ACKNOWLEDGEMENT

I acknowledgement my deep sincere gratitude with pleasure to my guide Mr.KUNHI MOOSA sir for his help and guidance his valuable guidance and encouragement has accomplished to achieve the knowledge of this seminar turned to unforgettable educational experience for me concerned.

I express my sincere gratitude to all other teaching and non-teaching staff of Civil Engineering Department with pleasure for whole hearted co-operations

Contents

ABSTRACT

Biochar has been used as an environment-friendly enhancer to improve the hydraulic properties (e.g. suction and water retention) of soil. However, variations in densities alter the properties of the soil–biochar mix. Such density variations are observed in agriculture (loosely compacted) and engineering (densely compacted) applications. The influence of biochar amendment on gas permeability of soil has been barely investigated, especially for soil with different densities. The major objective of this study is to investigate the water retention capacity, and gas permeability of biochar-amended soil (BAS) with different biochar contents under varying degree of compaction (DOC) conditions. In-house produced novel biochar was mixed with the soil at different amendment rates (i.e. biochar contents of 0%, 5% and 10%). All BAS samples were compacted at three DOCs (65%, 80% and 95%) in polyvinyl chloride (PVC) tubes. Each soil column was subjected to drying–wetting cycles, during which soil suction, water content, and gas permeability were measured. A simplified theoretical framework for estimating the void ratio of BAS was proposed. The experimental results reveal that the addition of biochar significantly decreased gas permeability kg as compared with that of bare soil (BS). However, the addition of 5% biochar is found to be optimum in decreasing kg with an increase of DOC (i.e. kg,65% ¿ kg,80% ¿ kg,95%) at a relatively low suction range (¡ 200 kPa) because both biochar and compaction treatment reduce the connected pores

List of Figures

Chapter 1

INTRODUCTION

Recent studies have engrossed in converting the agricultural and industrial wastes into biochar and using them to improve fertility and engineering properties of soil. (Addition of biochar to the soil can also improve its water retention and hence reduce the consumption of water in agricultural applications. The soils are usually compacted at around 65% degree of compaction (DOC) (i.e. 65% of the maximum dry unit weightand thus are more permeable and help to transport air and nutrients

On the other hand, previous literature has shown that amendment of biochar can improve the water retention of a dense soil (i.e. over 90% DOC) .Such high densities are often required in geotechnical infrastructures, such as man-made slopes, compacted embankments, and landfill covers. The soil used in landfills is more impermeable than those in other engineering structures for preventing the infiltration of leachate into the waste . and reducing the emission of greenhouse gases (CO2 and methane) into the atmosphere . Overall, gas permeability is an important property of soil (;), which is related to void space or DOC . Usually, the application of biochar to a loose soil may increase its gas permeability due to the porous structure of biochar, which results in the decrease in bulk density of biochar-amended soil (BAS) and increase in total porosity .

On the contrary, found that the addition of biochar can reduce gas permeability of compacted soils by 50%–65%. Moreover, organic particles of biochar enhance the bonding between large particles . There is a lack of systematic study on effects of DOC (i.e. dense and loose soils) on gas permeability and water retention properties of BAS. This study aims at providing an improved insight into this issue and clarifying soil–biochar–water interactions at different DOCs for agriculture and engineering applications.

In addition to improving soil properties, biochar production and its usage in agriculture and geo technical applications can help to manage waste. Biochar can be produced from various wastes and feed stocks, such as pig manure, wood, poultry litter, and crop residues . Water hyacinth is an invasive weed that is spread throughout the world ,especially in southern China, Thailand, and India, where the governments have been spending a huge amount of money on its control .Water hyacinth is rich in cellulose, making it a favorable material for biochar production .Therefore, it is important to explore the possible use of biochar obtained from water hyacinth in engineered and agricultural soils. The usage of water hyacinth can help to create micro-industries and hence increase income in rural areas (), where such invasive weeds are abundantly found.

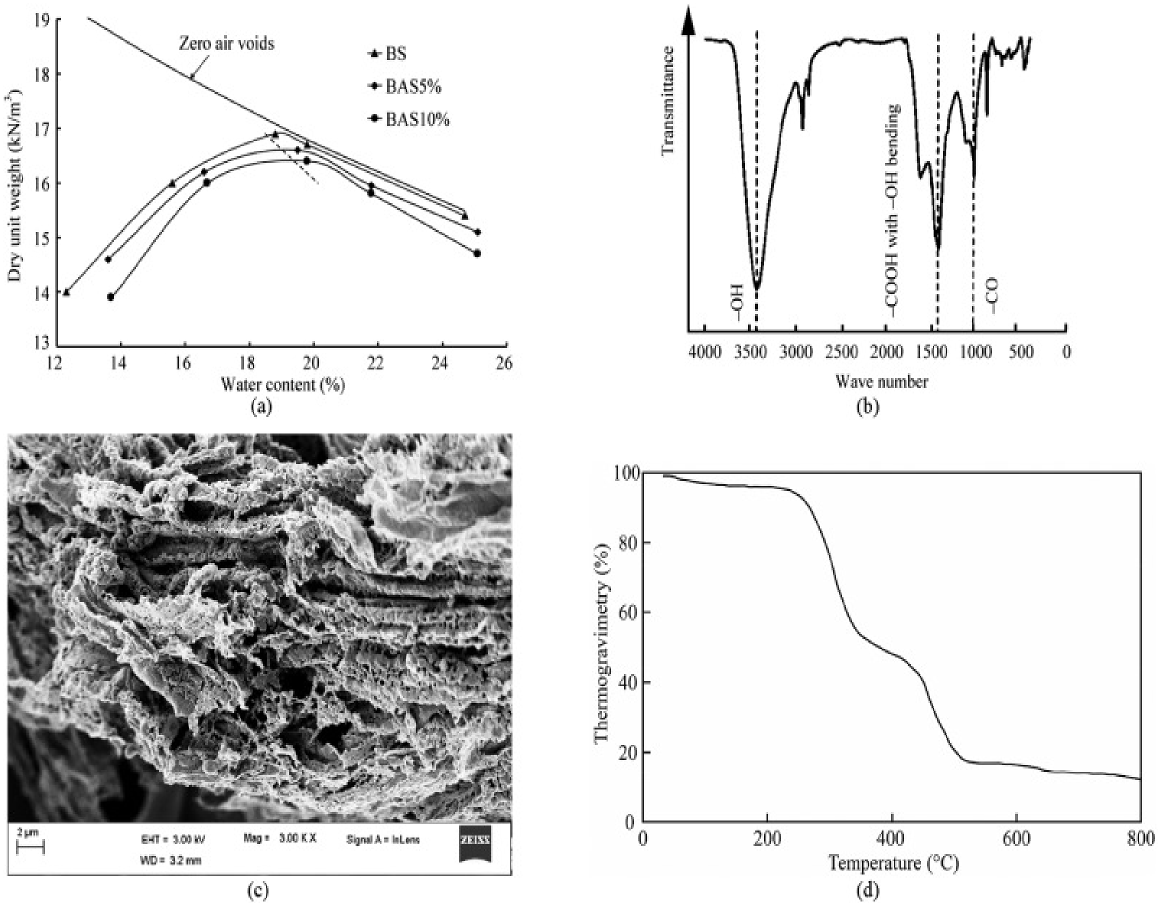


Figure 1.1: Fig. 1. (a) Compaction curves of BS and BAS; (b) FTIR analysis for biochar; (c) FE-SEM images for biochar; and (d) Thermogravimetric analysis of water hyacinth in the current study.

The major objective of this study is to investigate the effect of biochar addition and DOC on the soil–water characteristic curve (SWCC) and gas permeability. For this purpose, in-house produced biochar was amended to the soil at 0%, 5% and 10% (by weight) and compacted in fabricated columns under three DOCs (65%, 80% and 95%). All soil columns were subjected to a 49-d monitoring period, consisting of 42-d drying and 7-d wetting. The soil suction, moisture content, and gas permeability were measured during the testing period. Furthermore, a theoretical model was developed to comprehend the mechanism of soil–biochar interaction at different DOCs (i.e. void ratio). The outcome of this study helps to understand soil–biochar–water interactions at varying DOC for engineering applications.

Chapter 2

BIOCHAR

2.1 what biochar is and how it is produced

Biochar is a type of charcoal that is produced through the process of pyrolysis. It is made by heating organic matter, such as wood chips, agricultural waste, or other organic materials, in the absence of oxygen. The heat breaks down the organic matter into a form of carbon that is more stable and resistant to decomposition, resulting in the production of biochar.

Pyrolysis is typically carried out in a specialized reactor or kiln, which is designed to control the temperature and airflow conditions to ensure that the organic matter is converted into biochar in a safe and efficient manner. The production process can vary depending on the feedstock being used and the desired properties of the final product. Biochar has a number of beneficial properties, including its ability to retain moisture, increase soil aeration, and provide a long-lasting source of plant nutrients. Additionally, the production of biochar can also help to reduce greenhouse gas emissions by sequestering carbon in the soil and decreasing the amount of carbon released into the atmosphere through the decomposition of organic matter.

In conclusion, biochar is a type of charcoal produced through the process of pyrolysis. It is made by heating organic matter in the absence of oxygen to produce a form of carbon that is more stable and resistant to decomposition. The production of biochar has a number of benefits, including improved soil fertility, reduced greenhouse gas emissions, and improved soil health.

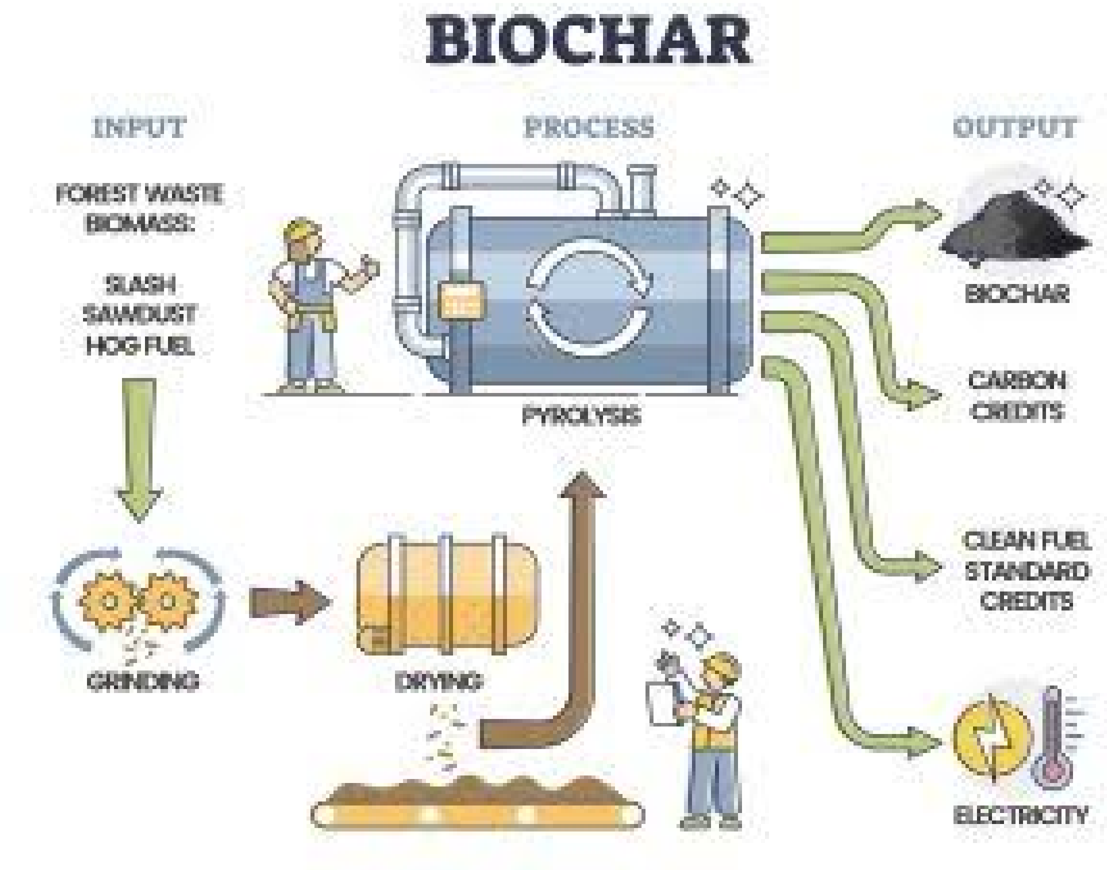


Figure 2.1: Fig. 2

2.2 why biochar is being added to soil, including its potential to improve soil fertility and reduce greenhouse gas emissions.

Biochar is being added to soil for a number of reasons, including its potential to improve soil fertility and reduce greenhouse gas emissions. Some of the key reasons include: Soil fertility improvement: Biochar has been shown to improve soil fertility by providing a long-lasting source of plant nutrients and improving soil structure. Biochar has a high surface area, which makes it an effective adsorbent for retaining moisture, nutrients, and other soil additives. This can help to reduce nutrient leaching and increase plant uptake of these essential elements.

Climate change mitigation: By sequestering carbon in the soil, the addition of biochar can help to reduce greenhouse gas emissions and mitigate the effects of climate change. Biochar is a form of stable carbon that can persist in the soil for hundreds to thousands of years, making it a valuable tool for reducing the amount of carbon in the atmosphere and mitigating the impacts of climate change.

Waste management: The production of biochar provides a means of managing waste, such as agricultural and forestry residues, and converting it into a valuable soil amendment. This can help to reduce the amount of organic waste that is sent to landfills, where it can emit greenhouse gases, and provide a more sustainable solution for managing these materials.

Improved soil health: Biochar has been shown to improve soil health by promoting soil biodiversity and increasing the populations of beneficial soil microorganisms. Biochar provides a substrate for these organisms, which can help to improve soil structure, increase nutrient cycling, and reduce the impact of soil-borne pathogens.

In conclusion, soil amendment with biochar has the potential to provide a number of benefits, including improved soil fertility, reduced greenhouse gas emissions, and improved soil health. The use of biochar in agriculture and forestry can help to provide a more sustainable solution for managing organic waste and reducing the impacts of climate change.

Chapter 3

MATERIALS AND METHOD

3.1 In-house biochar production and preparation of soil–biochar composites

Biochar used in the present study was produced from water hyacinth collected from a local pond in Shantou, China. The collected water hyacinth was preliminarily treated by cutting roots and leaves, and stems were retained for production of biochar. Subsequently, the treated water hyacinth was air-dried to remove the available free water for efficient pyrolysis. The water hyacinth biochar was produced in a pyrolysis furnace at 600 °C under zero-oxygen supply. Thermogravimetric analysis (TGA) of dried water hyacinth is shown in Fig. 1d, which yields around 20% of the product at 600 °C pyrolysis. Water hyacinth (mainly contains cellulose) breaks down when heated at 240 °C–350 °C, while higher temperature (600 °C) results in higher specific surface area and porosity of biochar (Liu et al., 2015). To understand the physical and chemical properties of biochar, field emission scanning electron microscopy (FE-SEM) and Fourier transform infra-red (FTIR) tests were conducted. The SEM images and FTIR analysis of a novel biochar produced are shown in Fig. 1. While SEM images suggest a very porous surface with numerous nano-pores and very high specific surface area (Bordoloi et al., 2018), FTIR analysis indicates three major surface functional groups (i.e. –OH, –COOH and –CO, as shown in Fig. 1b), which are hydrophilic. In the current study, biochar particles passing through 0.425 mm sieve were considered for experimentation.

The soil used in this study was collected from Shantou University, China. American Society for Testing and Materials (ASTM) standards were used to determine the geotechnical properties of the soil, as summarized in Table 1. Table 1 shows that the soil is dominated by coarse sand, and the major particle sizes are in the range of 1.18–2.36 mm and 2.36–4.75 mm (29.7% and 50%, respectively). The soil can be categorized as SP (poorly graded sand) according to the Unified Soil Classification System (USCS) (ASTM D2487-17, 2017). The compaction curves of bare soil (BS) and BAS with different biochar contents are presented in Fig. 1a. The maximum dry unit weight (MDUW) and optimum moisture content (OMC) of soil are found to be 16.9 kN/m3 and 18.8%, respectively. With an increase in biochar up to 5% and 10%, MDUW decreases by 1.8% and 2.4%, respectively. On the other hand, OMC increases by 3.7% and 5.3% with an increase in biochar by 5% and 10%, respectively. This is because the biochar particles are much lighter (i.e. very low specific gravity) as compared to that of soil. Thus, MDUW is expected to decrease when biochar particles replace the soil in a given volume (Bordoloi et al., 2018, Ni et al., 2020). The OMC increases due to high water adsorption properties of biochar (Reddy et al., 2015).

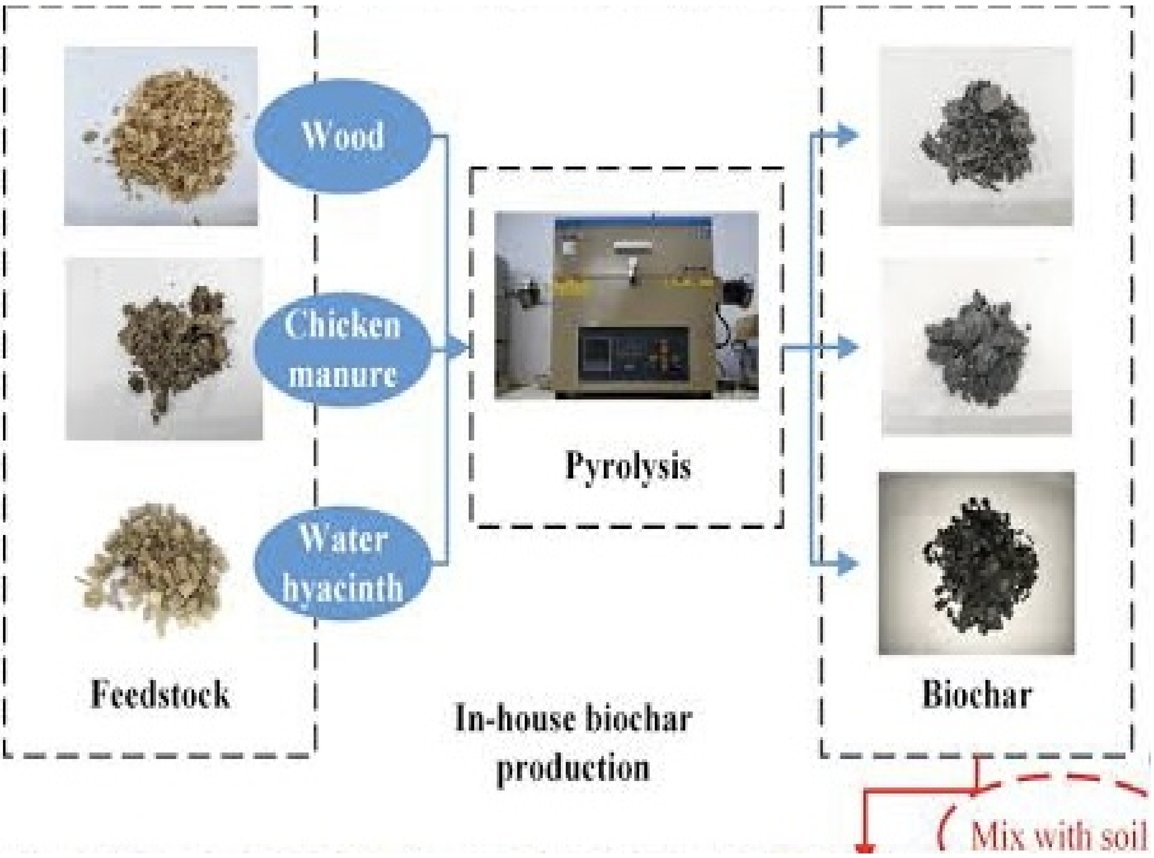


Figure 3.1: Fig. 3

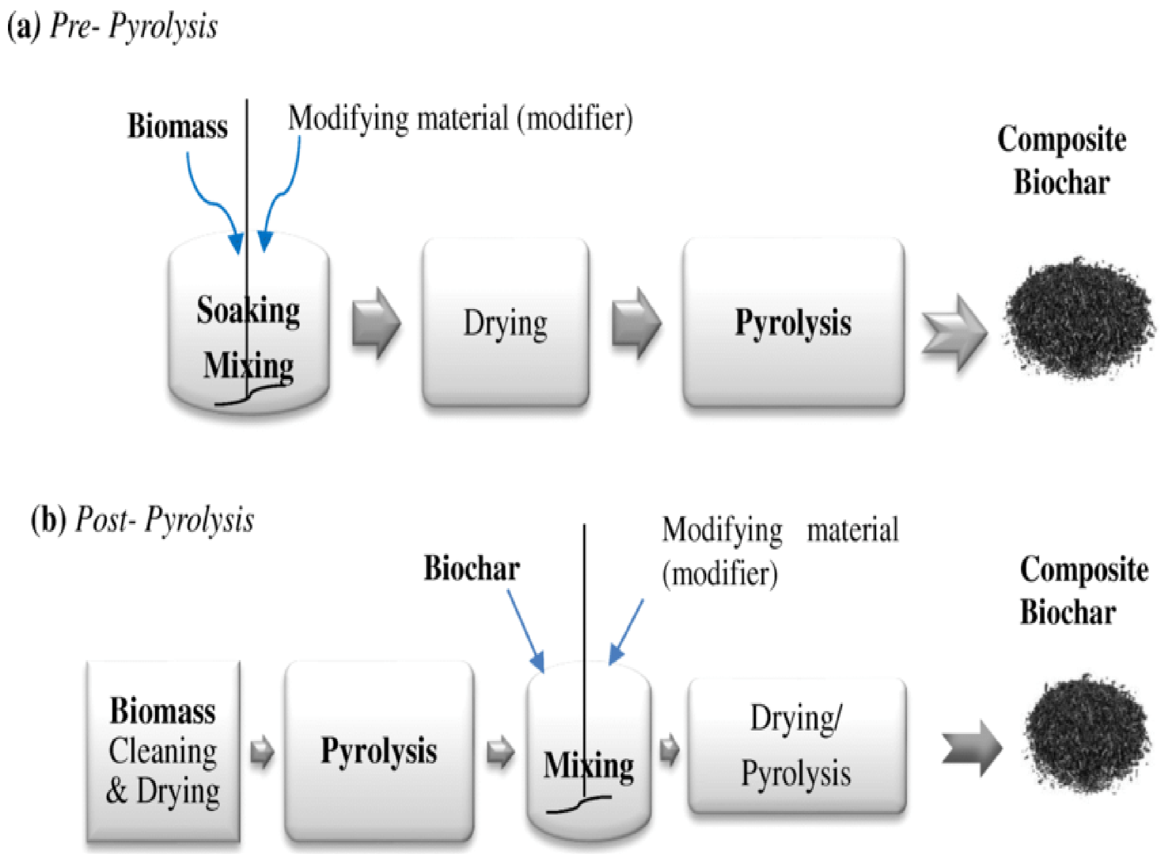


Figure 3.2: Fig. 4

3.2 benifit of producing biochar in house , such as cost saving and the ability to tailor the production process to specific soil type

The production of biochar in house, also known as on-farm or on-site production, has several benefits that make it an attractive option for farmers and landowners looking to improve soil quality and fertility. One of the primary benefits of in-house produced biochar is cost savings. By producing biochar on their own property, farmers can avoid the costs associated with purchasing pre-made biochar, such as transportation and handling fees. In-house production also allows farmers to use locally sourced and often waste materials, such as agricultural residue or wood chips, as feedstocks, which can further reduce costs.

Another advantage of in-house biochar production is the ability to tailor the production process to specific soil types. Biochar production conditions, such as temperature, residence time, and feedstock type, can all impact the final properties of the biochar produced, and farmers can adjust these conditions to produce biochar that is best suited for their specific soil type. This can result in a more effective and efficient application of biochar to the soil, which can lead to improved soil quality and fertility.

In addition, in-house biochar production also offers farmers the opportunity to incorporate the use of sustainable practices into their operations. For example, they can use the heat generated during the pyrolysis process to provide energy for other farm operations, such as heating or powering irrigation systems.

Overall, the ability to produce biochar in-house offers farmers and landowners significant cost savings, the ability to tailor the production process to their specific soil type, and the opportunity to incorporate sustainable practices into their operations. These benefits make in-house biochar production an attractive option for those looking to improve soil quality and fertility.

3.3 how in house produced biochar can be used to optimise soil density and improve gas permeability and water retention

In-house produced biochar can be used to optimize soil density and improve gas permeability and water retention by adjusting the production conditions and feedstocks used in the production process.

Biochar production conditions, such as temperature, residence time, and feedstock type, can all impact the final properties of the biochar produced, and by carefully selecting these conditions, farmers can produce biochar that is best suited to their specific soil type and the desired outcome. For example, higher temperatures and longer residence times can lead to the production of biochar with smaller particle sizes, which can increase soil porosity and improve gas permeability.

The type of feedstock used can also impact the final properties of the biochar produced. For example, using feedstocks with high ash content can result in biochar with higher mineral content, which can improve water retention in the soil. On the other hand, using feedstocks with high lignin content can result in biochar with higher carbon content, which can improve soil structure and stability.

Once the biochar has been produced, it can then be added to the soil in the desired amount and incorporated into the soil using tillage practices or other methods. The addition of biochar to soil can improve soil structure and stability, increase soil porosity, and reduce soil density. This, in turn, can improve gas permeability and water retention in the soil.

In conclusion, by carefully selecting the production conditions and feedstocks used in the production of in-house produced biochar, farmers can optimize soil density and improve gas permeability and water retention in the soil. The addition of biochar to the soil can also have long-term benefits for soil quality and fertility

Chapter 4

EXPERIMENTAL WORK

4.1 Test plan

All the experimental works were conducted in the greenhouse (Fig. 2c) established at Shantou University, China. The tests were divided into three different series, including one series of tests on BS samples and two sets on BAS with biochar contents of 5% and 10% (by weight). Three DOCs (65%, 80% and 95%) were used for each series of tests. All the soil columns were labeled as S-X-Z, where S-X represents the series with different biochar contents (0%, 5% and 10%) and Z represents the compaction state (i.e. DOCs of 65%, 80% and 95%). Thus, in the current study, a total of nine soil columns were monitored. The biochar percentages were considered based on the studies of Reddy et al. (2015), Wong et al. (2017) and Bordoloi et al. (2018). All of the nine soil samples were compacted in a custom-made polyvinyl chloride (PVC) column with a diameter of 300 mm and a height of 250 mm (Fig. 2b).

4.2 Test procedures

The compaction procedure was adopted from the studies of Li et al. (2016) and Huang et al. (2020). The compacted soil columns are shown in Fig. 2a and b. Holes were drilled at the bottom of the PVC column to allow water to drain without any loss of soil particles. Each sample was dry-mixed using a mechanical mixing device in three batches with a predetermined proportion of biochar (by weight). The composite with requisite water content was then compacted into three layers with the preset DOC using static compaction. Distilled water was used in the experimental study to avoid any error due to salinity in the suction measurement. It should be noted that the circumference of soil column was sealed using clay slurry to minimize any gas leakagealong the soil-column interface (Zhang and Rothfuchs, 2008).

After preparation of BAS, all the columns were placed in the greenhouse. To achieve the initial condition (i.e. suction close to 10 kPa), a sprayer device was used to irrigate each column thoroughly, and they were left overnight for water equilibrium. Then the soil columns were monitored for a 42-d drying and a 7-d wetting period, respectively. The experimental system used for monitoring the soil columns is shown in Fig. 2a–c. An MPS-6 suction sensor (10–100,000 kPa) and an EC-5 volumetric water content sensor (Decagon Devices Inc, 2016) were inserted 100 mm into the soil from the top. The two sensors were placed 100 mm apart to minimize the interaction, and connected to a data logger for minoring suction and water content, respectively (Huang et al., 2020). A digital environmental sensor was used to record temperature, relative humidity and evaporation, as shown in Fig. 2d. The average relative humidity of 70.4%, temperature of 16.9 °C–26.1 °C, and evaporation rate of 0.56–1.02 mm/d were observed during the monitoring period.

Fig shows the details of the gas permeability determining apparatus. Gas cylinder, flow meter, soil column, and pressure sensor were connected successively using rubber hosepipes. The gas cylinder was used to supply CO2 gas. Flow meter was used to measure the flow rate of CO2 flow, which was provided by the gas cylinder to pass through the soil column. Gas flow rate could be detected from 0 to 20 mL/min with a sensitivity of 0.1 mL/min. The digital pressure sensor (with a sensitivity of 1 Pa) was installed to measure the gas pressure (P) in the lower chamber of soil column. During the measurement of gas permeability, CO2 was supplied at a steady flow rate (q). The difference of gas pressure between the bottom and top of the soil column can be represented by gage pressure at the bottom, which is measured by a pressure sensor. The difference of gas pressure (p) is the driving head for flow permeating. Based on the Darcy's law, the gas permeability (kg) of soil column can be determined by the following equation (Damkjaer and Korsbech, 1992; Garg et al., 2019; Ni and Ng, 2019):(1)where A is the cross-sectional area of the soil column, L is the length of the soil column, and is the absolute viscosity of CO2 gas flow (14.8 × 106 N s/m2). The measurement of gas permeability was fulfilled by recording instantaneous measurements of gas pressure and flow rate.

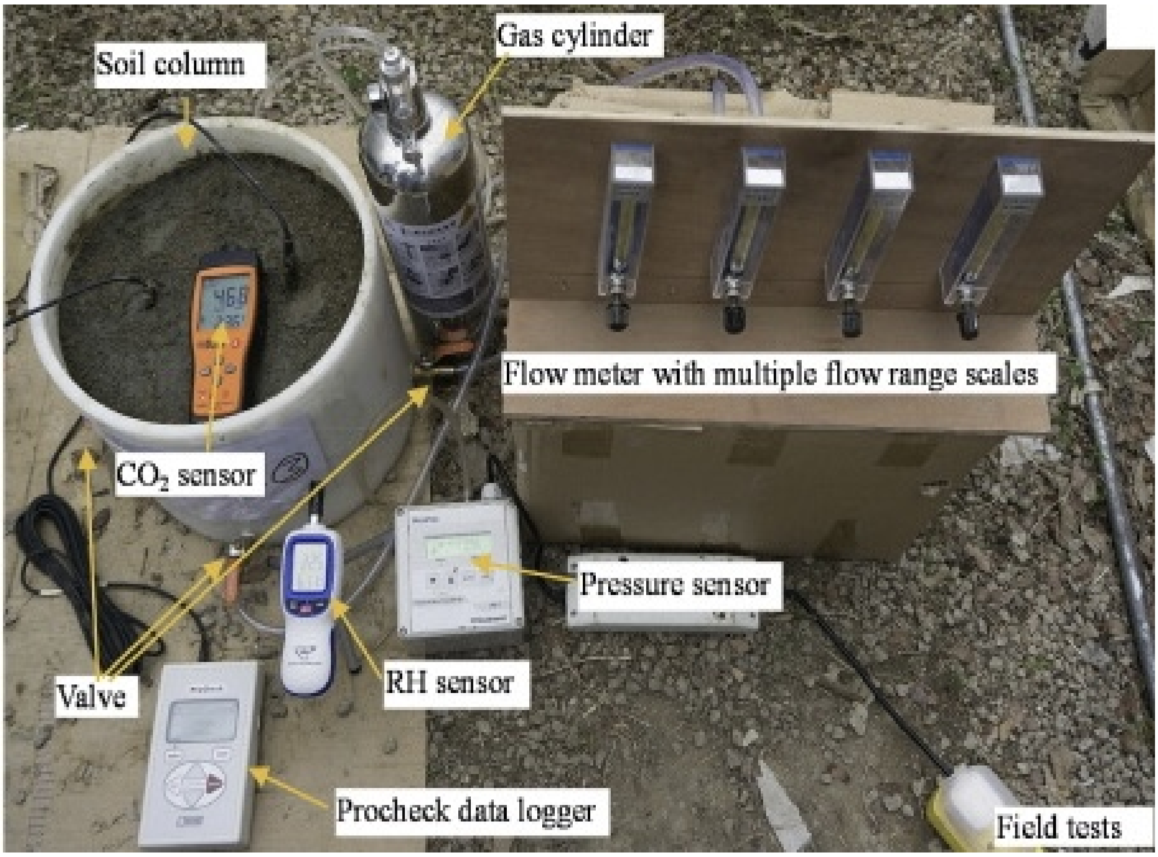


Figure 4.1: Test column in the greenhouse at Shantou University, China: (a) Original diagram of soil column measurement system

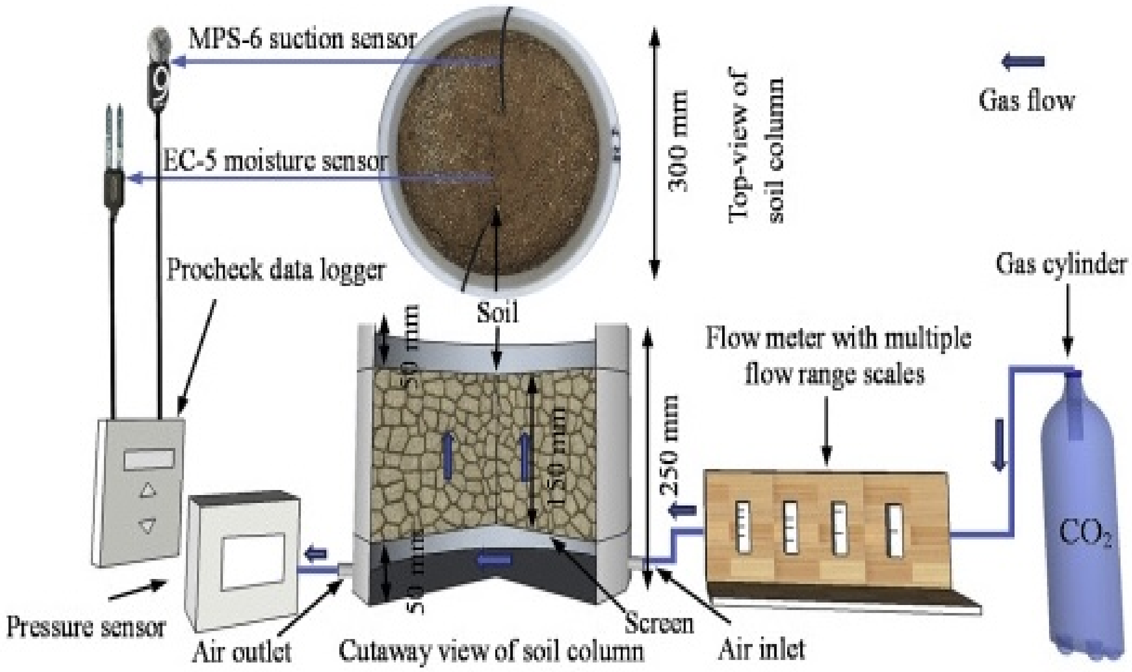
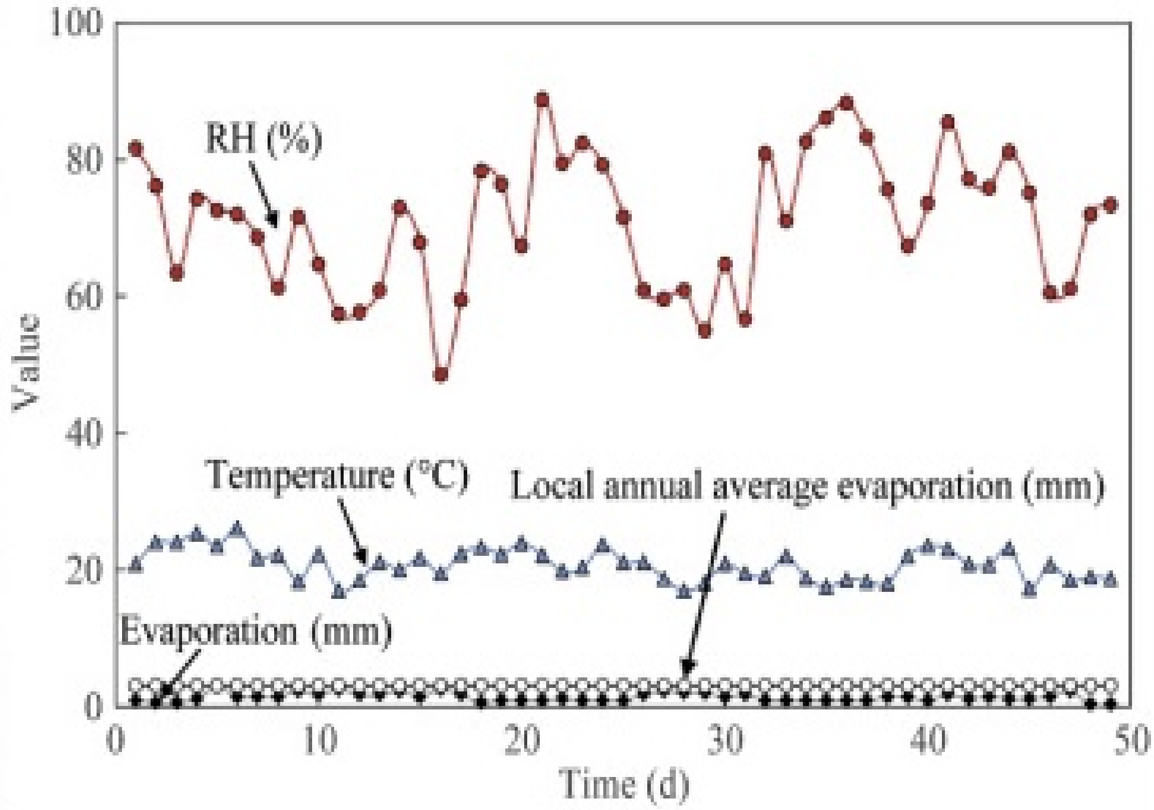


Figure 4.2: Schematic diagram of soil column measurement system

Figure 4.3: Greenhouse interior



RH (%)
Temperature (°C)
Local annual average evaporation (mm)
Evaporation (mm)
Value
Time (d)
100
80
60
40
20
0
0
10
20
30
40
50

(d)

Figure 4.4

4.3 Results and discussion

4.3.1 Variation of suction and water content for samples

Suction and water content are the two vital variables in SWCC. Hence these parameters were monitored for a period of 49 d. Fig. 3a shows the variation of suction with respect to time for BAS at different DOCs. From the 1st to the 41st day, the suction of all the columns increases in drying period, and from the 41st to the 48th day, the suction of each column declines for wetting period as expected in soil water retention properties. Fig. 3b shows the variation of volumetric water content for all columns with variation of time. The trend of volumetric water content is the same as suction measurements and can be used for plotting SWCCs in drying and wetting. Fluctuations in environmental condition occurred in the greenhouse at around the 25th, 30th, and 35th days because of humidity changes due to rainy weather (see Fig. 2d) and its consequence on suction and water content can be observed.

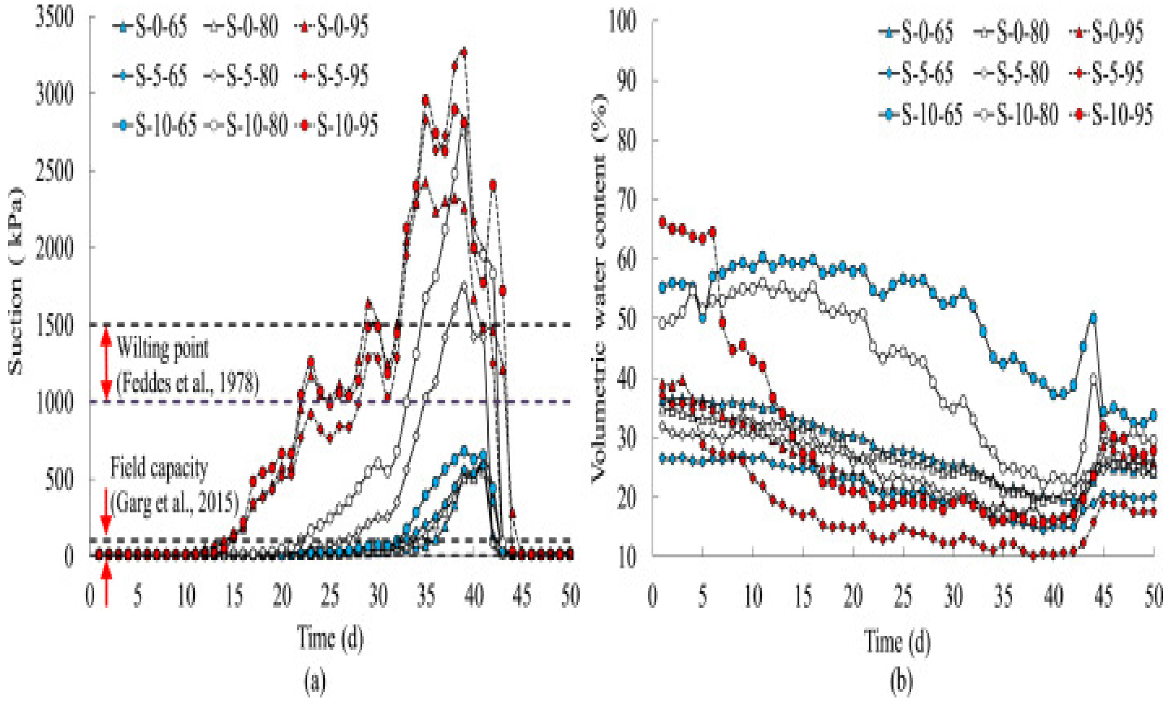


Figure 4.5: . Variations of (a) soil suction and (b) soil water content (Feddes et al., 1978).Among nine suction curves, the columns with higher DOC and higher biochar content (i.e. S-10-95, S-5-95 and S-10-80) achieve relatively higher suction compared to the columns with lower DOC and lower biochar content (S-0-65, S-0-80 and S-5-65). The results also show that the columns with lower DOC and higher biochar can retain more water among all the samples, as shown in Fig. 3a. Samples S-10-65 and S-10-80 retain the highest water contentand S-5-95 has the lowest water content. Under wetting period, BAS samples are able to retain more water under given suction. This is in agreement with the result of Abel et al. (2013) who studied the use of biochar on soil water retention capacity of sandy soil. This is mainly due to the increases in pore size distribution and pore volume of the BAS.

Chapter 5

INFLUENCE OF SOUL DENSITY

5.1 Influence of biochar on soil density: discuss the results of studies that have investigated the influence of biochar on soil density

Several studies have investigated the influence of biochar on soil density, and the results have been mixed. Some studies have found that the addition of biochar can increase soil density, while others have found no significant effect or even a decrease in soil density.

One possible explanation for the variability in results is that the effect of biochar on soil density may depend on factors such as soil type, biochar properties, and application rate. For example, some studies have suggested that biochar with a high ash content may be more effective at increasing soil density than biochar with a low ash content.

Another factor that may influence the effect of biochar on soil density is the length of time that the biochar has been in the soil. Some studies have suggested that the effect of biochar on soil density may be more pronounced in the short term, while others have found that the effect can persist for several years.

Overall, while the influence of biochar on soil density is still an area of active research, it appears that the effect is complex and may depend on a variety of factors.

5.2 how the addition of biochar can impact soil density and what the implications of these changes are for gas permeability and water rentension

The addition of biochar to soil can impact soil density in different ways depending on several factors such as the properties of the biochar, the soil type, and the application rate. Generally, the addition of biochar to soil can increase soil density due to the physical presence of the biochar particles in the soil matrix.

The implications of changes in soil density due to the addition of biochar can affect soil properties such as gas permeability and water retention. Increased soil density can decrease gas permeability as the space between soil particles is reduced, making it harder for gases to move through the soil. This can be beneficial in certain situations, such as reducing greenhouse gas emissions from the soil, but it can also negatively impact soil aeration, which can be important for plant root respiration. On the other hand, the addition of biochar can improve water retention by increasing the soil's water holding capacity, especially in sandy soils. Biochar has a high surface area, which can act as a sponge, absorbing and holding water. This can be beneficial for plant growth, especially in dry environments or during drought periods. However, too much biochar can decrease water infiltration rates and increase runoff, leading to soil erosion.

In summary, the addition of biochar to soil can impact soil density, which can have implications for soil gas permeability and water retention. The effects of biochar on these properties depend on various factors, including biochar properties, soil type, and application rate, highlighting the importance of carefully considering the application of biochar to soil systems.

Chapter 6

GAS PERMEABILITY

6.1 Gas permeability

The ability of a gas, or air, to diffuse through a material when the pressure of each side of the material is different, i.e. high pressure or a vacuum. Porous materials will allow the gas to pass through quickly. Materials with low gas permeability are often used as barriers in food packaging.

Intrinsic permeability K is defined as K = Cd2, where C is a dimensionless constant related to the geometry of soil pores, and d is the pore diameter. Accordingly, the gas permeability can be also defined as kg = (g/)K .Therefore, pore size and pore structure characteristics play a vital role in the gas permeability. As for external factors, the SWCC governs the behaviors of gas permeability. The flow of pore air in unsaturated soil is governed by the total potential (absolute pressure) of the air phase.

As kg is directly correlated with pore size distribution , it decreases as density increases. Thus, in this study, the increase of DOC apparently decreases the void pore size, resulting in a reduction of gas permeability. At high-suction range, samples under 95% DOC increase the gas permeability until the DOC is less than 65%. This is because of the high head gradient due to high suction .Biochar rich in surface hydrophilic groups ,can improve the water retention of sandy soils .

This means that the water content in the pore increases and hence slows down the gas transport in pore path .Therefore, the gas permeability in BS is generally higher than that in BAS .Comparison of the gas permeability perfectly meets the assumption of Eq. With increasing biochar content, as indicated in the void ratio changes following the sequence of 5% BAS ¿10% BAS ¿ BS, which results in various saturation states (relative saturation degree ranking: BS ¿ 10% BAS ¿ 5% BAS) and arises corresponding capillary effects (i.e. enhanced suction). Therefore, the gas permeability has a trend of BS ¿ 10% BAS ¿5% BAS, as shown in which conforms to the theory proposed. The slope of gas permeability–suction curve changes due to internal structure reorganized by DOC and biochar addition. In 5% BAS samples, biochar–biochar and soil–biochar particles replace some parts of the soil–soil particles, and smaller biochar particles make pore path narrow. As for the 10% BAS sample, the percentage of biochar–biochar and soil–biochar particles increases, especially the biochar–biochar particles, when increasing the dosage of biochars. Therefore, more soil–biochar and biochar–biochar interactions widen the pore path in some way compared to 5% BAS samples. investigated the influence of biochar on air permeability in unsaturated soils and also found that biochar reduced the air permeability.

However, the variations in gas permeability caused by biochar content in these two works are different. pointed out that the gas permeability decreased by up to 50% and 65% for 5% BAS and 10% BAS, respectively. On the contrary, the results of the current study illustrate that the gas permeability shows a magnitude order of BS ¿ 10% BAS ¿5% BAS for each DOC . The discrepancy could be attributed to the different gradations of soils used in the two studies. The former study uses SC (sand clay mixture, with around 81% sand and 19% clay) while the current study uses SP (poorly graded sand, see . Different soil gradations will probably influence the extent of variations in biochar affecting soil properties . including the gas permeability, A systematic review by found that effects of biochar can vary significantly depending on the type of soil. Biochar is able to improve water retention of coarser soil more effectively than that of fine soil.

biochar can vary significantly depending on the type of soil. Biochar is able to improve water retention of coarser soil more effectively than that of fine soil.

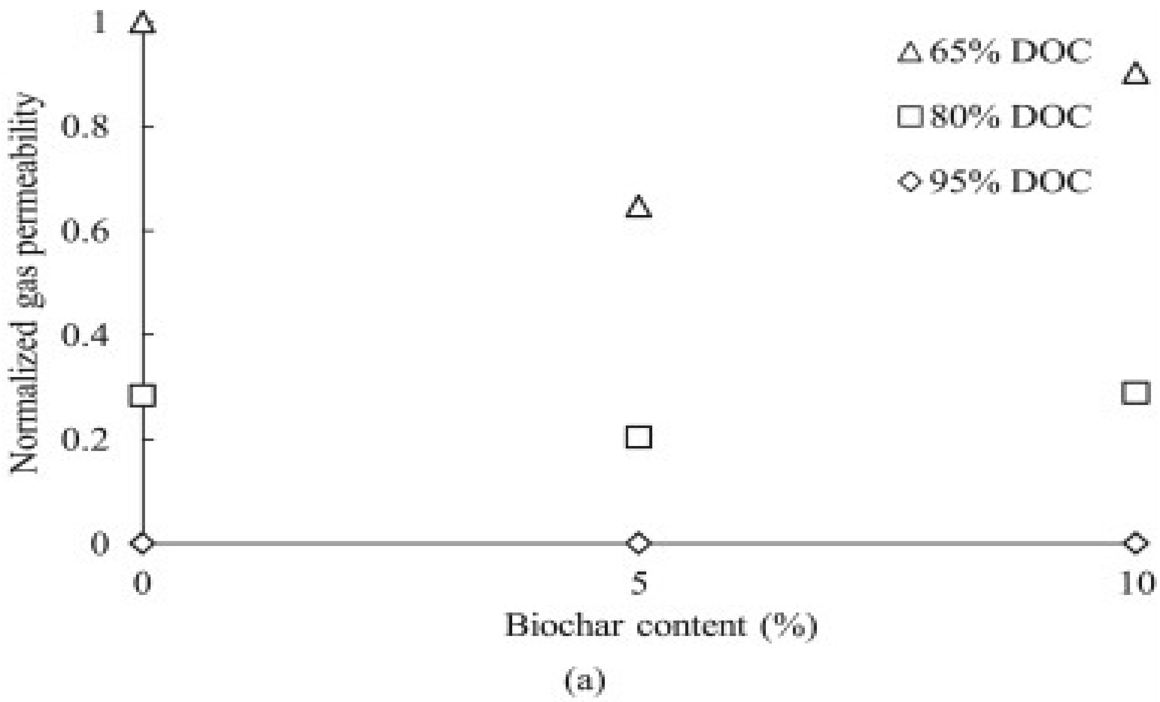


Figure 6.1: a

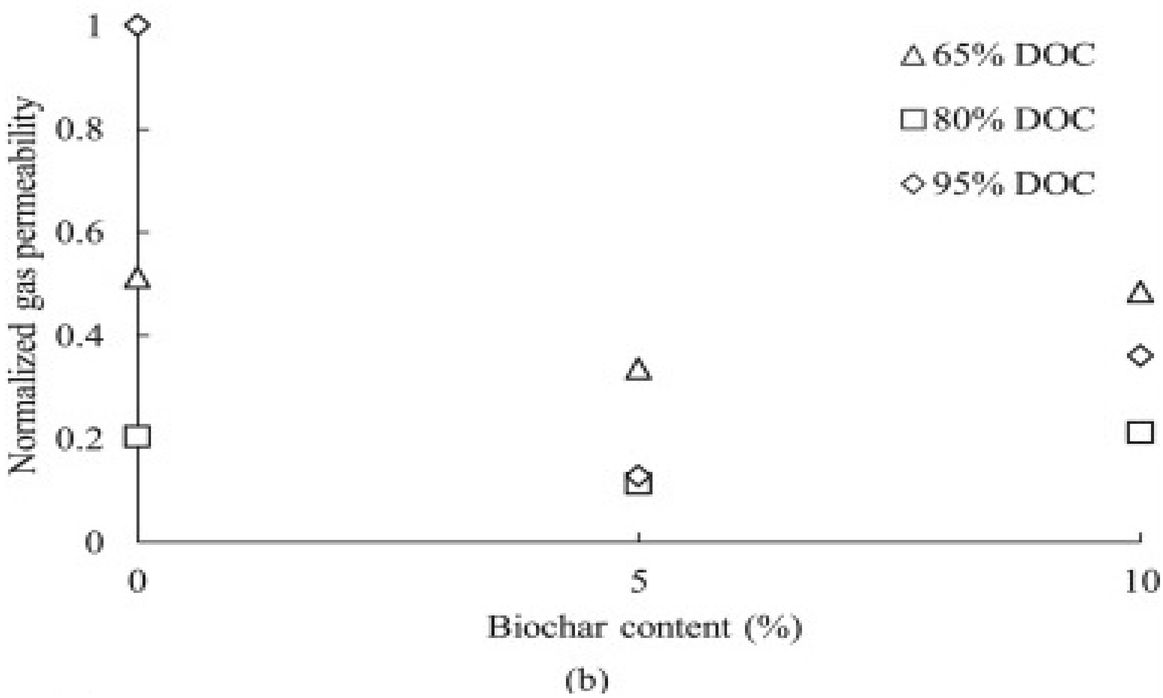
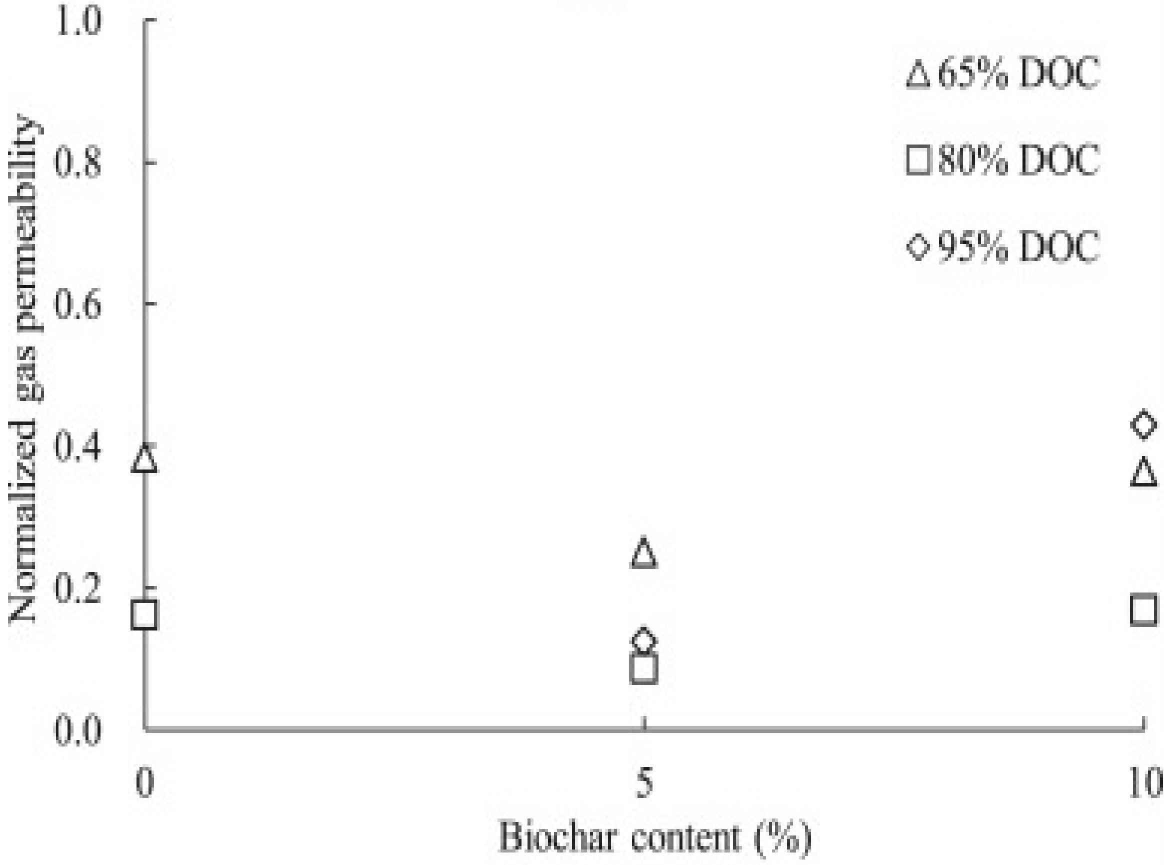


Figure 6.2: b



(c)

Figure 6.3: c Effects of biochar content and compacted state on gas permeability under different suctions: (a) 100 kPa, (b) 1000 kPa, and (c) 2000 kPa.

6.2 Variation of gas permeability

Gas permeability is related to the SWCC and reflects pore structure characteristics. Thus, the relationship of gas permeability–suction is plotted, as shown in Fig. 5. Comparisons among samples with different DOCs and biochar contents are illustrated in Fig. 5. Generally, due to high porosity, the gas permeability of sample under 65% DOC is higher than those of soils under 80% and 95% DOCs. However, in high suction range (i.e. about ¿1000 kPa), the gas permeability of samples under 95% DOC is higher than those under 80% and 65% DOCs. This phenomenon occurred in each sample treated with different biochar contents. Furthermore, the slope gradient of gas permeability–suction curves changes according to DOC, i.e. slope of 95% ¿ slope of 65% ¿ slope of 80%. The slopes of these curves are related to the pore structure characteristics (Brooks and Corey, 1964; Huang et al., 2020), which means that biochar addition changes the inner-structure of soil. In Fig. 5, for each DOC, gas permeability shows magnitude order of BS ¿ 10% BAS ¿5% BAS. Moreover, the slope of gas permeability trends to have a similar relationship. In addition, as shown in Fig. 5, Garg et al. (2019)found a similar trend, suggesting reduction of gas permeability with addition of biochar. It should be noted that their study was conducted for only one soil density (80% DOC). However, both the current and previous studies confirm the potential role of biochar in reducing gas permeability.

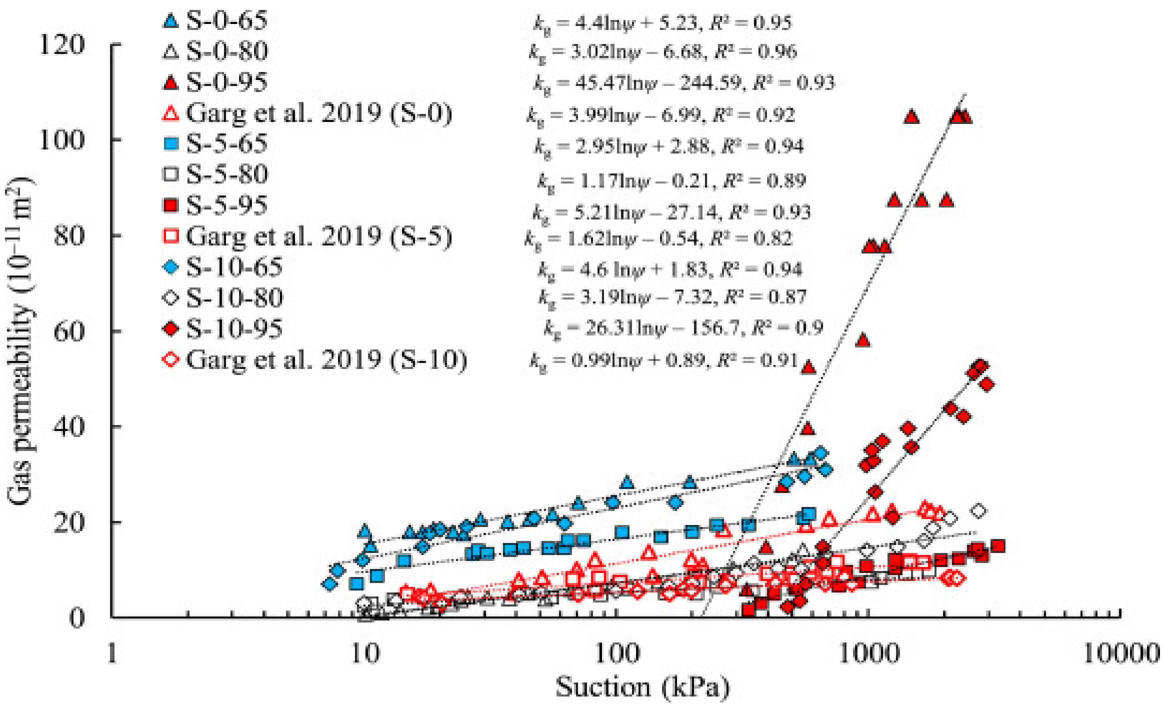


Figure 6.4: Comparisons of gas permeability varying with suction based on compaction state and biochar content

Chapter 7

APPLICATION OF BIOCHAR IN AGRICULTURE

7.1 Prospect of biochar in agriculture and engineering application

Biochar is mainly used in agriculture to enhance soil fertility, improve plant growth, and provide crop nutrition. As a result, it improves the overall farming productivity. It has also gained considerable attention in livestock farming as an animal feed. Fig. 6 shows the influence of biochar content and compacted state on gas permeability under three different suctions (low (100 kPa), moderate (1000 kPa), and high (2000 kPa) suctions). Gas permeability, as obtained from Fig. 5, is further normalized (0 kg,n 1) to interpret the effects of biochar content and compacted state on the gas permeability of samples. As shown in Fig. 6a, the gas permeability of 65% DOC samples is the highest at suctions near to 100 kPa. The gas permeability in 95% DOC samples at suction near to 100 kPa is almost negligible. In agriculture, air exchange is one of the most important parameters that directly impact plant growth and crop production (Tang et al., 2011). Thus, S-10-65 can be recommended for use in agriculture land. The effective soil gas exchange (high gas permeability) is higher even at higher water content (i.e. at field capacity).

On the contrary, in engineering applications such as landfills, less permeable soil is often desirable to minimize greenhouse gas emissions (Mohareb et al., 2011). From Fig. 6a–c, 80% DOC soils have lower gas permeability than other samples over a wide suction range (100 kPa, 1000 kPa and 2000 kPa). It should be noted that 95% DOC soils have the lowest gas permeability under low suction (100 kPa). However, the gas permeability of soils under 95% DOC increases rapidly with an increase in suction (suffering drought). Considering that the soils used in engineering applications are often subjected to heavy rain (which causes low suction) or prolonged drought (which causes high suction), 80% of DOC can be recommended for use in engineering applications. Besides, as shown in Fig. 6, soils with 5% biochar have lower gas permeability than other soil samples. Thus, the sample S-5-80 is strongly suggested for engineering applications. It should be noted that these are preliminary recommendations based on the soil and climate conditions given. Any optimal content of biochar will also depend on plant type and soil type (Razzaghi et al., 2020). Further systematic studies are needed to evaluate effects of biochar on shear strength considering simultaneous influence on plant growth in long term (Ni et al., 2020, Razzaghi et al., 2020).

Figure 7.1: application of biochar on agriculture

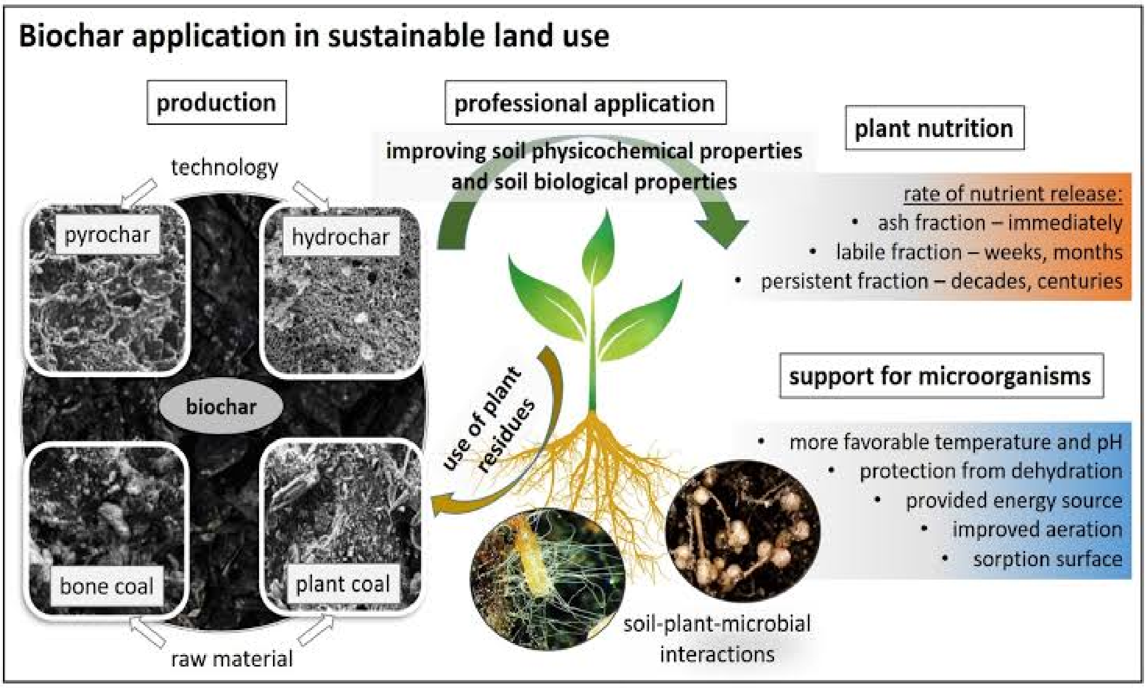

Biochar application in sustainable land use
production
professional application
plant nutrition
technology
improving soil physicochemical properties
and soil biological properties
pyrochar
hydrochar
rate of nutrient release:
• ash fraction – immediately
• labile fraction – weeks, months
• persistent fraction – decades, centuries
biochar
use of plant residues
support for microorganisms
• more favorable temperature and pH
• protection from dehydration
• provided energy source
• improved aeration
• sorption surface
bone coal
plant coal
raw material
soil-plant-microbial interactions

Figure 7.2

Chapter 8

CONCLUSIONS

The use of in-house produced biochar as a soil amendment has been shown to have a significant influence on soil density, gas permeability, and water retention. Biochar has a high surface area and porosity that can enhance soil structure, increase water-holding capacity, and improve nutrient availability for plants. The addition of biochar to soil can also improve soil aeration and reduce soil compaction, which can ultimately lead to improved plant growth and higher crop yields. The effect of biochar on soil properties is dependent on various factors, including biochar type, feedstock, and pyrolysis conditions. Therefore, further research is needed to determine the optimal biochar application rate and its long-term impact on soil quality and plant growth. Overall, the use of in-house produced biochar as a sustainable soil amendment has promising potential in improving soil fertility and promoting sustainable agriculture practices.

Chapter 9

REFERENCES

ASTM D2487-17, 2017

ASTM D2487-17

Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

ASTM International, West Conshohocken, USA (2017)

Google Scholar

ASTM D422-63e2, 2007

ASTM D422-63

Standard test method for particle-size analysis of soils

ASTM International, West Conshohocken, USA (2007)

2007

ASTM D4318-17e1, 2017

ASTM D4318-17e1

Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

ASTM International, West Conshohocken, USA (2017)

Google Scholar

ASTM D698-12e2, 2012

ASTM D698-12e2

Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft3(600 kN-m/m3))

ASTM International, West Conshohocken, USA (2012)

Google Scholar