place in sandy soil as well as fine-textured soils help plants to absorb its need for water.

Furthermore, salinity is a common restraint on sandy soils wherever irrigation water is used in arid and semi-arid regions. In sandy soil along the coast, salinity is related with intrusion of seawater as reported by White &

Broadley, 2001; Yuvaniyama, 2001). Acidity is common on sandy soils because the sandy soil dry out quickly and are low in plant nutrients (Kirk, 2004). It is also stated that the acidity of a soil could results to a range of deficiencies of nutrients in the rainfed crops (Dierolf et al., 2001). Sandy soils are normally, have high hydraulic conductivity and low water and nutrient ability and therefore make it difficult for the plant to survive in them. Prevedello et al., (1995) stated that in sandy soil, the saturated hydraulic conductivity measured was $1.1\times10^{-6} < 7.5 \times 10^{-5}$ m/s in tropical regions.These features mentioned above render sandy soil unsuitable for farming purposes without widespread use of soil amendments (eg., manures, fertilizers) and uninterrupted supply of water for irrigation purposes (Ibrahim et al., 2016; Asomaning et al., 2015).

Soil Amendments

Soil amendments are ingredients added to the soil to improve the chemical, biological, physical, and hydraulic properties and also increase yield in crops. There are a variety of amendments that could be applied to soils to serve many different purposes. These soil modifications usually involve the physical addition of a particular material or combination of materials as reported by (Waddington, 1992). A soil amendment is often added to the soil to help improve conditions in the soil and to make its use more favourable as reported by Waddington, (1992). It is further stated that in an agricultural systems, overall goal of using a soil amendment is to improve plant and soil dynamics as proved by Waddington, (1992). Improvements to soil water, air conditions, drainage, and compaction of soils are a few factors that could help improve problems in soil, which would then result in better plant growth as noted by Lal, (2008). Waddington, (1992) further stated that soil amendments can be classified as organic, inorganic or combinations of both amendments. It is important to establish good quality amendments at desired ratios so that there are not any adverse effects on crop growth, such as immobilization of nutrients (Raj & Antil, 2011).

Zeolites

Zeolites are aluminosilicates crystal of alkali and alkaline earth metals that have a vast three-dimensional crystal structure, which exists in more than 50 natural and 150 synthetic structures made up of corner-sharing SiO_4 and AlO_4 tetrahedra and have a composition very similar to sand (Sean &Yoshio, 2009). Zeolites structure is three-dimensional and crystalline networks of alumina anions or tetrahedra silica bonded strongly at every corner. It is stated that because of three dimensional and crystalline networks structural features of zeolites, it has low bulk density compared with that of other minerals.

Zeolite may allow molecules to move through and cause others to be removed or stopped due to the molecular sieving nature of zeolite. Zeolite materials are sponge-like because they have a very regular structure and pore sizes. Their pores hold water and or other molecules. Pore size range from about 2 to 12Å. Zeolites are also used to remove the toxic elements in the environment due to the open pore structure of the zeolite (Belviso et al., 2009). Studies have shown that they function in temperatures and pH regions necessary for cost and energy effectiveness (Pless et al., 2006). Zeolite porous structure helps keep the soil moist and aerated as well as active for an extensive period (Ramesh et al., 2010). Zeolite differs in terms of pore shape, pore diameter, and how the pores are organized. A negatively charged structure, due to the existence of alumina, is counterbalanced by cations resulting in a high cation exchange capacity (He et al., 2002; He et al., 2016).

Zeolite improved the water, micronutrients, absorption, and retention of plant nutrients because it is a beneficial soil amendment (Ghazavi et al., 2010). Due to the zeolite porous properties and the capillary force zeolite exerts, zeolites also assists water retention and infiltration in soil. Zeolite is an excellent amendment for non- wetting sands, it assists water distribution through soils and also acts as natural wetting agents. Zeolite can improve considerably sandy soil water retention capacity, and decrease soil bulk density, hence increase plant yield during the dry and famine seasons.

Discovery of Zeolite

In 1756, zeolite was found by Swedish physicist and mineralogist Cronstedt Fredicka (Kulprathipanja, 2010). He noticed that this characteristic mineral seriously loses water during warming. The name zeolite was gotten from Greek words dzeo signifying "bubbling" and lithos signifying "stone"(Szostak, 1989; Kwakye-Awuah, 2008). A delegate observational equation of a zeolite is

$$M_{2/n}O.\ Al_2O_3\ .wSiO_2\ .vH_2\ O \qquad (33)$$

where w is 2 – 200, M represents the exchangeable cation of valence n, **v** represents the water contained in the voids of the zeolite, n is the cation valence, M is generally alkali or alkaline earth metals.

The zeolite structure may contain discrete-sized channels and cages that are typically occupied by water (Ghobarkar et al., 1999). Zeolite can be natural or synthetic with 40 natural occurring zeolite and more than 150 zeolite types synthesized known (Szostak, 1989; Klein, 2002). Synthetic zeolites have many advantages compared to natural zeolites, such as purity, uniform pore size, and greater capacity for ion exchange. Because of their unique adsorption, ion-exchange, molecular sieve, and catalytic properties, both natural and synthetic zeolites are used commercially.

After the discovery of zeolite, it was detected that zeolite has high hydration properties, stable crystal structure when dehydrated, low density and high void volume when dehydrated, cation exchange capacity properties, uniform molecular-sized channels in dehydrated crystals, ability to absorb gasses, and high porosity properties (Szostak, 1989; Klein, 2002). Klein, (2002) and other researchers have described the properties of zeolite minerals as dehydration, adsorption, reversible, cation exchange, and porosity. (Byrappa & Yoshimura. 2001) showed that zeolite materials can exchange their constituent cations for others.

The hydration-dehydration property of zeolites was established by Damour, (1857). Weigel & Steinhof, (1925) separated gas molecules on the basis of size once the water had been removed from the zeolite internal structure. Klein, (2002) proposed that the structure of dehydrated zeolites consists of open porous frameworks. St. Claire Deville, (1862) cited by Byrappa & Yoshimura, (2001) reported the first hydrothermal synthesis of a zeolite, levynite, Friedel, (1896) developed the idea that the structure of dehydrated zeolites consists of open spongy frameworks after observing that various liquids such as alcohol, benzene, and chloroform were occluded by dehydrated zeolites. Leonard, (1927) was the first author to have reported the use of the first X-ray diffraction machine for identification in mineral synthesis. In 1930, Pauling, (1930) were the first researchers to have described the crystal structure of zeolite minerals first. In 1932, McBain wrote a book, and in the book, he used the word "molecular sieve" to distinct porous solid materials that performance as sieves on a molecular scale (McBain, 1932). In addition to that, the first molecular sieve effect was reported by Weigel & Steinhof, (1925). Therefore, the collected works that described the number of reported syntheses of zeolites as well as the adsorption, ion exchange capacity, molecular sieving, and structural properties of zeolite minerals during the mid-1930s were reported.

Furthermore, due to the incomplete characterization and the difficulty of experimental reproducibility the early synthetic work remains unsubstantiated. Barrer, (1938) successfully synthesized natural Chabazite and Mordenite, leading to an inspiring period of synthesization of zeolite in the search of new methods for the purification and separation of air. In addition to that, synthesization of low silica zeolite was done in 1940. The widespread industrial production of zeolites was the result of the application of low-temperature hydrothermal technique used. Between 1949 & 1959, Milton & Breck further discovered commercial significant zeolite types, A, X, and Y. In 1959, China first synthesized Zeolites A and X. In 1954, Union Carbide introduced synthetic zeolites as absorbers for industrial separations and purifications. Milton in 1967 began and developed molecular sieve zeolite. Van Bekkum et al., (2001) stated that the commercial applications of zeolite as selective adsorbents and catalysts is due to the initial findings and synthesis of A, X, and Y as new zeolites. It proved further that the beginning of the commercialization of the natural zeolites like erionite, mordenite, and chabazite, as molecular sieve zeolites were marked in the year 1962. Flanigen, (1980) reported the applications of natural clinoptilolite in wastewater treatment and radioactive waste in the 1960s were based on high cation exchange selectivity and stability features.

In 1962, a hydrocarbon cracking catalyst named synthetic zeolite X was introduced by Mobil Oil. More also, Mobil Oil stated that the synthesis of the ZSM-5 and high silica zeolite beta was done in 1967 – 1969. Finally, zeolites for ion exchange capacity was introduced by Union Carbide in 1977.

Natural Zeolites

Natural zeolites are found to be distributed rather unevenly in nature after they were discovered by Cronstedt. During the past 200 years, there are about 40 natural zeolites that have been known and more than 150 zeolites have been synthesized. From the last part of the 1950s to 1962 significant geologic discoveries uncovered the broad event of various natural zeolites in sedimentary deposits all through the western United States. A researcher like Clifton, (1987), stated that the formation of zeolites is in both geological system and various condition worldwide.

Iijima, (1980) proved further that zeolites are formed in numerous rock or sediment under changing chemical and physical conditions. Also, because of natural zeolite unique molecular sieve, adsorption, catalytic and ion-exchange properties, they are used commercially. The chemical reaction between the saline water and volcanic glass resulted in the formation of natural zeolite. The natural zeolite formation occurs at the temperatures ranges between 28°C to 56°C with a pH between 9 and 10. The natural zeolite formed is polluted by the quart, $Fe2^{+}$, amorphous glass, and other zeolites to varying degrees by other earth minerals. Occurring of certain zeolites in nearly monoamineralic and large deposits are appropriate for use in mining sectors. Mumpton, (1999) proved further that due to the adsorbent applications of natural zeolite like clinoptilolite, erionite, chabazite, and mordenite it have been commercialized. Potential uses of natural zeolites are found in fertilizer, as soil conditioners, fillers in the paper industry, as dietary supplements in animal husbandry, and in cement and concrete.

Synthetic Zeolites

Significant innovative work is being done to produce modify made synthesized zeolite. Systematic studies on zeolite synthesis have been revealed since the year 1940s. It was discovered that in the year 1884, Wöhler first recrystallized apphophylite which was carried out by heating it in water solutions at 180-190°C under 10-12 atmospheric pressure. After, Wöhler, St. Claire turn out to be the first man to use the hydrothermal method in the laboratory to synthesis levynite in 1862. It was proved that the zeolite that did not have a natural counterpart has been synthesized (Barrer, 1982). It was noticed that Barrer & Milton group has initiated zeolite technology on a large scale during the late 1940's. Barrer & Milton group also used hydrothermal synthesis on reactive alkali-metal aluminosilicate gel at pressure and low temperature to produced synthesized zeolite. A further study reported synthetic zeolite A structure (Reed & Breck, (1955). Synthetic zeolite X as a hydrocarbon cracking catalyst was also introduced by Mobil Oil in 1962.

Zeolite X

Szostak, (1989) stated that Zeolite X is a synthetic zeolite made from the naturally Faujasite mineral. It has probably the biggest cavity and cavity doors of any known zeolites (Szostak, 1989**)**. A further study shows that there are sodalite cages which are connected to the super cages by rings of six and four tetrahedral structure (Szostak, 1989). In the zeolite, cavities found exchangeable cations, which balance the charge of the anion the aluminosilicate framework. Because of aluminum and silicon contents, the zeolite chemical composition can change. Also, due to the zeolite large available pore volume and surface area and excellent stability of the crystal structure, zeolite X has a wide range of industrial applications (Kwakye-Awuah et al., 2008; Kwakye-Awuah, 2008).

Zeolite Structure

Zeolites have interesting properties due to their anionic framework and exchangeable cations. Primary and secondary units are building units contains in zeolite structures. In the zeolite structures a primary unit is a simpler building compared to the secondary unit. The results are due to the fact that the primary building unit of the zeolite structure has a dominant atom, aluminium (Al^{3+}), or silicon (Si^{4+}) with oxygen atoms of four sitting at the corners. A tetrahedron is formed with an oxygen atom being shared by two tetrahedra. In the zeolite structure, a three-dimensional framework and almost all oxygen ions are shared by two tetrahedra due to the primary building unit that is linked together. Aluminum (Al^{3+}) and silicon (Si^{4+}) are called framework cations hence not exchangeable under normal conditions (Top, 2001). Numerous distinctive structural polyhedra formed from primary building units is as results of different combinations of the same secondary building unit. At the surface of the zeolite structure, the net negative charge on the structure is balanced by divalent or monovalent cations, as shown in Figure 3:

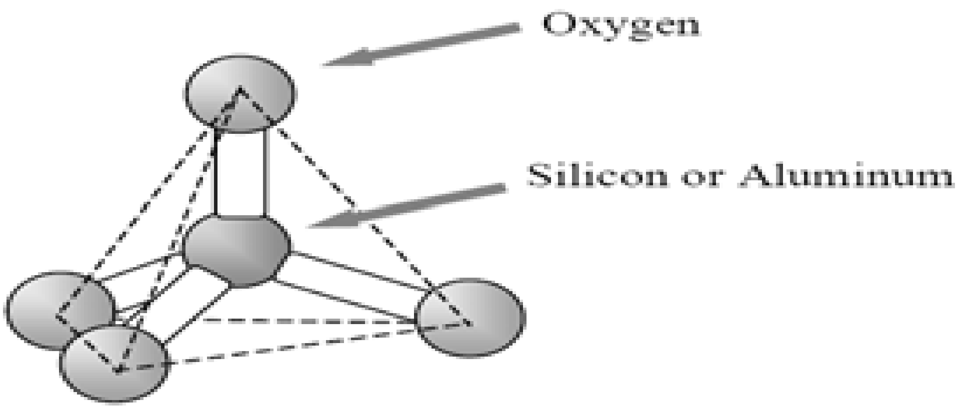

Figure 3: Zeolite frameworks (www.bza.org/zeolites.html).

Molecular Sieves

Flanigen, (2001) reported that zeolite molecular sieves structure are porous materials with pores of the size of molecular dimensions, 0.3 – 2.0 nm in diameter. It is stated that the molecular sieves were used for materials that exhibit properties of selective adsorption (zeolites, carbons, glasses, and oxides) (Kwakye- Awuah, 2008). A further prove shows that zeolites are crystalline with a uniform pore size described by their crystal structure (Breck, 1974). Zeolites are considered as the best recent commercial molecular sieves practices today.

Uses of Zeolite

Based on zeolite attractive adsorption, ion- exchange, high porosity, high surface area, and hydration and dehydration properties, numerous studies have been carried out using zeolite. Some uses are:

Gas Purification

Zeolites are used to remove impurities such as sulphur dioxide, water, and carbon dioxide in natural gases due to zeolite's molecular sieve properties. Zeolites have been used for quite a few years and generally oil refining and in cleansers as a replacement for phosphates (Kulprathipanja, 2010). Zeolite is also used for removal and recovery of volatile organic compounds that offer promise for significant market growth.

Ion Exchange

Zeolite enclosed cavities contain both water molecules and the metal cations, whereby the cations are loosely bound to the lattice and thus engage in ion exchange. It is reported that due to the ion exchange capacity of zeolite, the zeolites are used for removal of heavy metals and other pollutants (Rahmani & Mahvi, 2006). Barthomeuf, (2003) stated that zeolites can support a diverse range of catalytic reactions, including metal-induced and acid-base reactions which serve as acid catalysts and can be used to support active metals or reagents. Szostak, (1989) demonstrated further that zeolites are extremely useful as catalysts for several important reactions involving organic molecules. The most important are cracking, isomerization, and hydrocarbon synthesis. The reactions can take place within the pores of the zeolite, which allows a greater degree of product control (Szostak, 1989).

Detergent

Zeolites worldwide are used in detergent industry as a replacement for phosphates (Davis et al., 2009). Zeolites have been in use for several decades and mostly in petroleum refining and detergents as a substitution for a mineral such as phosphates (Kulprathipanja, 2010).

Waste Water Treatment

The zeolites play a significant role in reducing toxic waste in an environment. Szostak, 1989; Thompson, 1998) observed that due to the zeolite porous structure, it causes colloid particles from both mineral and organic origin to be removed from the water. Also, because certain natural zeolites have a high affinity for ammonium ions, they are used in a water treatment system.

Pool Filtration Medium

The highly porous structure of zeolites makes it captures pollutants down to 4 microns in size. A further study proved that creating changes in the pH of a swimming pool may be due to environmental factors as well as the quality of the fill water (Dyer & White, 1999). The use of zeolites results in lower chlorine consumption and a better swimming environment in pools. The zeolites also reducing and preventing their formation due to the adsorbing of ammonia and its compounds (Bergero et al., 1994; Dyer & White, 1999) as cited by Kwakye-Awuah (2008). Hillie & Hlophe, (2007) stated further that zeolite is used in the purification of irrigation water in traditional water treatment.

Fertilizers and Feed Additive

The use of zeolite as a fertilizer is believed to increase the plant's nutrient intake, the increased storage capacity of the soil, and reduced effects of the soil acidity (Ravali et al., 2020). Due to the cation exchange capacity of zeolite, nitrogen, and potassium nutrient of plants are held by the zeolite negatively charged structure and are released on request. The increase in body weights and feed efficiencies of animals is due to the addition of zeolite to the normal diets of ruminants, poultry, and swine. It is observed that reduction in illness in the digestive system of animals is a result of the addition of zeolite application on the daily diet of the animals. The addition of Clinoptilolite to the feed preparation of animals has a positive effect on the growing up of the animals. Bartko et al., (1983) proved further that the faeces of animals were found to be better formed, less odoriferous, and firmer.

Odour Control

Due to the excellent sorption properties of zeolites, they are used in a wide range of consumer products to remove both water, smell, and ammonia emissions. Application of zeolite is useful in our home in fridge deodorizers, dry sports shoes, and cupboards, reduces moisture in wardrobes, and boat deodorizers, elimination of pet odours, and commonly used to adsorb cigarette odours. Zeolite also acts as a very useful carpet cleaner material. Zeolites can be re-used over and over again and are totally harmless to humans and animals.

Aquaculture

Zeolite has been used as an ion- exchange removal of ammonia from fish hatchery water supplies. Bergero et al., (1994) found that for agricultural water effectively at both 2.5mg/l and 10 mg/l concentration for over 3 weeks, zeolite could be used to remove ammonia from recirculation systems. Bernal and Lopez-Real, (1993) also proved that the ammonia and ammonium adsorption properties of zeolite make that aerial ammonia adsorbed at a rate of 6- 14g/ kg of zeolite.

Advanced Solid-State Materials

In the 1980s and 1990s, a sensational new scientific direction arose for discovering molecular sieves of the zeolite as advanced solid-state materials. On the other hand, Ozin et al., (1989) in his 1989 review, predicted that the molecular sieves of zeolites represent a 'new frontier' of solid state chemistry with great opportunities for development and advanced research. Wang et al., (2001a) reported further that zeolites can be used as low dielectric materials for microprocessors.

Fillers

It is observed that in the papers and plastics industries, zeolites are used as fillers on a large scale (Kulprathipanja, 2010). Also, in the United

State of America, zeolite is routinely added to small air filters to adsorb gases and reduce allergy problems

Types of Soil Amendments on Sandy Soil

The process of increasing the ability of a soil to remove pollutants and refining the sorption properties of sandy, clay, and silt soils is termed amendment.

Zeolite Amendments

Authors have stated that the high nutrient retention and water adsorption of zeolite are because zeolites comprise of cage-like polyhedral units with high internal pores and high cation-exchange capability in crystal lattices of the zeolite (Zelazny et al., 1977). Also, since zeolite has a large specific area, low density, water receptivity, and high ion- exchange capacity it has been used extensively as amendments for poor clay and sandy soils. It's further established that to enhance the retention and absorption of water, micronutrients, and plant nutrients, zeolite is used because it is a beneficial soil amendment (Burriesci et al., 1984).

Furthermore, zeolite improves the cation- exchange capacity of sandy soils, remove ammonium from solution, and also increases the soil's ability to retain water longer after irrigation as reported by Philips, (1998). Further research proved that both natural and synthetics zeolite can restore the soil's physical properties, improving nutrient levels, by increasing the water retention, the clay-silt fractions, and reducing soil bulk density (Ming & Allen, 2001). Other findings show that zeolite lower the bulk density as low as 0.8

gcm^{-3}, and increase the silt and clay fractions, increase the water retention capacity, and thus helping the crops to grow due to the porous nature of the zeolite (Ming & Allen, 2001).

Kavoosi & Rahimi, (2000) reported that due to the particle sizes and the application rate of the zeolite, adding zeolite to fertilizers as solvent improved the soil water retention and physical conditions of the soil. Huang & Petrovic, (1995) concluded that when the particle size of the zeolite decreases and the amendments rate increased, the water available to the plants increased in sandy soil.

Further study by Githinji et al., (2011) proved that the addition of zeolite to sandy soil at a 15 percent (v/v) rate decreased the soil bulk density from 1.67 gcm^{-3} to 1.56 gcm^{-3} and enhanced the water content twice. In addition to that, zeolite increased shoot-growth rate of sand-based putting green turf (Huang & Petrovic, 1996). Lopez et al., (2008) proved further that reducing the dependence on irrigation in the drought area, zeolite is used to remediate the problem to the soil. Zeolite amendments can increase the soil pH, promote nutrient holding capacity and cation exchange capacity (Ming & Allen, 2001; Huang & Petkovic, 1995; Liu & LaI, 2012). Filcheva & Tsadila, 2000; Liu & LaI, 2012) noted that increase in the exchangeable potassium, soil pH, and improving salt and water retention of the soil is due to addition of zeolite.

Other researchers also pointed out that increases in the retention of plant nutrient, micronutrients supplements, and promoting plant growth is as a result of zeolite amendments (Ayan et al., 2005). Authors like Yasuda, (1998) argued that the amendment using zeolite is an actual way to advance soil conditions in a parched and semiarid background. Further research also proved that in greenhouses in Russia and field crops in Japan, zeolites have been used as a soil amendment on vegetables and trees to develop the drainage and aeration system of the soils. Al-Busaidi, et al., (2008); Kassam et al., 2007) experimented and found that zeolite could enhance nutrient balance, increase demand for food, and fibers and efficiently amend salinity stress in the sandy soil.

Researchers like Filchev & Tsadilas, (2002) noticed that synthetic zeolites also improve soil properties by improving solute and water retention capacity and increases the pH of the soil. Agriculturalists specifically in the third world countries use fertilizers and water intensively and the continuous use of groundwater depletes the groundwater table day by day and soil water retention capacity also depletes (Zalidis et al., 2002. Bernardi et al., 2010; Colombani et al., 2015) also stated that adding zeolite to soil increases the retention capacity of water available to plant.

Further research proved that the increase in the water retention and decrease in the filtration is due to the variations in the physical properties of soil carried out by the application of zeolites in the large-scale test (Colombani et al., 2015). Besides, zeolites improve nutrient retention because it remains in the soil and does not break down over time. Al-Busaidi et al., (2008) established that amending soil with zeolites improves the nutrient balance in the sandy soil and also has a great effect on the salinity of soil (Al-Busaidi et al., 2008). A further study proved that zeolite improved the output of crops by increasing the soil porosity and decreasing bulk density (Xiliang et al., 1991).

Effects of Zeolite on Soil Water Content

Shinde et al., (2010) stated that zeolite does not only increases the effect of mineral fertilizers on the soils but also increases the water retention of the soils. Other authors like Al-Busaidi et al., 2008; Bittelli et al., 2015) stated that an increase in both water content compared with unamended sand is as a result of applicate rates of zeolite applied to sandy soil which later results in an increased in water content compared with unamended sand. According to Ramesh et al., (2011), decreasing in soil bulk density and increasing in porosity by zeolite lead to water retention increase. Further prove shows that the application of zeolite to the light-textured soils increased water retention of the soil (Bernardi et al., 2013).

Moreover, a study conducted proved that zeolite assists water retention in the soil due to its very porous properties and the capillary pressure it exerts that makes it acts as a natural wetting agent, thereby assisting water distribution through the soils (Ghazavi, 2015; Kedziora et al., 2014). Zeolite increases the water-retention capacity of the soil is also reported by (Notariodel Pino, 1994). Some authors stated that the addition of zeolites increases water retention and also decreases soil bulk density (Colombani et al., 2015).

Effects of Zeolite on Hydraulic Conductivity

Gholizadeh-Sarabi & Sepaskhah, (2013) observed that although hydraulic conductivity is the capacity of soils to carry and retain water, it's also used for modeling water and solute flows in soils. More researchers have proved that an increase in crop production and efficient use of water in the agriculture system is a result of improvement in the hydraulic properties of soil Gholizadeh-Sarabi & Sepaskhah, 2013). Further research proved that zeolite improves soil hydraulic conductivity, and also degrades pastures (Behzadfar et al., 2017).

Enhanced Fertilizer

Many researchers like Burger & Zipper, (2011) conducted a study and concluded that mine soils lack nutrients like nitrogen and phosphorus, and therefore applying fertilizers would help the vegetation. They further noted that applying conventional fertilizers containing nitrogen often promotes the growth of poisonous weeds, and hence overwhelming the growth of crops and tree seedlings as reported by Burger & Zipper, (2011). Ming & Allen, (2001) further demonstrated that zeolites have been investigated and found to release more nutrients to support plant nutrients to increase crop yield.

Other researchers such as Ming & Allen, (2001) conducted a study and proved that using Clinoptilolite which is a natural zeolite is highly selective for ions such as potassium and ammonium and relative to sodium or divalent cations (calcium and magnesium). Perrin et al., (1998) also observed further that soil fertilized with $(NH4)_2SO_4$ leached when nitrogen was added. Moreover, some authors like Lewis et al., (1984) not only observed that clinoptilolite zeolite loaded with ammonium was an efficient slow-release nitrogen fertilizer. Barbarick & Pirela, (1994) proposed further that zeolites could be used proficiently in the agriculture system in removing ammonia toxicity in plants and increase crop yield in agriculture. Some authors have similar results when zeolite containing potassium has also been researched as a gentle-discharge potassium fertilizer (Carlino et al., 1998).

Jancinthe & LaI, (2007) further conducted a study and found that rehabilitation and reclaimed of mine soils and areas using apatites which is a natural zeolite is a significant nutrient crucial for reforestation and vegetation establishment. It is also observed by some authors that the addition of zeolites to fertilizer also helps to retain plant nutrients such as calcium, magnesium, and microelements in the soil and therefore, improving the soil quality as reported by (Hershey, 1980).

Removal of Heavy Metals and Radioactive Nuclides from Soils

Ming & Allen, (2001) stated that preventing the uptake of the radionuclide by plants in the soil is based on applying the zeolites on the soil. Vassilis & Inglezakis, (2005) also stated that in the purification of wastewaters, zeolites were used in removing the heavy metals and also used in ion-exchange applications in soil solution. Some authors have similar results indicate how zeolite removed aluminum, arsenic metals, chromium, cobalt, titanium, lead, zinc, and other metals (Pirsaheb et al., 2011).

Edward et al., (1999) conducted a study and proved that in addition to the adsorption properties of zeolite, zeolites increase soil pH and also help in the heavy metal removal. Other findings have been reported by some authors on how to remove heavy metals in the soil using a dilute acetate solution as reported Moirou et al., (2001). Chlopecka & Adriano, (1996) did further study and found that adding 1.5 percent of natural zeolite to a zinc-spike soil, enhanced plant growth, and increase crop yield. Knox et al., (2003) also reported that amending using less than six percent of zeolites to a metal-laden soil improved the growth of maize crops and also decreased the cadmium, lead, zinc accumulations in the plant tissues. Mahmoodabadi, (2010) did similar work and indicated that the application of natural zeolites increased the number of shoot and dry weight of the root nodule to the soybean (*Glycine max*) plants. Moreover, to these authors (Stead, 2002), zeolite additions reduce the vegetables and growth of some plants.

Activated Charcoal

Activated charcoal is produced from one of a variety of materials containing carbon. Further studies have shown that activated charcoal can be produced from a materials that is cost effective, with low mineral substances and better carbon concentration raw materials (Bae et al., 2014; Ioannidou & Zabaniotou, 2007). Other researchers have stated that there are a lot of fresh ingredients that activated charcoal can be made from in our environments.

All over the world, the use of agro-industrial byproducts, which are cheaper, plenty, as well as having low ash contents are used to produce activated charcoal. Other findings also proved that the use of biomass residues from the agricultural products in production of activated charcoal such as sawdust (Kini et al., 2015), rice husk (Alvarez et al., 2014; Rahman et al., 2013) as coal (Bae et al., 2014), tropical wood (Acharya et al., 2009; Janoš & Coskun, 2009), oil palm shells (Noor & Nawi, 2008), corn cobs (Jonglertjunya, 2008), coconut shells (Boopathy & Karthikeyan, 2013; Shaheed, 2015), walnut shells (Yang & Qiu, 2010), and plantain peels (Ioannidou & Zabaniotou, 2007).

Effects of Activated Charcoal on Soil

According to these authors (Laird et al., 2010; Zhang et al., 2012), a decrease in soil bulk density and a positive increase in porosity values of highly compacted soils is due to the addition of activated charcoal. Further investigation shows that the water retention capacity could be improved by adding activated charcoal in the sandy soils (Dugan et al., 2010; Karhu et al., 2011). Other findings proved that an increase in crop yield with activated charcoal has been proved for soil containing acid and extremely weathered humid field soils (Lehmann et al., 2003; Rondon et al., 2007; Steiner, 2007). Sohi et al., (2010) further proved that activated charcoal improves retention of water, improves soil nutrient retention, and increases crop growth because the activated charcoal can act as a soil conditioner.

The addition of activated charcoal to soils can change soil chemical, microbial and physical properties (Anderson et al., 2011; Horel et al., 2019); Jien & Wang, 2013; Liang et al., 2006; Novak et al., 2009; Sun & Lu, 2014). Other authors indicated that using activated charcoal as an amendment improved the soil water availability and nutrient retention (Belyaeva & Haynes, 2012; Sorrenti et al., 2016; Gao e t al., 2016; Yao et al., 2012). Further studies proved that the addition of activated charcoal improved the soil physical and hydraulic properties as reported by Uzoma et al., 2011; Verheijen et al., 2010).

Laird, (2010) & Radin et al., (2018) argued that activated charcoal is one of the best soil amendments tested and recommended to boost carbon sequestration in soils and enhanced soil physical, biological, and chemical properties. Piccolo et al., (1997) stated that activated charcoal amendments enriched water retention and aggregate stability of a soil, which enhanced crop water retention and reduced erosion. Glaser et al., (2002) proved further that there are increase in soil water retention when activated charcoal is applied in soils with large amounts of macropores particle.

Other researchers stated that because activated charcoal is very resilient to microbial decay, and improved carbon sequestration for a lengthy period when applied to the soil, makes it one of the soil amendment (Downie et al., 2011; Lehmann et al., 2006; Schmidt & Novak, 2000). Liang et al., (2006) noticed that activated charcoal improves the water retention and reduce irrigation requirements of dry or sandy soils. Atkinson et al., (2010) also stated that activated charcoal absorbs both excess humidity and some toxic elements which may be present in the soil which makes it acts as an antioxidant.

Ricigliano, (2011) proved further that due to the porous and high surface area of activated charcoal, it stabilizes the organic matter in the soil, increases cation exchange capacity, and water retention. Similar findings have proved that the addition of activated carbon to the soil reduces the soil bulk density and positively increases the porosity values of highly compacted soils (Zhang et al., 2012). Further studies have reported that activated charcoal application in sandy soil decreased hydraulic conductivity and increased water retention (Arthur & Ameed, 2017; Barnes et al., 2014; Sorrenti & Toselli, (2016)).

A further study proved that activated charcoal incorporation also changed the pore size distribution, soil structure, and density, with implications for soil water retention capacity, soil aeration, soil workability, and plant growth thereby improvement of soil fertility and crop yields

(Brandstaka et al., 2010; Downie et al., 2009; Schulz et al., 2013). Other studies show that the addition of activated charcoal may improve the available nutrients and also increase the soil cation exchange ability (Lehmann et al., 2003; Liang et al., 2006).

Liu et al., (2016) & Barnes et al., (2014) argued that activated charcoal application to sandy soil reduces interpore size and improves the tortuosity of the porous soil, which resulted in decreased in saturated hydraulic conductivity. It is also observed that due to the porous nature of activated charcoal, it is extremely active at increased water retention and absorbing water content (Blanco-Canqui, 2017). Activated charcoal amendments also have been reported to increase water retention, soil porosity, soil hydraulic conductivity and also decreases the bulk density of the soil (Abel et al., 2013; Jeffrey et al., 2011; Karhu et al., 2011). Many authors have also stated that activated charcoal added to the soils kept more nutrients (Kookana et al., 2011; Joseph et al., 2007; McHenry, 2011).

Furthermore, as a soil amendment, activated charcoal can greatly improve hydraulic conductivity, water retention, and chemical properties (e.g., pH, salinity, CEC), and other processes (Lehmann & Joseph, 2009; Liang et al., 2006; Major et al., 2010). Many studies have been reported that due to activated charcoal and rice husk ash high porosity and surface area, its application to soils affects soil structure, pore size distribution, and soil bulk density (Major et al., 2010; Downie et al., 2009). Similarly, Laird et al., (2010) proved that the hydraulic conductivity at saturation was not affected when activated charcoal amendments were applied to the typical Midwestern agricultural soil.

Rice Husk Ash

Rice husk ash is the by-product of rice husk which is considered to be an agricultural waste from the burning of rice husk that can have positive impacts on the soil physical, water retention, and hydraulic properties (Mohammed, 2016; Mohamed et al., 2015; Zhao et al., 2016). Further studies have shown that the ash from the rice husk can be produced from a materials that is cost effective, with low mineral substances and high amount of silica concentration (Adam et al., 2006; Rozainee et al., 2008 & Pode, 2016). Other researchers have stated that there are a lot of raw materials that rice husk ash can be made from in our environments.

All over the world, the use of agro-industrial byproducts, which are cheaper, abundant, as well as having high ash contents are used to produce rice husk ash (Mohamed et al., 2015). Other findings also proved that the use of biomass residues from the agricultural products in production of rice husk ash such as wheat straw (Chen et al., 2018), peanut (Gaskin et al., 2007; Gaskin et al., 2010) as wood (Major et al. (2012; Ajayi & Horn, 2016), rice husk (Alvarez et al., 2014; Rahman et al., 2013), swithgrass (Brockhoff et al., 2010), corn cobs (Jonglertjunya, 2008), walnut shells (Yang & Qiu, 2010).

Effects of Rice Husk Ash on Sandy Soil

Amending sandy soils using rice husk ash improved the water retention capacity, biological, and other soil properties as reported by Baronti et al., 2014: Laird et al., 2010). Other researchers like Liang et al., (2006) also stated that the rice husk ash improves water retention and reduces irrigation requirements of dry or sandy soils. Further studies indicate that rice husk ash has the prospective to increase plant yields and improve soil quality (Sohi et al., 2010). Other authors have established further that rice husk ash affects the properties of soils by improving the soil bulk density, water retention, and porosity, which lead to improvement in crop production (Glaser et al., 2002; Baronti et al., 2010; Verheijen et al., 2010; Lehmann et al., 2003b).

Several authors have proved that as a soil amendment, the rice husk ash improves soil physical, chemical, fertilizer use efficiency, and increases plant yields as reported by (Deenik et al., 2011 ; Herath et al., 2013; Masulili et al., 2010; Lu et al., 2014: Van Zwieten et al., 2010). Glaser et al., (2002) suggested further that the rice husk ash applies to soils might not only alter its physical properties but also affect chemical properties (water retention). Chan et al., (2007) proved further that the amending soil with rice husk ash enhances soil aggregation, and increases the water retention capacity.

Other authors have also proved that the addition of rice husk ash increased soil pH, potassium, calcium, magnesium, decrease in bulk density and cation exchange capacity (Chen et al., 2011; Hardie et al., 2014; Jien & Wang, 2013; Liang & Lehmann, 2006; Van Zwieten et al., 2010; Sun et al., 2013; Zhang et al., 2010; Herath et al., 2013). It is observed that amending soil with rice husk ash had a positive effect on initially infertile soil (Brandstaka et al., 2010; Glaser et al., 2002). Other findings have proved that due to the porous nature of rice husk ash, there is an increase in water retention capacity (Gaskin et al., 2007; Glaser et al., 2002; Pietikainen et al., 2000; Ogawa et al., 2006).

Other researchers have proved that rice husk ash biochar improved soil water retention, bulk density, hydraulic conductivity, soil pH, salinity, cation exchange capacity, and other practices (Lehmann & Joseph, 2009; Liang et al., 2006; Major et al., 2010). Further research shows that there is a reduction in inorganic fertilizer use by farmers when activated charcoal biochar application is applied (Duku et al., 2011).

Many studies reported that because of rice husk ash high porosity and high surface area, adding it to soil porosity and soil structure decreases soil bulk density, changes the pore size distribution and the surface area Major et al., 2010; Downie et al., 2009). Other studies have also proved that rice husk ash prepared using plant, improves the saturated hydraulic conductivity in a loam, clay, sandy soil (Major et al., (2010). Further research proved that using rice husk ash amendment on soil did not increase or decreased the saturated hydraulic conductivity of agricultural soil in the Midwestern (Laird et al., 2010).

Several studies have also shown that rice husk ash application significantly improves soil aggregation, hydraulic conductivity, and water retention curve (Abel et al., 2013; Asai et al., 2009; Brockhoff et al., 2010; Busscher et al., 2010; Herath et al. 2013; Jien & Wang, 2013; Masulili et al., 2010; Kammann et al., 2011; Major et al. 2010; Liu et al., 2014). Gaskin et al., (2007) also stated that amending soil using rice husk ash biochar will not change the water retention capacity of the bulk soil alone but also the soil matrix.

Furthermore, it is stated that adding rice husk ash to different soils can change soil chemical, microbial and other properties (Anderson et al., 2011; Horel et al., 2018; Horel et al., 2019; Jien & Wang, 2013; Liang et al., 2006; Liang et al., 2006; Novak et al., 2009; Sun & Lu, 2014). Other authors have proved that the addition of rice husk ash decreases the saturated hydraulic conductivity and increases water retention of sandy soil (Lim et al., 2016; Sorrenti &Toselli, 2016; Arthur & Ameed, 2017).

It is proven that amending sandy soil with rice husk ash decreases soil bulk density and increases water retention (Jeffrey et al., 2011; Karhu et al., 2011; Laird et al., 2010; Atkinson et al., 2010)). Similar findings by other authors proved that amended soils retained more nutrients in soils when rice husk ash is applied (Major et al., 2010; McHenry, 2011; Verheijen et al., 2009; Kookana et al., 2011). Other studies have shown that rice husk ash addition may improve the available nutrients and increase cation exchangeability in the soil (Lehmann et al., 2003; Liang et al., 2006).

Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR spectroscopy is a technique used to measure quantitative and qualitative features of active molecules in inorganic and organic phases of liquid, gas, and solids by the use of an interferometer.

Advantages of Fourier Transform Infrared Spectroscopy over other methods include its accuracy, less expensive, reliability, and no external calibration (Thermo Nicolet Co., 2001). Thus infrared spectroscopy analysis employs the group vibration of atoms of a molecule concept to determine how various functional groups in the molecule are present or absent. These spectra originate primarily from vibration stretching and bending modes within the molecules. Thus, the infrared technique is used as a fingerprint in the identification of molecular structure. The infrared spectra in this study were obtained in the range of wavenumbers (4000-400 cm^{-1}). This is to ensure that the range covered includes most of the useful vibrations active in the infrared.

Absorption Infrared Spectroscopy Techniques

In absorption spectroscopy, a photon from the incident radiation source excites a molecule to undergo a transition in energy states. The energy of this absorbed photon is indicative of the frequency of the radiation. Since the frequency is directly proportional to the energy of the photon, it is very common that the units of infrared radiation to be reported and displayed using wavenumber.

Transmission Infrared Spectroscopy Techniques

Stuart, (2004) stated that this method is established on basis of the absorption of IR radiation at particular wavelengths as it passes into the material. Some other authors have stated that the transmission technique is likely to examine the samples in solid, liquid, or gaseous state when used (Chalmers et al., 2012).

Attenuated Total Reflectance Spectroscopy Techniques

In the attenuated total reflectance, a total internal reflection phenomenon is used as shown in Figure 4. During the process, a radiation beam enters a crystal that undergoes total internal reflection. At that point, the angle of incidence at the interface between the crystal and the soil sample is greater than the critical angle(θ_c) where the crystal is a function of the refractive indices of the two surfaces. This critical angle depends on the refractive indices of the sample and attenuated total reflectance crystal according to:

$$\theta_c = sin^{-1}({}^{n_2}/_{n_1}) \qquad (34)$$

Where n_1 and n_2 are the crystal and soil refractive indices, respectively. Beyond the reflecting surface and the soil, the radiation beam penetrates a fraction of the wavelength, is in direct contact with the reflecting surface, the beam loses energy at the wavelength where the material absorbs. The resulting attenuated radiation is measured and graphed by the spectrometer as a function of the wavelength and gives rise to the soil sample's absorption spectral characteristics. The crystal used in attenuated total reflectance cells is made of materials with a very high refractive index and low water solubility (zinc selenide, germanium, and thallium- iodide).

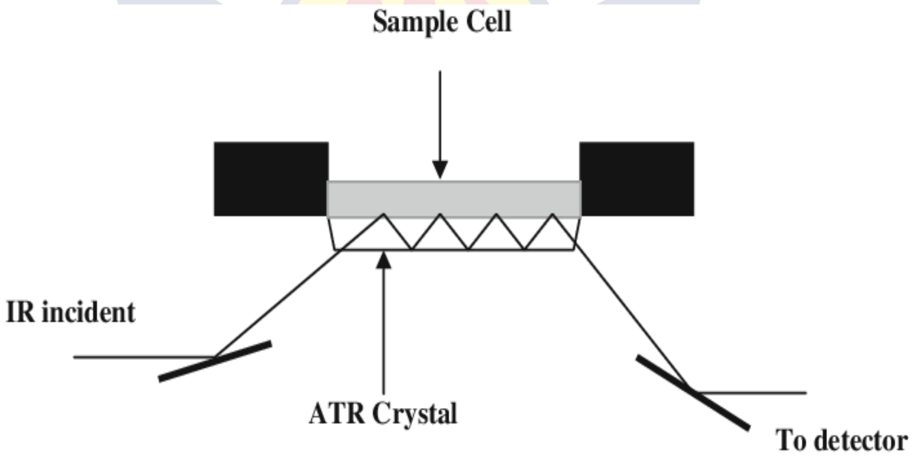

Figure 4: The diagram of a typical attenuated total reflectance in sample cell

The electromagnetic field reaches beyond the crystal surface for a short distance, known as the evanescent field, due to the quantum mechanical properties of light. If a sample is directly applied to the surface of the attenuated complete reflection crystal, this sample absorbs some of the infrared radiation (i.e., the evanescent wave) so that the sample absorbance spectrum can be obtained.

Chapter Summary

This chapter discussed in detailed the COMSOL Multiphysics software. It also discussed in detail the effect of zeolite, activated charcoal, and rice husk ash on soil physical, water retention, and hydraulic properties. The chapter also discussed the Fourier transform infrared spectroscopy. Theories underlying this work were also presented.

CHAPTER THREE

MATERIALS AND METHODS

Introduction

This thesis involved two parts: the first part dealt with the use of the COMSOL Multiphysics software (Version 5.0, COMSOL, Inc., Burlington, Ma.) in simulation of the effects of soil amendments on sandy soil while the second part involved the experimental work in the laboratory with and without zeolite, activated charcoal, and rice husk ash amendments on the sandy soil. This chapter provides details about the materials and experimental methods used in this research. Richards's equation in the COMSOL Multiphysics software is used to a large extent in this research to have a numerical solution solved to which we can compare our experimental values. In COMSOL Multiphysics, the processes involving specifying a geometry, defining all of the necessary materials, and physics, meshing and solving the model, and visualizing and post-processing the results will be shown. The model descriptions, relevant equations, and statistical tools used have also been presented in this chapter.

Description of the Study Area

The study area lies between the Keta lagoon to the north and the Gulf of Guinea to the south in the area within latitudes 5° 471 and 5° 551 N and longitudes 0° 531 and 1° 01 E), which is located in Keta, Vui, Tegbi, Woe, and Anloga, all in the Keta District of Ghana. The study areas are represented by the white square box. A map of the study area is shown in Figure 5.

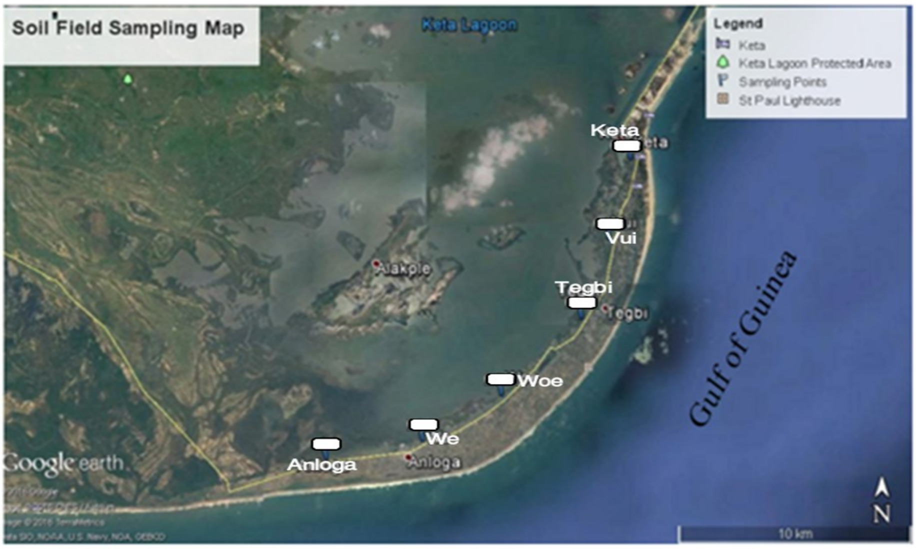

Figure 5: Location map of the study area, in Keta District of Ghana

The Climate of the Study Area

The climate of the study area lies within Ghana's dry Equatorial climate zone, which covers the country's entire coastal belt as well. With average daily temperatures ranging from 27-28 ° C and a mean monthly temperature of about 30 ° C, this area is the driest in the nation (Dickson & Benneh, 1995). A seasonal rainfall pattern with two well defined seasons, the rainy and dry seasons, has been produced by the North-East Trades and South-West Monsoons along the coastal lands of Ghana. Double maxima are exhibited in the rainy season, the main occurring between April-June and the minor between September-October. June was the wettest month in the study region. Normally, August and March are the coldest and the warmest months. The region's average annual precipitation is below 900 mm (Dickson and Benneh, 1995). In this area (Tamakloe, 1966), the normal tropical rains of squally nature accompanied by thunder are almost absent, rendering it distinct from many tropical regions in Ghana.

During the night and early morning, the relative humidity in the area is usually over 90 percent. With a seasonal change of 15 percent, the humidity falls to as low as 65 percent during the day (Christensen & Awadzi, 2000), making it distinct from many tropical regions. During the Harmattan, periods of low humidity occur. The study area is located within Ghana's coastal savanna region. Only the development of tropical grassland supports climatic conditions. It is estimated that the annual possible evapotranspiration is about 1500 mm, spread uniformly throughout the year, and that the monthly evapotranspiration ranges from 100 mm to 150 mm (Christensen & Awadzi, 2000; Dickson & Benneh, (1995).

In the study area, there are two main soils, namely the sand spit (Keta soil series) and the marshland (Ada soil series) (Lamptey et al., 2013). The sand spit is composed of white medium-sea sands forming small elongated beach ridges with small depressions between them and the low-laying marshes are present towards the lagoon. Naturally, the soil on the sand spit is infertile (Awadzi et al., 2008). The Ada sequence is clayey and mildly acidic (Asiamah, 1995). Salty and unsuitable for farming are the soils on the marshes. They are Solonet, according to the WRB method (ISSS / ISRIC / FAO, 1998), and Natraqualf, according to Soil Taxonomy (Soil Survey Workers, 1998).

Farming

Farming in the area is carried out only on the Keta sand spit where a thin shallow groundwater is established. For the farming system, the existence of this ground water is necessary because irrigation plays an important part.

Three main seasons of farming are observed. The first season is the rainy season, followed by the partial rainfall, while the dry season that needs to be irrigated is the last but not the least (Ocloo, 1996). To suit the physical climate, crops grown in the region have been selected and all the significant crops have a maturity period of 2-3 months. Shallot is the first crop to be planted, since the main crop in which the other crops revolve is shallot. Shallots, tomatoes, okro, and pepper are the main crops grown in the region on sandy soils. Maize or cassava are grown for domestic use in some cases (Awadzi et al., 2008).

Irrigation

Irrigation forms a key component of the agricultural system in the region under review. This irrigation-free tropical study area is unlikely because the annual precipitation is less than 900 mm, so it is difficult to grow crops on sandy soils during the year. During the January-February-March dry season, irrigation is carried out throughout the season. This time is exceptionally dry and the average precipitation barely reaches 25 mm in January and February (Awadzi et al., 2008). Water is extracted from tube wells using buckets to irrigate the crops. Certain methods of irrigation are also used on farmland.

Fertilization

Due to the infertile nature of the soil in the study area, fertilization forms a very important aspect of the farming system (Awadzi et al., 2008). Cow dung, poultry droppings, and chemical fertilizers are used in the area to improve the fertility of the soil, the soil structure, and water retention. Due to the high cost of NPK fertilizer and generation of heat by cow dung, a low cost and environmentally friendly material are needed to improve the structure, fertility, and water retention capacity of the soils.

Simulation Method

COMSOL Multiphysics Model

In the study, the Earth Science Module of the COMSOL Multiphysics software was used to simulate the effects of soil amendments on water retention, and hydraulic properties of the sandy soil.

Simulation Procedure

The Earth Science Module of COMSOL Multiphysics 5.0 which solves the Richards equation, a partial differential equation (PDE) numerically was employed for the simulation. During the process, a hypothetical homogeneous soil column with 0.15 m by 0.19 m dimensions in 2D geometry was drawn. A significant assumption in this investigation is that the air phase plays a trivial role in the water flow (Šimůnek et al., 2012) and that the Richards equation is only applicable to water since the soil is at atmospheric pressure. The Partial differential equations describing Richard equation as the governing equation for the model is given as:

$$(C + S_e\, S)\frac{\partial H_p}{\partial t} + \nabla \cdot \left(-K\nabla\left(H_p + D\right)\right) = 0 \qquad (35)$$

in which H_p represent the pressure head (m), C indicates specific water capacity ($m^{-1)}$, Se is the effective saturation, S is a storage coefficient (m^{-1}), t is the time (s), K is the hydraulic conductivity (m/s) and D is the direction (z) (m), and θ is water content (constitutive connection). In equation (35), the first term on the left side is associated with storage coefficients due to compression and expansion of the pore spaces and the water when the soil is fully wet, while on the right side of equation (35), is the second term which is associated with diffusion transport due to capillarity.

The specific water capacity, C, relate variations in water content to pressure head as:

$$C = \frac{\partial \theta}{\partial H_p} \tag{36}$$

In the Richards governing equation, C defines storage changes produced by varying water content because:

$$\frac{C\partial\theta}{\partial_t} = \frac{\partial\theta}{\partial t} \tag{37}$$

Because C, goes to zero at saturation, time change in storage relates to compression of the water under saturated conditions.

The storage coefficient (S) is calculated using:

$$S = \frac{\theta_s - \theta_r}{1[m]\cdot\rho g} \tag{38}$$

in which θ_s and θ_r represent the water content at saturation and residual respectively and ρ is the density of water.

The water retention curve $\theta(H_p)$ and the hydraulic properties $K(\theta)$ for the van Genuchten relation were calculated using equation (39) and (40). In this software, the water retention curve is described with the equation of van Genuchten- Mualem (1991). The COMSOL Multiphysics was used to fit van Genuchten water retention model relation with Mualem – based restriction (m

=1-1/n). The equations of van Genuchten - Mualem for the soil water retention curve and soil hydraulic properties are stated in equation 39, and 40:

$$\theta(\mathrm{H_p}) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{\left[1+\left|\alpha \mathrm{H}_p\right|^{\mathrm{n}}\right]^{\mathrm{m}}} & \mathrm{H}_p < 0 \\ \theta_s & \mathrm{H}_p \geq 0 \end{cases} \tag{39}$$

$$\mathrm{K}(S_e) = K_s S_e{}^{l}\left[1-\left(1-S_e{}^{1/\mathrm{m}}\right)^{\mathrm{m}}\right]^2 \tag{40}$$

Where $\mathbf{S_e}$ is effective saturation as shown in equation (41) and m is defined as m = 1-1/n where n > 1

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \quad = \quad \theta_r + \frac{\theta_s - \theta_r}{\left[1+\left|\alpha \mathrm{H_p}\right|^{\mathrm{n}}\right]^{\mathrm{m}}} \tag{41}$$

where S_e is effective saturation, θ is water content, θs, is the saturated water content, θ_r, is the residual water content, and m is represented as m = 1-1/n, (provided n > 1). Additional parameters are α, the inverse of air entry value, n the pore size distribution index, l is pore-connectivity assumed to be 0.5 for sandy soil (Mualem, 1976), Ks is the saturated hydraulic conductivity, and K, is hydraulic conductivity.

During the simulation process, parameters like θr, and θs, was read from the water retention curve experimental data and α and n parameters were estimated by the use of pedotransfer function using measured data of sand, silt, and clay contents shown in (Table 4). In the study, the soil is considered saturated when the pressure head is zero ($\mathrm{H_p} = 0$) and unsaturated when the pressure head is less than zero ($\mathrm{H_p} < 0$). Both conditions were used in the study.

Model Type, Geometry, and Boundary Conditions

The Earth Science Model of COMSOL Multiphysics was used. A two - dimensional (2D) geometry for a better illustration of the results was chosen**.** The geometry was defined by a rectangular shape soil column at 0.15 m depth and a width of 0.19 m (figure 6). The 2D model geometry used has initial and boundary conditions during the simulation processes (figure 6). For the simulation, water flows are assigned an influx boundary at the top surface of the soil. At the left wall, boundary was assigned no flux and the right wall boundary was assigned also no flux condition**.** Finally, at the bottom (base) wall boundary was assigned no-flow condition. Simulations were done for 300 minutes with a time step of 1 second (s). The following expressions summarize the boundary conditions used in this study:

$$n \cdot \left[-K\nabla\left(H_p + D\right)\right] = 0, \text{ No flow at the boundaries}$$

$$H_p = H_p 0, \qquad \text{Pressure head at the surface}$$

$$n \cdot \rho\left[-K\nabla\left(H_p + D\right)\right] = N_0, \qquad \text{No mass flux at the bottom}$$

where n represents the unit vector normal to the boundary, ρ represents the density of the fluid, K represents the hydraulic conductivity, D represents the elevation, and H_p represents the pressure head.

Simulations were done for the water retention and hydraulic properties of sand–zeolite, activated charcoal, and rice husk ash addition for 300 minutes with a time step of 1 seconds (s).

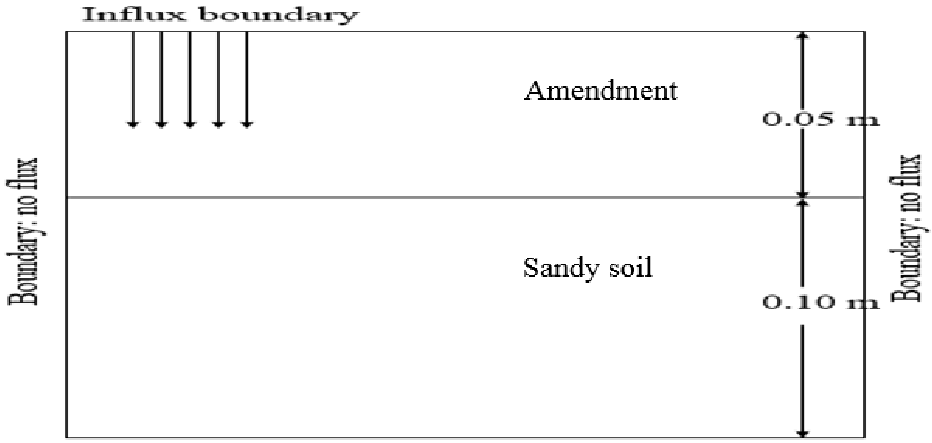

Figure 6: 2D geometry of soil column model

Experimental Design for Sample Fetching

The sample fetching was carried out in the agricultural farm in Keta District of Ghana. The soil was collected from a land parcel (5° 471, 5° 551 N, and 0° 531 1° 01 E) in the town of Keta, found in the dry and semi-arid regions of Ghana. The field was located at an altitude of 9 m above sea level with arid and semi-arid typical climate. According to long term weather data, total rainfall was less than 900 mm and the mean annual temperature was 30 °C. The soil for the experiment sites belongs to the Keta series, classified according to FAO, (1990) as Solonet. Three samples were randomly collected from the location with a 10 cm diameter core at depths of 0- 40 cm. These samples were mixed, parcelled and transported to the laboratory to determine various physical, hydraulic and soil water retention parameters. The analysis of soil particle size distribution conducted at CSIR, Accra, Ghana are presented in Table 4.

Table 4: Particles Size Distribution of the Sandy Used

	Clay (%)	Silt (%)	Sand (%)	Texture(USDA)
Soil	0.57	0.94	98.49	Sandy

*CSIR- Council for Scientific and Industrial Research.

The Pot Experiments

The pot experiments were performed prior to and after the amendment to estimate the soil water retention curve of the sandy soil taken from an agricultural farm in Keta District.The experiment was laid - out in 2018-2019**.** The treatments were set up in a plastic container of height 15 cm and a diameter of 19 cm (Figure 7). All treatments were duplicated. The value of the two measurements was used for all the parameters under consideration. The experiments were carried out in control of natural conditions.

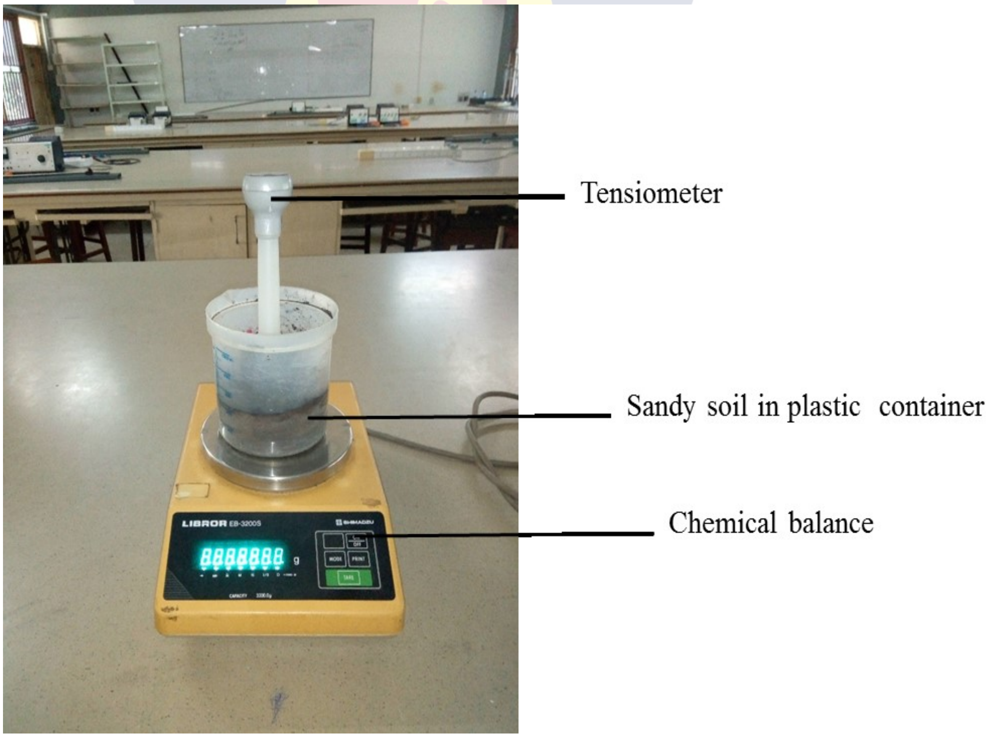

Figure 7: A photograph showing the pot experiments

Preparation and Characterization of the Soil Amendments

Activated charcoal and rice husk ash are some of the amendments used in the work. Preparation of rice husk ash (RHA) was carried out in the Department of Chemistry, University of Cape Coast. Five hundred grams of raw rice husk was washed and soaked in distilled water for two hours. Rice particles were removed by handpicking after absorbing water from the soaking process. The washed rice husk was sun-dried and combusted in a furnace at 550^0C with a residence time of 2 hours 30 minutes. The carbonized rice husk was grinded and sieved with a sieve size of 0.5 mm. The rice husk ash was used in the soil amendments process. In preparation of activated charcoal, coconut shell was also used. The activated charcoal was produced by pyrolysis coconut shell in the heater chamber at 500 °C, for 2 hours at the Chemistry Department, University of Cape Coast.

Other amendment used is the synthetic zeolite X. The synthetic zeolite X used was purchased from the Department of Physics, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, from a research center store. In order to describe the properties of the zeolite, some analyses, including the use of the AmScope 7X to 45X Stereo Simul-Focal Microscope fitted with eyepiece and trinocular port and FTIR, were used. Using a Perkin Elmer Spectrum 74v FTIR Spectrometer with a wavelength range of 4000-400 cm^{-1}, the zeolite spectrums were described. The morphology of the zeolite samples was studied using an AmScope 7X to 45X Stereo Simul-Focal Microscope.

Some analyses, including the use of microscopy and Fourier transform infrared spectroscopy, were used to characterize the properties of the activated charcoal and rice husk ash. By using microscopy, the morphology of zeolite X, activated charcoal, and rice husk ash samples were examined (figure 8).

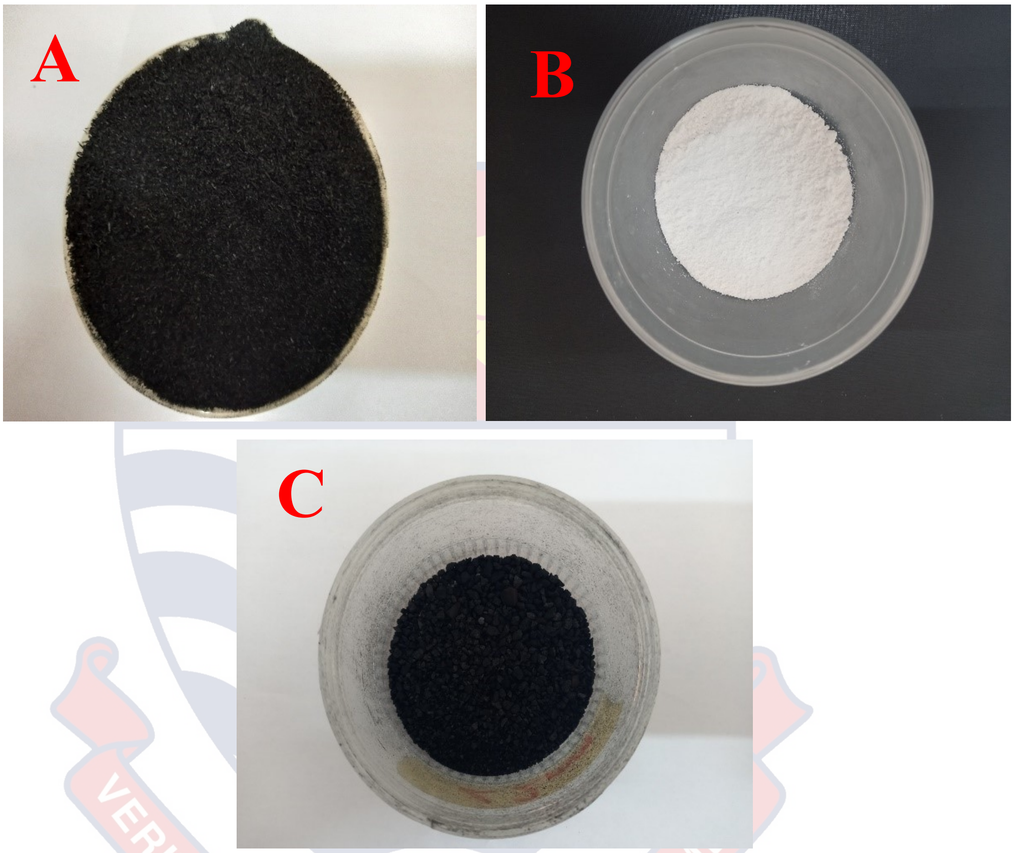

Figure 8: Photographic images of the amendments used. (A) Rice husk ash with particle size < 1 mm; (B) Zeolite X, and (C) Activated charcoal with particle size < 2 mm

Microscopy Studies

Morphological analysis of the rice husk ash, zeolite, and activated charcoal were carried out on an AmScope 7X to 45X Stereo Simul-Focal Microscope equipped with eyepieces and the trinocular port. Then a container containing the samples was positioned under the microscope and the analysis was conducted automatically. A Computer was used to displace the behaviours of the samples. These analyses were to find out the porous nature of rice husk ash, zeolite, and activated charcoal samples.

FTIR Studies

The soil amendments (rice husk ash, zeolite, and activated charcoal) spectrums were identified using the Perkin Elmer Spectrum Vertex 70v FTIR spectrometer with a range spectrum of the wavelength of 4000-400cm^{-1} and a scan rate of 24.

Laboratory Analysis of Soil Samples

A number of experiments were conducted in the laboratory to determine the physical properties, water retention curve, and hydraulic properties of sandy soil before and after the zeolite, activated charcoal, and rice husk ash soil- amendments.

Physical Properties of Soil

Various methods were used to assess the physical properties of the soil, such as bulk density, porosity, retention of water, and hydraulic conductivity.

Soil Bulk Density

In the determination of the soil bulk density, a cylinder method was employed Mathieu & Pieltain (1998). In this method, a quantity of the dried soil samples collected was poured into a known volume of the graduated cylinder. The soil in the graduated cylinder was poured into a beaker and its mass determined using a chemical balance, Model ADP 3100L. Bulk density was calculated as follows:

$$\rho_b = \frac{M_s}{V_t} \tag{42}$$

Where ρ_b the soil bulk density, V_s is the volume of dry soil and M_s is the mass of dry soil.

Porosity

The porosity of soil was also determined from the ratio of bulk density to soil particle density. The particle density of most soils is usually taken to be 2.65 g/cm^3. Therefore, soil porosity was calculated based on the soil bulk density as follows:

$$\rho_f = \left(1 - \frac{\rho_b}{\rho_s}\right) X100 \tag{43}$$

in which ρ_s is soil's particle density and ρ_b represents bulk density of the sandy soil.

Soil pH and Salinity

The soil pH of the soil samples were measured using a pH meter (Eutech PC450). Twenty (20) grams of the sample of sand-zeolite amended soil was weighed with a chemical balance and placed into a 200*ml* beaker. 50*ml* of distilled water was added to it and shaken for 10 minutes. The pH of the soil sample was measured and recorded by inserting the electrode of the pH meter into the beaker. The process was repeated for the other soil samples of activated charcoal and rice husk ash. The pH of each sample was measured four (4) times and then averaged. The same procedure was used to measure the soil salinity but this time the EC meter was used.

Water Retention Curve

The soil sample was placed in small clear plastic containers (19 cm diameter, 15 cm long). A tensiometer was implanted in the middle of the soil samples. The soil sample was saturated from the top with distilled water and was left to evaporation. During the drying process, no device was used to accelerate evaporation. Monitoring water content was performed by the gravimetric method (using chemical balance) and the pressure head by the tensiometer reading (figure 7). The measurements were made daily for 36 days. A graph of water content(θ) and pressure head (H_ρ) was plotted.

Saturated Hydraulic Conductivity (Ks)

The hydraulic conductivity at saturation was measured using the constant head method (ASTM, 2010), using polyvinyl chloride (PVC) pipe of 11cm in diameter and 30 cm in height. The soil samples were placed in the pipe to a height of 15 cm at a uniform bulk density. Then, the polyvinyl chloride container was dipped into a water bath and left for 24 hours. After 24hours, the container was removed from the water bath and clamped. Water was then poured to the brim of the PVC container. Then, the water flows steadily through the soil sample for a period of five (5) minutes and it quantity measured. Finally, the hydraulic conductivity at saturation (K_s) is calculated using the formula:

$$K_s = \frac{QL}{AT\Delta h} \tag{44}$$

Where K_s represent the saturated hydraulic conductivity, A represents the cross-sectional area of the sample, $\Delta h = h_1 - h_2$ representing the difference in the hydraulic head of the sample, Q represents the flux density, t represents the time and L represents the sample.

Unsaturated hydraulic conductivity (K)

The unsaturated hydraulic conductivity function (change in hydraulic conductivity with pressure head or soil water content) was determined using an indirect (theoretical) method proposed by researchers such as (van Genuchten, 1980). This estimated method required the water retention curve$(\theta)(\mathrm{Hp})$ and saturated hydraulic conductivity (K_s) values as inputs data to calculate the unsaturated hydraulic conductivity of the soils. Therefore, according to the van Genuchten model (1980) equation (42), the unsaturated hydraulic conductivity $K(\theta)$ of the sandy soil was estimated as follows:

$$K(\theta) = K_s\, \theta^{\lambda} \left[1 - \left(1 - \theta^{1/m}\right)^m\right]^2 \tag{45}$$

Where $K(\theta)$, represent the hydraulic conductivity (m/s) corresponding to water content(θ), K_s saturated hydraulic conductivity (m/s), θ is water content, λ is pore connectivity taken to be 0.5 (Mualem, 1976), m is empirical parameters (m = 1-1/n), and n is an empirical parameter.

Soil Amendments on Water Retention Curve

The water retention curve was measured using the tensiometer apparatus (Blumat DIGITAL, GERMANY). Firstly, a sandy soil sample from the Keta site was packed in clear plastic containers of diameter 19 cm and a height of 15 cm. Then, 21.0 g of zeolite, activated charcoal, and rice husk ash, respectively were added in a band to the soil samples at the top of the soil (Figure 9). After that, a tensiometer was inserted in the middle of the soil samples. A distilled water was poured from the top surface of the sample to saturate the samples and then left to evaporation. Again the experiment was repeated with 15.0 g of zeolite, activated charcoal, and rice husk ash respectively. Throughout the experiments, no device was used to accelerate evaporation during the drying process of the experiment. At the soil equilibrated point, the water contents (θ) were determined gravimetrically by chemical balance (Blumat DIGITAL, GERMANY) and the pressure head was also measured by using a tensiometer as shown in (Figure 9). The measurements were made daily for 36 days. The observed data was plotted as a graph of pressure head (H_p) verses water content (θ).

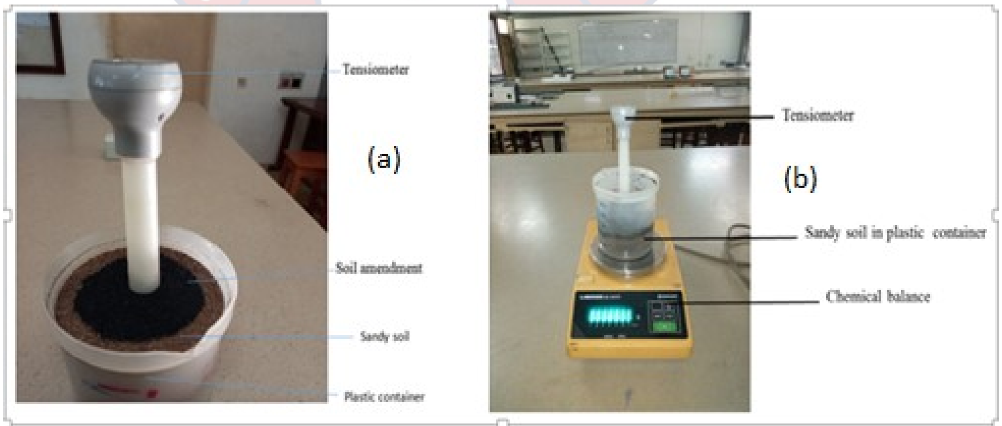

Figure 9: An experimental set-up for measuring water content and pressure head of raw and amended sandy soil

Soil Amendments on Soil Bulk Density and Porosity

The bulk density of the activated charcoal, zeolite, and rice husk ash - amended soil was determined using the cylinder method (Mathieu & Pieltain, 1998). In this method, a quantity of the amended soil samples was poured into a known volume of the graduated cylinder. The soil in the graduated cylinder was then poured into a beaker and its mass determined using a chemical balance, Model ADP 3100L. The bulk density was calculated using equation (42) stated above. The porosity on other hand was computed using the bulk density measured and the sandy soil particle density of 2.65 g/cm^3. The experiment was repeated but this time using another amendment, the activated charcoal, and rice husk ash biochar. The same materials, methods, and procedures were used.

Soil Amendments on Hydraulic Conductivity

The constant head method (ASTM, 2010) was again used to measure the saturated hydraulic conductivity (Ks) in the laboratory using polyvinyl chloride (PVC) pipe of 11cm in diameter and 30 cm in height. The amended soil samples were placed in the pipe to a height of 15 cm at a uniform bulk density. Then, the polyvinyl chloride container was dipped into a water bath and left for 24 hours. After 24 hours, the polyvinyl chloride container was removed from the water bath and then clamped. Water was then poured to the brim of the PVC container. Then, the water flows steadily through the soil sample for five (5) minutes and its quantity measured. Finally, the hydraulic conductivity at saturation (K_s) is calculated using the formula:

$$K_s = \frac{QL}{AT\Delta h} \qquad (46)$$

Where K_s represents the saturated hydraulic conductivity, A represents the samples cross-sectional area, $\Delta h = h_1 - h_2$ representing the difference in a hydraulic head sample, Q is the flux density, t represents the time, and L represents the sample length.

On the other hand, the unsaturated hydraulic conductivity (K) of amended sandy soil was calculated according to the van Genuchten model (1980) equation (45) shown. The experiment was repeated on the activated charcoal, and rice husk ash using the same method and procedure.

Infrared Spectra (IR) Measurement

The infrared spectra for sandy soil amended samples were measure using a Vertex 70 spectrometer (GERMANY) equipped with a universal attenuated total reflectance accessory (Figure 10). This instrument is a compact, powerful, easy to use, and robust instrument used for measuring the infrared spectra of solids, liquids, powders, gels, and pastes. This instrument consists of an optical system and a computer control and data visualization.

The spectrum software of the spectrometer was set to acquire the IR at a resolution of 2 cm^{-1} from an average of 24 scans. Measurement was taken first by taking the background spectrum of the diamond attenuated total reflection plate and saved as the background spectrum. Then, the soil sample was fetched by spatula and placed on the diamond plate. The soil sample was pressed when the soil is on the crystal surface of the diamond plate, and its spectrum was also measured. This was saved as the sample spectrum. The spectrum software generates the absorption spectrum of the soil sample which gives a change in intensity at each frequency. The measurement was repeated for the other soil amended with zeolite, activated charcoal, and rice husk ash amendments. Each infrared (IR) spectrum obtained was the average of 24 scans (Figure 10).

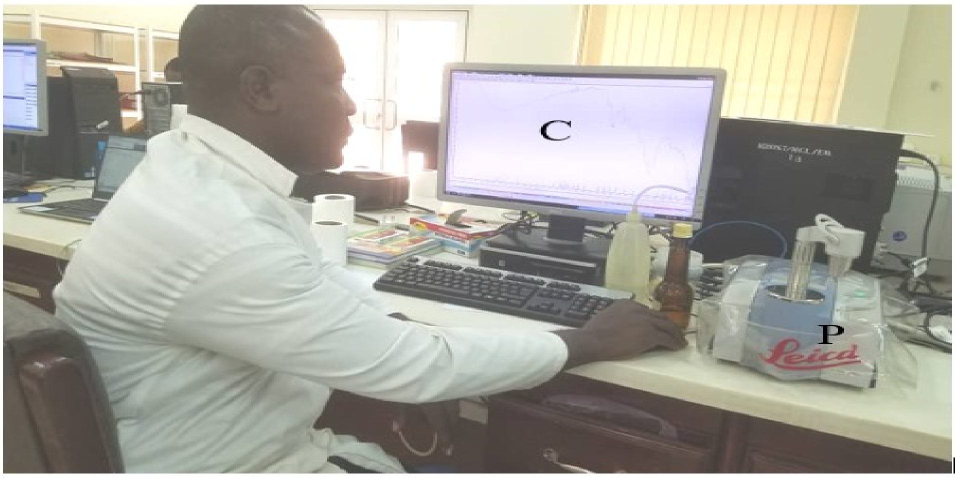

Figure 10: IR absorbance spectra (4000 - 400 cm^{-1}) of samples collected with Vertex 70v FTIR spectrometer

Statistical Analysis

The Microsoft Excel (2010), MATLAB, and Minitab were used to plot the graphs. A statistical analysis using analysis of variance (One-ANOVA) followed by Tukey's mean test at 95 % confidence level was also used to show the mean difference of various soil amendments on water content, pressure head, and hydraulic conductivity of the sandy soil.

Chapter Summary

In summary, simulation on the effects of amended and unamended sandy soil was performed using COMSOL Multiphysics software. The effects of soil amendments on physical, water retention curves and hydraulic properties of the sandy soil before and after amendments were also determined in the laboratory. The results obtained are analyzed and discussed in Chapter four (4) of this thesis.

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

This section provides an overview of what is contained in this chapter. The chapter presents results and discussion of the simulation and experiment on soil physical properties, water retention curve, and hydraulic properties of soil samples.

Characterization of Activated Charcoal, Rice husk Ash, and Zeolite X

Morphological Analysis of Rice Husk Ash

The microstructure of rice husk ash was determined using the AmScope 7X to 45X Stereo Simul-Focal Microscope which is presented in figure 11. The microscopy photographs show the silica nature of the rice husk ash. A close look at the microscopy images also proved that rice husk ash is highly porous and heterogeneous which agrees with other researchers (Zhang & Malhotra, 1996). The porous nature of rice husk ash and its honeycombed structure is responsible for its high specific surface and hence making it suitable for soil amendments.

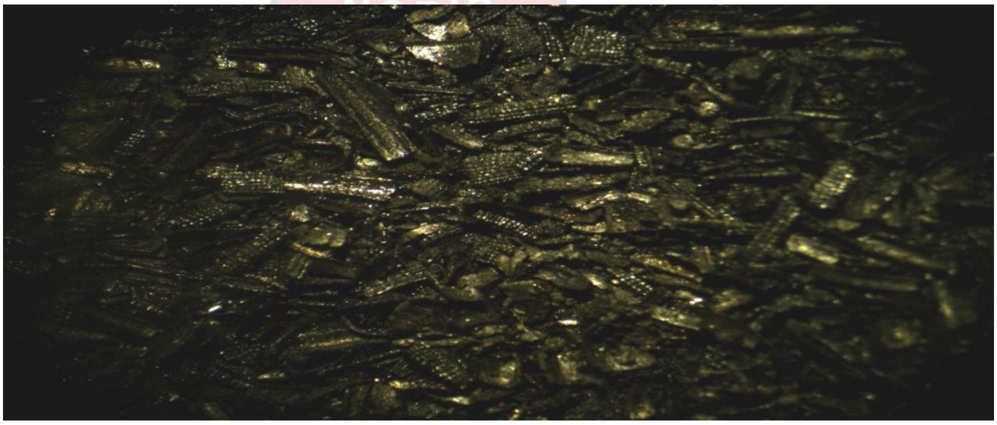

Figure 11: Microstructure of rice husk ash (RHA) used as an amendment

Morphological Analysis of Activated Charcoal

The activated charcoal produced in this study was observed with an AmScope 7X to 45X Stereo Simul-Focal Microscope to identify the morphological structure, which is shown in figure 12. The microscopy photomicrograph revealed that the activated charcoal samples looked spongy in their structures consisting of many and larger pores. On the other hand, microscopy photomicrograph images have indicated that the activated charcoal material is a very porous, fibrous utilizing high surface area and honeycombed microstructure (Zhang et al., 1996).

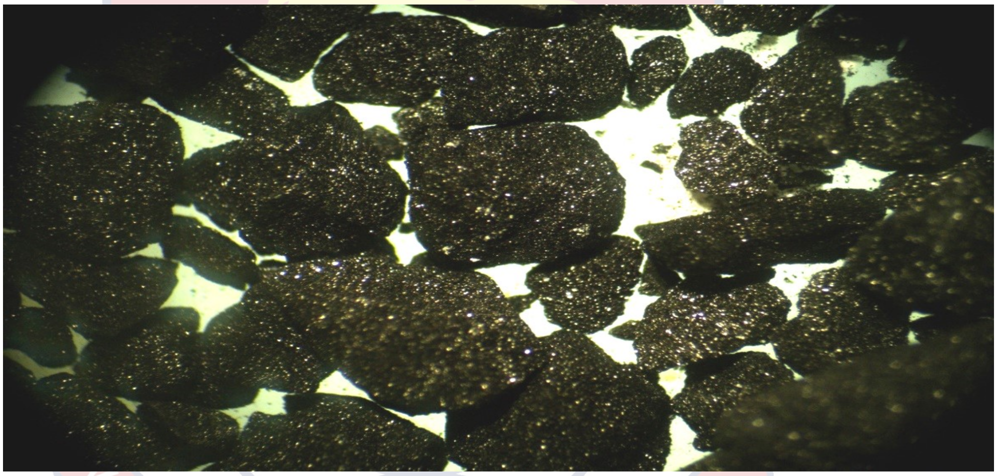

Figure 12: Microstructure of activated charcoal used as an amendment

Morphological Analysis of Zeolite

The AmScope 7X to 45X Stereo Simul-Focal was used to measure the zeolite X morphological structures and the microscopy photograph of the zeolite X is shown in figure 13. The microscopy images shown in figure 10 revealed that zeolite X is largely sphere-shaped in the form with a variation in broad particle sizes and fairly smooth surface texture. A close look at the microscopy images also proved that the zeolite is highly porous which agree with other authors. Further analysis proved that zeolite X particles have a shape in the form of a hexagon which demonstrates how zeolite X has a crystal-like structure which is obvious from the microscopy photographs. The porous nature of zeolite is responsible for its high specific surface area and a good substitute for soil amendments.

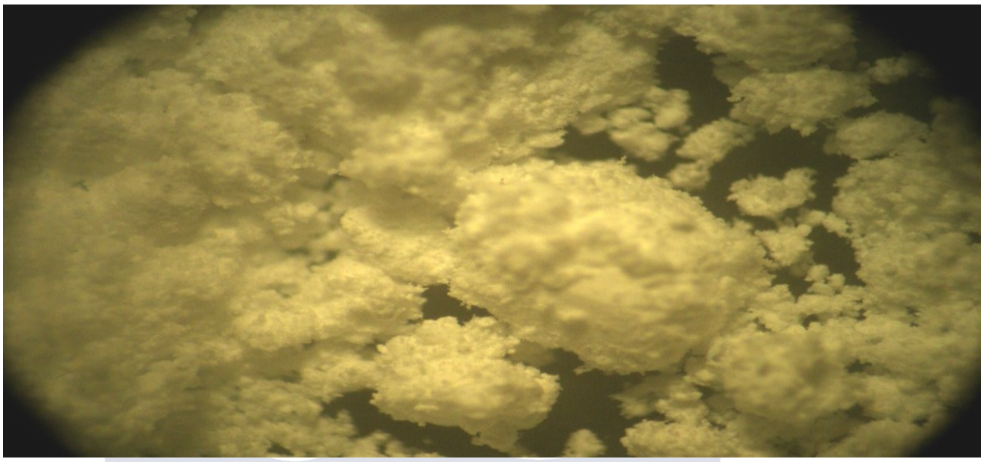

Figure 13: Microstructure of synthetic zeolite X used as an amendment

Attenuated Total Reflection-Fourier Transform Infrared (ATR-FTIR) Analysis

The infrared spectra of the 10 sandy soil amended with zeolite, activated charcoal, and rice husk ash samples obtained using the Vertex 70v FTIR spectrometer equipped with an attenuated total reflection accessory are shown in figure 14 to figure 16. The spectra show several stretching and bending bands which were attributed to the mineral and the organic components in soil. The sharp peaks in this spectral region (4000-400 cm^{-1}), indicate that the sandy soil amended with zeolite, activated charcoal, and rice husk ash samples have a rich chemical, and structural composition. The peaks assignment for the samples is compared with the standard chart (Smith, 1998;

Socrates, 2001; Stuart, 2005). In figures 14-16, O-H and N-H stretching vibrations from hydroxyl and kaolinite can be linked with the absorption band around 4000-3500 cm^{-1} whilst the C-H stretching is caused by hydroxyl absorbs around 3000 cm^{-1}.

Figure 14 shows the FTIR spectra of the synthetic zeolite X amended with sandy soil. The presence of bands at the ranges of 3200 – 3400 cm^{-1}, 2911– 2927cm^{-1}, 1683 – 1695 cm^{-1}, 1597 – 1643 cm^{-1}, 979 - 1030 cm^{-1}, 458 – 478 cm^{-1}, and 675-689 cm^{-1} are clearly visible. The bands situated in the range of 3200 – 3400 cm^{-1} are attributed to hydroxyl groups and adsorbed water respectively. The bands from the range of 2911–2927cm^{-1} are attributed to the C-H stretching vibrations. The peak at 1683 – 1695 cm^{-1} and 1597–1643 cm^{-1} can be due to a C=O stretching in carboxyl. The peaks at 675-689 cm^{-1} attributed to the N-H bending group.

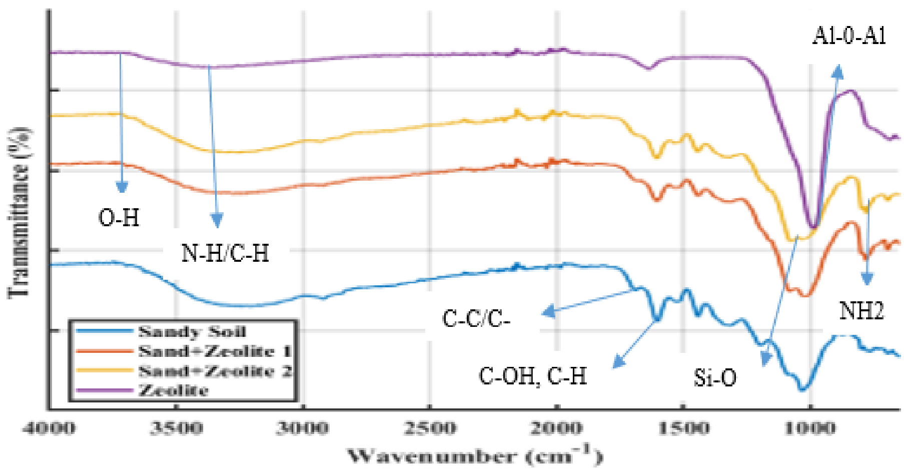

Figure 14: FTIR spectrum of sand soil-zeolite amendment

The band observed at 1700 - 1710 cm^{-1} was assigned to the C-O stretching of alcohols and carboxylic acids. The bands at 1030 cm^{-1} and 979

cm^{-1} can be attributed to the asymmetric and symmetric stretching vibration modes of Si−O tetrahedra and Al-O bending vibrations. The band at 3400 cm^{-1} occur the free water due to the stretching vibration of water molecules (Flanigen et al., 1971), This also agrees with (Wang et al., 2013) at 3500cm^{-1} and 3489 cm^{-1} which in the range of very broad hydroxyl groups between 3600 cm^{-1} to 2500 cm^{-1}. The observed results of the FTIR spectrum of zeolite X amended with sandy soil in this study also agree with the reported literature (Flanigen et al., 1971; Wang et al., 2013). The Si-O bending or Al –O-H stretching in the soil amendments were the major nutrients that contributed to the amendment of the sandy soil.

Also, figure 15 shows the result of the spectra of activated charcoal -sand amendment. From this figure 15, it can be seen that the FTIR spectra present distinct peaks in the following bands: 3400 cm^{-1}, 2900cm^{-1}, 2350 cm^{-1}, 1700 cm^{-1}, 1570 cm^{-1}, 1458 cm^{-1}, and 689 cm^{-1}. The bands located at 3400 cm^{-1} comprised of the OH of sorbed water and hydrous minerals and might be ascribed to the overlapping of N-H stretching.

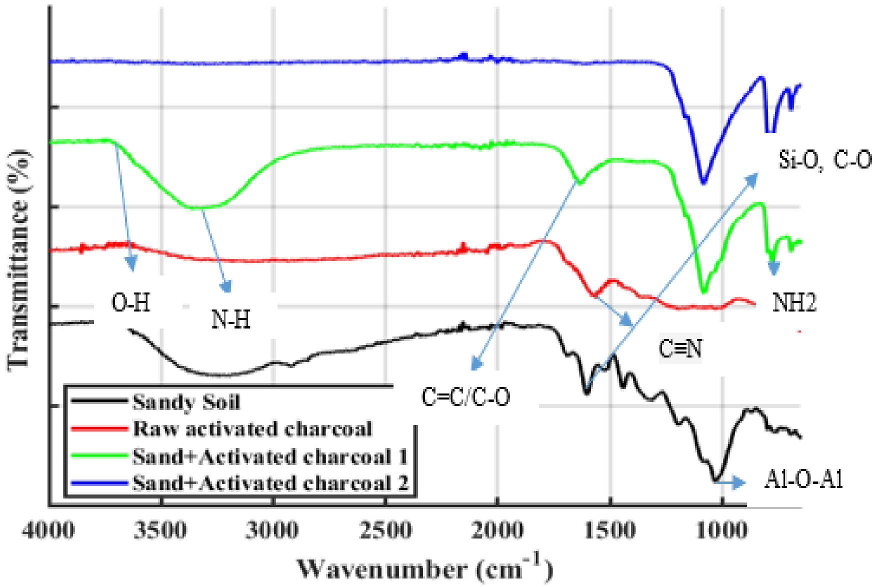

Figure 15: FTIR spectrum of sandy soil-activated charcoal amendment

The band at the 2927cm^{-1} is attributed to the stretching of C–H vibrations (figure 15). The strong peak at 1700 cm^{-1} and 1570 cm^{-1} corresponds to C= O aldehyde and acetone groups and C-N nitriles groups. The peak at 1450 cm^{-1} attributed to the C= C aromatic group. The bands in the spectral region from 3000-2800 cm^{-1} could be attributed to the C-H stretching vibrations present in the studied soil samples. This is in agreement with those reported by Janik & Skjemstad, 1995 & Haberhauer et al., (1998). Bands around 1500-500 cm^{-1} in the "fingerprint region" indicate several modes such as Si-O bending or Al –O-H stretching (Figures 12). On the other hand, the bands at 1100 cm^{-1} assigned as Al-O -Al (Xu et al., 2000). The Si-O bending or Al –O-H stretching in the soil amendments were the major nutrients that contributed to the amendment of the sandy soil. The FTIR spectra provided direct evidence that is consistent with the results confirming the abundance of aromatic, and methylene groups in the activated charcoal. Moreover, it can be seen that the present of bands at the following ranges 3200 – 3400 cm^{-1}, 2911– 2927cm^{-1}, 1683 – 1695 cm^{-1}, 1597 – 1643 cm^{-1}, 979 - 1030 cm^{-1}, 458 – 478 cm^{-1}, and 675-689 cm^{-1} are clearly visible (figure 15).

From figure 16, the bands located in the range of 3200 – 3400 cm^{-1} could be due to the overlapping of O-H and N-H stretching. The band range of 2911– 2927cm^{-1} is also due to the C-H stretching. Various peaks at 1683 – 1695 cm^{-1} and 1597 – 1643 cm^{-1} could be attributed to a C=O stretching. The peak at 675-689 cm^{-1} attributed to N-H bending. The band observed at 1700 - 1710 cm^{-1} was assigned to the C-O stretching of carboxylic acids and alcohol. The bands observed between 1200 and 500 cm^{-1} were due to the Si-O/Al-O bending vibrations as shown in figure 16 (Ibrahim et al., 2008). From these results, rice husk ash amended soil can be located under three distinct bands. Firstly, the bands located at 790 cm^{-1} belong to Si-O symmetrical bending vibrations which are in agreement with Javed et al., (2009); MusićI et al., 2011; Ferraro et al., 2010).

Furthermore, bands occurring at 1100 cm^{-1} also showed the presence of Si-O stretching (Javed et al., 2009) at 1095 cm^{-1} to 1005 cm^{-1} and Ferraro et al., (2010) at 1010 cm^{-1}. Lastly, at 3300 cm^{-1} occurred the free water due to the stretching vibration of water molecules which agree with MusićI et al., (2011). Similar results are observed in Javed et al., (2009); Ferraro et al., 2010).

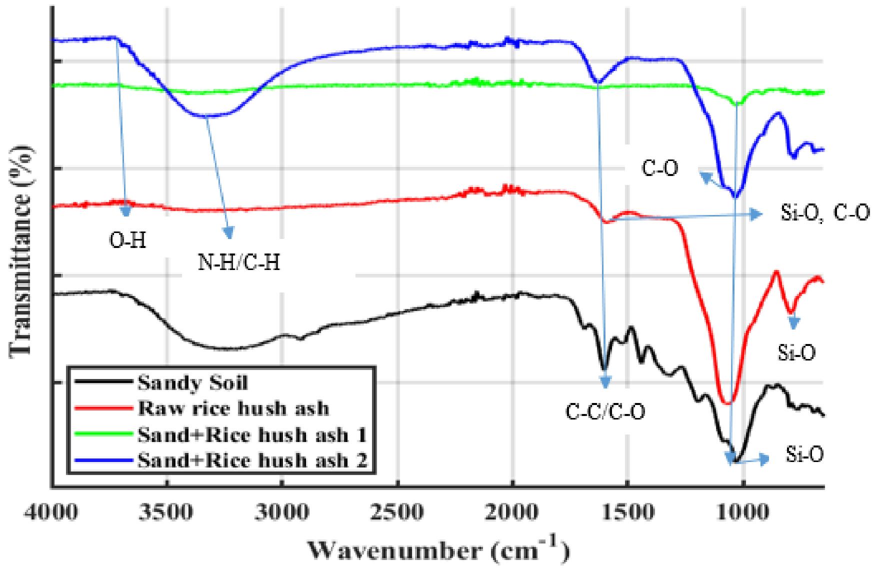

Figure 16: FTIR spectrum of sandy soil-rice husk ash amendment

Results of Simulation and Experiment on Soil Physical Properties, Water Retention Curve, and Hydraulic Properties of the Sandy Soil Samples

The simulation and experimental study were conducted to find out how zeolite, activated charcoal, and rice husk ash could improve the soil's physical, water retention, and hydraulic properties. The simulation results are then compared with the experimental results.

Effects of Soil Amendments on Sandy Soil

The Effects of Zeolite on Soil Bulk Density and Porosity

In this study, the effect of zeolite addition to sandy soil on both soil bulk density and porosity of sandy soil is more pronounced (Table 5). The bulk density of the soil containing zeolite was significantly lower than the unamended soil. This observation is consistent with the findings of some authors (Jein &Wang, 2013; Karhu et al., 2011; Vaccari et al., 2011). Table 5 reveals a good improvement in both bulk density and porosity status due to the zeolite addition. Bulk density of sandy soil decreased from 1.52 g cm^{-3} to 1.31 g cm^{-3} and 1.32 g cm^{-3}, respectively for the zeolite 1 and 2 applications rate (Table 5), which in the other hand reflected an increase in porosity when compared to the initial bulk density value of the control soil (sandy). Zeolite also has been found to have a highly porous structure than the sandy soil and therefore, as the proportion of this material in the soil increases, the bulk density decreases, and porosity increases (Litaor et al., 2017). The decrease in bulk density may be due to the fact that the application of zeolite to the soil, increases porosity due to its crystalline structure (high pore volume), and thereby reduces the bulk density of the soil.

Similar results were obtained by Litaor et al., (2017) who observed that the bulk density of soil was lower in treatment where the application of 2 % zeolite alone was done. Reduction in soil bulk density by zeolite would lead to an improvement in aeration, total porosity, increased water retention capacity, and also improved the growth of the plants (Ramesh et al., 2011). The decrease in bulk density modifies the distribution of pore size and thus increases the relative number of small pores, especially for sandy soils. The bulk density depends not only on the amendment percentages in soil but also on the amendments particle size; the bigger the particles, the lower the bulk density. The porosity of the soil was also increased by the soil amendments.

Furthermore, the reduction in soil bulk density of the amended soils may be linked to modifications of soil aggregate sizes caused by the zeolite, activated charcoal, and rice husk ash-soil interaction (Tejada & Gonzalez (2007). The obvious change in porosity was considered as the formation of macro-pores and rearrangement of soil particles. Further research established that the capillary porosity values increased when the sand is amended with zeolite, which also is in agreement with other findings as reported by Bigelow et al., (2004); Walz et al., 2003).

Table 5: Average Values of Bulk Density, Porosity, pH, and Soil Salinity before and after Soil Amendments

Soil	Bulk density(g/cm^3)	Porosity (%)	pH	Salinity (ppt)
Sandy	1.53	43	7.2	2
Zeolite 1+ sandy	1.31	50	7.4	0
Zeolite 2+ sandy	1.32	50	7.6	0
Activated charcoal 1+sandy	1.38	48	7.3	0
Activated charcoal 2+sandy	1.40	47	7.3	0
Rice husk ash 1+sandy	1.34	49	7.4	0
Rice husk ash 2+ sandy soil	1.35	49	7.5	0

Where 1 and 2 signify the masses 21.0 g and 15.0 g, respectively.

These findings using zeolite also agreed well with results obtained by Al-Omran et al., 2002; Waltz et al. 2003; Al-Busaidi et al., 2008) on sandy soil. Other researchers such as Gholizadeh-Sarabi & Sepaskhah, (2013) have reported that the decrease in soil bulk density is due to the pore sizes (micro-pore) of the zeolite particle. Similar to our results, many studies have proved that zeolite additions increased the porosity in sandy soil (Al-Busaidi et al., 2008; Sarkar & Naidu, 2015). The increase in porosity with the addition of zeolite occurred because the zeolite is a material with high porosity, composed by approximately 60 percent of pore volume, hence which increases in water retention and nutrient retention capacities. Similar effects were reported by Ramesh et al., (2011) in a laboratory and on the field. A slight decrease in bulk density could be due to the porosity changes. The results established that any improvement in soil physical properties after the addition of zeolite is linked with the amount of zeolite applied.

The Effects of Activated Charcoal on Soil Bulk Density and Porosity

The results obtained in Table 5 indicate that the activated charcoal application rate significantly affected the bulk density of the sandy soil by reducing the bulk density and increasing porosity values. Here, the activated charcoal decreases the bulk density of sandy soil from 1.52 g cm^{-3} to 1.38 g cm^{-3} and 1.40 g cm^{-3}, respectively for the activated 1 and 2 applications rate as shown in Table 5, which in the other hand reflected an increase in soil porosity. The soil bulk density measured for the amended soils were lower than the unamended soil (sand). These findings are in agreement with some researchers (Jein & Wang, 2013, Karhu et al., 2011; Vaccari et al., 2011).

More also, activated charcoal has been found to have a lower bulk density and high porous structure than sandy soil and therefore, as the proportion of this material in the soil increases, the bulk density decreases and porosity increases with time (Tejada & Gonzalez, 2007; Verheijen et al., 2009). Other researchers (Githinji, 2013; Mukherjee & Lal, 2013: Herath et al., 2013; Dugan et al., 2010) have also reported that Improvements in soil physical properties, such as bulk density, have also been recorded with as little as one percent addition of activated charcoal. The decrease in bulk density of soil could be attributed to the density of the amendment compared with that of sandy soil, which is clearly obvious after the application in coarse-textured soils (Celik et al., 2004; Glab, 2014).

In addition, changes in soil composition and changes in soil aggregate sizes may also be due to a decrease in the activated charcoal-amended soil bulk density (Tejada & Gonzalez, 2007; Jien & Wang, 2013). A further decrease in soil bulk density has also been reported in other studies (Mukherjee et al., 2014; Pathan et al., 2003; Laird et al., 2010 ; Brewer et al., 2014; Rogovska et al., 2014). It is proved further that the soil bulk density depends not only on the amendment percentages in soil but also on the amendments particle size; the bigger the particles, the lower the bulk density. Furthermore, the decrease in soil bulk density of the amended soils may be linked to changes in soil aggregate sizes caused by activated charcoal -soil interaction (Tejada & Gonzalez, (2007).

Contrary to bulk density results, porosity increased with activated charcoal applications (Table 5). For the unamended soil, porosity was 43 %, increasing to 48 % and 47%, respectively, for 21.0 g and 15.0 g rates of activated charcoal application. It is also observed in this study that the porosity of the amended soil was increased by the activated charcoal amendments as the soil bulk density decreases as shown in Table 5. A further study proved that the decrease in soil bulk density by the addition of activated charcoal increasing total porosity (Jones et al., 2010; Oguntunde et al., 2008).

Other researchers have stated that both micropores and macrospores improve soil aeration and water holding capacity which is vital for crop root health in the soil (Brady & Weil 2002). It is observed in this study that an increase in porosity in the activated charcoal-amended soil resulted from the creation of large macropores in the sandy soil surrounding the amendments particles. The obvious change in porosity was considered as the formation of macro-pores and rearrangement of soil particles. These results show that the addition of activated charcoal improved the capillary porosity of the mixtures of sand-amendments, which also agree with other findings by Bigelow et al., (2004) & Walz et al., (2003).

The Effects of Rice Husk Ash on Soil Bulk Density and Porosity

Table 5 shows the results obtained when rice husk ash amendments were applied to the sandy soil. It is observed that the rice husk ash decreases the bulk density of sandy soil from 1.52 g cm^{-3} to 1.34 g cm^{-3} and 1.35 g cm^{-3}, respectively for the rice husk ash 1 and 2. The measured bulk density of sandy soil containing rice husk ash was significantly lower than the unamended soil (Table 5). The alteration of soil with less dense materials can be due to these changes in soil bulk density, which is clearly evident immediately after application to sandy soils, as demonstrated by the transition in soil with less dense materials (Celik et al., 2004; Glab, 2014).

Furthermore, the decrease in bulk density of rice husk ash-amended soils could also be attributed to changes in soil structure and soil aggregate sizes (Tejada & Gonzalez, 2007; Jien & Wang, 2013). Furthermore, it is found that rice husk ash has a lower bulk density and high porous structure than sandy soil and therefore, as the proportion of this material in the soil increases, the bulk density decreases and porosity increase which agree with Tejada & Gonzalez, (2007); Verheijen et al., 2009). Other authors (Githinji, 2013; Mukherjee & Lal, 2013: Herath et al., 2013; Dugan et al., 2010) have also reported a decrease in bulk density of soil with as low as 1 percent addition of rice husk ash. The reduction in the bulk density results in changes in the pore size distribution and thus increases the relative number of small pores, especially for sandy soils. The bulk density depends not only on the amendment percentages in soil but also on the amendments particle size; the smaller the particles, the lower the bulk density. Further work proved that decrease in soil bulk density could be attributed to rich silicon content and potassium found in the rice hush ash. This is due to the fact that silicon content and potassium are nutrients that have great potential for amending soil (Yamato et al., 2006).

In addition to that, a further decrease in soil bulk density could lead to an increase in water retention capacity, improved aeration in the crop root zone, and increased levels of exchangeable potassium and magnesium (Jein & Wang, 2013; Karhu et al., 2011; FFTC, 2001). Further decrease in soil bulk density has also been observed in studies (Mukherjee et al., 2014; Brewer et al., 2014; Rogovska et al., 2014). Furthermore, the decrease in bulk density of the amended soils may be linked to changes in soil aggregate sizes caused by the rice husk ash-soil interaction (Tejada & Gonzalez (2007). However, soil bulk density alone is not considered to be an adequate predictor of an effective amendments-soil mixture, as stated by Githinji et al., (2011).

Unlike the results of soil bulk density, porosity increased with the rice husk ash application rate (Table 5). For the control soil, porosity was 43 %, increasing to 49 % and 49 %, respectively, for 21.0 g and 15.0 g rates of rice husk ash application. The obvious change in the soil porosity was considered as the formation of macro-pores and micropores rearrangement of soil particles. These findings show that rice husk ash applications increased the porosity of the amended soil which agreed with similar results (Bigelow et al., 2004; Walz et al., 2003). It is further observed that an increase in porosity in the rice husk ash-amended soil resulted from the creation of large macropores and mesopores in the sandy soil surrounding the amendments particles. Therefore, zeolite micropores increase water retaining ability and increase soil aeration, which is essential for plant roots to grow in the soil (Brady & Weil 2002). A further study established that the bulk density of a soil decrease by increasing porosity when rice husk ash is applied to sandy soil (Jones et al., 2010).

Effect of Soil Amendments on Soil pH and Salinity

The Effect of Zeolite on Soil pH and Salinity

Zeolite increased soil pH from 7.2 of sandy soil to 7.4 and 7.6 respectively after the amendments which agreed with Ramesh & Reddy, (2011); Zhang et al., 2010) as shown in Table 5. In this study, zeolite has significantly increased soil pH. The highest soil pH was recorded in treatment receiving 15.0 g zeolite (7.6), followed by the treatment receiving 21.0g zeolite (7.4). The relatively modest increase in soil pH observed after an amendment is due to zeolite catalytic ability (ion exchange capacity) and parental material structure (porous nature). This observation agrees with the reports of Ramesh et al., (2015); Rabai et al., 2013; Radulescu, 2013) who also observed an increase in the soil pH with the application of zeolite on sandy soil.

A further study proved that the soil pH increases the acidic soil when the zeolite is added (Szerement et al., 2014). This may be due to increases in the concentration of alkaline metal oxides in the zeolite and a reduced concentration of soluble soil (Oste et al., 2002). It is stated that the nutrient intake of crops and the storage capacity of soils increases when the zeolite is applied to the soil (Ravali et al., 2020). Soil pH is important because it is influenced by nutrient uptake by plants. Most plants nutrient are optimally available at soil pH 6.0-7.6 (Brady & Well, 2008).

Similarly, salinity decreased from 2 ppt to 0 ppt in both treatments using the zeolite (Table 5). The decrease is due to the relatively large ion exchange capacity of the zeolite which makes it to adsorb cations from the soil solutions, hence a decrease in soil salinity which agrees with this study. The decrease in salinity is in agreement with Al-Busaidi et al., (2008) who used zeolite to amend sandy soil and found consistent decreases in salinity and an increase in pH. Other findings have shown that zeolite addition could be useful to decrease the negative effects of high salinity (Li et al., 2000).

The Effects of Activated Charcoal on Soil pH and Salinity

Sandy soil pH increases from 7.2 to 7.3 and 7.3 respectively in the activated charcoal amended soils than control soils (Table 5). In this study, both treatments (21.0 g & 15.0 g) soil pH recorded the same value (7.3). The increases in soil pH may be due to the fact that activated charcoal is an alkaline pH in generally and therefore might alter the soil pH of most plants in a favourable condition (Chan & Xu, 2009). Hence, an increase in soil pH after amendments. The findings agree with those of Nigussie et al., (2012). Many findings have shown soil pH increases due to activated charcoal application (Yuan et al., 2011). From this study's results, the values of the soil pH recorded is also in agreement with other researchers (Nigussie et al., 2012;

Zhang et al., 2012; Zheng et al., 2010). Also, the ash content containing silica and potassium of the activated charcoal is primarily responsible for the increase of the soil's pH. This is due to the fact that silicate content and potassium are nutrients that have great potential for amending soil (Yamato et al., 2006). Other researchers also stated that amending soil with rice husk ash, increased soil pH (Pinto et al., 2009; Sandrini 2010). Soil pH is important because it is influenced by nutrient uptake by plants. Most plants nutrient are optimally available at soil pH 6.0-7.6 (Brady & Well, 2008).

This study further observed a decrease in salinity compared to the control soil (Table 5). Both treatments (21.0 g and 15.0 g) decrease from 2.0 ppt to 0 ppt. The decrease in soil salinity can be attributed to the porous structure and high specific surface area of the activated charcoal. In this study, a reduction in salinity could also be ascribed to the cation exchange capacity of the activated charcoal (K, Ca, & Mg).

The Effects of Rice Husk Ash biochar on Soil pH and Salinity

The soil pH increases in the rice husk ash amended soils than control soils as shown in Table 5. The results show that rice husk ash has considerably increased the pH of the sandy soil. The highest soil pH was recorded in treatment receiving 15.0 g rice husk ash (7.5), followed by the treatment receiving 21.0 g rice husk ash (7.4). This increase in pH agree well with Chan et al., 2007; Van Zwieten et al., 2010; Uzoma et al., 2011b; Rogovska et al., 2014). It is stated further that the increases in soil pH may as a result of the alkaline nature of rice hush ash pH, which is due to the high ash content being dominated by silicate and potassium as agreed by Dai et al., (2014). A further study has proved that due to the high ion exchange capacity of rice hush ash, there is an increase in soil pH in amended soils (Chintala et al., 2014). The findings agree perfectly well with Nigussie et al., (2012); Zwieten et al., 2010) who attributed the increased to ash deposit. Soil pH is important because it is influenced by nutrient uptake by plants. Most plants nutrient are optimally available at soil pH 6.0-7.6 (Brady & Well, 2008).

Furthermore, this study observed a decrease in salinity compare to the unamended soil (Table 5). The decrease in salinity can be attributed to the porous structure and high ash content existing in the rice husk ash. Also, the ash content is highly dominated by carbonates, silica, and potassium nutrients, which have great potential for amending soil, hence a decrease in soil salinity (Varella et al., 2013). In this study, a reduction in salinity could be attributed to exchangeable Potassium (K), Calcium (Ca), and Manganese (Mg) in soil.

The Effects of Soil Amendments on the Water Retention Curve

Water retention curves of sandy soil amended with zeolite, activated charcoal, and rice husk ash using simulation and experimental methods, respectively are shown in figure 17 and figure 18. The results in figure 17 show that sandy soil held less water at all pressure heads compared with the zeolite X, rice husk ash, and activated charcoal-sand amendments. At low-pressure head of 0 cm, the saturated water content (θ_s), ranges from 0.727(1) for the control (sandy soil), 0.734(1), and 0.739(1) for zeolites 1 &2 respectively, 0.734(1) and 0.739(1) for rice husk ash 1&2 respectively, and 0.7314(1) and 0.7332(1) for activated charcoal 1&2, respectively. In figure 17, it is observed that the rice husk ash (Rha) 1 & 2 retained more water at a pressure head greater than 300 cm followed by zeolite (Zeo) 1 & 2, and activated charcoal (Act) 1 & 2 compared with the unamended soil (pure sand).

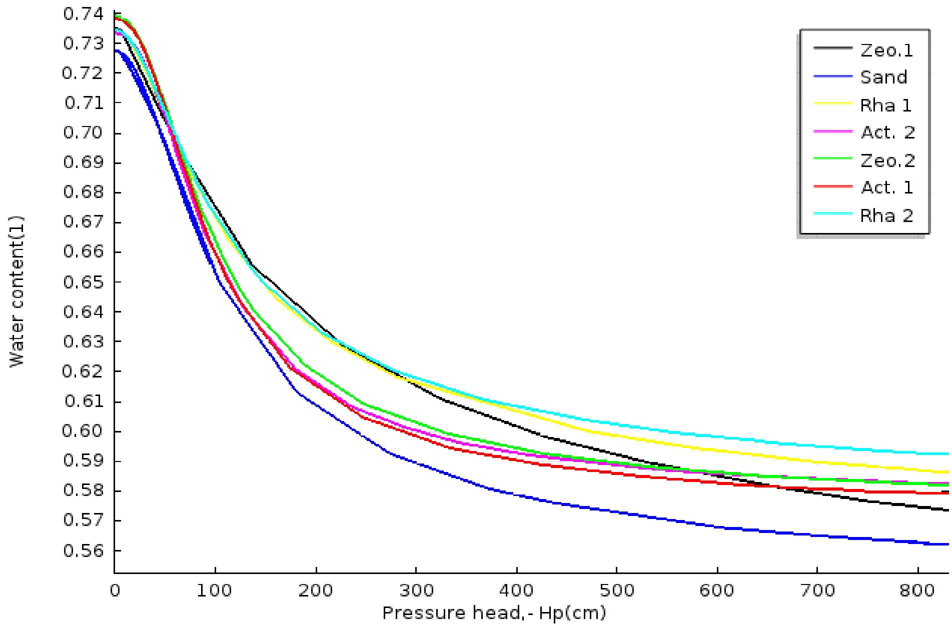

Figure 17: Water retention curve of zeolite, rice husk ash, and activated charcoal amendments on sandy soil (simulation)

Also, figures 18 represent the water retention curve experimentally. It is observed from the curve that there was no substantial difference in water content among the treatments (figure 18). The result showed increased water retention for zeolite 1&2, and rice husk ash 1&2 amended soils for all pressure head as compared to the unamended soils. This suggests that more water was retained within the soil amendments as the pressure head increased and the soil becomes unsaturated. This is because zeolite decreases the soil bulk density and increases the porosity, which subsequently increases the water retention.

It is also noted that comparing the addition of 21.0 g and 15.0 g, respectively, of activated charcoal 1 & 2 with the unamended soil (pure sand), the activated charcoal had no effect or did not increase or decrease the water retention of the soil. This is due to the amount of activated charcoal applied, the temperature at which it is produced, and the particle sizes. Smaller activated charcoal particles can easily interact more with soil particles to form aggregates than large activated charcoal (Jeffery et al., 2015; Hardie et al., 2014). In this study, the particle size of activated charcoal used was larger than the sand particle size and therefore the decrease in soil bulk density resulted in porosity increase. In general (figure 18), the shapes of the curves differ between the treatments particularly in the pressure head range between 0 and 100 cm. It is observed further in figure 18 that most of the water retention curves show an equally consistent slope, which indicates that the release of water was generally very gradual as the pressure head was increased.

Also, in figure 18 rice husk ash and zeolite amendments except activated charcoal increased water retention at most of the pressure head considered. This implies more water was retained within the zeolite and rice husk ash as the pressure head increased and the soil becomes unsaturated. The changes in water retention are due to the open pore network channels of zeolite acting as a permanent water reservoir, natural wetting agent and assist water distribution through soils which agreed well with recent results of (Szerment et al., 2014; Sangeetha & Baskar, 2016). This finding also agrees with the results of Laird et al., (2010). At above 100 cm, the highest water retention values recorded for all the amended soil were significant (figure 18). The differences between the water retention curves of amended soil appeared not only within a low-pressure head value but also in a high-pressure head range. The retention of water at higher pressure head primarily depends upon capillarity, while at lower pressure head is due mainly to adsorption at the surface. The zeolite amendment increased the retention of the soil, followed by rice husk ash, and the activated charcoal compared to the control (sand). However, the scale of this result depended on amendments particle size, its application rate, pyrolysis temperature, and the type of feedstock used. It is further proved that the effect of zeolites on water retention is attributed to the porous nature and the capillary suctions it exerts which make zeolites act as an outstanding amendment for non-wetting sands which is in agreement with Ramesh et al., (2011); Al-Busaidi et al., 2008).

Also, it is indicated that zeolite, activated charcoal, and rice husk ash amendments greatly affected the water retention properties of the soil (figure 18). These findings agree with previous findings by Abel et al., 2013; Glaser et al., 2002; Ippolito et al., 2011). Besides, the shape of the curves shows that the zeolite and rice husk ash amendments retain more water and drain their water more gradually than sandy soil containing activated charcoal. This may be due to the high water retention capacity of the zeolite (Sangeetha & Baskar, 2016).

Ippolito et al., (2011) also noticed that the mixing of zeolite with sand improved soil water retention. Bernardi et al., (2010) also observed that the use of zeolite in sandy soil increased available water retention capacity. Other researchers also proved that reduction in soil bulk density due to the addition of the zeolite and rice husk ash leads to increased water retention capacity, aeration, infiltration, and crop root growth in the soil (Githinji, 2013;

Mukherjee & LaI, 2013; Herath et al., 2013). It is stated further that the effect of zeolite, activated charcoal, rice husk ash applications on the water retention was linked to the macro and medium pores increase which decreases the bulk density (Narjary et al., 2012). A further study proved that the differences observed in water content between unamended and amended soil are attributed to the porosity changes of amended soil, which permit more water to be physically retained (Narjary et al., 2012).The mechanism behind the increase in water retention capacity of sandy soil might be due to the hydrophobic nature, high surface area, organic matter content of the amendments, and changes in the pore size distribution of the soil. The water retention curve obtained using simulation seem to agree with the experimental graph obtained although it displays slight differences at some pressure head values (Baroni et al., 2010; Ghanabarian-Alarijeh et al., 2010; Bigelow et al., 2004; Walz et al., 2003; Abel et al., 2013; Ippolito et al., 2011; Xiubin & Zhanbin, 2001 &Glaser et al., 2002). Similar results also agree well with Baronti et al., (2014); Herath et al., 2013; Verheijep et al., 2010; Brockhoff et al., 2010; Uzoma et al., 2011; Bruun et al., 2014; Abel et al., 2013; Glaser et al., 2002; Emani & Astaraei, 2012). As the incorporation of zeolite and rice husk ash increases both the volume of water stored and the pH in the soil, hence continuous irrigation may reduce which may have positive impacts on the growth of plants during drought seasons.

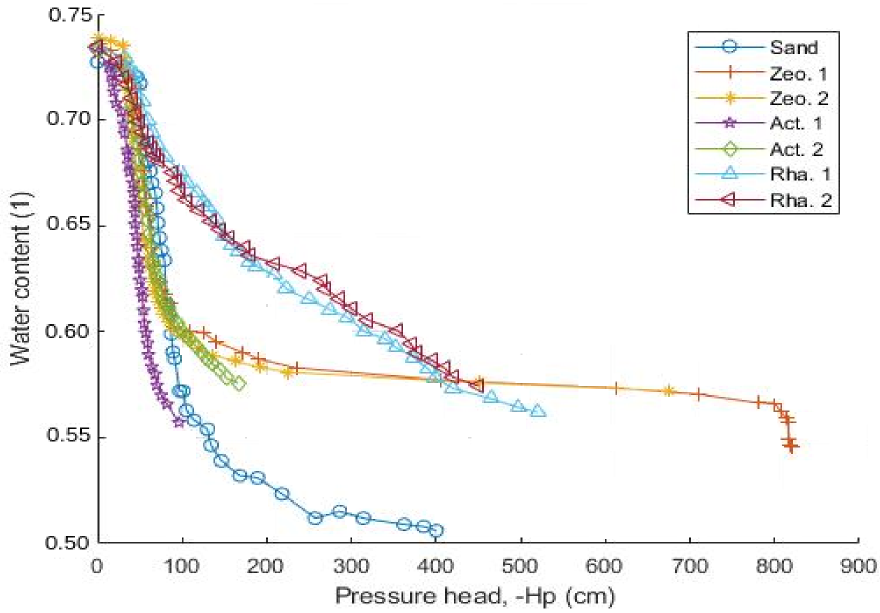

Figure 18: Water retention curve of zeolite, rice husk ash, and activated charcoal amendments on sandy soil (experiment)

The Effects of Soil Amendments on Soil Hydraulic Properties

Figure 19 shows the hydraulic conductivity against water content K (θ) for all the three amendments. It is observed that the water content decrease as hydraulic conductivity also decreases. This shows that as the water content continuously reducing, the path available for water flow reduces, which, therefore, decreases the hydraulic conductivity. In comparing K (θ) curve among the rice husk ash, activated charcoal, and zeolite amendments, the rice husk ash 1 amended soil deviate slightly from the rest (figure 19).

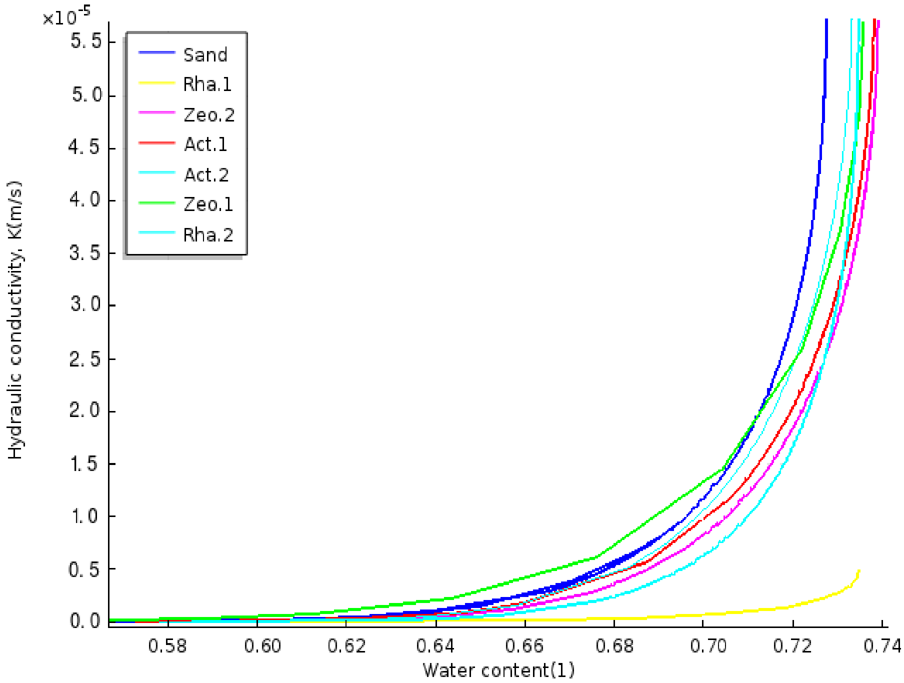

Figure 19: Soil hydraulic conductivity curve (Hydraulic conductivity vrs Water content) of zeolite, rice husk ash, and activated charcoal amendments on sandy soil (simulation)

Figure 20 represents a graph of the hydraulic conductivity and water content, K (θ) obtained from the experimental measurements. It could be expected that zeolite, activated, and rice ash amendments should improve the hydraulic properties of soil. However, in this study, zeolite, activated charcoal, and rice husk ash applications rate of 21.0 g and 15.0 g respectively neither increase nor decrease the hydraulic conductivity of the sandy. Similar findings were reported by Gaskin et al., (2007) when 22 Mg/ha was used to amend sandy soil.

Some studies reported that the amending sandy soil with rice husk ash and activated charcoal may significantly decrease or have no effect on the sandy soil hydraulic conductivity (Rogovska et al., 2014; Hardie et al., 2014). These findings are attributed to the fact that the scale of these results depended on amendments particle size, application rate, shape, and type of feedstock (Major et al., 2012; Eastman, 2011; Laird et al., 2010). Blanco-Canqui, 2017; Liu et al., (2017) reported similar result that the effect of activated charcoal and rice husk on the sandy soil hydraulic properties were greatly connected to activated charcoal and rice husk biochar properties (e.g., feedstock type used, particle size, amount of amendments applied, temperature, soil type, and shape).

Previously reported effects of activated charcoal and rice husk ash on hydraulic conductivity vary due to the variability of soil texture, amendment types, dosage added, and their maturity in the field. Other authors like Gardner, and numerous extra researchers, proved that as the water content decreased, the hydraulic conductivity also decreased rapidly. A further study also proved that during the first stages of the reduction of water content, the hydraulic conductivity reduced very sharply (Childs, 1957). The decrease is ascribed to the fact that a reduction in water content decreases the total porosity.

Also, it is found out that the hydraulic conductivity decreased very fast as water content decreased Philip, (1957). The decrease is due to the fact that the larger pores are first emptied, which greatly affects the paths available for the flow of water. Therefore, in this work, the decrease in the hydraulic conductivity was also highly ascribed to the change in the average particle size of the soil, different amendment rates, soil properties, shape, and threshold effects of the amendments rate. However, the zeolite 1 amendment recorded the larger effect on K (θ) compared with rice husk ash and activated charcoal (Enders et al., 2012; Xiubin & Zhanbin, 2001; Verheijen et al., 2010;

Verheijen et al., 2009). Our findings are also agreed with earlier work which proved that sandy soil hydraulic conductivity reduced with the addition of zeolite, activated charcoal, and rice husk ash (Saeedi & Sepaskhah, 2013; Lim et al., 2016; Sun et al., 2013). Similar findings were also described in a new research, supporting these observations as reported by Lin et al., (1998).

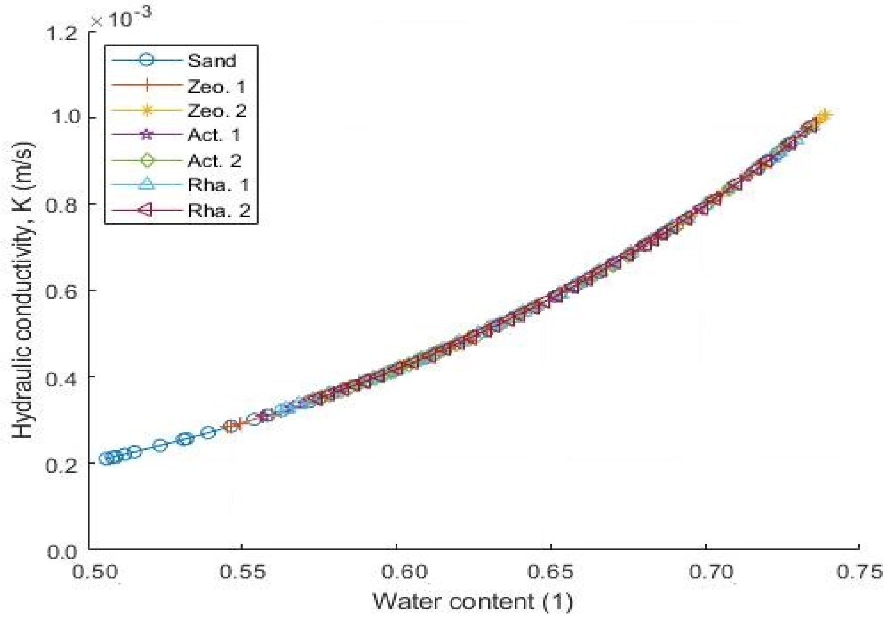

Figure 20: Soil hydraulic conductivity curve (Hydraulic conductivity vrs Water content) of zeolite, rice husk ash, and activated charcoal amendments on sandy soil (experiment)

Figure 21 and figure 22 show a graph of hydraulic conductivity and pressure head for the simulation and the experimental respectively. Comparing the simulation curve to that of the experimental curve, the water content values of Zeolite 1 (Zeo1) at a hydraulic conductivity of 0.5 m/s differ slightly (figure 21 and figure 22). Differences in the hydraulic conductivity curve were mainly from uncertainties in the fitted value of saturated hydraulic conductivity (Ks), which was affected by the need to extrapolate beyond the conditions set up in the experiment.

In figure 22, it is observed that as the soil hydraulic conductivity decreases, the pressure head (H_p) also increases (or water content decreases). The observed reductions in hydraulic conductivity are attributed to the porous structure of the amendments despite the decreased bulk density and increased in the porosity of the soil. A further decrease in hydraulic conductivity might be due to the amendments high field capacity (Glaser et al., 2002). The results proved that the additions of zeolite, rice husk ash, and activated charcoal decreased hydraulic conductivity in the treated soils at all pressure heads compared with the unamended soil (sand).

Further observation shows that the effects of amendments on hydraulic conductivity are clearer in zeolite-treated soil, followed by the rice husk ash and activated charcoal. However, zeolite 1 amendments observed a larger effect on K (H_p) compared with the rice husk ash and activated charcoal which agree with Abel et al., (2013); Saeedi & Sepaskhah, 2013; Lim et al., 2016). The addition of zeolite, rice husk ash, and activated charcoal made a hydraulic conductivity tortuous with empty pores that decrease the tortuosity of the sandy soil contributing to flow of water in the unsaturated soil (Liu et al., 2016); Blanco-Canqui, 2017). The insignificance changes of K (H_p) to the amendments of activated charcoal is in agreement with further research where no change or few changes occur in K (H_p) on activated charcoal amended soils. The discrepancies between the effects of zeolite and activated charcoal on the hydraulic properties of the soil may be due to changes in the chemical and physical properties of the soil (Xiubin & Zhanbin, 2001; Verheijen et al., 2009). Rice hush ash 1 sample deviated slightly from the rest of the amendments. This is due to the presence of high ash content containing silica content and potassium and the hydrophobicity of the organic matter present in rice husk ash. At the pressure head of 0 cm, saturated hydraulic conductivity is equal to about 5.5x 10^{-5} m/s, which is a reasonable value for sandy soil (figure 22). The unamended soil (control) has the highest values at 0 cm pressure head, followed by zeolite, rice husk ash while the activated charcoal is least saturated. At any pressure head, the effects of amendments on hydraulic conductivity were more evident in zeolite -amended soil, than rice husk ash and activated charcoal. The effect of zeolite and rice hush ash amendments on hydraulic conductivity, hydraulic conductivity versus pressure head (K (H_p) did also agree well in all pressure heads compared with the unamended soil (sand). Nevertheless, the addition of zeolite 1 observed a better effect on K (H_p) compared with rice husk ash and activated charcoal.

It is stated that due to the absence of response of K (H_p) for zeolite and rice husk ash applications at the pressure heads may be ascribed to the increase in the tortuosity of the soil. However, the activated charcoal 2 amended soil had significantly lower hydraulic conductivity values above -100 cm (figure 22). At other pressure heads below -100 cm, activated charcoal had no significant effect on hydraulic conductivity. Differences in results are ascribed to the amount of amendment applied, amendments particle size, and type of soil. There was no significant difference in hydraulic conductivity among all the treatments. Furthermore, in figure 18 and figure 19, relatively good agreement between the simulated and experimental curves for pressure head less than -100 cm is observed.

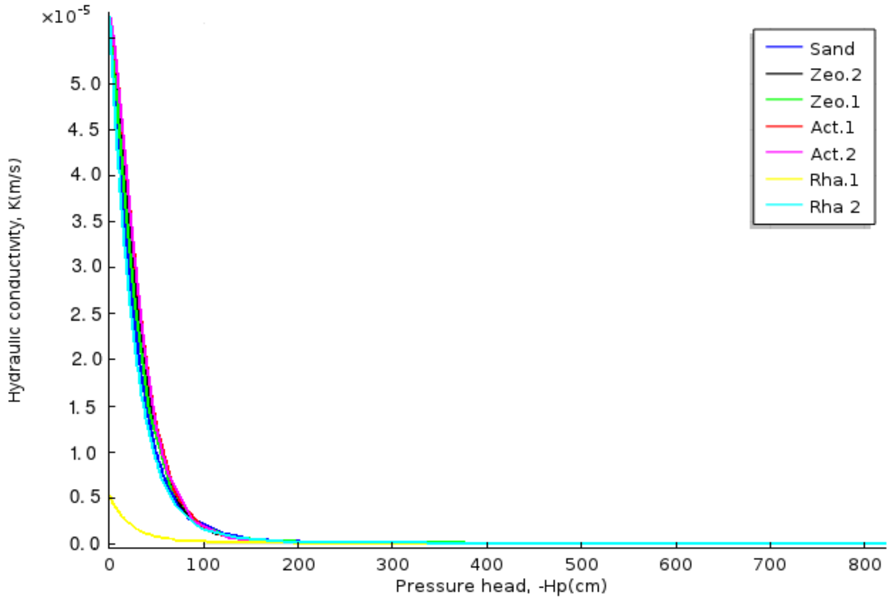

Figure 21: Soil hydraulic conductivity curve (Hydraulic conductivity vrs Pressure head) of zeolite, rice husk ash, and activated charcoal amendments on sandy soil (simulation)

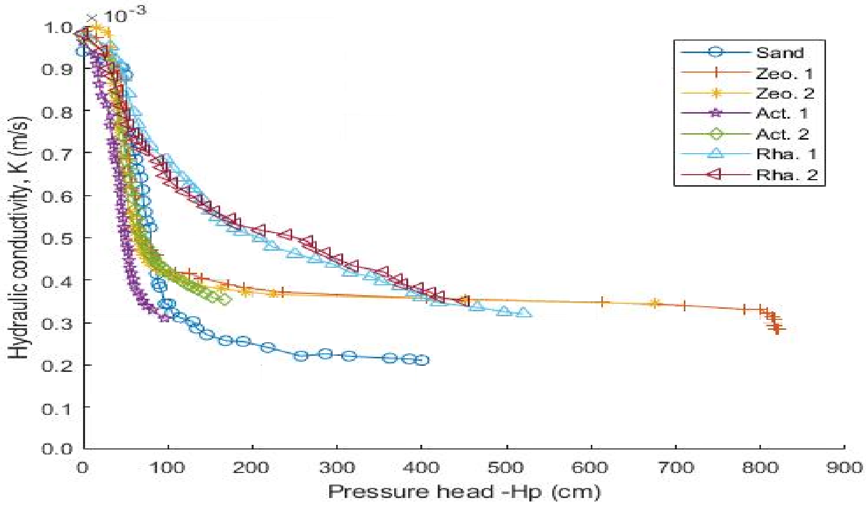

Figure 22: Soil hydraulic conductivity curve (Hydraulic conductivity vrs Pressure head) of zeolite, rice husk ash, and activated charcoal amendments on sandy soil (experiment)

Effects of Soil Amendments on Pressure Head with Time

Results of the changes in pressure head for the soil amended at varying zeolite, activated charcoal, and rice husk ash rates are shown in figure 23. The plot showed an increase in pressure head (positive values) as time elapsed. This is attributed to the fact that water was not refilled during the experiment. The pressure head for the control soil (sand) observes a gradual increase over time but realizes more pressure head after day 26, causing a change in the path of increase and there reaching a height of about 400 cm. This is ascribed to the dominant macro and mesopore systems present in sandy soil. Pressure heads of Act1 and Act 2 observes a smaller height in the water column as compared to the control soil (sand). These samples, with the exception of Zeo2, continue on a steady increasing path throughout the period and therefore recording an increase in pressure head up to about 100 cm. Zeo2 tends to veer off its normal path after day 31 and therefore reaching a pressure head of 700 cm at day 36. Zeo1 follows the behaviour of the control until day 20 when it takes on another drastic increasing path in the height of its water column of about 800 cm by day 36. Little variation was noticed with regards to the mean of soil amendments and that of the control between day 20 and day 32, with the amendments observing and increasing bump during that period. This bump might be due to the high-pressure head attained by Zeo1 as a result of the cavitation. As different soil amendments were applied, these findings also showed higher pressure head values.

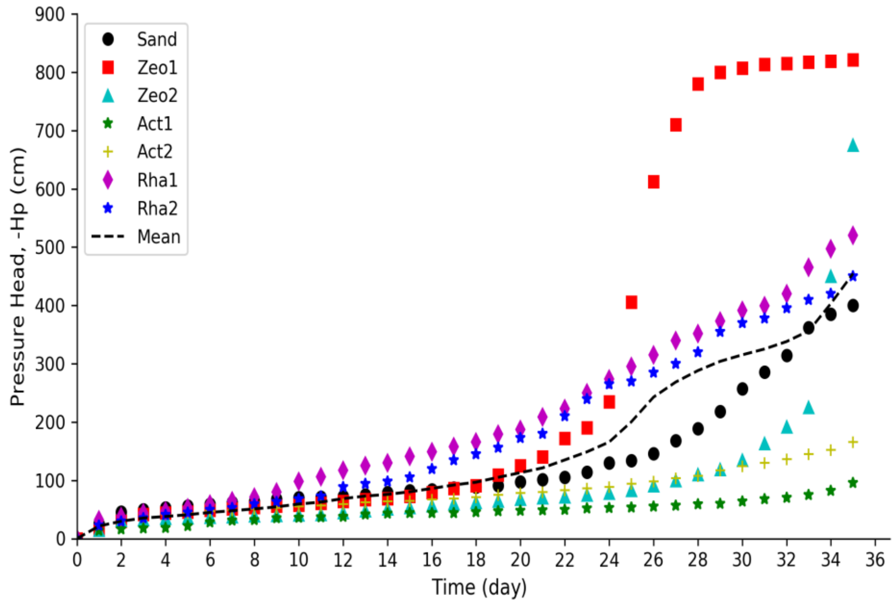

Figure 23: Change in pressure head for sandy soil and soil amended at varying zeolite, activated charcoal, and rice husk ash-treated rates. Dashes represent the mean of soil amendments

Effects of Soil Amendments on Hydraulic Conductivity with Time

A gradual decline is observed in the hydraulic conductivity for 36 days for which data were collected (figure 24). The hydraulic conductivity of the control soil (sand) tends to decrease over a wider range of 0.0007 m/s with Rha1 realizing the narrowest fall of 0.0005 m/s over the period. This is due to the presence of high rich silica content and potash content in rice husk ash. Comparing the hydraulic conductivity of control soil to other soil samples treated with zeolite, activated charcoal, and rice husk, it can be observed that all samples behave similarly to each other. The mean of amended samples decreases at a slower rate as compared to the control soil. Several scientists, including Gardner, have shown that as the water content declined, hydraulic conductivity decreased rapidly. Childs (1957) reported that in the first stages of water content reduction, hydraulic conductivity is very sharply reduced. He related this decline to the effective porosity being decreased by a decrease in water content. This finding is in accordance with (Ghazavi, 2015; Sun et al., 2015; Sun et al., 2013).

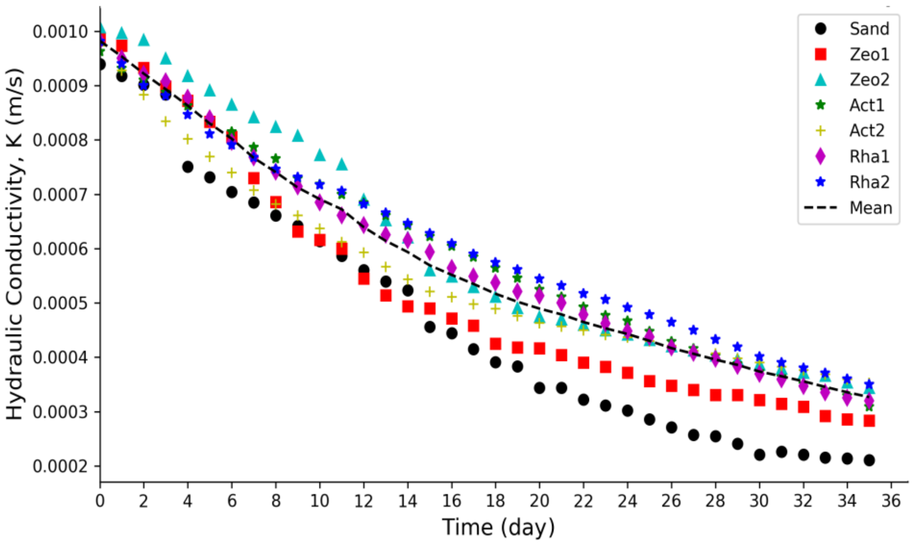

Figure 24: Change in hydraulic conductivity for sandy soil and soil amended at varying zeolite, activated charcoal, and rice husk ash-treated rates. Dashes represent the mean of soil amendments

Effects of Soil Amendments on Water Content with Time

The effects of zeolite, activated charcoal, and rice husk on water content with time are illustrated in figure 25. According to this figure, the water content in soil amendments decreased over 36 days. The rate of change in water content (figure 25) tends to behave similarly to the rate of change in hydraulic conductivity (figure 23). The water content of soil amendments is higher than that of the control (sandy soil) although they all realize a decreasing trend over the period, signifying an increase in the capacity of treated soil with zeolite, activated charcoal, and rice husk in the retention of water in drought and general conditions as compared to control soil (Xiubin & Zhambin, (2001). Similar results are also recorded in Bernardi et al., (2013).

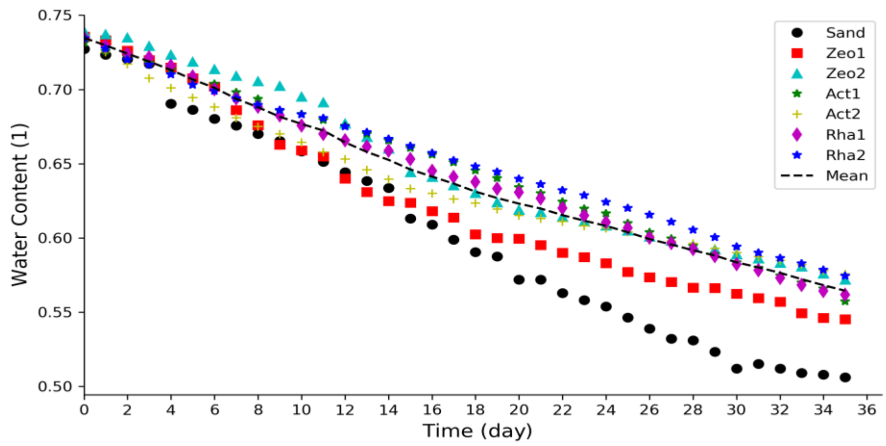

Figure 25: Change in water content for sandy soil and soil amended at varying zeolite, activated charcoal, and rice husk ash-treated rates. Dashes represent the mean of soil amendments

Statistical Analysis

Results of descriptive analysis of soil amendments performance on water content, hydraulic conductivity and pressure head of a sandy soil.

Descriptive Analysis of Soil Amendments Performance on Water Content of a Sandy Soil

The box plot shows the performance of soil amendments on the water content of sandy soil (figure 26). It can be observed that the medians of all the amendments differ slightly from one other. The rest of the summary is presented in Table 6.

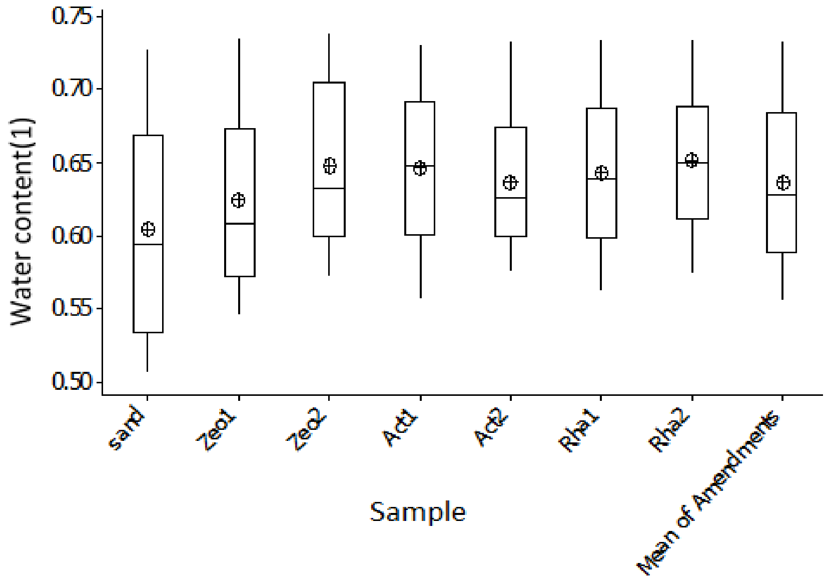

Figure 26: Box plot showing performance of soil amendments on water content of a sandy soil

Table 6: Performance of Soil Amendments on Water Content of a Sandy Soil

Variable	Mean	Standard Deviation	Minimum	Maximum	Skewness
Sand	0.60370	0.07260	0.50610	0.7273	0.21
Zeo1	0.62390	0.06030	0.54520	0.7356	0.53
Zeo2	0.64799	0.05538	0.57200	0.73890	0.33
Act1	0.64662	0.05199	0.55710	0.73140	-0.04
Act2	0.63693	0.04590	0.57570	0.73320	0.59
Rha1	0.64321	0.05228	0.56180	0.73460	0.15
Rha2	0.65110	0.04649	0.57440	0.73450	0.03
Mean of amendments	0.63634	0.05495	0.55604	0.73364	0.27

Table 6 shows the descriptive statistics of soil amendments on water content. It can be observed from the Table 6 that on average, rice husk ash 2 (Rha2) soil has the best performance on water content and only exceeded zeolite 2 (Zeo2) which is followed by 0.00311. These findings agree with Bigelow et al., (2004); Walz et al., 2003; Abel et al., 2013; Glaser et al., 2002). These results are also in agreement with recent results of Ippolito et al., (2011); Xiubin & Zhanbin, (2001) showed an increase in water retention of sandy soil when the zeolite is added**.** Activated charcoal 1 (Act1) followed with an average as small as 0.00137 less than zeolite 2. This is attributed to the particle sizes of the activated charcoal used. However, the Table 6 revealed that rice husk ash 1 (Rha1), activated charcoal 2 (Act1), and the average of combining all the amendments (Mean of amendments) performed better than zeolite 1 (Zeo1). In addition, sand was observed to have the smallest mean (0.60370) which gives a clear indication that all the other amendments have better water retaining ability as compared to sand. These findings also agree with Abel et al., (2013); Feoli et al., 2002; Glaser et al., 2002; Rawls et al., 2003) when rice husk ash, zeolite, and activated charcoal improved water retention of sandy soils. The skewness values for activated charcoal 1 and rice husk ash 2 (-0.04 and 0.03 respectively) are nearly zero and suggest that their observations are normally distributed. High skewness values of zeolite 1 and activated charcoal 2 (0.53 and 0.59 correspondingly) propose that observations in those variables are not entirely normally distributed.

In comparing the variations existing between each variable, it can be observed that sand has the highest dispersion (0.07260) among its observations while activated charcoal 2 has the lowest of 0.04590. The information suggests that activated charcoal 2 has better water retaining capacity as compared to the other amendments. This finding is in support of research conducted by some other authors Szerment et al., (2014) who in their study observed that water content increase when activated charcoal is applied. However, the findings in this research contradict the finding of researchers such as Hardie et al., (2014) who argued that activated charcoal did not improve water retention.

Nevertheless, such an assumption can be misleading, and will therefore be prudent to conduct an Analysis of Variance test to confirm the results. One-way ANOVA was used to determine the significant differences between means of all soil water content characteristics under different zeolite, activated charcoal, and rice husk ash-amended soil treatments.

Let $\mu_0, \mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7$ be the mean performances of sand (control), zeolite 1, zeolite 2, activated charcoal 1, activated charcoal 2, rice husk ash 1, rice husk ash 2, and mean of all the amendments respectively.

$$\mathrm{H}_0 : \mu_0 = \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6 = \mu_7$$

$$\mathrm{H}_i : \mu_i \neq \mu_j, i \neq j$$

Table 7: One way ANOVA for Water Contents in Soil Amendments

Source	DF	SS	MS	F	P
Factor	7	0.06217	0.00888	2.88	0.006
Error	280	0.86418	0.00309		
Total	286	0.92635			

The F – test ($p-$value of 0.006) indicates that there is sufficient evidence (at α = 0.05) to claim that not all the means are equal. However, a follow-up a test using a Tukey 95% simultaneous confidence interval was perform as a check to know which of the means really differed from each other, and to protect against false-positive results. The significant differences between the means were tested using Tukey honestly significant difference test at the 5% level.

Table 8: Tukey 95% Simultaneous Confidence Interval for all Pairwise Comparisons of Water Content in Soil Amendments

Difference of Level	Difference of Means	95% confidence intervals
Zeo1 – Sand	0.0202	(-0.01959, 0.05986)
Zeo2 – Sand	0.04429	(0.00455, 0.08399)
Act1 – Sand	0.04292	(0.00318, 0.08262)
Act2 – Sand	0.03323	(-0.00651, 0.07294)
Rha1 – Sand	0.03951	(-0.00023, 0.07922)
Rha2 – Sand	0.0474	(0.00766, 0.08711)
Mean of Amendments – Sand	0.03264	(-0.00710, 0.07234)

The 95% simultaneous confidence level in Table 8 indicates that the researcher is 95% confident that the interval contains the true differences. The pairs which contain zero in their confidence intervals do not differ from each other. Though the means of zeolite 1, activated charcoal 2, and the average of all the amendments had higher means in water content than sand, the Tukey's simultaneous test shows that the difference is not statistically significant. Since the 95% confidence interval of zeolite 2 and sand (0.00455, 0.08399), activated charcoal 1 and sand (0.00318, 0.08262), and rice husk ash 2 and sand (0.00766, 0.08711) did not contain zero, there is strong evidence that there is a significant difference between each of the pairs. This result is due to the particle sizes of the activated charcoal.

In this normal probability plot (figure 27), the residuals appear to generally follow a straight line. Though a few at the extremes deviate slightly, it can be confirmed that the normality assumption for residuals is not violated, and suggests that the output is reliable.

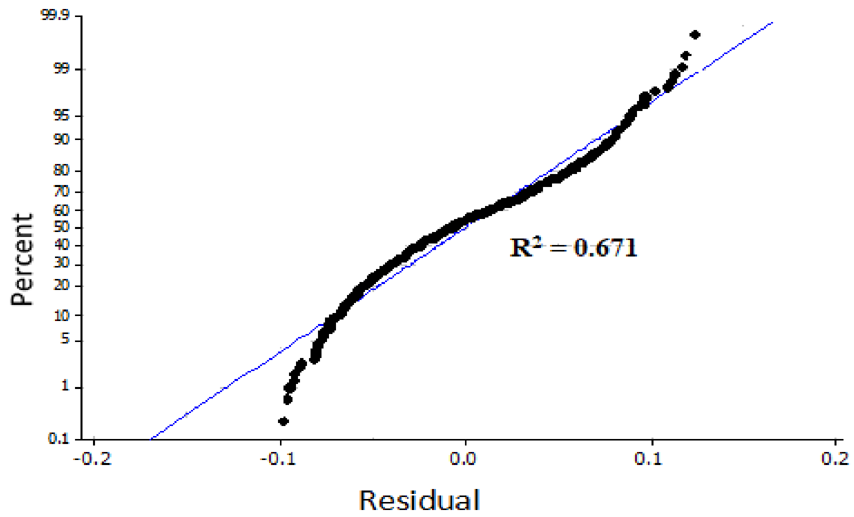

Figure 27: Residual plot of soil amendment of water content of a sandy soil

Descriptive Analysis of Soil Amendments Performance on Hydraulic Conductivity of a Sandy Soil

Figure 28 shows box and whiskers plots of the performance of soil amendments on hydraulic conductivity of sandy soil. The box and whisker plots are explanatory graphs, created by John Tukey, used to show the distribution of the dataset (at glance). It can be observed in figure 28 that the medians of all the amendments differ slightly from each other. The rest of the summary is presented in Table 9.

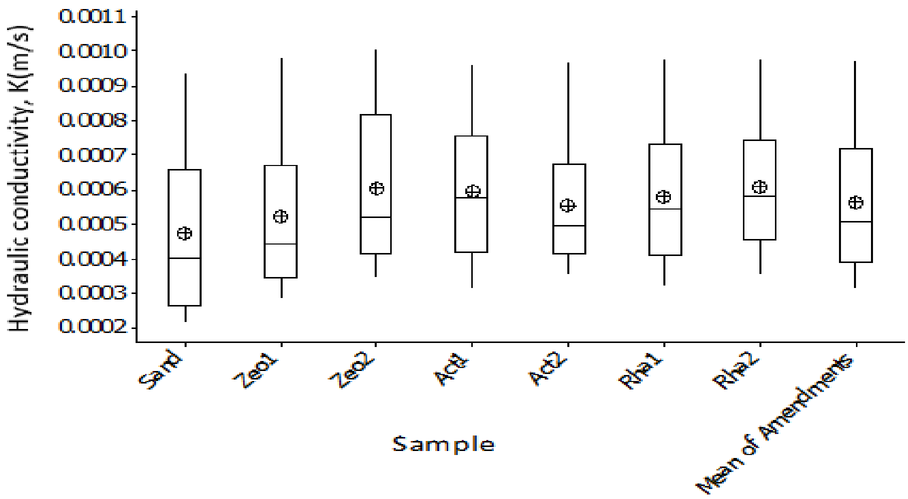

Figure 28: Box plot showing performance of soil amendments on hydraulic conductivity of a sandy soil

Table 9: Performance of Soil Amendments on Hydraulic Conductivity of a Sandy Soil

Variable	Mean	Standard Deviation	Minimum	Maximum	Skewness
Sand	0.000471	0.000231	0.000261	0.000940	0.63
Zeo1	0.000524	0.000220	0.000284	0.000987	0.87
Zeo2	0.000605	0.000220	0.000344	0.001007	0.56
Act1	0.000595	0.000195	0.000309	0.000963	0.30
Act2	0.000555	0.000176	0.000353	0.000973	0.91
Rha1	0.000583	0.000198	0.000320	0.000982	0.52
Rha2	0.000607	0.000180	0.000350	0.000981	0.38
Mean of amendments	0.000563	0.000202	0.000310	0.000976	0.60

Table 9 shows a box and whiskers plot of the performance of soil amendments on hydraulic conductivity. It can be observed that the hydraulic conductivity of rice husk ash 2 had the highest mean of 0.000607. Sand had both the least minimum and maximum hydraulic conductivity. Though all the means varied from one another, they all were barely zero. This gives an empirical suggestion that the difference in means among the various soil amendments may not be significant. Once again, an Analysis of Variance (ANOVA) test will be needed just to avoid a hasty conclusion.

Let $\mu_0, \mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7$ be the mean hydraulic performances of sand (control), zeolite 1, zeolite 2, activated charcoal 1, activated charcoal 2, rice husk ash 1, rice husk ash 2, and average of all the amendments respectively.

$$H_0 : \mu_0 = \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6 = \mu_7$$

$$H_1 : \mu_i \neq \mu_j, i \neq j$$

Table 10: One way ANOVA for Hydraulic Conductivity in Soil Amendments

Source	DF	SS	MS	F	P
Factor	7	0.0000005	0.0000001	1.88	0.072
Error	280	0.0000116	0.0000000		
Total	287	0.0000122			

Since the F – test ($p-$value (0.072) is greater than the significant (α) value of 0.05, we fail to reject the null hypothesis and conclude that the means of hydraulic conductivity of all the amendments were equal. This shows that an equal trend/response was proportionally the same and present for the unamended and amended treatment. These findings is in support of research conducted by some other. Ghazavi, (2015); Behazadfar et al., 2017; Gholizadeh – Sarabi & Sepaskhah, 2013) reported that rice husk ash, zeolite, and activated charcoal amendments do significantly improve the hydraulic conductivity of sandy soil. Similarly, Saeedi & Sepaskhah, 2013; Lim et al.,

2016) in their study observed that hydraulic conductivity does not improve much when zeolite, activated charcoal, and rice husk is applied to sandy soil.

The points on residual plot of soil amendments on hydraulic conductivity of sandy soil in figure 29 generally follow a straight line, though a few at the extremes deviate slightly. It can be confirmed that the normality assumption for residuals is not violated, and suggests that the output is reliable.

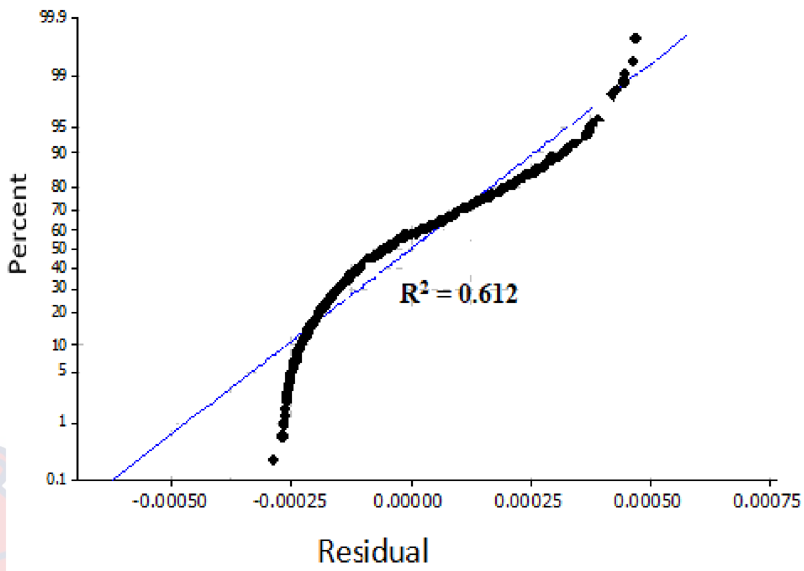

Figure 29: Residual plot of soil amendments' hydraulic conductivity of a sandy soil

Descriptive Analysis of Soil Amendments Performance on Pressure Head of a Sandy Soil

Figure 30 shows the box and whiskers plots of the performance of soil amendments on the pressure head of a sandy soil. It can be observed that the medians of all the amendments differ slightly from each other. The remaining summary is presented in Table 11.

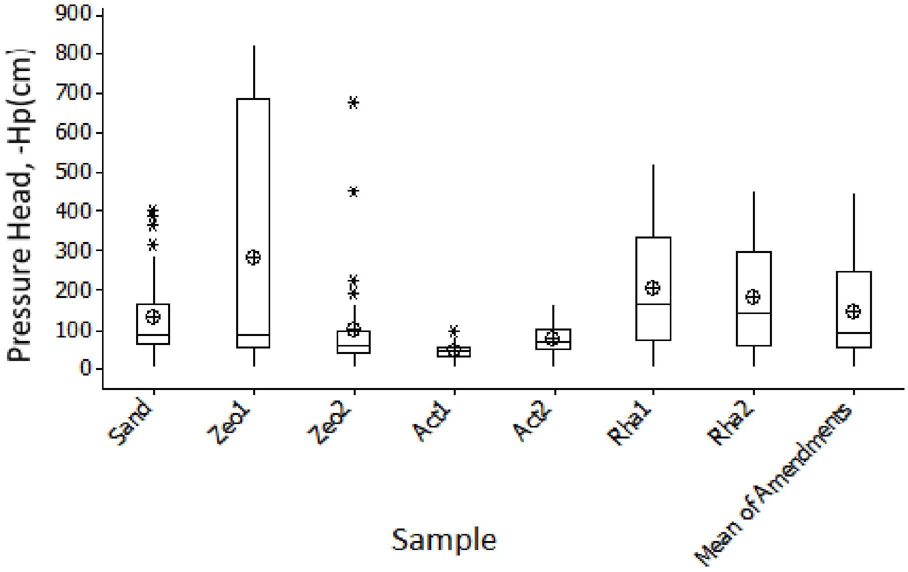

Figure 30: Box plot showing performance of soil amendments on pressure head of a sandy soil

Table 11: Performance of Soil Amendments on a Pressure Head of a Sandy Soil

Variable	Mean	Standard Deviation	Minimum	Maximum	Skewness
Sand	130.3	103.9	0.000	400.0	0.21
Zeo1	283.5	321.6	0.000	821.0	0.53
Zeo2	98.2	126.5	0.000	675.0	0.33
Act1	45.22	20.02	0.000	96.0	-0.04
Act2	78.47	37.55	0.000	166.0	0.59
Rha1	204.7	148.1	0.000	520.0	0.15
Rha2	180.6	137.3	0.000	450.0	0.03
Mean of amendments	145.4	121.4	0.000	446.0	0.27

It can be observed that all the amendments had a minimum value of 0.0cm. A high variation occurred in the amendment of zeolite 1 than the other amendments, and suggest a possible cause of the presence of outliers. Table 11 also shows that zeolite 1 has the best performance in pressure head (283.5) and exceeded rice husk 1, which recorded the next highest, pressure head by a significant value of 78.2. The highest values recorded by zeolite 1 is due to the finer pores and cavitation (Dwi, 2006; Toll et al., 2013). The table 11 however revealed that all the amendments performed significantly better than activated charcoal 1. This observation is due to the particle sizes of the activated charcoal. Only activated charcoal 1 and rice husk 2 had skewness values closer to zero and suggests that there is a significant shift in the values of the other soil amendments. The information suggests that empirically, zeolite 1 performed significantly better. These results are in agreement with recent results of Ippolito et al., (2011); Xiubin & Zhanbin, 2001) which stated that zeolite retains more water in sandy soil for a longer time hence increase in pressure head values. It further observation suggested that activated charcoal 1, activated charcoal 2, and zeolite 2 are evenly distributed. Nevertheless, an assenting test should be run to compare the significant differences in the means.

Let $\mu_0, \mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7$ be the mean hydraulic performances of sand (control), zeolite 1, zeolite 2, activated charcoal 1, activated charcoal 2, rice husk ash 1, rice husk ash 2, and average of all the amendments respectively.

$$\mathrm{H}_0 : \mu_0 = \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6 = \mu_7$$

$$\mathrm{H}_1 : \mu_i \neq \mu_j, i \neq j$$

Table 12: One way ANOVA for Pressure Head in Soil Amendments

Source	DF	SS	MS	F	P
Factor	7	1468649	209807	8.95	0.000
Error	280	6564356	23444		
Total	287	8033005			

The F – test ($p-$value of 0.000) shows that there is an ample evidence (at α = 0.05) to claim that not all the means are equal. However, a follow up test using a Tukey 95% simultaneous confidence interval was perform as a checked to know which of the means really differed from each other, and to protect against false positive results.

Table 13: Tukey 95% Simultaneous Confidence Interval for all Pairwise Comparisons of Pressure Head in Soil Amendments

Difference of Level	Difference of Means	95% confidence intervals
Zeo1 – Sand	153.2	(43.7, 262.7)
Zeo2 – Sand	-32.1	(-141.6, 77.4)
Act1 – Sand	-85.08	(-194.6, 24.4)
Act2 – Sand	-51.83	(-161.3, 57.6)
Rha1 – Sand	74.4	(-35.1, 183.8)
Rha2 – Sand	50.3	(-59.1, 159.8)
Mean of amendments – Sand	15.1	(-94.4, 124.5)

Table 13 indicates that the researcher is 95% confidence that the interval contains true differences. The pairs, which contains zero in their confidence intervals, do not differ significantly from each other. On the other hand, pairs, which do not contain zero in their confidence interval, differ significantly from each other. In comparing sand to all the amendments, it can be realized that only zeolite 1 differed significantly from sand, which indicates that the pressure head of sand, zeolite 2, activated charcoal 1, activated charcoal 2, rice husk ash 1, and rice husk ash 2, and the average of all the amendments were the same.

The points on residual plot of soil amendments of pressure head of sandy soil in figure 31 do not generally follow a straight line. This could be due to the presence of many outliers. Nevertheless, since the deviation is not very great, it can be confirmed that the normality assumption for residuals is barely violated, and suggests that the output is reliable.

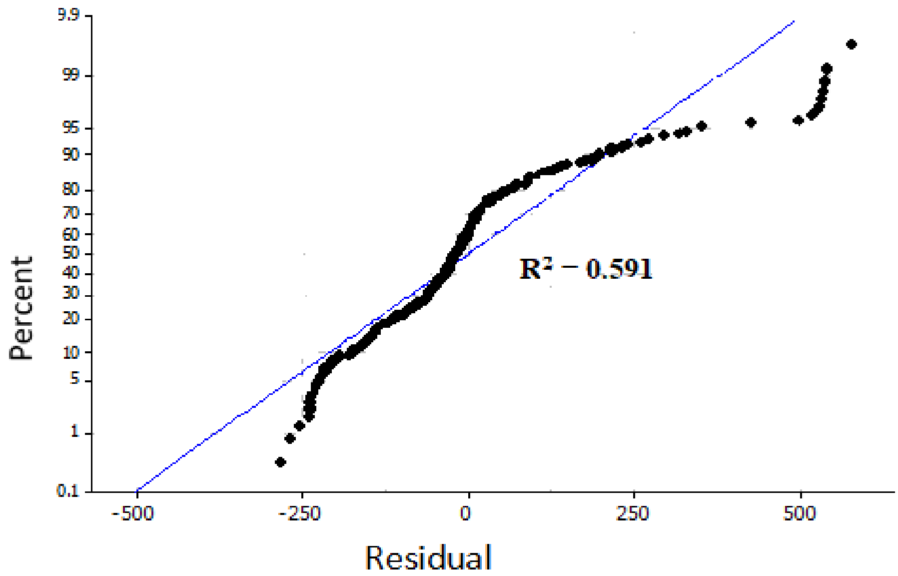

Figure 31: Residual plot of soil amendments' pressure head of a sandy soil

Chapter Summary

In this chapter, results from soil amended samples using COMSOL Multiphysics software and laboratory (evaporation) methods have been presented and discussed. The physical properties, water retention curve and hydraulic conductivity parameters considered under zeolite, activated charcoal, and rice husk ash soil amendments showed good improvements in the sandy soil. The results obtained from each of the methods were compared. Descriptive analysis of soil amendments performance on water content, hydraulic conductivity, and pressure head of a sandy soil was also done using statistical tools such as Tukey's software and ANOVA. Finally, results of the soil amendments used on the sandy soils sample show that zeolite, activated charcoal, and rice husk ash can be used to amend any other soil. They can be considered environmentally friendly and cost effective.

CHAPTER FIVE

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Overview

The effect of zeolite, activated charcoal, and rice husk ash on soil physical properties, water retention curve, and hydraulic properties of sandy soils was carried out using the COMSOL Multiphysics model and the laboratory method. This chapter will focus on the conclusions made with regards to the simulation and experimental results obtained in the study. The recommendations and pertinent suggestions made in relation to the study will be addressed as well.

Summary

The thesis is composed of five main chapters. In Chapter One, a background to the study and an introduction to the simulation using COMSOL Multiphysics was discussed. The general and specific objective (s) as well as the scope of the work and the organization of the thesis were also discussed. Chapter Two reviewed literature on soil physical, hydraulic properties, water retention, soil amendments, COMSOL Multiphysics and the principles underlying the theory used in the study. In Chapter Three, a COMSOL Multiphysics model was used to simulate the water retention curve, physical, and hydraulic properties. The results, analysis, and discussion on the simulation, and experimental work were presented graphically in Chapter Four. In this Chapter, the conclusions and pertinent suggestions are drawn from the study and recommendations made to understand the importance of the COMSOL Multiphysics model are presented.

Conclusions

The main objective of this study had been to simulate and estimate soil physical, water retention curve, and hydraulic properties of sandy soil for scenarios with and without soil amendment applications. The study which has been conducted using the COMSOL Multiphysics and evaporation methods indicated that the simulation curves showed a relatively good agreement with the experimental curves (see relevant plots). An advantage of the proposed method (COMSOL Multiphysics) is that it mimics the real situation in the fields efficiently. Furthermore, this method is cheaper and possibly easier to use than the laboratory method since the COMSOL Multiphysics software is based on Multiphysics concepts.

The simulation result testified the small but significant changes in the soil physical, water retention, and hydraulic properties brought by the application of zeolites, activated charcoal, and rice husk ash, like the higher water content, proposing that the application of soil amendments to sandy soil confirms several benefits in terms of improvement of the physical, water retention, and hydraulic properties. Moreover, the simulation results indicated that the addition to the top layer of a relatively small amount of activated charcoal, rice husk ash, and zeolite behave as a slow-release source of nutrients.

Comparing our observation using simulation, the water retention, and hydraulic properties curve is consistent with our observations from the experiment conducted in the laboratory during the period. Soil physical, water retention, and hydraulic properties of soils have been observed as critical in plant growth which influences crop yield. From this work, we can draw conclusion that the simulation method could be used to mimics the real situation in the fields and compare them with the experimental results. This study further demonstrates that amending soil with activated charcoal, rice husk ash, and zeolite can modify the physical, water retention, and hydraulic properties of the soil and ultimately can be an adequate technique for decreasing chemical fertilizer application rates and improving the sustainability of agricultural systems. We conclude further that amending sandy soil with zeolite, activated charcoal, and rice husk ash significantly improve the physical, water retention, and hydraulic properties of sandy soil, and increased water content. These results suggest there are multiple benefits of amended sandy soil in terms of improvement of the physical, water retention, and hydraulic properties of sandy soil. This work could be extended to other soils. Thus, it is concluded that in the case of limited water availability, rice husk ash, zeolite, and activated charcoal in combination with deficit irrigation should be the people of Keta and University of Cape Coast practiced as a strategy for conserving water and enhancing crop productivity, hence, improving crop water use efficiency.

Recommendations

Based on the conclusions of the study, the study recommends the following suggestions to the farmers, agronomists, and agriculturalists. It is possible to extend the time since in this study the experiments were conducted for 36 days which might not be long enough to better find out how the soil amendments affected the sandy It also actually see the long-term effect of zeolite, activated charcoal, and rice husk ash on soil chemical, physical, water retention, and hydrological properties.

Further studies are recommended to well understand the influence of soil amendments particle sizes, the rate of applications, the types of feedstock used and time of interaction, on physical, water retention, and hydraulic conductivity of soils.

Furthermore, more work can be done on the soil amendments since the use of zeolite, activated charcoal, rice husk ash in agriculture has recently been considered as an obvious solution, that when added to the soil can combat climate change and simultaneously contribute to the improvement of sandy soils properties. Lastly, further work can also be done by increasing the dosage of zeolite, activated charcoal, and rice husk ash amendments.

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APPENDICES

APPENDIX A: VALUES OF PRESSURE HEAD OF SANDY SOIL AND VARIOUS SOIL AMENDMENTS

Hp sand (-cm)	Hp zeo.1 (-cm)	Hp zeo.2 (-cm)	Hp ac 1 (-cm)	Hp ac 2 (-cm)	Hprha1 (-cm)	Hprha 2 (-cm)
0	0	0	0	0	0	0
26	15	15	14	31	32	23
46	30	31	16	34	38	30
50	42	33	18	40	44	35
53	44	35	19	42	47	41
56	46	36	22	44	53	45
59	49	37	28	47	59	50
62	51	38	31	49	65	53
64	54	39	32	51	71	59
68	56	40	35	53	80	63
70	58	41	36	55	98	68
71	61	42	37	57	106	73
73	64	45	38	59	117	89
75	67	48	42	62	125	94
79	69	51	43	64	130	98
82	73	54	44	65	141	105
84	79	57	44	67	149	120
87	86	60	44	69	158	135
89	91	62	46	71	166	145
91	109	65	47	75	179	156
97	125	68	48	78	187	173
101	140	70	49	80	209	180
105	172	72	50	83	223	210
114	190	75	52	86	250	240
130	235	78	53	89	274	265
134	406	83	54	94	295	270
146	612	91	55	98	315	285
168	710	100	57	104	340	300
189	780	110	59	108	352	320
218	800	119	60	117	373	355
257	807	135	64	124	391	370
286	813	163	68	130	399	378
314	815	192	70	136	420	395
362	817	225	75	145	465	410
385	819	450	82	152	497	420
400	821	675	96	166	520	450

APPENDIX B: VALUES OF WATER CONTENT OF SANDY SOIL AND VARIOUS SOIL AMENDMENTS

θ sand (1)	θ zeo.1 (1)	θ zeo.2 (1)	θ ac.1 (1)	θ ac.2 (1)	θ rha1 (1)	θ rh2 (1)
0.7273	0.7356	0.7389	0.7314	0.7332	0.7346	0.7345
0.7234	0.7332	0.7371	0.7259	0.7252	0.7292	0.7274
0.7204	0.7261	0.735	0.722	0.717	0.7241	0.7201
0.7172	0.7198	0.7292	0.7179	0.7076	0.7215	0.7167
0.6905	0.7149	0.7234	0.7132	0.7011	0.716	0.7101
0.6863	0.7075	0.7186	0.7079	0.6944	0.7087	0.703
0.6802	0.7019	0.7136	0.7038	0.6881	0.7001	0.699
0.6758	0.686	0.7092	0.698	0.6809	0.6941	0.6941
0.6701	0.6759	0.7056	0.6936	0.6751	0.6884	0.6894
0.6654	0.6629	0.7024	0.6857	0.67	0.6824	0.6862
0.6583	0.6589	0.6951	0.6834	0.6643	0.6757	0.6831
0.6513	0.6548	0.6914	0.6792	0.6579	0.6701	0.6806
0.6443	0.6399	0.677	0.6755	0.653	0.6657	0.675
0.6384	0.6309	0.6681	0.6701	0.6459	0.6614	0.6712
0.6337	0.6248	0.6602	0.6656	0.6395	0.6587	0.6666
0.613	0.6238	0.6442	0.6606	0.6331	0.6531	0.6620
0.609	0.618	0.6411	0.6561	0.6301	0.6452	0.6572
0.5989	0.6137	0.6354	0.6508	0.6262	0.6411	0.6521
0.5904	0.6024	0.6302	0.6453	0.6234	0.6377	0.648
0.5874	0.6000	0.6239	0.6401	0.6194	0.6331	0.6444
0.5719	0.5996	0.619	0.6341	0.6151	0.6308	0.6397
0.5719	0.5951	0.6174	0.6300	0.6131	0.6267	0.6362
0.5628	0.5901	0.6143	0.6244	0.611	0.6201	0.632
0.5582	0.5871	0.611	0.6196	0.6081	0.615	0.6287
0.5539	0.5829	0.6082	0.6164	0.6065	0.6105	0.6241
0.5464	0.5771	0.6049	0.6100	0.6041	0.6068	0.6201
0.5390	0.5734	0.6009	0.6039	0.6012	0.6001	0.6156
0.5320	0.5704	0.5982	0.5994	0.598	0.5965	0.6108
0.5310	0.5664	0.5949	0.5945	0.5963	0.5925	0.6053
0.5234	0.5663	0.5923	0.5891	0.5930	0.5878	0.6004
0.5119	0.5623	0.5889	0.5835	0.5901	0.5822	0.5941
0.5151	0.5594	0.5861	0.5799	0.5872	0.5783	0.5900
0.5119	0.5569	0.5831	0.5747	0.5847	0.5731	0.5864
0.5090	0.5493	0.5808	0.5699	0.5819	0.5683	0.5827
0.5080	0.5462	0.5759	0.5657	0.5781	0.5642	0.5785
0.5061	0.5452	0.572	0.5571	0.5757	0.5618	0.5744

APPENDIX C: VALUES OF HYDRAULIC CONDUCTIVITY OF SANDY SOIL AND VARIOUS SOIL AMENDMENTS

K sand (m/s)	K zeo.1 (m/s)	K zeo.2 (m/s)	K ac.1 (m/s)	K ac.2 (m/s)	K rha 1 (m/s)	K rha 2 (m/s)
0.00094	0.000987	0.001007	0.000963	0.000973	0.000982	0.000981
0.000918	0.000973	0.000996	0.000932	0.000928	0.00095	0.00094
0.000901	0.000933	0.000984	0.00091	0.000883	0.000922	0.00090
0.000884	0.000898	0.00095	0.000888	0.000834	0.000907	0.000881
0.000751	0.000872	0.000918	0.000863	0.000801	0.000878	0.000847
0.000732	0.000833	0.000892	0.000835	0.000769	0.00084	0.000811
0.000704	0.000805	0.000865	0.000815	0.00074	0.000797	0.000791
0.000685	0.00073	0.000842	0.000786	0.000707	0.000768	0.000768
0.000661	0.000686	0.000824	0.000765	0.000682	0.000741	0.000746
0.000642	0.000632	0.000808	0.000729	0.000661	0.000714	0.000731
0.000613	0.000616	0.000772	0.000718	0.000637	0.000685	0.000717
0.000587	0.0006	0.000755	0.0007	0.000612	0.000661	0.000706
0.000561	0.000545	0.00069	0.000684	0.000593	0.000643	0.000682
0.00054	0.000514	0.000653	0.000661	0.000567	0.000626	0.000666
0.000523	0.000494	0.000621	0.000643	0.000543	0.000615	0.000647
0.000456	0.00049	0.00056	0.000622	0.000521	0.000593	0.000628
0.000444	0.000472	0.000549	0.000605	0.000511	0.000564	0.000609
0.000415	0.000458	0.000529	0.000585	0.000498	0.000549	0.00059
0.000391	0.000425	0.000511	0.000564	0.000489	0.000537	0.000574
0.000383	0.000418	0.000491	0.000546	0.000476	0.000521	0.000561
0.000344	0.000417	0.000475	0.000525	0.000463	0.000513	0.000544
0.000344	0.000404	0.00047	0.000511	0.000457	0.0005	0.000532
0.000322	0.00039	0.00046	0.000492	0.00045	0.000478	0.000518
0.000312	0.000382	0.00045	0.000477	0.000441	0.000462	0.000506
0.000302	0.000371	0.000442	0.000467	0.000437	0.000449	0.000491
0.000286	0.000357	0.000432	0.000447	0.00043	0.000438	0.000478
0.000271	0.000347	0.00042	0.000429	0.000421	0.000418	0.000464
0.000257	0.00034	0.000413	0.000416	0.000412	0.000408	0.00045
0.000255	0.000331	0.000404	0.000402	0.000407	0.000397	0.000433
0.000241	0.00033	0.000396	0.000388	0.000398	0.000384	0.000419
0.000221	0.000321	0.000387	0.000373	0.00039	0.00037	0.000401
0.000226	0.000314	0.00038	0.000364	0.000383	0.00036	0.00039
0.000221	0.000309	0.000372	0.000351	0.000376	0.000347	0.000381
0.000216	0.000292	0.000366	0.000339	0.000369	0.000335	0.000371
0.000214	0.000286	0.000354	0.000329	0.000359	0.000325	0.00036
0.000211	0.000284	0.000344	0.000309	0.000353	0.00032	0.00035