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Influence of biochar admixture in soil on near saturated hydraulic conductivity

DIPLOMA THESIS

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Declaration

I declare that the Diploma Thesis “Influence of biochar admixture in soil on near saturated hydraulic conductivity” is my own work and all the scientific literature and sources that I used are listed in the References.

In Prague, on July 23, 2020

War War Mon

Acknowledgment

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Influence of biochar admixture in soil on near saturated hydraulic conductivity

Summary

Hydraulic properties of soil are the basis for understanding and responsible for water flow and nutrient transport. Biochar amendment is effective for the physical and hydraulic properties of soils. Due to its adsorption capacity (AC) and high cation exchange capacity (CEC), biochar becomes not only a nutrient carrier but also habitats of microorganisms. However, the addition of biochar without activation could lead to adverse effects in either fixing of available nutrients or water in the soil. The aim of this research was to evaluate the changes of near saturated hydraulic conductivity *K(h)* of clay loam soil measured by Mini Disk Infiltrometer after the application of several types of activated biochar admixtures.

The study was conducted in-situ in Plant Production Station Uhříněves belonging to the Department of Agroecology and Crop Production on clay loam soil during two vegetation terms of the mustard crop (*Sinapis alba* L.) in July and October 2019. Experimental parcels were treated by different compost and activated biochar admixtures, including bokashi fermentation and Azotobag (Farma Žiro, Ltd., CZ) preconditioning. The experiment was carried out either in field (11 treatments) and irrigated greenhouse conditions (4 treatments), both in 3 replicates, in total on 45 parcels. Unsaturated hydraulic conductivity K(h) was measured by using the Mini Disk Infiltrometer (METER Group, Inc., USA). In total, 216 infiltration tests were conducted, 84 in greenhouse and 132 in field, at set tension 2 cm. Soil water content (θ) was measured by using the 5TE soil moisture sensor both before and after infiltration. In addition, 45 undisturbed soil samples were taken in July.

The results showed that several types of activated biochar admixtures are significantly different in unsaturated hydraulic conductivity. The application of compost bokashi treated biochar (KBB) had significant effect on unsaturated hydraulic conductivity, also showing improvements in dry bulk density compared with pure compost (K) in the greenhouse. For the field, 2% of Agrouhel biochar treated with bokashi (A2Bo) was statistically significant among the other treatments in July, while no statistically significant variant is observed for *K(h)* on different soil treatments in October. The negative correlation between unsaturated hydraulic conductivity *K(h)* and initial water content is also visible, indicating decreasing *K(h)* with increasing initial water content.

Key Words: Biochar, Compost, Unsaturated Hydraulic Conductivity, Mini Disk Infiltrometer

Contents

List of Tables

List of Figures

1 Introduction

Atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) become increasing globally, consequently, they cause adverse effects on climatic patterns. Soil is a key part of regulating the cycling, production, consumption, and storage of these gases (Gärdenäs et al., 2011). As strategies of soil management, it is important to maintain an appropriate level of soil organic matter and effective biological cycling of nutrients (Bationo et al., 2007; Vanlauwe et al., 2010). Application of organic matter from a variety of different sources have emerged as a strategy to improve soil fertility, carbon sequestration and restoring degraded land (Agegnehu et al., 2017). Recently, biochar has been investigated as a useful substrate for organic matter applications such as biochar-compost mixtures to produce effective biochar-based slow-release organic fertilizers (Schmidt and Kammann et al., 2014; Ye et al., 2016). Biochar has been proposed as a product from pyrolysis of heterogeneous feedstocks that vary in their chemical and physical properties. This variability depends either on the parameters involved in pyrolysis or on the materials used to produce biochar (Atkinson et al., 2010; Gundale and DeLuca, 2006).

The largest part of the worldwide fresh water is consumed by the agricultural sector and improving the water-use efficiency is important to save water resources (Jha et al., 2019). The saturated and unsaturated hydraulic properties of soil are functioning as an indicator of soil structure responsible for water flow and consequently nutrient transport etc. Many factors such as porosity of soil and initial water content of the soil profile could influence the movement and transport of water (Matula et al, 2015). Castellini et al. (2015) and Kameyama et al. (2012) reported that biochar admixture is governing soil hydraulic conductivity by altering soil porosity, pore shape, pore connectivity and tortuosity of the conducting soil pores.

Due to its adsorption capacity (AC) and high cation exchange capacity (CEC), biochar becomes not only a nutrient carrier but also habitat of microorganisms. However, by adding biochar to the soil without activation lead to absorption and fixing of available nutrients and water in the soil, finally, it could limit the growth of plants (Schmidt, 2008). Most studies have assessed that biochar application is effective on soil properties, crop productivity and hydraulic conductivity (Agegnehu et al., 2017). However, it may be limited knowledge about activated biochar in various ways and its effects on hydraulic conductivity.

2 Objectives

Hypothesis

The application of organic matter to the soil positively changes soil structure and infiltration capacity of the soil. Biochar activated in various ways can improve soil hydrophysical properties in clay loam soil.

Objectives

The main objective of this study is to evaluate the changes of near saturated hydraulic conductivity K(h) of clay loam soil measured by Mini Disk Infiltrometer after the application of several types of activated biochar admixtures.

3 Literature Review

3.1 Use of biochar in agriculture

Severe soil fertility depletion and declining agricultural productivity are rapid due to industrial development and human activities (El-Nagger et al., 2019). Soil fertility is the ability of soil to maintain crop productivity, whereas, fertile soil can provide nutrients and water for plant growth without containing any toxic elements (Voltr, 2012). Typically, the physical, chemical and biological characteristics of soils can control soil fertility (Igalavithana et al., 2015). Since the Green Revolution in the 1960s, application of inorganic fertilizers has gained attention as a way to increase agricultural productivity (Vanlauwe et al., 2010a). However, only use of inorganic fertilizers to maintain soil fertility and crop yields is not the right way for the long-term and sustainable agricultural production (Srinivasarao et al., 2014; Usman et al., 2015). Regarding those problems, biochar has been proposed as a solution for agronomic benefits. Besides, biochar in different ways such as the application of biochar as soil amendment together with inorganic and organic fertilizers (Fig. 1) have been carried out as extended research (Agegnehu et al., 2015).

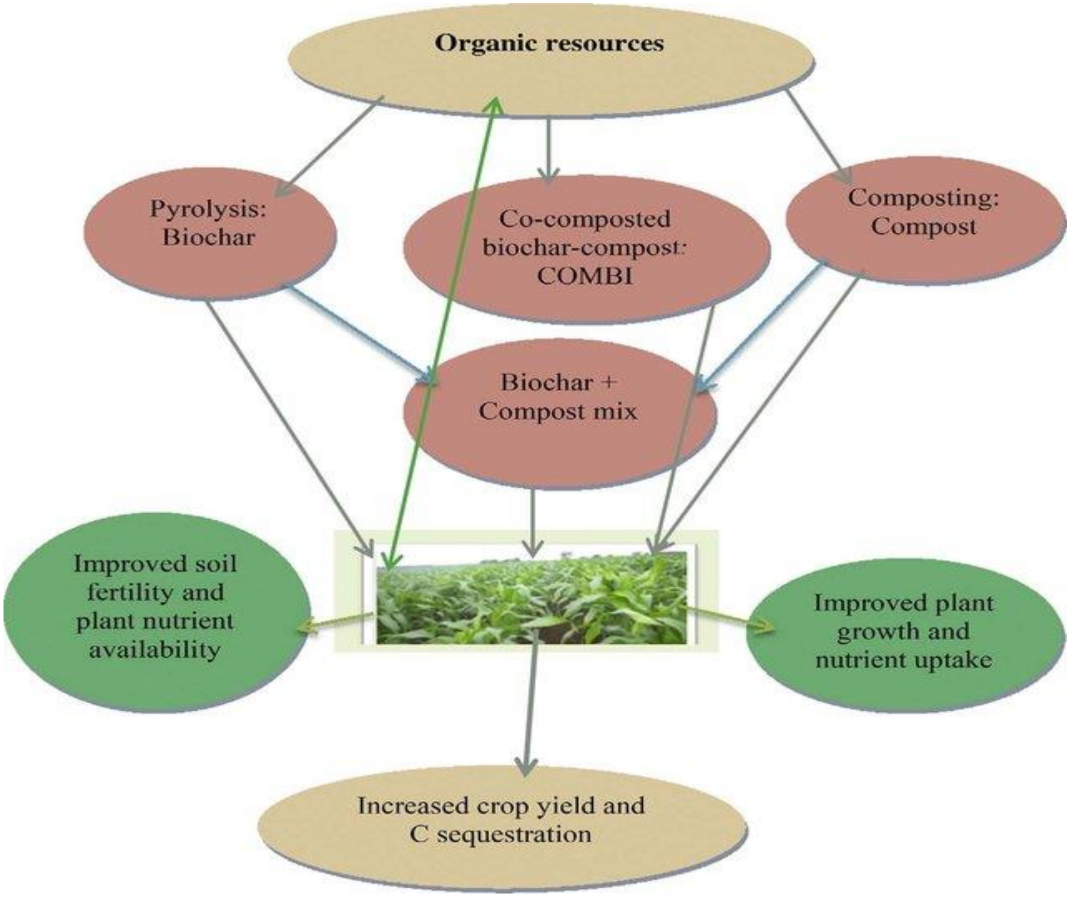


Figure 1 Conceptual Framework for organic amendments and plant-soil relationship (Agegnehu, 2017)

3.1.1 Background of biochar

Biochar, also known as carbon-rich material, derived from the pyrolysis of biomass in an oxygen-limited environment (see Fig. 2). Biochar is mostly produced by using a temperature of 250-500 °C with partial combustion of feedstocks under limited oxygen supply (Baldock and Smernik, 2002; Rizwan et al., 2016). Two types of pyrolysis are most commonly used in biochar production: fast and slow pyrolysis associated with different heating rates and heating duration. Slow pyrolysis may be set as continuous delivery of oxygen-free raw materials through external kiln (removal of volatile gas, char appears at the other end). Fast pyrolysis is very quick heat transfer, usually fine biomass particles are blown through hot gases in the confined oxygen-free chamber (Sohi et al., 2010). The condition used for each process is different such as temperature, pressure, heating rate, residence time to enhance the production of one or more products depending on product quality and quantity. Slow pyrolysis of biochar is a product of traditional heating of feedstocks under oxygen-limiting conditions by heating the feedstocks at temperatures from 300°C to 800°C at atmospheric pressure for hours to days. Fast pyrolysis is heating of biomass like slow pyrolysis, unlike slow pyrolysis is characterized by a high temperature (400°C–1000°C) with fast heating rates (Brewer and Brown, 2012).

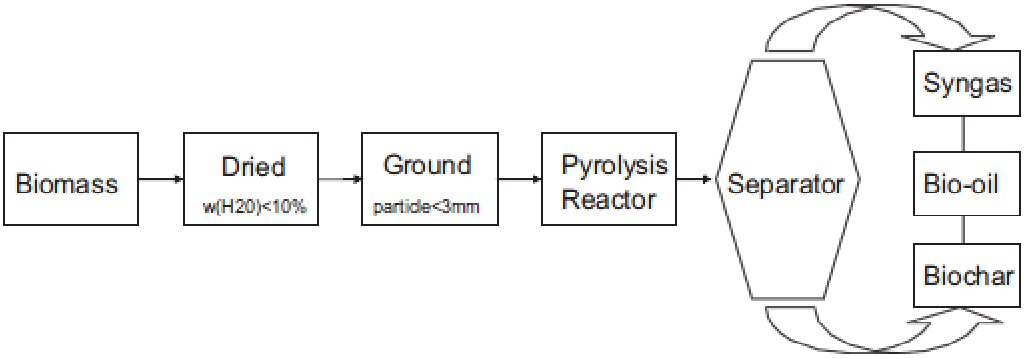


Figure 2 Flowchart and products of biochar production (Xu, 2012)

The typical characteristics of biochar are richness in organic carbon (Sohi et al., 2010) and highly porous structure (Zhoua et al., 2019). Much of the previous work have been conducted on its potential to increase carbon sequestration and stable organic carbon compounds of biochar (Lehmann, 2007). Biochar has not only a high storage of carbon but also significantly low emission of greenhouse gases into the atmosphere because of transformation from energy to heat is relatively low during pyrolysis process. There are many varieties of raw materials to produce biochar including wood chips, plant residues, organic wastes industry, and poultry manure (Xu, 2012). Depending on feedstock and production temperature, these characteristics can vary among biochars. Biochars produced from manure and crop residue are more abundant in nutrients, tend to have higher pH and greater surface area than wood-derived biochars. The important characteristics of pyrolyzed biochars exerting on soil N and P cycling are pH, high surface area and nutrient content (Gul et al., 2015; Mohanty et al., 2013; Novak et al., 2013; Singh et al., 2010).

The mechanisms of biochar’s function in the soil are recognized to cause an enhancement of nutrient availability, an improvement of soil physical properties, the interaction with different biogeochemical cycles and an increase of crop productions (Sohi et al., 2010). In addition, with the use of biochar, increases in pH (especially when made of materials such as wood ash), modifying pH and changes in nutrient availability, particularly P and K, were observed (Mahmood et al., 2003). Kuppusamy et al. (2016) also suggested that biochar has a positive effect on reducing greenhouse gas emissions, waste management, renewable energy, carbon sequestration, and environmental remediation. Furthermore, biochar received intensive interest in the last decade because of a cost-effective amendment for the management and rehabilitation of infertile soils (Park et al., 2015; Rizwan et al., 2016). Other proposed mechanisms of biochar include decreasing plant diseases (Graber et al., 2014) and enhancing rhizosphere interactions (Prendergast-Miller et al., 2014). Application of biochar (BC) at either minimum or optimum rate can improve soil fertility and crop production, however, the excessive amount of BC will not have economic benefits. The method of BC application such as topsoil incorporation, deep application, top-dressing is also influencing on soil function and processes. Inappropriate application of BC can lead to leaching of BC and decrease BC benefits on soil fertility (El-Naggar et al., 2018).

3.1.2 Nutrients in biochar

Considerable amounts of nutrients contained in many biochars are in the form of either water-soluble or insoluble compound, however, it is little known about the release of these nutrients in the soil (Limwikrana et al., 2018). There are various changes in the original nutrient content and form of nutrients due to the conversion of biomass to biochar. Biochars contain different forms of organic and inorganic N and P such as including NO_3^-, NH_4^+, ortho-P and amide groups (Jindo et al., 2014; Kookana et al., 2011).

Besides, the availability of the macro-nutrients such as N and P, and some metal ions (e.g Ca and Mg) will be different depending on the utilization of biochar feedstocks when incorporated into the soil (Gundale and DeLuca, 2006; Major et al., 2010). Nutrient-rich-based biochars like manure and crop residues generally have higher nutrient content than biochars produced from ligno-cellulosic feedstocks. The production temperature can affect nitrogen form in biochar in which biochars produced at higher temperatures have more NO_3^- while biochars produced at lower temperatures have more NH_4^+ (DeLuca et al., 2009). Fertilizer conservation of biochar is related to not only its pore structure but also adsorption properties and it is considered as higher utilization of nutrients from plants is promoted by the adsorption of nutrients. As an example, the adsorption capacity for N and P is increased by biochar due to its pore structure and well developed specific surface area (Yu et al., 2018). In this context Bruun et al. (2012) found that biochar can influence the mineralization and immobilization of soil nitrogen. Fresh and fast pyrolysis biochar immobilize 43% of nitrogen in soil while the slow pyrolysis biochar mineralizes the 7% nitrogen in amended soil. In fast pyrolysis biochar, carbon loss is high and strongly influencing the microbial communities of soils. Biochar also involves as a source of soluble P in soil application (Parvage et al., 2013). During pyrolysis, biochar assimilates P and further transformation concentrates P in biochar (Bruun et al., 2014; Rehman et al., 2018). Application of biochar into soil can reduce P sorption capacity and it makes plant-available P uptake via the soil solution (Qayyum et al., 2015). Amendment of biochar about 10 tonnes per hectare to agricultural land will provide a great deal of substantial nutrition for plants. It is especially important for organic agriculture, which prohibits the use of chemical fertilizers (Oshunsanya et al., 2016). Liang et al., 2014 has suggested that the application of BC together with fertilizers and manure has more benefits for agriculture than adding several soil amendments separately and reduces application costs.

3.1.3 Activation of biochar

The diversity of soil organisms that live all or part of their lives in the soil creates soil food web (De Vries et al., 2012). The by-products of root and plant residues are fed by soil organisms to survive, vice versa, soil organisms help in the decomposition of organic matter, support nutrient cycle and enhance soil structure (Bokhorst et al., 2017). When pure and fresh biochar is applied to the soil without activation, it will result in nutrients and water fixation. Therefore, biochar should be colonized with microorganisms to be sure to get the nutrients by plants and also aged by oxidation to take the maximum CEC before the application of biochar. There are various methods to activate biochar depending on location, climate, culture and existing techniques. According to Schmidt (2008), there are generally four techniques for the practical implementation of biochar activation: biochar with compost, biochar with manure from livestock, biochar with liquid fertilizers and biochar bokashi (lactic acid fermentation of biomass). One of the world's most commonly used biofertilizers is 'Effective microorganisms' (EM), also called Bokashi in the Japanese term, which is fermented organic matter, the undisclosed mixture of naturally occurring microorganisms. The fermented Bokashi is a kind of compost obtained from the lactic fermentation of several types of organic matter (Kyan et al., 1999).

Recently, some researches have indicated that charging of biochar with compost enhanced soil fertility, water holding capacity, crop yield and C sequestration (Agegnehu et al., 2016; Schulz and Glaser, 2012). Two methods are possible for biochar with compost. The first one is that biochar does is not included at the beginning of the composting process and after finishing composting, biochar and compost are mixed and added to the soil. The other method is that biochar is added into the composting process, the product gained from this process is called biochar based compost which is applied to the soil (Naeem et al., 2018). The application of biochar into composting leads in interaction with each other’s properties. Biochar has some benefits for physico-chemical properties, microorganisms, degradation, humification, and gas emission of composting, vice versa, composting could change the physico-chemical properties and facial functional groups of biochar, such as the improvement of nutrients, CEC, functional groups and organic matter (Wu et al., 2017). Besides, biochar by addition with compost could enhance compost properties and a much better carbon sequestration potential due to the long-term stability of biochar (Fischer and Glaser, 2012).

Application of plant-growth promoting bacteria (PGPR) as biofertilizers become popular alternative in sustainable systems for organic and low-input agriculture, as well as a tool to reduce the use of chemicals in intensive agriculture (Boraste et al., 2009). *Azotobacteria* are non-symbiotic, Gram-negative, heterotrophic, aerobic, and free-living bacteria. The positive effects of these bacteria are not only to fix nitrogen but also to promote plant growth stimulants (Montgomery et al., 2001). The main effect of *Azotobacter* sp. application as a biofertilizer is to promote the fixation of nitrogen. There are several approaches that have been investigated on the relationship between enzyme activity of *Azotobacter* sp. and soil, whereas, *Azotobacter* sp. application along with the organic amendments decreases the toxicity of metals and success revegetation even of contaminated soils (Kumar et al, 2008).

3.1.4 Soil organic matter

Soil organic matter (SOM) is a kind of organic compound containing carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), and phosphorus (P) from the decomposition of plant and animal tissues (Fig. 3). Soil organic matter is concern about soil fertility by retaining nutrients as well as pollutants in the soil, consequently, it is important for sustainable agricultural systems, crop productivity and global warming mitigation. Some factors determine the amount of organic matter in the soil: application of organic matter, the rate of organic matter decomposition, the rate of existing soil organic matter mineralization, climate, soil texture and soil structure.

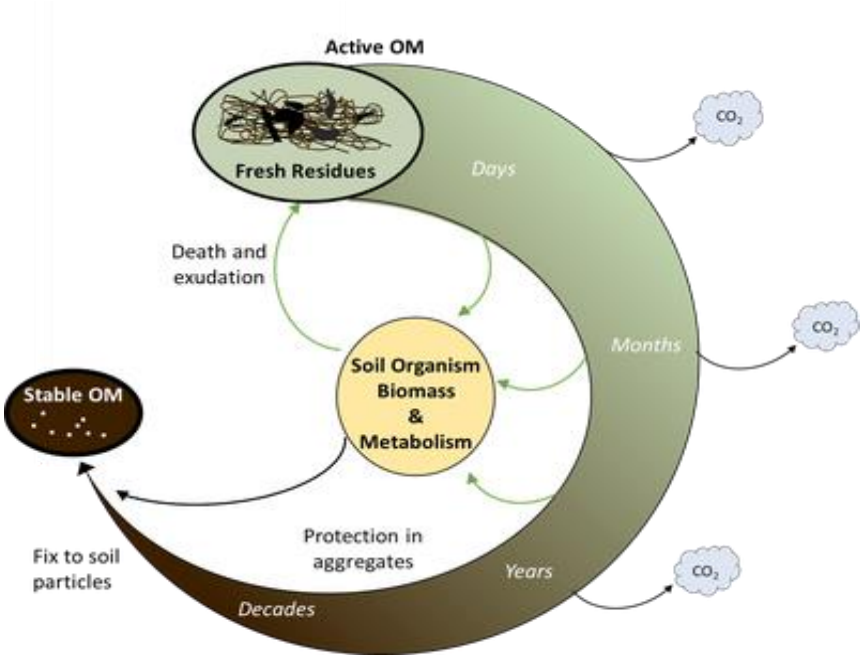


Figure 3 Organic Matter Cycling (Gasch et al., 2019)

The input of organic matter and its decomposition is related to agricultural practices. By using different types of materials - crop residues, manures, composts, and growing cover crops are enhanced organic materials and nutrients cycle without having excessive levels of nutrients. Soil microorganisms decompose the added and existing organic matter and time of decomposition depends on carbon source for the microbes, temperature, and the availability of oxygen and water. Soil texture likewise clay soil helps to stabilize SOM and limits its decomposition (Johnston et al, 2009). In general, organic matter can be classified into active and stable organic matter. Active organic matter, also referred to as detritus, is a small fraction of total soil's organic matter, however, this fraction rapidly cycles and supplies the nutrients to the plants. Stable organic matter accumulates from undecomposed plant and animal tissues through several microbial ingestions and transformations to fairly stable brown and black material often called humus. Stable organic matter is less influential than active organic matter but it is responsible for soil structure, soil tilth, and cation exchange capacity. The application of soil additives such as manure and compost provide a source of active organic matter for soil organisms. When microbes die they release carbon and nutrients from their bodies for other microbes and plants, otherwise, they may stick to soil particles (Gasch et al, 2019).

In particular, some studies reported that biochar could enhance mineralization rates of native soil organic matter (SOM). Luo et al. (2011) tested the effect of biochar in short-term changes in the rate of mineralization of native soil organic carbon (C). They used *Miscanthus giganteus* (a C_4

plant) derived biochar which was produced at 350°C and 700°C and applied to a clay-loam soil at pH 3.7 and 7.6. When they applied the biochars to the soil, they compared with and without ryegrass as a substrate. They found positive priming effects of biochar on native SOM. Singh and Cowie (2014) experimented with the long-term effect of biochar on native organic carbon mineralization. They showed that biochar stimulated soil organic carbon (SOC) mineralization caused a loss of 4 to 44 mg C/g SOC over 2-3 years in a clayey, unplanted soil (0.42% OC).

3.2 Effects of compost as soil amendment

Compost application commonly improves soil structure by decreasing soil bulk density due to the admixture of low-density organic matter OM into the mineral soil fraction, and increasing in porosity because of the interactions between organic and inorganic fractions (Amlinger et al., 2007). Agnew and Leonard (2003) suggested that compost application decreased bulk density, increased porosity and enhanced water retention and availability of water by plants. However, the effect of compost on soil properties depends on the composition of the organic waste and the management of factors such as the raw materials including nutrients, OM and fiber content, carbon/nitrogen ratio (C/N), pH, particle size distribution and bulk density that determine the biological conversion of OM (Bernal et al., 2009). Futhermore, Parkinson et al. (2004) reported that OM and nutrient content in compost may be affected by climate with different ways such as differences between temperate and tropical regions in terms of the composting procedures, differences in the levels of the properties of the raw materials used for composting and in the initial blend, and differences in the weather factors affecting the decomposition of compost OM and nutrient losses during composting; e.g. temperature and rainfall. One of the benefit application of compost is to increase the ability of soil to maintain green water such as rainfall, and irrigation water stored in the soil as soil moisture; consequently, it can reduce uptake of blue water, for example, water from surface and groundwater resources. As a result, blue water could be saved in that area where irrigation is not possible. In this case, the effective amount of water saved could influence several sites and crop conditions (Blanco et al., 2013). Decomposition of organic matter by the biological activities under controlled, aerobic conditions into a humus-like, stable product is called compost (López-González et al., 2015). Although there are different composting methods and systems varying based on from small to large compost producers, the fundamental biological, chemical and physical aspects of composting remain always the same (Fischer and Glaser, 2012). Composts are mostly used to improve soil fertility and crop yields (Fig. 4). Application of compost to soil provides benefits such as organic matter and micro- and macro-nutrients (Naeth and Wilkinson, 2013).

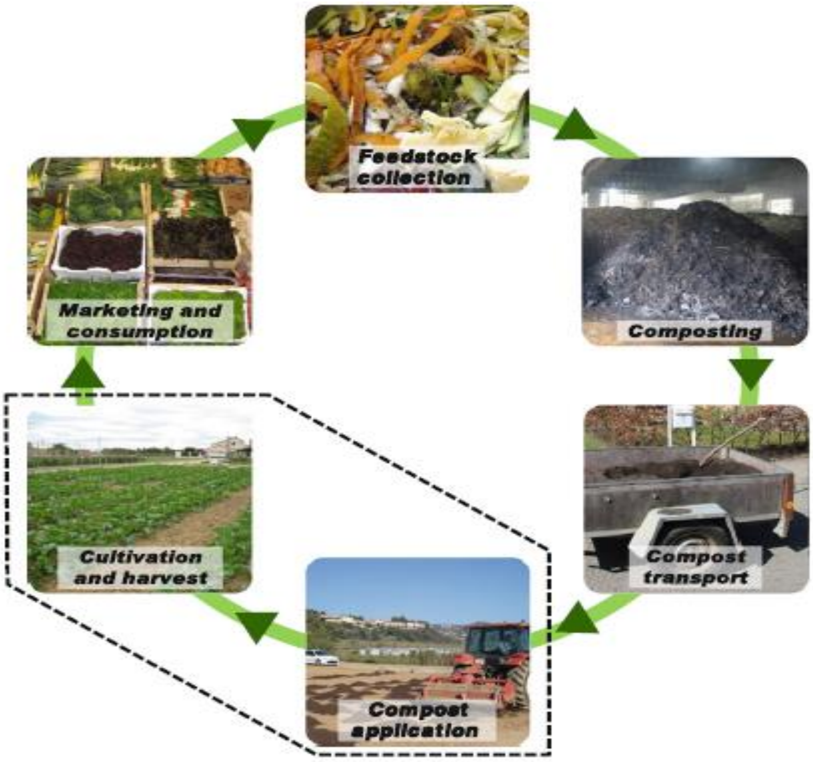


Figure 4 Overview of the life cycle of compost production and use in agriculture (Blanco et al., 2013)

Ouedraogo et al. (2001) proved that compost amendment resulted in an increase of CEC due to the input of stabilized OM being rich in functional groups into soil. According to Amlinger et al. (2007), SOM contributes about 20 – 70% to the CEC of many soils. In absolute terms, CEC of OM varies from 300 to 1,400 $cmol_c/kg$ being much higher than CEC of any inorganic material.

3.3 Effect of organic matter admixture on carbon sequestration

In the last few decades, global warming is often reported to be caused by greenhouse gases emission. Greenhouse gases are gases that absorb and emit radiant energy within the thermal infrared range and cause the greenhouse effect. Carbon dioxide, methane, and nitrous oxide (N_2O) are the most serious greenhouse gases (Liu et al., 2019). In the atmosphere, carbon dioxide contributes to other molecules to the greenhouse effect and causes global warming, consequently, it impacts on the global ecosystem. Application of biochar which is a porous carbonaceous material produced through the thermochemical conversion of organic materials in oxygen-depleted conditions has emerged as a cost-effective green sorbent to maintain environmental quality by capturing CO_2, see Fig. 5 (Dissanayake et al., 2019).

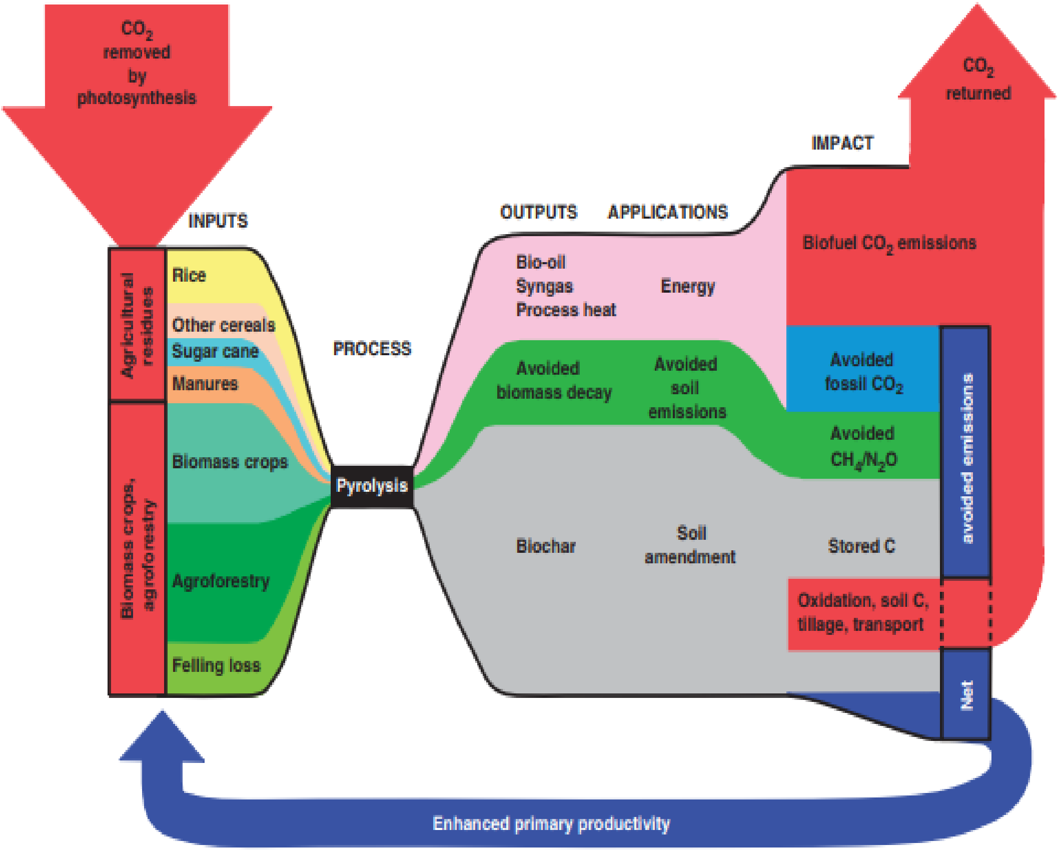


Figure 5 Overview of the sustainable biochar concept (Woolf et al., 2010)

The process of carbon sequestration is the most efficient and environmentally safe approach that involves the absorption of carbon dioxide from the air and then stores it in plant tissues in the form of carbohydrates or other organic forms of carbon in the soil (Khorramdel et al., 2018). Application of biochar produced from abundant organic waste for CO_2 capture is considered as sustainable waste management. Carbon dioxide in the atmosphere is firstly removed by green plants through photosynthesis; part of it will be then bound to the final carbonaceous structure of biochar without liberating for hundreds of years. The removal of CO_2 by photosynthesis is enhanced by biochar amendments to previously infertile soils. Therefore, biochar has the potential for even greater impact on climate through its enhancement of the productivity of infertile soils and its effects on soil greenhouse gases fluxes (Woolf et al., 2010). The physicochemical properties of the biochar, such as the surface area, pore size, pore-volume, basicity of biochar surface, presence of surface functional groups, presence of alkali and alkali earth metals, hydrophobicity, polarity, and aromaticity can influence the CO_2 adsorption capacity of biochar that is the amount of CO_2 adsorbed per unit weight of biochar (Chiang and Juand, 2017).

Several studies indicated that compost amendment to soil has important benefits on several plants and soil parameters. Compost application becomes an interesting option because of its soil restoration purposes as well as the advantage of its fertilizer properties. Compost addition increases SOM content, enhances aggregation and stability, thereby ameliorates soil structure (Diacono and Montemurro, 2010). Favoino and Hogg (2008) and Marmo (2008) reported that increasing SOM levels promote carbon sequestration. However, the initial raw waste material can influence not only the nutrient content of biowaste compost (Boldrin et al., 2009), but also the proportion resistant C pool and C sequestration rates (Diacono and Montemurro 2010).

3.4 Effects of biochar amendments to the soil

3.4.1 Effects on physical properties

The surface area of soils is important physical features for water- and nutrient-holding capacities, aeration, and microbial activities. There is a relationship between the surface area of soil and size of soil particles which is the larger the surface area, the greater the soil's water- and nutrient holding capacities. However, it is particularly true for fine-textured soils. Biochar-amended soils are likely related to the higher surface area of the biochar–soil mixtures. Due to the high surface area of biochar, it could create the space for formation of the bonds and complexes with cations and anions with metals and elements of soil on its surface, consequently, enhance the nutrient retention capacity of the soil. The total porosity or pore size distribution of biochar may play an important role in changing the properties of biochar-amended soils. (Oshunsanya et al., 2016). Depending on the factors: (i) rate of biochar application, (ii) biochar type, and (iii) time of application, the response of soils to biochar admixture could change. Bulk density decreases with increasing biochar application, inversely, surface area, porosity, and water holding capacity significantly improved with increase biochar utilization rates (Mukherjee et al., 2013), see Fig. 6. Compared to the control, mesoporosity increased due to the expense of macropores in waste-derived biochar treated soil. Therefore, biochar could be a good substitute for farming practices, which may increase porosity in the short-term (Jones et al., 2010). The surface area of biochar retains more moisture and hence, low bulk density of biochar and its highly stable organic carbon to soils can reduce soil bulk density and accordingly increase total soil porosity (Gwenzi et al., 2014). A column experiment conducted by Barnes et al. (2014) explained that application of biochar decreases bulk density about 17% in sand and 20% in clay. Soil amendment with wheat straw biochar led to increase in soil organic matter content and a net reduction in soil bulk density (Zhang et al., 2012).

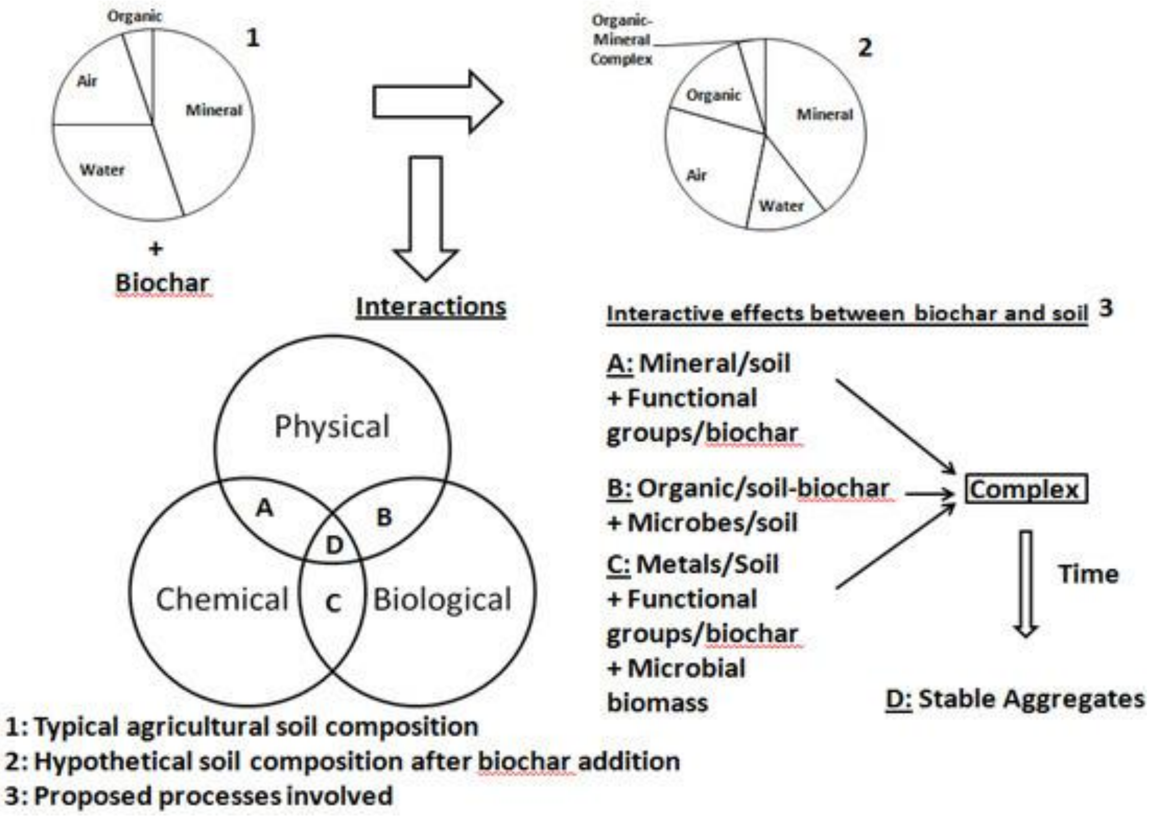


Figure 6 Schematic representation of interactions between biochar and soil (Mukherjee et al., 2013)

3.4.2 Effect on cation exchange capacity of soil

Soil cation-exchange capacity (CEC) is a measurement of how many cations (i.e., Ca^{++}, K^{+}) can be retained on soil particle surfaces and available for plants and prevent from leaching to ground and surface waters (Joseph et al., 2010). After fertilizer or manure application, CEC can control the flush of positively charged ammonium ions under favorable environmental conditions and rapid mineralization of soil organic matter (Sohi et al., 2010). Cations can be electro-statically bound and exchanged on the reactive surface area of biochar, which has negatively charged sites. Cation competes not only with each other but also with water molecules and the pore size in the charged area can be removed if they are smaller than their size (Verheijen et al., 2010). Biochar derived from the residues of high CEC value such as crop residues, its negative surface charges, and high specific surface area can potentially increase CEC of the soil, however, it is dependent on biochar properties and aging of amended biochar in the soil (Gaskin et al., 2008; Yuan et al., 2011). Naturally, aged biochars have much higher negative charge compared to either fresh or artificially aged biochar (Cheng et al., 2008). Fresh biochar showed a very low surface negative charge in the pH range of 7.0–11.0, with a positive charge only below pH 7.0 (Li et al., 2014) and surface negative charge increased until pH 3.5 following artificial oxidation of biochar (Silber et al., 2010). However, naturally aged biochar showed a comparatively higher negative surface charge than either fresh biochar or artificially aged biochar (Cheng et al., 2008). It is difficult to assess the CEC in biochar depending on different feedstocks and temperatures of production due to the lack of standardized methodology (Kookana et al., 2011). Gaskin et al. (2008) showed that increasing pyrolysis temperature leads to decrease of CEC of the biochar, while, Singh et al. (2010) found that CEC increases with increasing temperature. CEC values significantly increase up to two times in soil-biochar mixture compared to the adjacent soils in the Brazilian Amazon (Liang et al., 2006). Lehmann et al. (2003) reported that the addition of biochar to soils significantly decrease the leaching of fertilizers. El-Naggar et al. (2018) and Igalavithana et al. (2015) suggested that the high ash content of some biochars is reason for their positive effect on soil CEC.

3.4.3 Effect of biochar admixture concerning crop yield

Many studies demonstrated that the application of biochar improves not only the biophysical but also chemical properties of the soil, as well as nutrient supply to plants. Using biochar in low fertile soil can cause more agricultural land available while increasing crop yields so that the need for expansion of agricultural land area decreases (Barrow, 2012). Application of biochar along with compost can increase crop yields through several mechanisms including the direct supply of nutrients, improving soil pH, improving nutrient use efficiency, increasing soil CEC and improving water holding capacity (Agegnehu et al., 2015; Jeffery et al., 2011). Biochar as soil amendment significantly increased in root biomass, crop growth and followed by high yield (Abiven et al., 2015; Agegnehu et al., 2015). The forms such as dust, fine particles, coarse grain and the methods of BC application to soil (surface application, top dressing, drilling) can influence the effect of biochar on soil health and crop productivity (Oshunsanya et al., 2016). However, some studies such as in an Australian study for wheat (Blackwell et al., 2007) show no significant yield response at low rates of application. Positive yield effects from biochar addition were reported by Steiner et al. (2008), biochar maintaining crop yields through increased fertilizer use efficiency after forest clearance in Amazonia is essentially a recreation of *terra preta.* Agegnehu et al. (2015) suggested that peanut yield increased by 23% and 24% from the applications of biochar and co-composted biochar-compost. A pot study of maize showed higher biological nitrogen fixation with biochar addition due to nutrient effects (Rondon et al., 2007); higher yield and N uptake reported in pot trials using radish (Chan et al., 2007, 2008). A key consideration highlighted in several studies is the potential for biochar to immobilize previously plant-available N. This could be from the mineralization of labile, high C–to–N fractions of biochar drawing N into microbial biomass, sorption of ammonium, or sequestration of soil solution into fine pores.

3.5 Effect of biochar on soil hydrophysical properties

3.5.1 Soil water content

The form of soil water can be described in two ways, (1) soil water content which indicate amount of water either as volume or mass related to volume or mass unit of soil, (2) soil water potential which relates to the energy level to hold the water in the soil (McKenzie, 2002). Soil water content is an important link for the hydrologic cycle such as improvement of soil water management as well as microbial activity (Topp and Ferré, 2002). Soil water content is a key factor for the mineralization of nutrients through microbial activities. However, the excess soil water content can affect the activity of aerobic microorganisms because there is a limitation for oxygen diffusion in water and its diffusion is much lower than in air, which will reduce the activity of aerobic microorganisms (Skopp et al., 1990). Soil water balance is required for plant development and solute transport. Variation of soil moisture and movement of water to the environment depends on rainfall, irrigation periods and temperature.

According to Or and Wraith (2002), the soil water content can be described in two different parameters based on mass water content and volumetric water content.

(a) Mass water content is the mass of the water-related to the mass of dry soil (equation 1). Mass water content is often referred to as gravimetric water content (Or and Wraith, 2002), however, gravimetric method is used to obtain both the mass and volumetric water contents.

$$w_m = \frac{m_w}{m_s} \qquad (1)$$

Where:
m_w…………………mass of water (g)
m_s…………………..mass of the soil (g)

(b) Volumetric water content is the volume of water per total volume of soil (equation2).

$$\theta_v = \frac{V_w}{V_s} \qquad (2)$$

Where:
V_w…………………volume of water (cm^3)
V_s…………………..volume of the soil (cm^3)

3.5.2 Soil water potential

The soil water potential is the energy related to a unit of water. In general, there are two types of energy, potential, and kinetic energy, which too small to be considered in soil water flow. The flow of the water in the soil is from the point of higher potential energy to the point of the lower one (Or and Wraith, 2000).

According to Hillel (2004), soil water potential can be expressed in three different units:

Potential per unit mass (μ): μ = potential/mass = (J/kg)

Potential per unit volume (ψ): ψ = potential/volume = (Pa)

Potential per unit weight (h): h = potential/weight = (m) = equivalent height of water

Total soil water potential will be zero if the pure water in saturated soil is in the same condition with reference elevation, pressure, and temperature. The total potential can be described in either potential or head.

- Expressed as the energy related to a unit mass of water (this is called potential, equation 3)

$$\psi_t = \psi_g + \psi_w + \psi_o + \psi_a + \psi_e + \psi_{pt} \qquad (3)$$

Or more often expressed as the energy related to a unit weight of water (this is called head; equation 4).

$$H = h_g + h_w + h_o + h_a + h_e + h_{pt} \qquad (4)$$

Where:

ψ_t - total soil water potential (J/kg), H - total soil water head (m), Ψ_g/ h_g - gravitational water potential, vertical distance between the reference and point of question, Ψ_w/ h_w - matric potential, representing the height above a point of fictitious free water surface,Ψ_o/ h_o - osmotic potential, presence of solutes in the water, can be neglected in non-saline soils, Ψ_a/ h_a - pneumatic potential, if the air pressure in soil is different from the air pressure at the free water level, Ψ_e/ h_e – envelope potential, Ψ_{pt}/ h_{pt} – potential of groundwater.

3.5.3 Soil water infiltration

Water infiltration into soil is a part of the hydrologic cycle. Infiltration is a process of penetration of water through the soil surface into the soil with downward direction. Infiltration rate expresses how fast water seeps into the soil, it is volume flux of water flowing into the soil profile per unit of soil surface area. Maximum infiltration rate also termed as infiltration capacity is the maximum rate of water that is absorbed by the soil (Brouwer et al., 1985; Hillel, 2004).

Infiltration is a key factor to control surface runoff and directly related to runoff: if water cannot infiltrate into the soil, it can form runoff. The conditions such as rainfall or irrigation intensity and the soil hydraulic properties also influence water infiltration and runoff (Hillel, 2004).

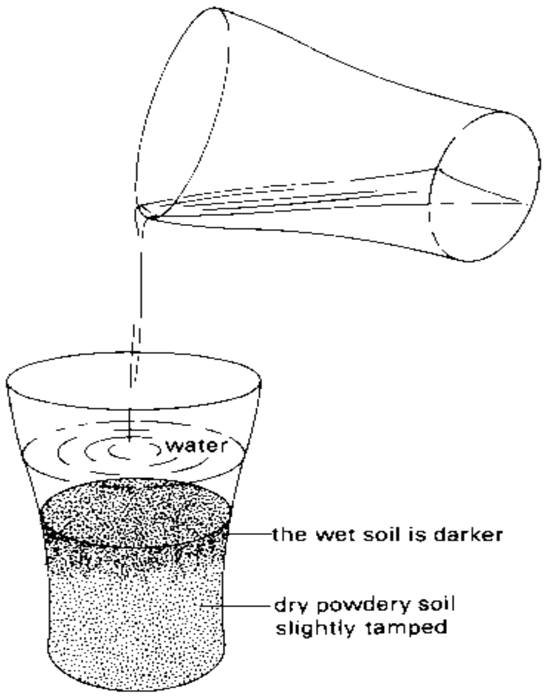


Figure 7 Infiltration of water into the soil (Brouwer et al., 1985).

Infiltration rate can differ depending on soil type especially the portion of sand, silt and clay in soil and soil moisture content, as well as soil structure. The infiltration into the sand is higher than into the clay soil because water can move easily through the large pores of coarse soil (sandy soil). Similarly, compacted soil will have lower infiltration than granular. The water infiltration is faster in dry soil than the wet soil. We can imagine that when we apply irrigation water into the field, the water infiltrates as fast as possible in dry soil but it will be opposite in very wet soil. Moreover, agricultural processes such as the tillage system can influence water infiltration (Brouwer et al., 1985).

3.5.4 Soil water retention in biochar treated soil

Soil water retention curve (SWRC) and hydraulic conductivity are the key elements in soil hydraulic properties that can determine water transport in soils and availability of water for plants (Cornelis et al., 2005). Soil water retention is the ability of soil to hold a considerable amount of water and it determines uptake and transport of water by plants which are important for plant physiology and yield (Razzaghia et al., 2019). SWRC represents the relationship between matric potential (h) and soil water content (θ) that is the function for the modeling of the hydro-mechanical behavior of porous media. SWRC is affected by not only soil structure but also soil texture. Soil structure influences the amount of water retained at relatively low suctions through capillary effects and the soil pore-size distribution. Soil texture and the specific surface area of a soil can increase water retention at higher suction associated with adsorption. Fine-textured soils (clay soil) that have much broader pore-size distribution can retain much more water compared to coarse-textured soil such as sandy soil. SWRC is strongly hysteretic, which means, that the curve follows different paths depending upon the drying and wetting history of the soil (see Fig. 8). When the soil is fully saturated (wetting), the suction is gradually lowered and water content is higher than the same suction of dry sample (drying). These two main curves are called the primary drying curve and the primary wetting curve (Jain et al, 2004).

Rasa et al. (2018) suggested that soil water retention properties are changed by the amendment of biochar that could modify soil structure. Soil properties and soil water dynamics are effectively supported by small particle size and high porosity of biochar (Dokoohaki et al., 2018). Use of biochar in sandy soils which has low water holding capacity, and high leaching of soil nutrients, is a sustainable option to provide long-lasting improvements in soil fertility (Lehmann et al., 2003; Novak et al., 2009) because of its ability to maintain nutrients and to improve soil water holding capacity. Increasing water holding capacity can enhance water use efficiency in agricultural production (Basso et al., 2013). Biochar amendment to the soil can influence soil water retention properties by decreasing soil bulk density (Abel et al., 2013), increasing total soil pore volume and altering the pore-size distribution (Obia et al., 2016).

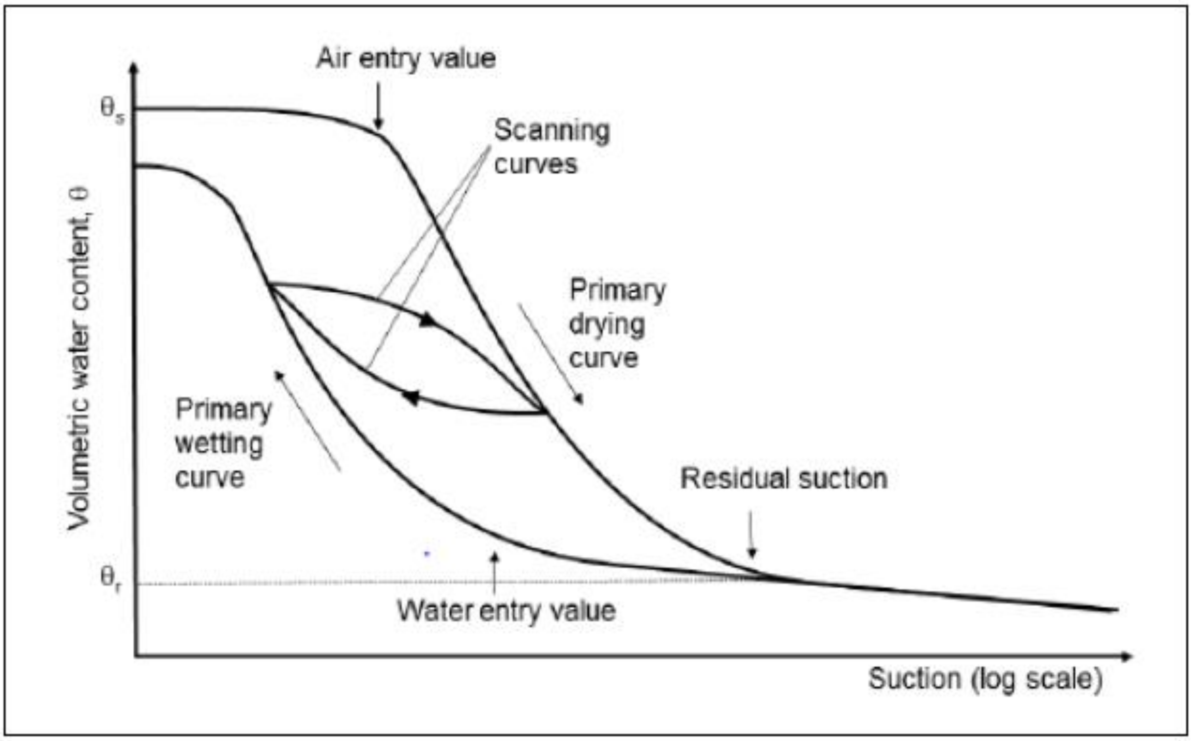


Figure 8 Hysteresis of soil water retention curve (Toll et al., 2015).

3.5.5 Hydraulic conductivity of biochar amended soil

Hydraulic conductivity is the soil's ability to transmit water under saturated or unsaturated conditions. Agricultural decisions such as irrigation rates, prevention of erosion and nutrient leaching are based on soil hydraulic conductivity.

Saturated hydraulic conductivity (K_s) is one of the most important hydrophysical properties of soil that governs water movement and water storage through the soil profile. Therefore, its value is needed to accurately describe the transport of water and dissolved or suspended constituents in soils and sediments, or calculate groundwater transport and recharge and many other purposes (Wang et al., 2013). The saturated hydraulic conductivity is characterized by Darcy's law. In Darcy's law, saturated hydraulic conductivity is a constant proportionality (equation 5).

$$Q = K_s \cdot \frac{dH}{dx} \tag{5}$$

Where,

Q ....the flux (m/s)
K_s ....the saturated hydraulic conductivity (m/s)
dH ....the head difference (m)
dx...........................the distance (m).

The unsaturated hydraulic conductivity is a measure of how water and solute can flow through the soil profile under unsaturated conditions of the soil. The vadose zone is a place involving the soil-water-atmosphere-plant interaction as natural processes. The relationship between unsaturated hydraulic conductivity (K) and volumetric water content (θ) is required for solving problems in water quality and quantity, agricultural water management and infiltration capability of the soil, nutrient cycling, soil development, and natural hazards such as flooding and landslides (Matula et al., 2015).

Recently, biochar has been tested for its potential to affect soil hydraulic properties, for instance, saturated hydraulic conductivity (K_s) and soil water retention curve that are related to the rainwater infiltration through the cover system. Lim et al. (2016) investigated experimentally the impact of biochar derived from a variety of biomass materials on water movement through amended soil. The objective was to evaluate the impact of biochar additions on (K_s) through several soils of different texture. They extracted overall soil textures: coarse sand, fine sand, silt loam, and clay loam texture soil. Before applying, all the soils were air-dried, sieved to <2 mm, kept in room temperature. Biochars derived from various feedstock materials such as hardwood wood pellets, pinewood chips, hardwood chips, and oat hulls were used. All the soils were combined with 1%, 2%, and 5% by mass of four different biochars and all of them were thoroughly mixed to be a homogeneous mixture. The soil, or soil mixtures, were repacked into soil column and K_s was measured by using a falling head method. They reported that the rate and type of biochar, as well as the original particle size of soil, significantly influenced the K_s of the biochar amended soils. Their result showed that biochar addition decreases K_s in sandy soils and increases K_s in clay-rich soils. There is an approach to fill the gap of knowledge to understand the decreasing effect of biochar on K_s; (1) the obstruction of water flow through effective soil pores by biochar particles (Lim et al., 2016), (2) a decrease of effective pores volume to absorb water, (3) the gradual clogging of soil pores by moving biochar particles (Wang et al., 2013) and (4) an increase in the number of micropores (<1 μm), which bind water by strong capillary and/or adsorptive forces (Lim et al., 2016).

Similarly, Zhang et al. (2016) conducted a study to describe the characteristics of biochar and its impact on hydraulic conductivity in sandy soil, to test the mechanism of biochar’s effect on soil water evaporation, and help to choose the right biochar and application method. For their research, pine (*Pinus sylvestris* var. *mongolica Litv*) and poplar (*Populus davidiana*) based biochars were prepared at 450 and 550°C, respectively. The particle size of the biochar was about 5–8 mm in diameter after pyrolysis. The characteristics of soil used in their research: sandy soil, with the 99.5% sand content and 0.5% silt content, pH was 8.6 and particle size of the sandy soil was 0.28 mm. Different amounts of biochar were added into the sandy soil column by uniformly mixing or in one layer separately, the aim is to evaluate the influence of the biochar on soil saturated hydraulic conductivity. The constant-head method was employed to determine K_s. They reported that in sandy soil, an increased amount of biochar application was gradually decreasing saturated hydraulic conductivity. Large pore volume and average pore diameter of biochar influenced water retention, as well as the single-layer method, could retain more water. Moreover, the hydraulic properties of the soil were significantly changed by the particle size of the applied biochar.

3.6 Measurements of hydraulic conductivity

3.6.1 Laboratory measurements of saturated hydraulic conductivity

There are two standard methods to measure K_s in the laboratory: one is the falling-head method and the other is the constant-head method (Stibigner, 2014).

In the falling-head method, firstly, the soil sample is saturated with water under a specific head condition. The water is allowed to flow through the soil without maintaining a constant pressure head. The head of inflow fluid decreases from H_0 to H_1 as a function of time (t). The falling head permeameter (Fig. 9) is used rather for cohesive sediment with low hydraulic conductivity. The calculation of K_s from the measurement that is obtained from the laboratory test is carried out by Darcy's law which is stated below (equation 6).

$$K_s = \frac{r^2 L}{r_s^2 t} ln \frac{H_0}{H_1} \qquad (6)$$

Where;

K_s (L/T).............................the saturated hydraulic conductivity

r (L)...................................the radius of the tube

r_s (L)..................................radius of the cylindrical sample

L (L)...................................the high of the sample

t (T).....................................time

H_0 (L).................................the initial water level in the tube

H_1 (L).................................the final water level at the time t

In constant-head permeameter (Fig. 10), the inflow of fluid is maintained at a constant head (h) above a datum and outflow is measured as a function of time (t). This method is commonly used to determine the permeability of granular soils like sands and gravels. Using Darcy's law, the hydraulic conductivity can be determined using the following equation after the outflow rate has become constant (equation 7).

$$K_{s=} \frac{(V\Delta z)}{(A_S \Delta ht)} \qquad (7)$$

Where;

V ....volume (m^3)

A ……………………cross-sectional area of the sample (m^2)

t...............................time (s)

Δh...........................difference of water levels (m)

Δz .... height of sample (m)

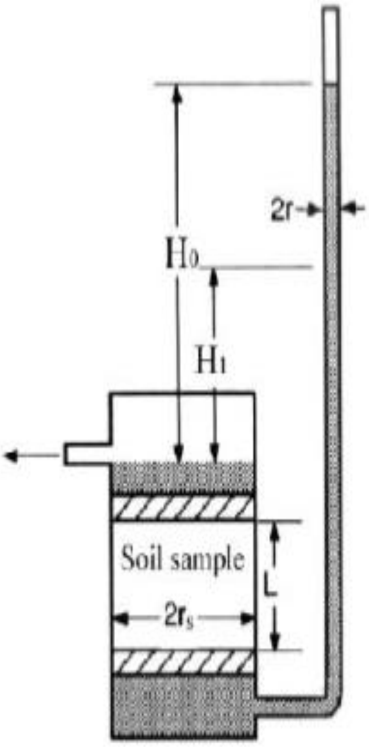


Figure 9 The falling head apparatus (source: https://echo2.epfl.ch/VICAIRE/mod_3/chapt_8/main.htm)

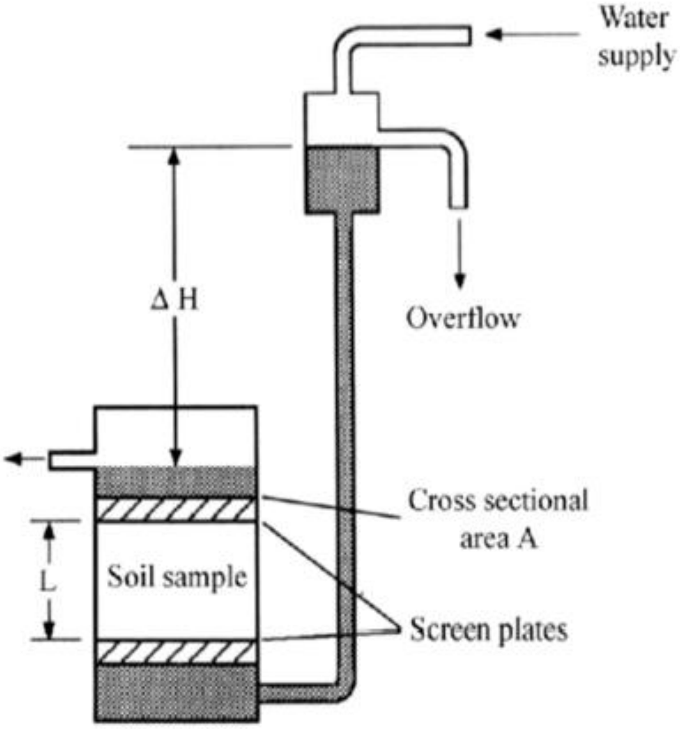


Figure 10 The constant head apparatus (source: https://echo2.epfl.ch/VICAIRE/mod_3/chapt_8/main.htm).

3.6.2 Field measurement of saturated hydraulic conductivity

Under the field condition, it is difficult to reach completely saturated soil due to the pore spaces filled with air. There are various methods to determine the saturated hydraulic conductivity of the soils in situ at or near the soil surface. Among them, commonly used methods without disturbing soil are; the auger hole and piezometer methods (Ernst, 1950), if the groundwater level is close to the soil surface. When the groundwater level is deeply located, infiltration test is used and measurement takes place above the ground water level in vadose zone. In general, there are two types of infiltrometer; (1) Pressure infiltrometers, such as double-ring infiltrometer, pressure infiltrometer for K_s measurement and (2) Tension infiltrometers such as disc infiltrometer, hood infiltrometer and mini-disk infiltrometer for unsaturated hydraulic conductivity $K(h)$ measurement (Báťková et al., 2013).

3.6.3 Mini Disk Infiltrometer

It is possible to estimate the soil hydraulic conductivity either in the laboratory or in situ using infiltrometer tests. In situ measurement of soil hydraulic properties such as sorptivity (S), and hydraulic conductivity $K(h)$ requires to describe field infiltration and runoff processes. Reynolds and Elrick (1991) suggested that tension infiltrometer is an efficient technique that can give information on soil hydraulic properties. One of the most important features of tension disc infiltrometers is capability of measuring the unsaturated hydraulic conductivity of the soil. Water flow through the unsaturated soil is more complex than saturated pore spaces because some of the pores in unsaturated soil are filled by air. The conductivity decreases when the air moves into the soil to replace the water, as a consequence, the soil dries. Therefore, the hydraulic conductivity of soil mainly depends on detailed pore geometry and water content (Brady and Weil, 1999; Rose, 1966).

The Mini Disk Infiltrometer (manufacted by Decagon Devices, Inc. in 1997, now produced by METER Group, Inc., USA) is typically used for measuring $K(h)$ on soil surface due to its compact size which can be carried to the field without much difficulty and the small amount of water needed for their operation. The disk infiltrometer is designed to maintain negative water pressure that is less than atmospheric pressure at the soil surface. With the Mini Disk Infiltrometer, the suction head can be adjusted from -0.5 to -6 cm at the soil surface and the volume of the water reservoir is about 100 ml (see Fig. 11).

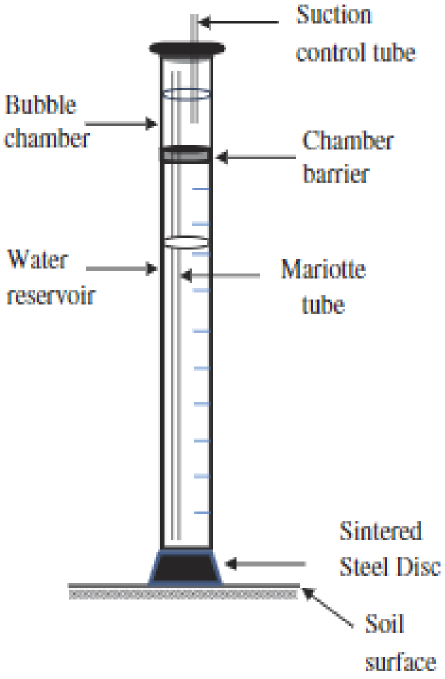


Figure 11 Schematic diagram of Mini Disk Infiltrometer (Decagon Devices, 2006)

There are several techniques based on either steady-state flow data or transient flow data to determine soil hydraulic properties from disk infiltrometer measurements. The measurement data from a steady-state flow can be calculated by using the method proposed by Zhang (1997) which is based on Philip (1957). It is simple and works well for the measurements of infiltration into dry soil (equation 8):

$$I = C_1 t + C_2\sqrt{t} \qquad (8)$$

Where;

I is cumulative infiltration (L)

C_1 is related to hydraulic conductivity

C_2 is the soil sorptivity ($L/T^{0.5}$)

t is the time (T)

The hydraulic conductivity for the soil $K(h)$can be computed from equation 9.

$$K(h) = \frac{C_1}{A} \qquad (9)$$

Where,

C_1 is the slope of the curve of the cumulative infiltration versus the square root of time,

A is a value relating the van Genuchten soil water retention curve parameters for a given soil type to the suction rate and radius of the infitrometer disk.

A can be calculated from one of the following equations 10 and 11.

$$A = \frac{11.65(n^{0.1})exp[2.92(n-1.9) \propto h_0]}{(\propto r_0)^{0.91}} \quad (10)$$

$$A = \frac{11.65(n^{0.1}-1)exp[7.5(n-1.9)] \propto h_0}{(\propto r_0)^{0.91}} \quad (11)$$

Where,

n and α are the van Genuchten parameters for the soil,

r_o is the disk radius, and h_o is the suction at the disk surface (Báťková et al., 2013; METER Group, 2018).

4 Materials & Methods

4.1 Location

This study was conducted in-situ in Plant Production Station Uhříněves belonging to the Department of Agroecology and Crop Production, Czech University of Life Sciences Prague, located in Praha - Uhříněves. The experiment was carried out in both drip irrigated greenhouse (50°02'00.8"N 14°36'32.4"E; Fig. 12) and non-irrigated field (50°01'59.1"N 14°37'03.7"E; Fig. 13) conditions two times during vegetation season of mustard in 2019.

Figure 12 Location of the Greenhouse Experiment (Source- maps.google.com)

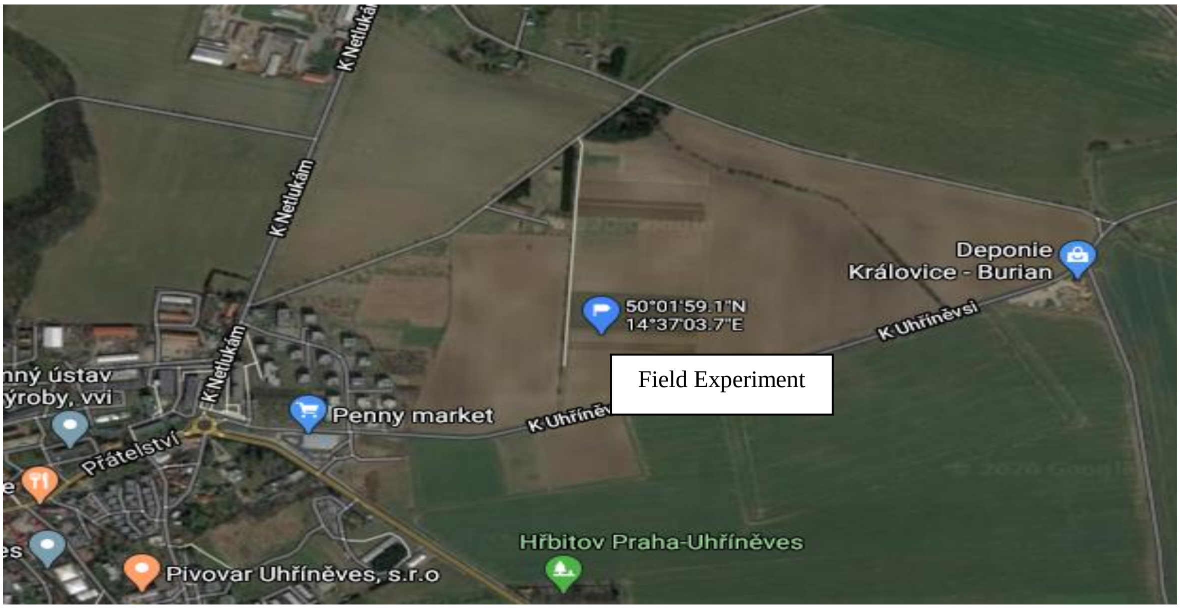


Figure 13 Location of the Field Experiment (Source- maps.google.com)

4.2 Information about the soil

Plant Production Station Uhříněves is situated at the elevation of 295 m a.s.l whereas average temperature is 8.4°C and average sum of precipitation is 575 mm (Capouchová et al., 2015; Dvořák et al., 2015). The soil type is Haplic Luvisol (IUSS Working Group WRB, 2015) which developed on loessic parent material with clay loam texture. It is deep fertile soil with organic matter content between 1.74 – 2.12 % (Tomášek and Dvořák, 2009).

4.3 Information about Biochar and Its Activation

The two commercially available biochars, Agrouhel (produced by BIOUHEL.CZ s.r.o.) and Agro-Protect-Soil (produced by Ekogrill s.r.o.) which are raw biochars without activation were used for this experiment. "Agrouhel" biochar was manufactured from silage maize rests in a biogas station and wheat straw in a ratio of approximately 1:1. The pyrolysis was with a temperature of 460 °C in 18 minutes (Kidane, 2016). "Agro-Protect-Soil" biochar was produced from beech wood.

We applied 20% (by mass) of biochar and 20 t/ha of compost in the greenhouse. For the field, we used two concentrations of biochar, 2 and 20% in the compost, and the rate of compost was 20 t/ha.

Azotobag (produced by Farma Žiro s.r.o.) is a kind of bio-fertilizer including *Azotobacter* sp., *Bacillus megatherium* and *Rhizobium* sp. We applied the Azotobag for both greenhouse and field with the rate of 10 ml/ha by using the spraying method 15 days before biochar and compost addition according to the recommendation of producer.

Biochar treated with bokashi was obtained from the Department of Water Resources. The main materials for the activation of biochar with bokashi were: non-activated / fresh biochar, sawdust for carbon sources of microbial population, grass trimmings to obtain traces elements and enzymes, sugar and rice leachate solution and experimental soil. The main reason the use of experimental soil was to include the natural bacterial population of the experimental area and to be sure for the adaption of native microorganisms after application of organic matter. See the fermentation procedure in Fig. 14. (Bokashi in the figure was used in the greenhouse, while in the field was used bokashi prepared in a bigger scale and with slightly different ingredients, molassa was used instead of sugar solution and old silage was used instead of saw dust and grass trimmings.)

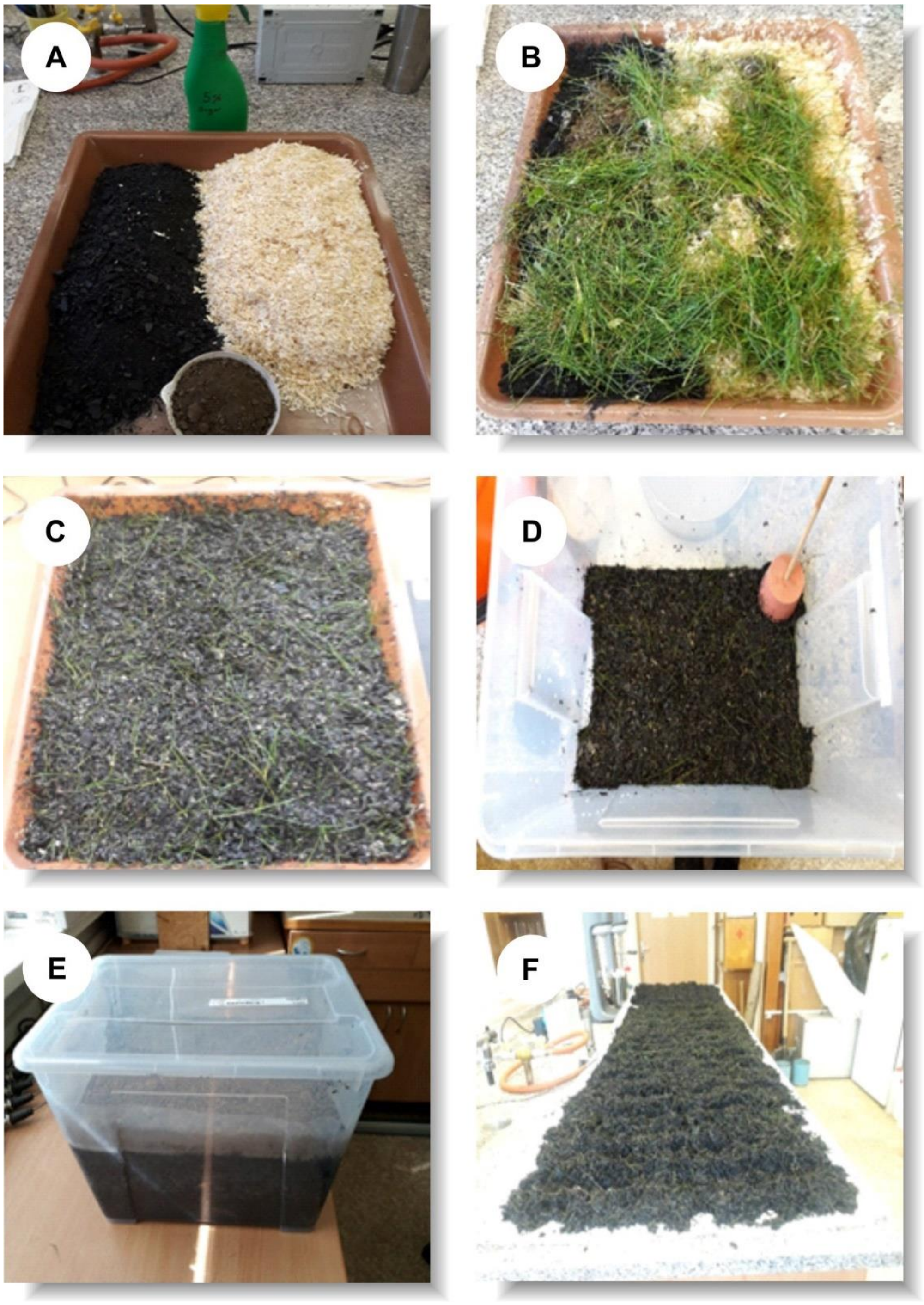


Figure 14 Bokashi treated biochar compost: (A) showing the mixture of 6 unit biochar+ 2.5 unit sawdust, 5 (M/M) sugar solution, (B) Adding 1 unit experimental soil and 1 unit grass trimming, (C) The mixture sprayed with 5% sugar solution which includes 1.10^6 colony-forming units of Lactobacillus spp.+Bifidobacterium spp., (D) making the anaerobic conditions by packing into plastic container layer by layer, (E) fermentation process by sealing the container with polymeric foam and covering with soil (F), aeration of bokashi treated biochar for two days to eliminate the phytotoxicity risks of organic residual from lactic acid fermentation (source: Department of Water Resources)

4.4 Experimental treatments and design

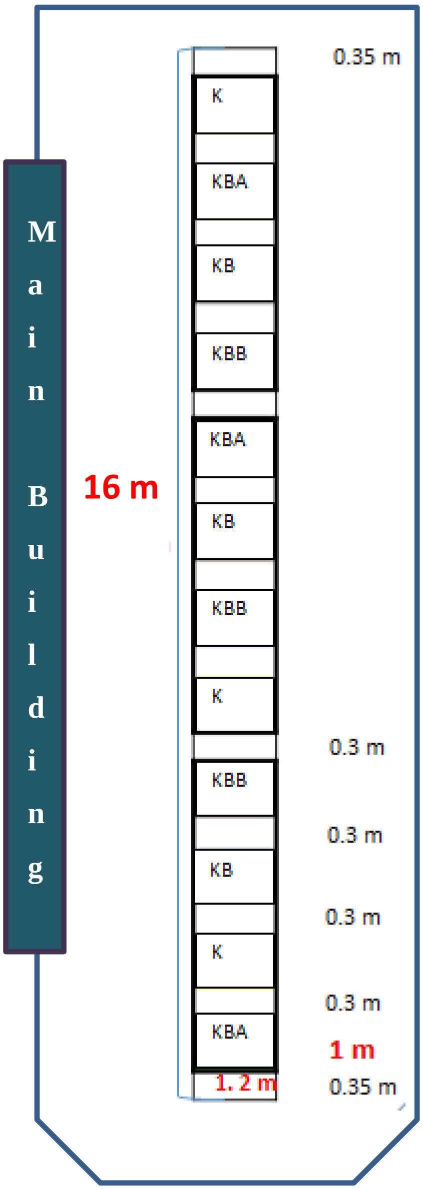
Experimental design for both greenhouse and field were laid out in a randomized block design. In greenhouse experiment, there were four treatments with three replication and in total 12 parcels of area 1.2 m^2. The treatments were distributed as following (see the scheme on Fig. 15).

-Compost application 20 t/ha (as control) (denoted as K)

-Compost+Biochar (Agro-Protect_Soil) 20% (denoted as KB)

-Compost+Biochar (Agro-Protect_Soil) 20% treated by bokashi (denoted as KBB)

-Compost+Biochar (Agro-Protect_Soil) 20% treated by Azotobag (denoted as KBA)



K: Compost application (20 t/ha)

KB: Compost + biochar (20 %)

KBA: Compost + biochar (20 %) application to Azoter inoculated field

KBB: Compost + bokashi treated biochar (20 %) application

Figure 15 Schematic representation of experimental design in greenhouse

In the field was more space for different treatments. There were three controls, pure compost as blind control, compost treated with Azotobag, and compost treated with bokashi without biochar. Both kinds of biochar were used, in two concentrations (2 and 20% by mass) and each variant was treated either by bokashi and Azotobag. Altogether 11 treatments and each comprising of 3 repetitions, 33 parcels in total, whereas each parcel had 5 m^2. The experimental design is on the scheme on Fig. 16, all treatments are described in details in the legend.

11	**KK**	**A20AZ**	**KBO**
10	**A2BO**	**E20AZ**	**A20BO**
9	**E2BO**	**KAZ**	**E20BO**
8	**A2AZ**	**KK**	**A20AZ**
7	**E2AZ**	**A2BO**	**E20AZ**
6	**KBO**	**E2BO**	**KAZ**
5	**A20BO**	**A2AZ**	**KK**
4	**E20BO**	**E2AZ**	**A2BO**
3	**A20AZ**	**KBO**	**E2BO**
2	**E20AZ**	**A20BO**	**A2AZ**
1	**KAZ**	**E20BO**	**E2AZ**

Legend

KAz = Compost treated with Azotobag

E20Az = 20% of Agro-Protect-Soil biochar treated with Azotobag

A20Az = 20% of Agrouhel biochar treated with Azotobag

E20Bo = 20% of Agro-Protect-Soil biochar treated with bokashi

A20Bo = 20% of Agrouhel biochar treated with bokashi

KBo = Compost treated with bokashi

E2Az = 2% of Agro-Protect-Soil biochar treated with Azotobag

A2Az = 2% of Agrouhel biochar treated with Azotobag

E2Bo = 2% of Agro-Protect-Soil biochar treated with bokashi

A2Bo = 2% of Agrouhel biochar treated with bokashi

KK = Pure compost (Blind Control)

Figure 16 Schematic representation of experimental design in field

4.5 Preparation of the infiltrometer

Mini Disk infiltrometer is a kind of tension infiltrometer and it can be used to measure the hydraulic conductivity in the unsaturated medium (near to saturation). The Mini Disk Infiltrometer‘s design is described in Table 1.

Table 1 Information about Mini Disk Infiltrometer (METER Group, Inc., USA, 2018)

Total Length	32.7 cm
Diameter of tube	3.1 cm
Sintered stainless steel disk	4.5 cm diameter, 3 mm thick
Length of suction regulation tube	10.2 cm
Suction range	0.5 to 7 cm of suction
Length of water reservoir	21.2 cm
Length of mariotte tube	28 cm
Volume of water required to operate	135 ml

Mini Disk Infiltrometer consists of two chambers; upper and lower chamber. Both two chambers were filled with water. The top chamber also called the bubble chamber controls the suction head and at the lower chamber whereas the infiltration water was stored. The rate of water infiltrating into the soil depends on soil type, especially sandy soil takes part in conducting the water rapidly. By adjusting the suction rate on the Mini Disk Infiltrometer, the rate of water moving out through the infiltrometer disk can be adapted. The sequential decrease of negative pressure head leads to draining the water through the base of infiltrometer disk to the smaller and smaller pore. According to the procedure of METER Group (2018), the suction rate or tension (which is absolute value of negative pressure head) of 2 cm is adequate for most soils while for sandy soil an adjustment should be 6 cm and for the compact soil with slower infiltration should be the suction rate of 0.5 cm. In this study, we set the suction rate of 2 cm in clay loam soil. Infiltration time for each pressure head was at least 20 min in order to reach the steady state flow.

It is important to be sure a good hydraulic contact between the measuring device membrane and the soil. Therefore, a smooth spot on the representative soil surface was carefully created by removing the surrounding vegetation cover. See an example of the measurement in field in Fig. 17.

Figure 17 Measurement of unsaturated hydraulic conductivity with Mini Disk Infiltrometer (Source War War Mon)

Before starting infiltration measurement, water volume was recorded. At time zero, the Mini Disk infiltrometer was placed on the soil surface. The volume of infiltration water in time interval 1 min was recorded during each measurement. The collected infiltration data were calculated using the methodology recommended by the producers. The measurement data from a steady-state flow were calculated by using the method proposed by Zhang (1997) (equation 8).

Van Genuchten parameter *n* of the present soil with is less than 1.35, therefore, we used Dohnal's et al. (2010) equation as the recommendation of manual to calculate the *K(h)* (equation 12).

$$K = \frac{C_1(\propto r_0)^{0.6}}{11.65(n^{0.82}-1)exp[34.65(n-1.19)\propto h_0]} \qquad (12)$$

n and α are the van Genuchten parameters for the soil,

r_o is the disk radius,

h_o is the suction at the disk surface.

4.6 Description of the measurements

The infiltration tests were carried out in situ during vegetation season of the mustard crop (*Sinapis alba* L.) between July 2019 and October 2019. Mustard was sown two times during the vegetation season and harvested as green biomass. Activated bichar was applied once before first sowing.

The **first term** from sowing to harvest was between 14 May and 9 July, **second term** was between 27 August and 14 October. Infiltration tests were conducted near harvesting time. In the first term, undisturbed soil samples were taken from both experimental sites in order to obtain dry bulk density, actual water content and saturated water content.

In the **greenhouse**, there were 4 treatments in 3 replicates, in total 12 parcels. Three measurements with Mini Disk Infiltrometer were conducted on each parcel, thus 12 measurements for each treatment, 48 altogether. However, in the first term, three parcels were excluded from the experiment, because they were not representative due to problems with drip irrigation system, thus only 36 measurements were done. In total, 36+48=84 infiltration measurements in the greenhouse.

In the **field**, there were 11 treatments in 3 replicates, in total 33 parcels. Two measurements with Mini Disk Infiltrometer were conducted on each parcel, thus 6 measurements for each treatment, 66 altogether. In total, 66+66=132 infiltration measurements in the field.

Soil water content (θ) was measured by using the 5TE soil moisture sensor (METER Group Inc., USA) both before and after infiltration measurements in order to obtain initial (θ_i) and final water content (θ_f), see Fig. 18.

Figure 18 Measurement of water content with 5TE sensor (Source War War Mon)

Undisturbed soil samples (250 cm^3) were taken both in the greenhouse and in the field in the first term. Actual water content and saturated water content were determined by gravimetric method. Dry bulk density was determined after drying the samples in oven at 105°C to the constant weight. Each experimental parcel was sampled, in total 45 undisturbed samples (12 in greenhouse and 33 in field). Sampling was carried out with significant help of my consultant.

4.7 Statistical analysis

Statistical software SPSS version 20 (IBM, SPSS, USA) was used to carry out data analysis. One-way ANOVAs were also used to check statistical difference among the treatments on unsaturated hydraulic conductivity at significance level description $p<0.05$. To compare the data, which is higher or lower, Duncan test was performed.

5 Results

5.1 Soil dry bulk density and soil water content

The values of dry bulk density were determined for each treatment in the first vegetation term in July within 3 replications (2 samples were damaged). The average bulk density of the greenhouse experiments under different treatments ranged from 1.21-1.25 g/cm^3 (Figure 19), and for the field, it was from 0.96-1.09 g/cm^3 (Figure 20).

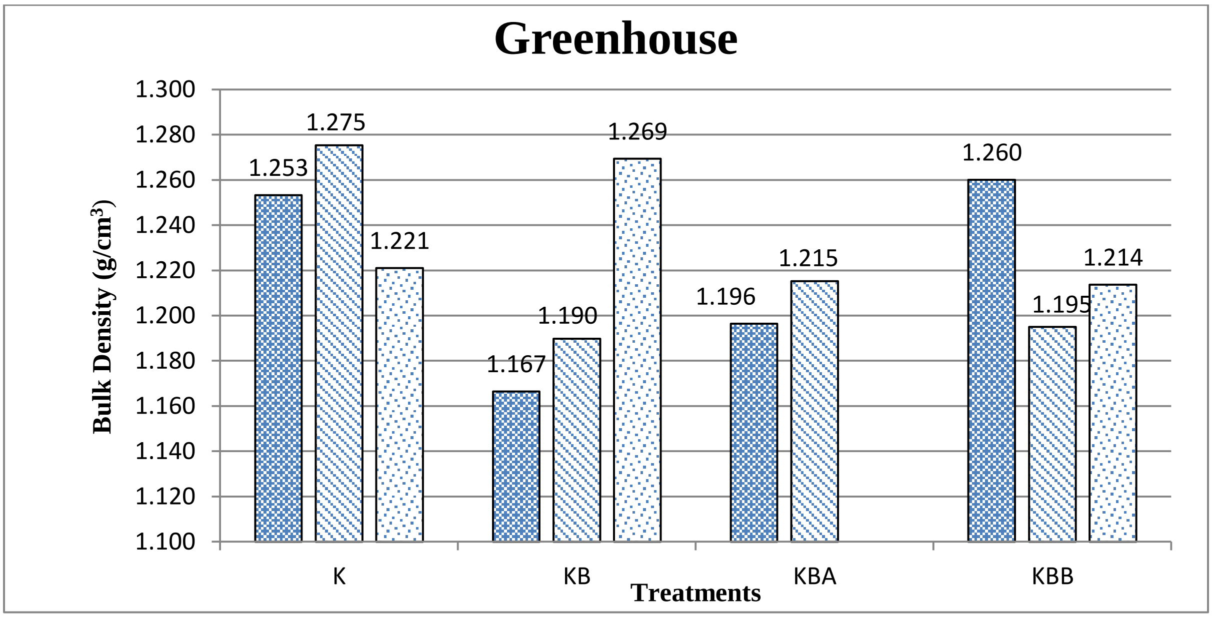


Figure 19 Dry bulk densities of the soil obtained from each organic matter treatment in the greenhouse.

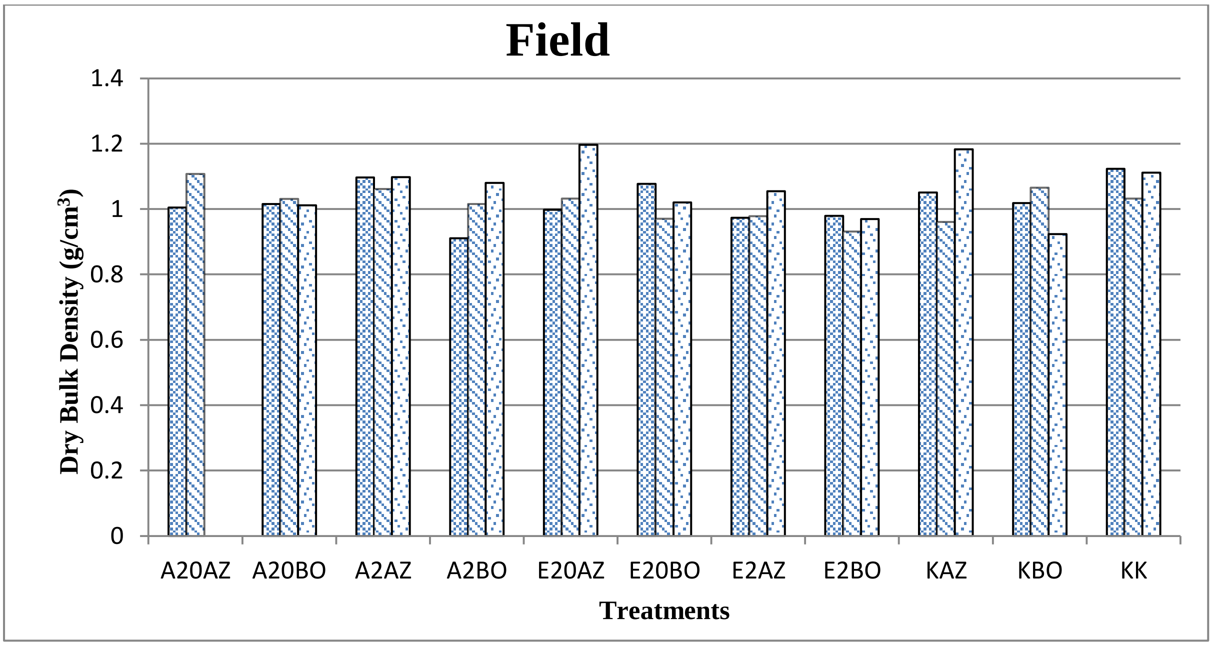


Figure 20 Dry bulk densities of the soil obtained from each organic matter treatment in the field

The results of measured dry bulk density obtained from laboratory analysis were statistically evaluated. Table 2 and 3 show precision of sampling for dry bulk density, actual water content, and saturated water content including coefficient of variation.

Table 2 Precision of the sampling obtained from laboratory analysis for each treatment in greenhouse

Treatments	**Dry Bulk Density**		**Actual Water Content**		**Saturated Water Content**	
	g/cm^3	**CV%**	**g/g**	**CV%**	**g/g**	**CV%**
K	1.25	2.19	21.86	6.23	39.97	2.52
KB	1.21	4.46	19.38	7.61	36.87	5.48
KBA	1.21	1.10	19.52	2.02	36.91	6.11
KBB	1.22	2.74	20.36	5.21	39.30	4.92

Table 3 Precision of the sampling obtained from laboratory analysis for each treatment in the field

Treatments	**Dry Bulk Density**		**Actual Water Content**		**Saturated Water Content**	
	g/cm^3	**CV%**	**g/g**	**CV%**	**g/g**	**CV%**
A20Az	1.06	6.89	22.11	1.93	49.49	7.21
A20Bo	1.02	1.05	22.27	3.92	50.69	2.18
A2Az	1.09	1.89	21.12	6.51	47.68	3.18
A2Bo	1.00	8.53	22.44	13.63	49.04	7.21
E20Az	1.08	9.87	21.08	4.94	48.41	13.23
E20Bo	1.02	5.20	23.21	10.53	51.13	13.60
E2Az	1.00	4.55	21.66	6.66	51.90	2.28
E2Bo	0.96	2.68	22.65	6.85	53.36	3.12
KAz	1.06	10.47	21.62	4.35	48.91	12.81
KBo	1.00	7.24	23.25	4.29	51.01	7.48
KK	1.09	4.57	22.10	2.75	46.77	4.93

The coefficient of variation is important because it is a helpful statistics in comparing the degree of variation in the data series. The coefficient of variation was calculated as (standard deviation/ mean *100). For both greenhouse and field measurement, the results of CV were very low and it means that the average values are representative to compare with other treatments. From the table 2, we can see that the dry bulk density of KBA had the smallest value of CV and the treatment of KB vary the most in greenhouse. Saturated water content is the maximum amount of water that can be stored in the soil. The results of the greenhouse are shown in Figure 21 and the result of the field can be seen in Figure 22.

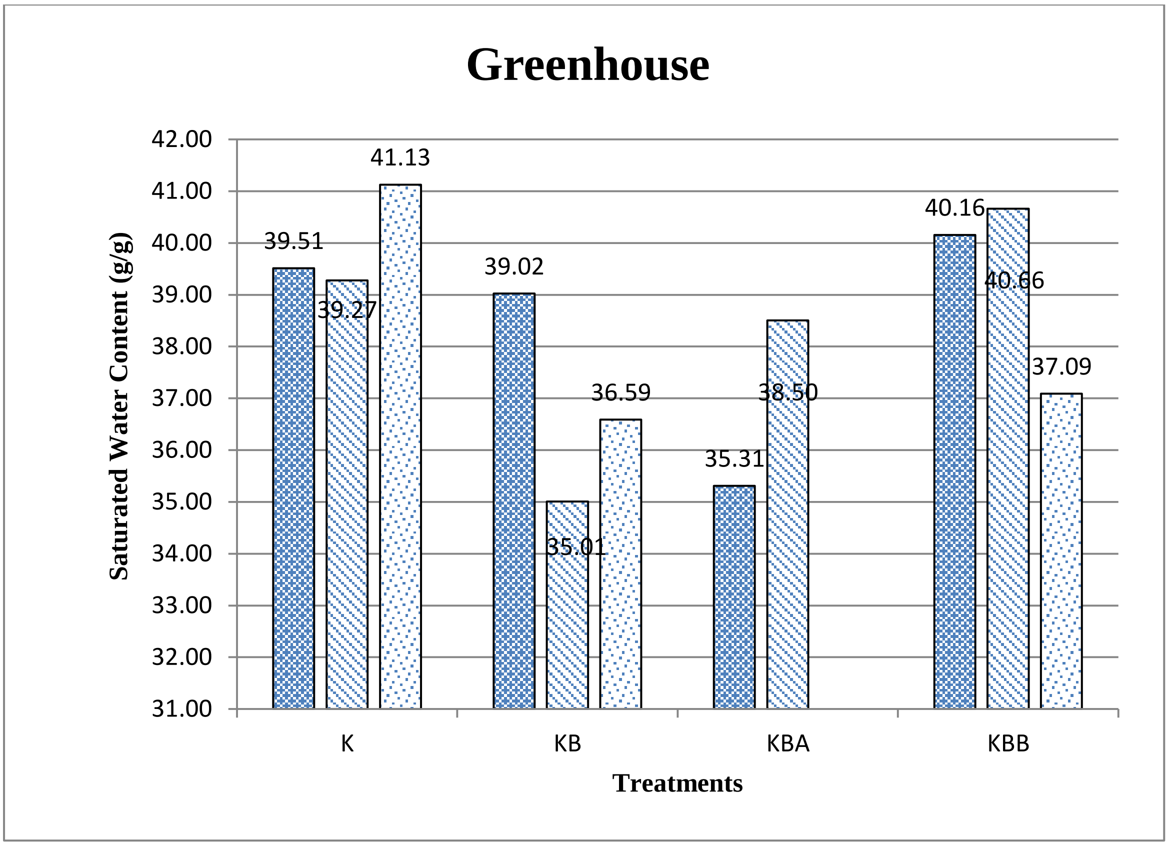


Figure 21 Saturated water content of the soil obtained after saturation of the soil samples in the laboratory from each organic matter treatment in the greenhouse.

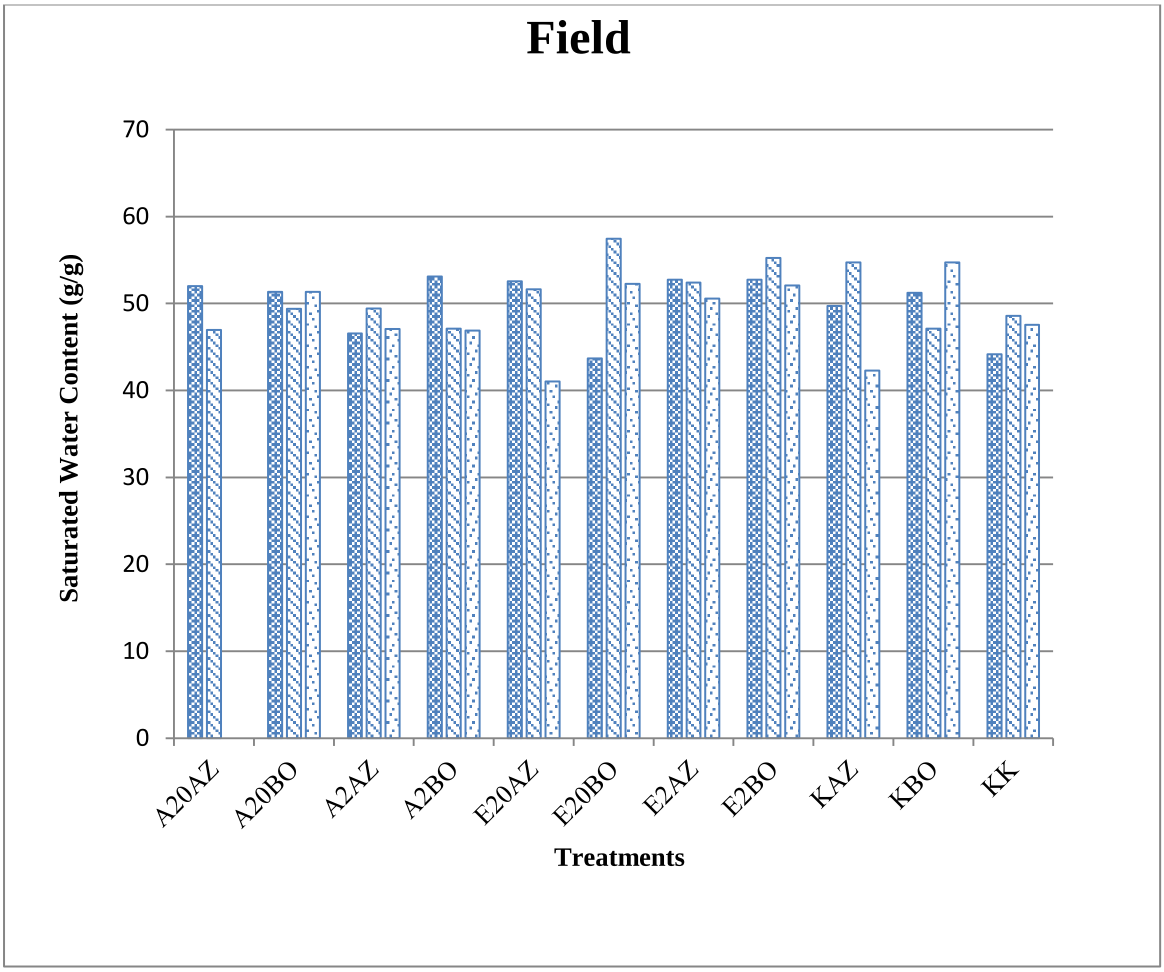


Figure 22 Saturated water content of the soil obtained after saturation of the soil samples in the laboratory from each organic matter treatment in the field.

5.2 Unsaturated hydraulic conductivity

Unsaturated hydraulic conductivities of the soil were measured for each parcel by using Mini Disk Infiltrometer at the field and in the greenhouse. According to the user's manual, pressure head was set -2 cm for the clay loam soil and unsaturated hydraulic conductivities were measured in sufficient number of replicates, 2 or 3 replications, in field or in greenhouse, respectively, for each parcel of the treatment. Infiltration tests were conducted in July and October 2019. Soil water content was measured by using 5TE soil moisture sensor, which is a sensor for indirect soil water content determination, for all treatments before and after infiltration test. Mean values of measurement in both greenhouse and field are seen in Tables 4 and 5; there are initial water content θ_i (m^3/m^3), final water content θ_f (m^3/m^3) and calculated unsaturated hydraulic conductivity *K(h)* at 2 cm tension.

5.2.1 Measurement of unsaturated hydraulic conductivity in July

Table 4 Greenhouse experiment measured in July; soil moisture content (θ_i and θ_f) and unsaturated hydraulic conductivity K(h) of each treatment

Treatments	**θi (m^3/m^3)**	**θf (m^3/m^3)**	**K(h) (m/s)**
K	0.12	0.25	7.59E-06
KB	0.12	0.25	8.26E-06
KBA	0.11	0.27	1.15E-05
KBB	0.11	0.24	1.19E-05

Table 5 Field experiment measured in July; soil moisture content (θ_i and θ_f) and unsaturated hydraulic conductivity K(h) of each treatment

Treatments	**θi (m^3/m^3)**	**θf (m^3/m^3)**	**K(h) (m/s)**
KAz	0.15	0.26	4.46E-06
E20Az	0.13	0.23	5.72E-06
A20Az	0.13	0.23	5.00E-06
E20Bo	0.14	0.22	4.82E-06
A20Bo	0.14	0.24	2.68E-06
Kbo	0.16	0.23	3.45E-06
E2Az	0.14	0.22	4.55E-06
A2Az	0.15	0.21	3.30E-06
E2Bo	0.13	0.23	5.72E-06
A2Bo	0.12	0.23	8.48E-06
KK	0.12	0.23	6.16E-06

The values of unsaturated hydraulic conductivity *K(h)* at various treatments were evaluated and plotted below for both measurements in the greenhouse and field in July (Figures 23 and 24).

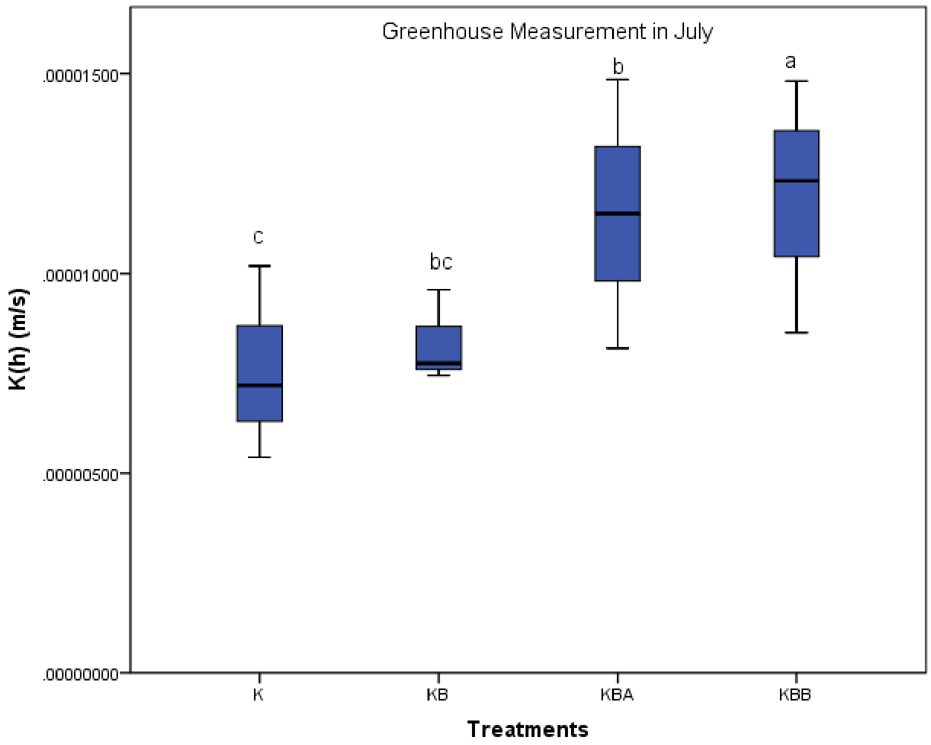


Figure 23 Unsaturated Hydraulic conductivity of the soil obtained from each organic matter treatment at the Greenhouse in July ($p < 0.05$) (Note: K(h) values with describing a, b, c, where "a" is the highest value, followed by "b", "c", and "bc" indicates non significance)

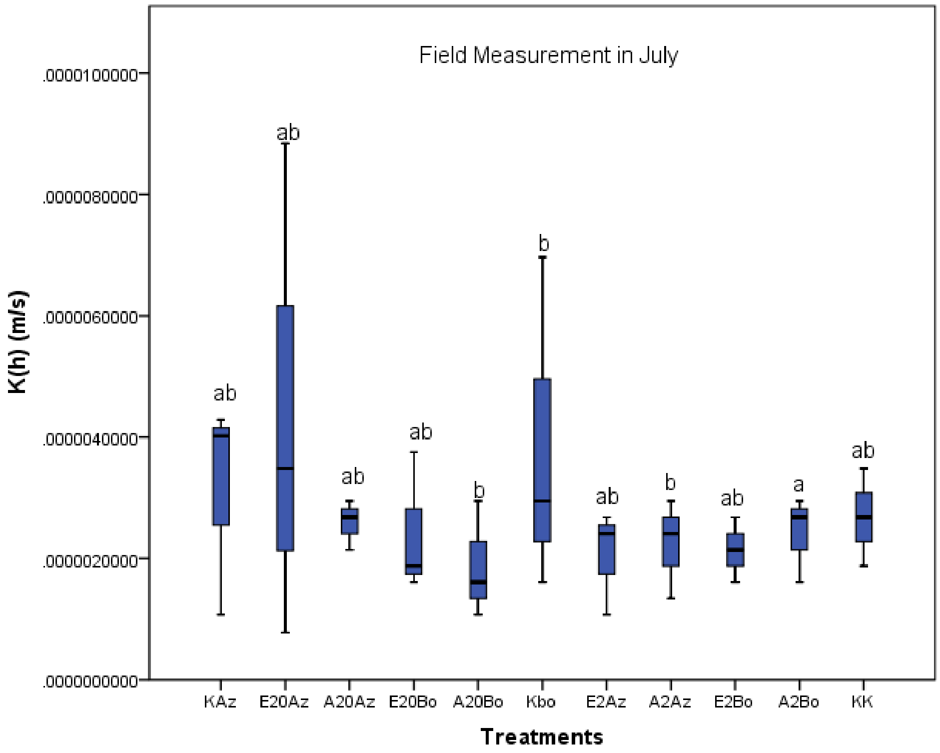


Figure 24 Unsaturated hydraulic conductivity of the soil obtained from each organic matter treatment at the field in July (Note: K(h) values with describing a, b where "a" is the highest value, followed by "b" and "ab" indicates non significance)

5.2.2 Measurement of unsaturated hydraulic conductivity K(h) in October

For the measurement of unsaturated hydraulic conductivity in October, we carried out the same procedures as for the measurement in July (Tables 6 and 7).

Table 6 Greenhouse experiment measured in October; soil moisture content (θ_i and θ_f) and unsaturated hydraulic conductivity K(h) of each treatment

Treatments	**θ_i (m^3/m^3)**	**θ_f (m^3/m^3)**	**K(h) (m/s)**
K	0.12	0.20	4.23E-06
KB	0.12	0.19	4.65E-06
KBA	0.12	0.20	8.20E-06
KBB	0.11	0.17	1.21E-05

Table 7 Field experiment measured in October; soil moisture content (θ_i and θ_f) and unsaturated hydraulic conductivity K(h) of each treatment

Treatments	**θ_i (m^3/m^3)**	**θ_f (m^3/m^3)**	**K(h) (m/s)**
KAz	0.12	0.18	3.13E-06
E20Az	0.08	0.14	4.37E-06
A20Az	0.12	0.21	2.59E-06
E20Bo	0.12	0.20	2.41E-06
A20Bo	0.14	0.21	1.88E-06
Kbo	0.09	0.16	3.84E-06
E2Az	0.13	0.18	2.05E-06
A2Az	0.11	0.19	2.23E-06
E2Bo	0.11	0.18	2.14E-06
A2Bo	0.12	0.16	2.41E-06
KK	0.11	0.19	2.68E-06

The measurement of unsaturated hydraulic conductivity *K(h)* in greenhouse and field in October are shown in Figures 25 and 26. There was also significant difference between unsaturated hydraulic conductivity and organic matter additives, p-value=0.003 at confidence interval 95% (see in Figure 25). In Figure 26 it can be observed that there are relatively insignificant changes in *K(h)* by the addition of different organic matter.

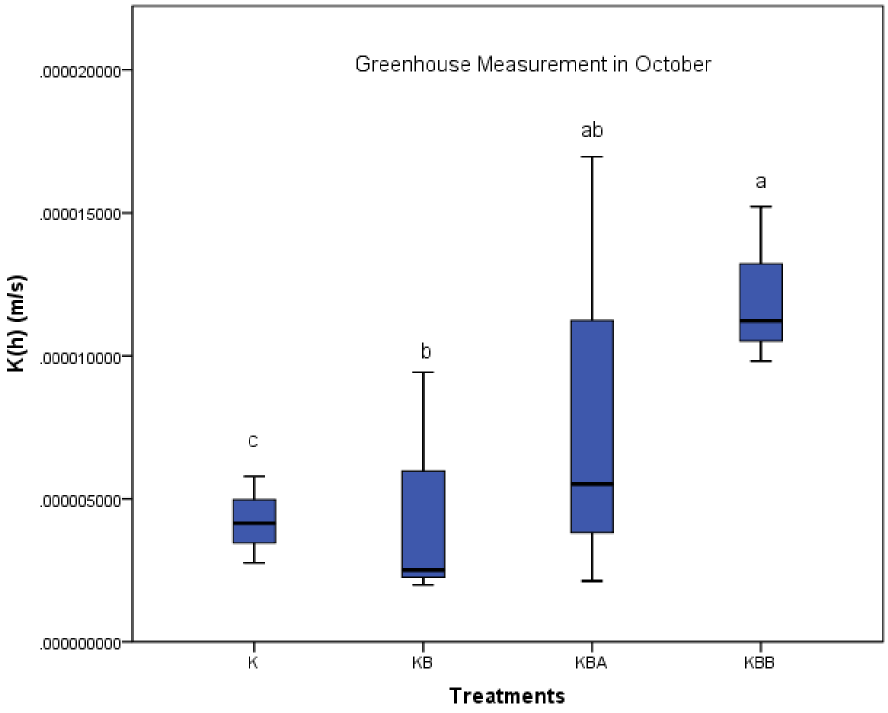


Figure 25 Unsaturated hydraulic conductivity of the soil obtained from each organic matter treatment at the greenhouse in October ($p < 0.05$)(Note: k(h) values with describing a, b, c, where "a" is the highest value, followed by "b", "c", and "ab" indicates non significance)

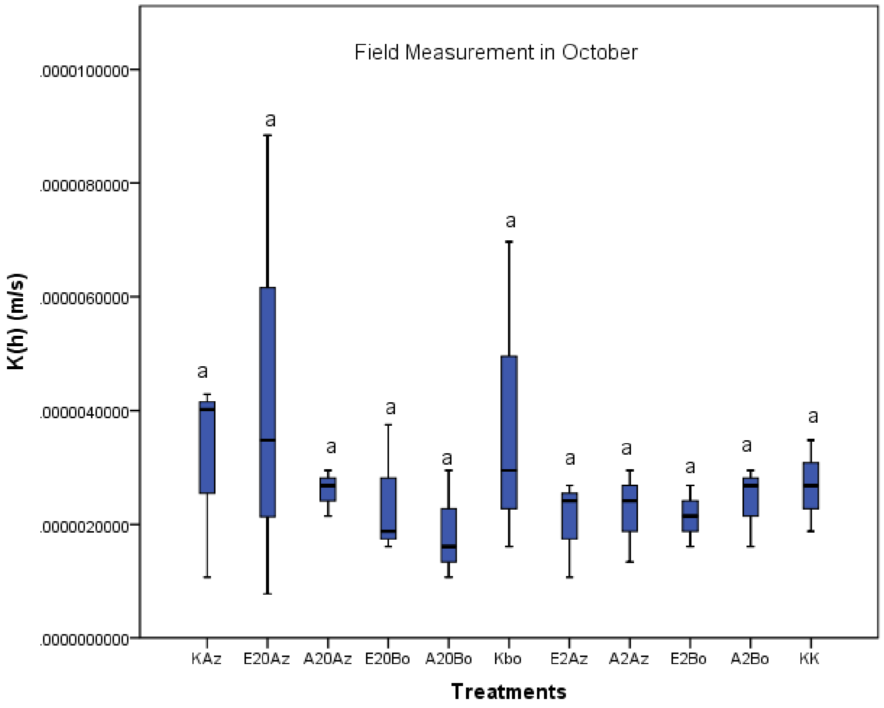


Figure 26 Unsaturated hydraulic conductivity of the soil obtained from each organic matter treatment at the field in October ($p > 0.05$) (Note; the same letters indicate no significant differences)

5.2.3 Correlation between initial water content and unsaturated hydraulic conductivity

In this research, the correlation between initial water content and unsaturated hydraulic conductivity was also studied. The graphs of correlation are shown on Figures 27-30. Figure 27 shows the linear relationship between *K(h)* and initial water content and it has very strong correlation, R^2 = 97.9% in greenhouse in July.

Figure 28 shows the relationship between *K(h)* and initial water content, and it also has significant correlation, R^2 = 76.3% in the greenhouse in October. As we see in Figures 27 and 28, the trend of the first measurement was stronger than the second measurement.

Figures 29 and 30 show the relationship between *K(h)* and initial water content in the field. We can see a strong correlation, R^2 = 63.4% in July, and a very high correlation, R^2 =74% was found in October at the field measurement. To summarize the results, it is clearly seen that we obtained with the increasing initial water content the decreasing unsaturated hydraulic conductivity also in the field. The initial water content in greenhouse was very similar for both terms and all treatments, while in field the first term was slightly more wet and the second term drier than in greenhouse.

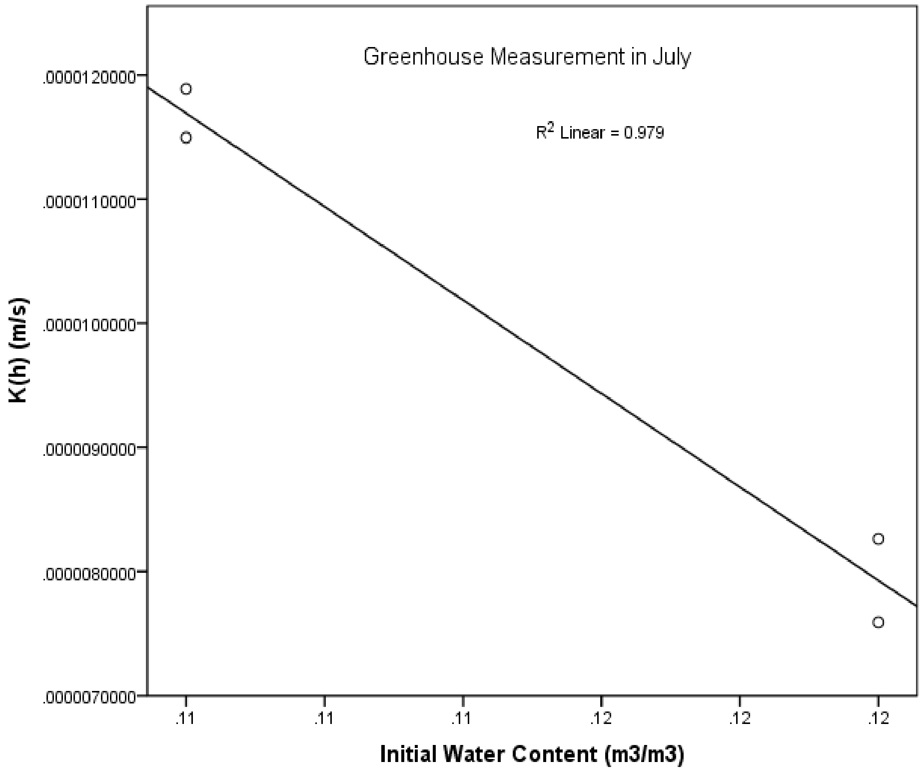


Figure 27 Correlation between unsaturated hydraulic conductivity K(h) and initial water content in the greenhouse in July

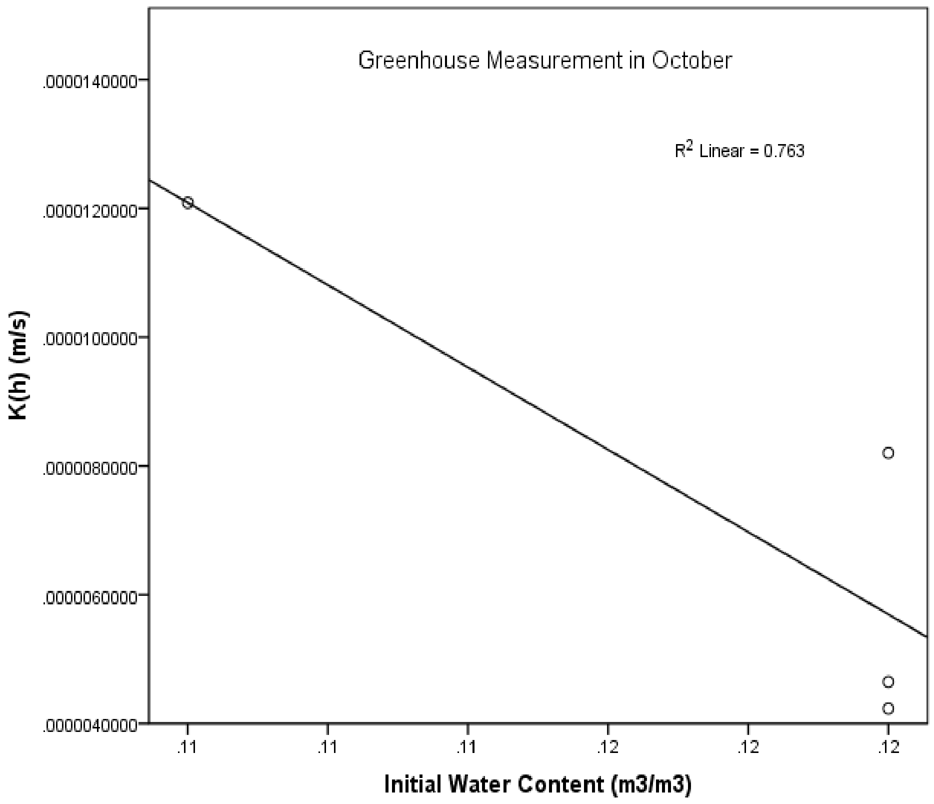


Figure 28 Correlation between unsaturated hydraulic conductivity K(h) and initial water content in the greenhouse in October

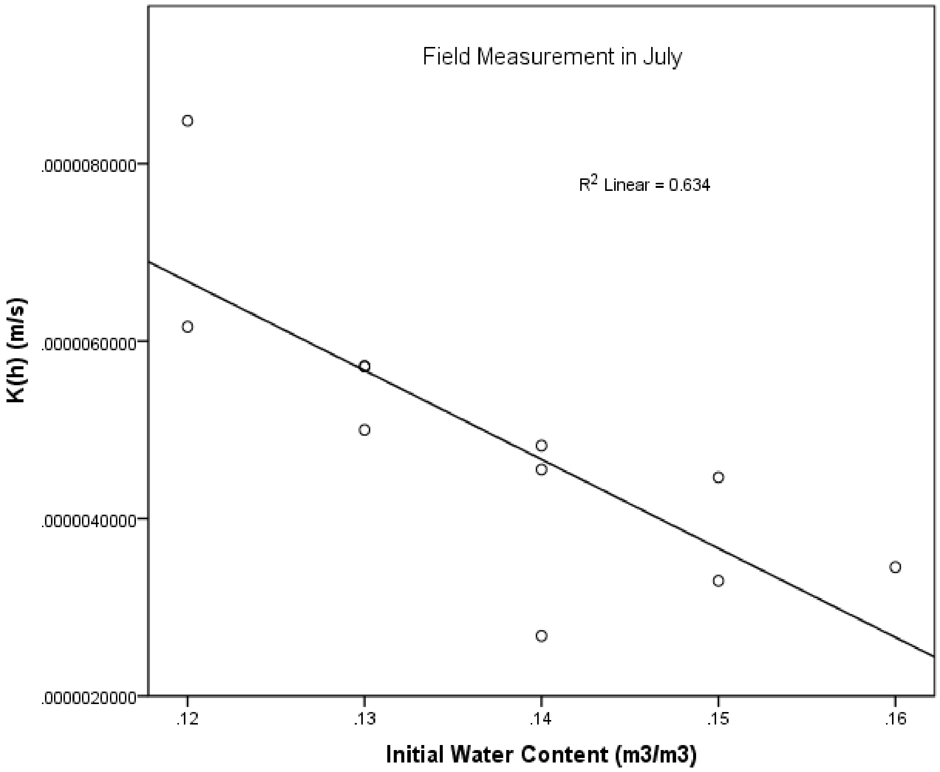


Figure 29 Correlation between unsaturated hydraulic conductivity K(h) and initial water content in the field in July

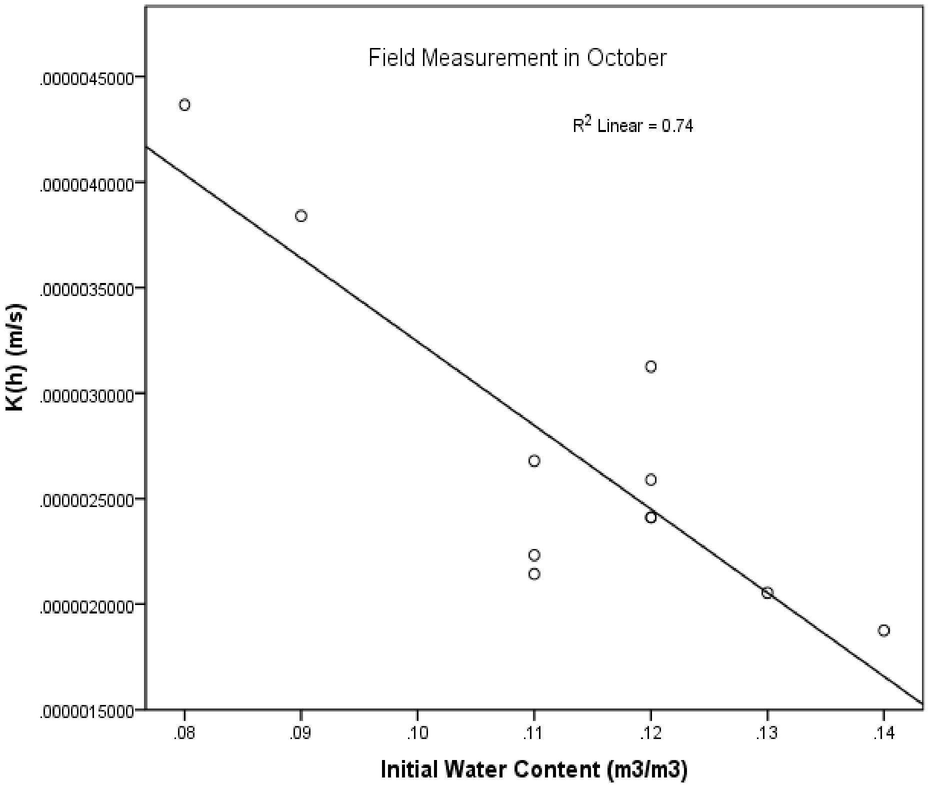


Figure 30 Correlation between unsaturated hydraulic conductivity K(h) and initial water content in the field in October

6 Discussion

6.1. Different organic matter application and its effect on soil bulk density

Soil dry bulk density measurements are important because of their direct effects on soil quality and health, which are related to hydraulic conductivity, porosity, and soil water content. The dry bulk density is known as the mass of the soil per unit volume. There are several studies that reported organic amendments could reduce bulk density while some studies found opposite results. Blanco-Canqui et al. (2015) showed that the application of organic manure reduced 6% of soil bulk density compared to control, and Zhou et al. (2016) has reported that long-term application of organic amendments plus chemical application decreased soil bulk density by 0.2 g/cm^3. Yu et al. (2020) suggested that long-term organic fertilization increased soil bulk density when compared to the control treatments. In contrast, Dunjana et al. (2012) showed that soil bulk density was not significantly changed after long-term amendment of organic matter.

According to the analysis of the results obtained from the laboratory, the average values of dry bulk density were 1.25 g/cm^3 for K, 1.21 g/cm^3 for both KB and KBA, and 1.22 g/cm^3 for KBB in greenhouse (seen in Table 2). We can see that application of traditional compost without biochar showed the highest bulk density and the other treatments were not different so much. It means that the application of biochar as a substrate in organic fertilizer application was better than the application of compost without biochar on soil bulk density. Bulk density will change with the mineral composition of the soil solids, with the way in which the solid particles pack together, as well as organic matter content. Replacement of any solid components into the soil that can change the action of solid particles that will alter the amount of air space and lead to change bulk density (Baver, 1974). Verheijen et al. (2010) reported that the bulk density of most biochars is considerably lower than BDs of common agricultural soils, as a result, biochar amendments are likely to reduce the BD of most general agricultural soils.

For the field, the highest dry bulk densities were observed for pure compost (KK) and 2% of Agrouhel biochar treated with Azotobag (A2Az) with the value of 1.09 g/cm3, and we can see clearly the values of dry bulk density in 2% of Agro-Protect-Soil biochar treated with Bokashi (E2Bo) was significantly lower (seen in Table 3). The result of bulk density values obtained by different treatments was arranged from the highest to lowest value and the order was as follows:

KK = A2Az > E20Az > KAz = A20Az > E20Bo = A20Bo > A2Bo = KBo = E2Az > E2Bo

Comparatively, low values of dry bulk density can be noticed for various kinds of bokashi treated biochar. Husson (2013) observed that the application of highly oxidized co-composted biochar with high soil redox potential (Eh) could have a positive effect on crop yield but in aerobic soils, high Eh could negatively affect the soil-plant-microorganism system due to oxidation process. In this case, strongly reduced low-Eh bokashi fermented biochar (Lacto-fermentation) could have a positive effect on highly oxidized soils thereby maintaining a healthy soil ecosystem. Kammann et al. (2016) showed that co-composted biochar-bokashi has significant growth in promoting features compared with biochar and compost alone. This is due to the activity of lactobacilli in bokashi fermentation that increases the amount of available nutrients in soil and a subsequent positive effect on crop growth and development (Dou et al., 2012).

6.2. Effect of different organic matter additive on saturated water content

Saturated water content is the amount of water that can be stored in the soil. Soil water content can be expressed at mass or volume basis. Saturated water content in the greenhouse was 39.97 g/g for K, 36.87 g/g for KB, 36.91 g/g for KBA, and 39.30 g/g for KBB (see in Table 2). Saturated water content from each treatment in the greenhouse were observed in this order: K > KBB > KBA> KB. It is visible that the difference is very small between the application of compost K and compost bokashi treated biochar KBB in the greenhouse.

As seen in Table 3, the highest value of saturated water content 53.36 g/g was found in 2% of Agro-Protect-Soil biochar treated with bokashi (E2Bo) and the lowest was pure compost (KK) with the value of 46.77 g/g in the field. The observed trend in this experiment showed that bokashi treated biochar had the highest saturated water content for both greenhouse and field. It could be a result of low bulk density of bokashi treated biochar, consequently, improved soil structure and available water content. Czekała et al. (2016) reported that biochar is a useful substrate for composting dynamics by causing a faster decomposition of organic matter, and by increasing the porosity and the water holding capacity. The application of biochar significantly increases macroporosity and the mesoporosity of soil, thus improves aeration and water availability for plant roots (Herath et al., 2013). Agegnehu et al. (2015) and Schmidt et al. (2014) suggested that biochar substrate with compost mixture is suitable, allowing the reduction of fertilizer inputs, stabilizing the soil structure, and improving its nutrient content and water retention capacity. Lactic acid bacteria (LAB) which are included in biochar - bokashi stored nitrogen, phosphorus, sulfur, and carbon in their cell tissues. Activation of biochar with lactic acid bacteria promotes soil activity and humus formation (Schmidt, 2014).

6.3. Effect of different organic matter additive on unsaturated hydraulic conductivity

The direct measurement of unsaturated hydraulic conductivity is time-consuming and costly. Therefore, indirect methods became common to estimate hydraulic conductivity. However, the direct measurement is inevitable in comparative studies where effect of different soil amendments is observed.

It can be observed from ANOVA results, unsaturated hydraulic conductivity of clay loam soil at the locality was significantly changed by the application of KBB, KBA, and K compared to KB at the measurement of July. It can be seen that the average value of *K*(-2) in greenhouse for compost (K) was 7.59-06 m/s, compost + biochar (20%) (KB) was 8.26E-06 m/s, compost + biochar (20%) + Azotobag innoculation (KBA) was 1.15E-05 m/s and compost + bokashi treated biochar (20%) (KBB) was 1.19E-05 m/s in July (see Table 4).

We can see the order as follows;

KBB > KBA > KB > K.

The explanation of why KBB had the highest value of *K(h)* could be that the application of KBB reduced the soil bulk density and improved water content (as mentioned before), consequently, unsaturated hydraulic conductivity increased. It can be evaluated as positive result, as the soil is rather heavy. Lehmann and Joseph (2009) indicated that biochar substrate incorporation into the soil may improve not only physical properties but also hydraulic properties of the porous medium by reducing bulk density, increasing water retention and improving hydraulic conductivity, porosity, and penetration resistance due to the main effect of both biochar's porous structure and the exposed surface area. Large surface amendment preparations of biochar support the absorption properties of soil and potentially improves pore size distribution and bulk density and this leads to increased water availability needed for crop growth and development (Oshunsanya et al., 2016). Also, hydraulic properties such as water retention, hydraulic conductivity, and infiltration capacity were positively affected by the application of biochar (Ajayi et al., 2016; Busscher et al., 2010; Laird et al., 2010; Obia et al., 2016).

According to the ANOVA results, there were significant changes among A2Bo, KBo, A20B0, and A2Az in field which is presented in Figure 24. We can see that 2% of Agrouhel biochar treated with bokashi (A2BO) had the highest hydraulic conductivity 8.48E-06 m/s and the lowest one was observed at 20% of Agrouhel biochar treated with bokashi (A20Bo), 2.68E-06 m/s in the measurement in field in July. The changes of *K(h)* values depending on various kinds of treatments were found in such order in the field, July:

A2Bo > KK > A2B0 = E20Az > A20Az > E20Bo > E2Az > KAz > Kbo > A2Az > A20

BoLiu et al. (2012) indicated that under field conditions biochar mixed with compost had a positive effect on soil nutrient contents and water-holding capacity. Khaliq et al. (2006), Okorski et al. (2008) and Van Vliet et al. (2006) reported that the application of EM bokashi even in small amounts could increase crop yields, plant development, and soil ecology.

The measurement results of *K(h)* for different organic matter amendments were 4.23E-06 m/s for K, KB had 4.65E-06 m/s, KBA had 8.20E-05 m/s, and KBB had 1.21E-05 m/s at the greenhouse measurement in October. We found the same order as in the first term; KBB > KBA > KB > K. By experimenting in the greenhouse, we can avoid extreme climatic conditions. It means that the influence of environmental factors is minimum, and the homogeneity of soil conditions is highest in the greenhouse experiment.

For the field experiment in October, the highest *K(h)* values were visible in 20% of Agro-Protec-Soil biochar treated with bokashi (E20Az) 4.37E-06 m/s and followed by compost treated with bokashi (KB0) 3.84E-06 m/s, and the lowest value was observed at 20% Agrouhel biochar treated with Azotobag (A20Bo) 1.88 E-06 m/s. We can see the following order:

E20Az > Kbo > KAz > KK > A20Az > E20Bo = A2Bo > E2Bo > A2Az > E2A z> A20Bo

However, all the values are in the same order of magnitude and the differences are insignificant. In-situ measurements, many environmental factors that could influence hydraulic conductivity such as temperature, humidity, wind, rain, and changes in root zone condition due to growth of vegetation, consequently, it is difficult to reach the homogenous conditions for all measurements. Another reason may be that sometimes, wind interrupted the good hydraulic contact between the infiltrometer disk and soil content during measuring in the field. It should be noted, that the field experiment was negatively affected by either fertilization of neighboring field (thus our randomized parcels in close vicinity of that field were influenced with clear fading effect), either by enormously high population density of vole (*Microtus arvalis*) in the potato field which was along our experimental setup.

To summarize the results, it can be observed that the application of various organic amendments caused variations in unsaturated hydraulic conductivity. As can be seen in the tables 4 and 6, compost + bokashi treated biochar (20%) (KBB) has significant effect on unsaturated hydraulic conductivity for both measurements in July and October in greenhouse. For the field, Analysis of variance (ANOVA) detected a significant difference in the *K(h)* by several types of activated biochar admixtures in July. However, according to ANOVA result, no significant differences were observed for *K(h)* on different kinds of soil treatments in the field, October. More interesting is that the *K(h)* results obtained from the measurement in July showed significantly higher values than in October (see Figures 31 and 32).

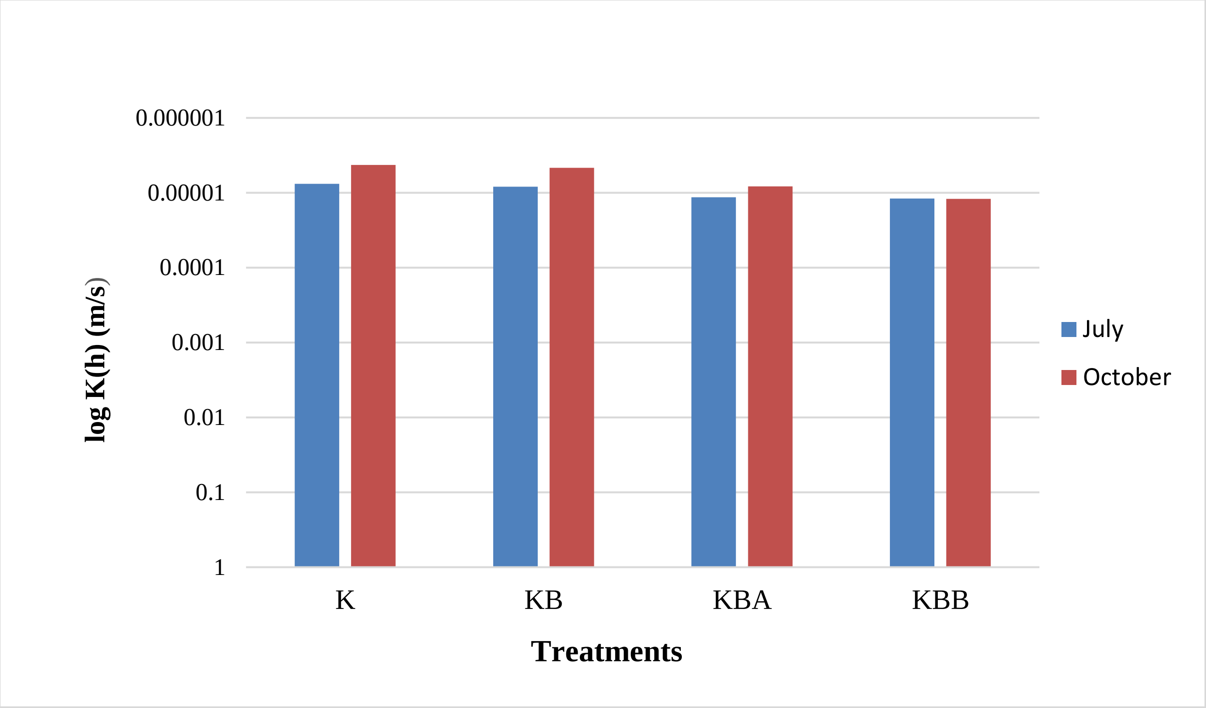


Figure 31 Comparison of the averaged Log K(h) values measured in July and October in the greenhouse.

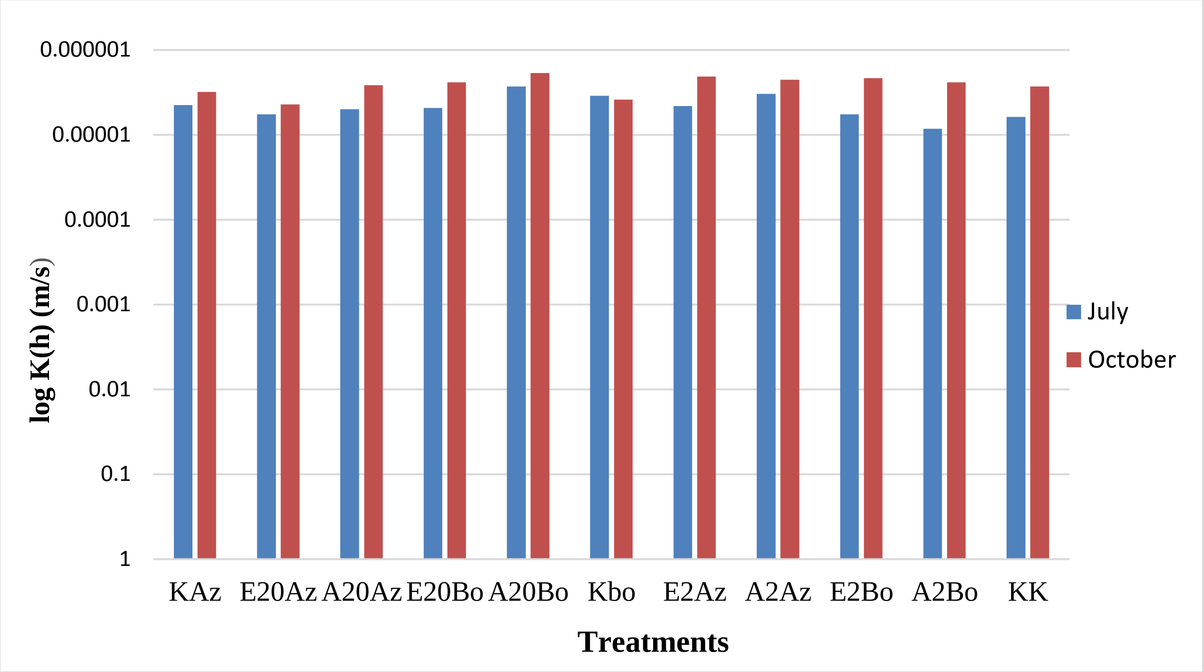


Figure 32 Comparison of the averaged Log K(h) values measured in July and October in the field

It may be that the measurements of unsaturated hydraulic conductivity of clay loam soil can be influenced by heterogeneity of soil and biological activity of earthworms. Strudley et al. (2008) reported that hydraulic properties of agricultural soil can be influenced by many different factors such as soil texture, type of crops, and agricultural practices such as soil tillage and irrigation.

Kribaa et al. (2001) and Osunbitan et al. (2005) observed the trend that hydraulic conductivity of soil on near saturated hydraulic conductivity becomes decreasing with time due to pore-space morphology of cultivated soil and compacting effects of rainfall.

6.4. Initial water content and unsaturated hydraulic conductivity

In this research, we found that hydraulic conductivity fluctuated over the measurements with strong relation to initial water content for both greenhouse and field experiments. Many researchers such as Benson et al. (1994), Benson and Daniel (1990), Benson and Trast (1995), Hawke et al. (2006) and Matula at al. (2015) obtained the relationship between initial water content and hydraulic conductivity of soil. Benson et al. (1994) stated the trend of the lower unsaturated hydraulic conductivity with increasing initial water content and Benson and Trast (1995) also discovered the strength dependence of the hydraulic conductivity on the initial water content. Rainfall intensity and initial soil water content influenced the changes in hydraulic conductivity (Hawke et al., 2006). The research conducted by Matula et al. (2015) showed the decreasing trend of hydraulic conductivity with increasing the initial water content.

However, the reverse trend was observed by Logsdon (1993). They experimented by measuring hydraulic conductivity on clay loam soil by using tension infiltrometer. They found that there was weak relationship between hydraulic conductivity and initial water content.

7 Conclusions

The storage of water in the soil is important for the plants because they require water for their development and typically take water from the soil. Understanding the soil hydraulic properties, especially unsaturated hydraulic conductivity, plays an essential role in determining the water flow and transport of nutrients and solutions.

This study evaluated the influence of biochar incorporation on hydraulic conductivity of clay loam soil in-situ. The effect of initial water content on unsaturated hydraulic conductivity was also studied. According to the result, unsaturated hydraulic conductivity of soil is significantly different in several types of activated biochar admixtures. For the greenhouse measurement, compost bokashi treated biochar (KBB) was significantly higher than blind control with pure compost (K) on unsaturated hydraulic conductivity of the clay loam soil. Moreover, the application of KBB is also the most effective factor in dry bulk density and saturated water content improvement. For the field, we found that 2% of Agrouhel biochar treated with Bokashi (A2Bo) was statistically significant among the other treatment in July. It indicates, that even small amount of biochar, which is economically feasible, can have positive effect. However, there were no statistically significant differences in *K(h)* by different soil treatments in October measurement for the field.

We observed the strong trend of decreasing *K(h)* with increasing initial water content in both greenhouse and field experiments. As a result, the null hypothesis biochar activated with various ways can improve soil hydrophysical properties in clay loam soil was fulfilled.

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9 Symbols and Abbreviations

AC= Adsorption Capacity
CEC= Cation Exchange Capacity
K(h)=Unsaturated Hydraulic Conductivity
θ= Soil Water Content
TDR= Time-Domain Reflectometer
CO2= Carbon Dioxide
CH_4 =Methane
N_2O= Nitrous Oxide
BC= Biochar
EM=Effective microorganisms
PGPR= Plant-Growth Promoting Bacteria
C= Carbon
H=Hydrogen
O=Oxygen
N=Nitrogen
S= Sulfur
P=Phoshporous
SOM=Soil Organic Matter
C/N= Carbon/Nitrogen ratio
SWRC= Soil water-retention curve
K_s =Saturated hydraulic conductivity
GW= Ground Water
CaCO3= Calcium Carbonate
DRI= Double-ring infiltrometer method
S= Sorptivity
CV= Coefficient of Variation
Eh = Soil Redox
LAB =Lactic Acid Bacteria
θi =Initial Water Content
θf= Final Water Content
ANOVA= Analysis of Variance
GH=Greenhouse