



**T.R.
ONDOKUZ MAYIS UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
DEPARTMENT OF SOIL SCIENCE AND PLANT NUTRITION**

**EFFECT OF BIOCHAR AND COMPOST APPLICATION ON
RECLAIMING THE HYDROPHYSICAL PROPERTIES OF
SOIL INFLUENCED BY SODIUM SALT**

Master's Thesis

Sapana PARAJULI

I. Supervisor
Prof. Dr. Coşkun GÜLSER

II. Supervisor
Prof. Dr. Tomasz ZALESKI

SAMSUN
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2023

ACCEPTANCE AND APPROVAL OF THE THESIS

The study entitled “EFFECT OF BIOCHAR AND COMPOST APPLICATION ON RECLAIMING THE HYDRO-PHYSICAL PROPERTIES OF SOIL INFLUENCED BY SODIUM AND OTHER SALTS” prepared by **Sapana PARAJULI**, and supervised by **Prof. Dr. Coşkun GÜLSER** and **Prof. Dr. Tomasz ZALESKI**, was found successful and unanimously accepted by committee members as Master thesis, following the examination on the date 15.8.2023 .

	Title Name SURNAME University Department/Art	Final Decision	
Chairman	Prof. Dr. Coşkun GÜLSER	☒	Accept
	Ondokuz Mayıs University Department of Soil Science and Plant Nutrition	☐	Reject
Member	Prof. Dr. Violina ANGELOVA	☒	Accept
	Agricultural University Plovdiv Department of General Chemistry	☐	Reject
Member	Prof. Dr. Rıdvan KIZILKAYA	☒	Accept
	Ondokuz Mayıs University Department of Soil Science and Plant Nutrition	☐	Reject

This thesis has been approved by the committee members that already stated above and determined by the Institute Executive Board.

Prof. Dr. Ahmet TABAK
Head of Institute of Graduate Studies

DECLARATION OF COMPLIANCE WITH SCIENTIFIC ETHIC

I hereby declare and undertake that I complied with scientific ethics and academic rules in all stages of my Master's Thesis , that I have referred to each quotation that I use directly or indirectly in the study and that the works I have used consist of those shown in the sources, that it was written in accordance with the institute writing guide and that the situations stated in the article 3, section 9 of the Regulation for TÜBİTAK Research and Publication Ethics Board were not violated.

Is Ethics Committee Necessary?

Yes ☐ (If it necessary, please add appendices.)

No ☒

12 /07/ 2023

Sapana PARAJULI

DECLARATION OF THE THESIS STUDY ORIGINALITY REPORT

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ÖZET

SODYUM TUZUNUN ETKİSİNDE OLAN TOPRAKLARIN HİDROFİZİKSEL ÖZELLİKLERİNİN GELİŞTİRİLMESİNDE BİYOÇAR VE KOMPOST UYGULAMALARININ ETKİSİ

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Yüksek Lisans, Temmuz/2023
Danışman: Prof. Dr. Coşkun GÜLSER
II. Danışman: Prof. Dr Tomasz ZALESKI

Sera denemesi Ekim 2022'den Ocak 2023'e kadar Ondokuz Mayıs Üniversitesi Ziraat Fakültesi'nde (Samsun, Türkiye) organik katkı maddelerinin (Biochar ve Compost) tuzdan etkilenen toprakların hidrofiziksel özellikleri üzerindeki etkisini incelemek amacıyla tuzlu toprakta yüksek konsantrasyonlarda Ca ve Mg ilave edilmiş, sodik toprakta yüksek NaCl içeriği eklenmiş ve tuzlu sodik karışımı olan üç farklı toprak kullanılarak kuruldu. Deneme üç tekrarlamalı tek faktörlü Şansa bağlı tesadüf parselleri (RCPD) desenine göre yapıldı. Sonuçlar, çeşitli toprak özelliklerinde önemli değişiklikleri göstermektedir. Sodik ve tuzlu-sodik toprakta yüksek düzeyde sodyum tuzu, toprağın özellikleri üzerinde önemli bir etkiye sahiptir. ESP, tuzlu toprağa kıyasla sodik ve tuzlu-sodik toprakta anlamlı olarak ($p<0.01$) daha yüksekti. Organik karbon ve CEC, tuzlu toprağa göre sodik ve tuzlu toprakta önemli ölçüde daha düşüktü. DR, AS, SSI ve Ks gibi diğer toprak özellikleri de sodyum tuzunun sodik ve tuzlu-sodik topraktaki zararlı etkisinden olumsuz etkilenmiştir. Buna karşılık, biyokömür ve/veya kompost katkı maddeleri, üç toprak için ölçülen toprağın özellikleri üzerinde olumlu bir etki sergiledi. Biyokömür uygulaması, tuzdan etkilenen üç toprakta da pH'ta önemli bir artışa yol açarken, kompostla işlenmiş topraklarda önemli bir düşüş yaşanırken, toprağın pH'ı dikkate değer değişiklikler sergiledi. Değiştirilen tüm topraklarda organik karbon içeriği ve Katyon değişim kapasitesi (CEC) önemli ölçüde artırıldı. Değiştirilebilir sodyum yüzdesi (ESP), tüm değiştirilmiş topraklarda net bir düşüş sergileyerek toprak sodalılığını düşürdü. Hacim ağırlığı (BD) değerleri, kontrole kıyasla değiştirilmiş topraklarda önemli ölçüde daha düşüktü. Dispersiyon oranı (DR) önemli ölçüde azaltıldı ve toplam gözeneklilik (F), Agregat stabilitesi (AS), Sütrüktür Stabilite indeksi (SSI) ve Doygun hidrolik iletkenlik (Ks) düzenleyici uygulanan topraklarda önemli ölçüde artarak daha iyi toprak yapısı, su sızması ve değiştirilmiş topraklarda tutma. Ayrıca, değişiklikler, tarla kapasitesi (FC), kalıcı solma noktası (PWP) ve bitki kullanılabilir suyu (PAW) dahil olmak üzere toprak nemi sabitlerini olumlu yönde etkiledi. Bu bulgular, tuzdan etkilenmiş toprakların hidro-fiziksel özelliklerini iyileştirme ve iyileştirmede biyokömür ve kompost iyileştirmelerinin etkinliğini vurgulayarak, zorlu ortamlarda tarımsal üretkenlik için sürdürülebilir toprak yönetimi stratejilerine ilişkin değerli bilgiler vermiştir.

Anahtar Sözcükler: Tuzdan etkilenen toprak, Sodisite, Organik Düzenleyiciler, Biyokömür, Kompost, Toprak ıslahı, Hidrofiziksel özellikler

ABSTRACT

EFFECT OF BIOCHAR AND COMPOST APPLICATION ON RECLAIMING THE HYDROPHYSICAL PROPERTIES OF SOIL INFLUENCED BY SODIUM SALT

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A greenhouse experiment was conducted from Oct 2022 to Jan 2023 in the Agriculture faculty of Ondokuz Mayıs University, Samsun, Turkey to study the efficacy of organic amendments (Biochar and Compost) on the hydro physical properties of salt-affected soils. Three different soils namely: Saline, Saline sodic, and Sodic were made artificially by adding the different salt contents where high concentrations of Ca and Mg were added in saline soil, and high NaCl content was added in Sodic soil and Saline sodic was the mixture of two soils. A single-factor Randomized Complete Block Design (RCBD) design with three replications was followed. The Results indicate significant alterations in various soil properties. An elevated level of sodium salt in the sodic and saline-sodic soil possesses a significant impact on the properties of the soil. ESP was significantly ($p<0.01$) higher in sodic and saline-sodic soil compared to saline soil. Organic carbon and CEC were significantly lower in sodic and saline soil relative to saline soil. Other soil properties like DR, AS, SSI, and Ks were also negatively influenced by the harmful effect of sodium salt in sodic and saline-sodic soil. In contrast, the biochar and/or compost amendments exhibited a positive effect on the properties of soil measured for three soils. The pH of the soil exhibited notable changes, with compost-treated soils experiencing a significant reduction, while biochar application led to a substantial increase in pH across all three salt-affected soils. Organic carbon content and Cation exchange capacity (CEC) were significantly enhanced in all amended soils. Exchangeable sodium percentage (ESP) exhibited a clear decline in all amended soils, lowering soil sodicity. Bulk density (BD) values were significantly lower in amended soils compared to the control. Dispersion ratio (DR) was significantly decreased and Total porosity (F), Aggregate stability (AS), Structural Stability index (SSI), and Saturated hydraulic conductivity (Ks) increased significantly in amended soils, enabling better soil structure, water infiltration, and retention in amended soils. Moreover, amendments positively influenced soil moisture constants, including field capacity (FC), permanent wilting point (PWP), and plant available water (PAW). These findings underscore the effectiveness of biochar and compost amendments in reclaiming and improving the hydro-physical properties of salt-affected soils, thereby offering valuable insights into sustainable soil management strategies for agricultural productivity in challenging environments

Keywords: Salt-affected soil, Sodicity, Organic Amendments, Biochar, Compost, Soil reclamation, Hydrophysical properties

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ABBREVIATION OF TERMS

B	:Biochar
C	:Compost
B + C	:Biochar and Compost
K	:Control
S	:Saline soil
S-Na	:Saline sodic soil
Na	:Sodic soil
Ca	:Calcium
Mg	:Magnesium
pH	:Power of Hydrogen
EC	:Electrical Conductivity
OC	:Organic Carbon
CEC	:Cation Exchange Capacity
ESP	:Exchangeable Sodium Percentage
BD	:Bulk Density
F	:Total Porosity
DR	:Dispersion Ratio
AS	:Aggregate Stability
SSI	:Structural Stability Index
Ks	:Saturated Hydraulic Conductivity
FC	:Field Capacity
PWP	:Permanent Wilting Point
PAW	:Plant Available Water
%	:Percentage
gm	:Grams
meq	:Milli equivalent
cm	: Centimeters
dS	: Deci Siemens

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1. INTRODUCTION

Soil deterioration resulting from the processes of salinization and sodification is a significant global issue posing a significant threat to agricultural practices, particularly in arid, semi-arid, and coastal areas.(Fan et al., 2016; Qadir et al., 1996). Rainfall, mineral weathering, irrigation, various surface waters and groundwater, chemical applications, and human disturbances are the primary origins of salts in salt-affected regions (Makoi & Ndakidemi, 2007). However, modern environmental challenges such as global temperature rise, deforestation, change in climate, irrigation, and drainage problem exacerbated the salinity issue, even though natural causes account for the vast majority of salinity and sodicity(Leogrande & Vitti, 2019). Issues arising from sodic soils, have been recognized as a great challenge and are anticipated to worsen in the near future(Levy, 2012). However, the increasing requirements for high-quality water by urban and industrial areas, and the need to feed a growing global population lead to salinization lowering the quality of water and soils. Therefore, it is crucial to increase our knowledge of how sodicity and salt interact to affect agriculture and the soil environment to manage sodic soils for crop production and preserve sustainable agriculture globally. Soil salinization and sodification might lead to desertification(G. Tóth et al., 2008). According to a report by the Land and Plant Nutrition Management Service of the Food and Agriculture Organization (FAO) in 2008, salinity and sodicity have a global impact, impacting over 6% of the Earth's terrestrial surface. Around one billion hectares of soil worldwide are affected by salinization and sodification (FAO, 1988). Approximately 250 Mha of the area in Asia and Australia is covered by sodic soils, Europe comprises more than one of Asia and Australia, about one-fifth in Latin America, one-eighth in Africa, and roughly about one-twentieth in North America and the Near East (including the Arab countries Israel, Iraq, Lebanon, Jordan, Palestinian territories, Syria, Turkey, Cyprus, Egypt, and Arabian Peninsula) (Ghassemi et al., 1955; T. Tóth, 2022). In Turkey, about 2.77 million hectares are affected by salt-affected soils and drainage issues(Temiz & Cayci, 2018). The physical condition of salt-affected soils needs to be improved and maintained in order to promote soil health and support the sustained production of crops.

Salinity and sodicity are typically associated with severe structural degradation and low productivity. The buildup of salts in the soils can alter their physicochemical characteristics, including hydraulic conductivity and soil structure (Rengasamy et al., 1984). Salinity impairs crop development and yield due to its toxic impact on plants, whereas sodicity/alkalinity possesses a detrimental impact on the physical condition of the soil, where degradation of soil structure and stability occurs due to the dispersive effect of sodium salt. Elevated sodium concentrations are primarily characterized by soil dispersion and clay platelet and aggregate swelling. Saline, as well as sodic soils, are attributed to their poor soil–water and soil–air relations which adversely affect plant growth (Tang et al., 2020). Salts in the soil hinder aggregate formation and destroy the soil structure. Plant growth and development can be negatively impacted by sodium and other salts due to alterations in soil properties such as swelling, porosity, water retention, and permeability (Zewd & Sibin, 2021). Thus, understanding how sodicity and alkalinity affect soil properties is essential for soil reclamation and improvement.

To reduce salt stress, proper and cost-effective strategies must be adopted which include appropriate irrigation and drainage techniques, leaching, crop rotation, use of amendments like gypsum and organic materials, and so on. Excess sodium on the exchange site of soil must be replaced with calcium ions for recovering sodic soils. So, the calcium can be supplied in the form of amendments. An effective approach to restoring the properties of salt-affected soils has been the use of amendments as chelating agents. Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), calcite (CaCO_3), and calcium chloride (CaCl_2) are been commonly used chemical amendments around the world to reclaim this degraded soil. These amendments each have a specific way of reclaiming the degraded soil, such as either supplying calcium (Ca^{2+}) directly to the soil or replacing excess Na^+ from the exchange complex and dissolution of CaCO_3 (Qadir & Oster, 2002). However, In alkaline soil with low moisture content, organic amendments can serve as an effective strategy for reclaiming the hydrophysical properties of sodic soil (P. N. Nelson & Oades, 1998). The use of organic amendments has experienced a growing demand in recent years due to their recognized ability for improving the soil structure, reclaiming degraded salt-affected soils, and maintaining soil fertility (Meena et al., 2022). It has also been proven that some organic sources can be used to restore salt- and sodium-affected soils. Various organic amendments, such as mulch, manures,

composts, biochar, fly ash, municipal solid waste, etc. have recently been studied for their efficacy in soil reclamation which is a more economical, easy, eco-friendly, resilient, and efficient approach to reclamation. Organic amendments like animal waste composts, biochar, etc. increase soil organic carbon and contribute to macro-aggregation and structure formation and these processes increase soil permeability and decrease evaporation rates, reducing salt accumulation in the surface soil layer and thus facilitating the leaching of salts from the rhizosphere(Lakhdar et al., 2009; Stavi et al., 2021). It is found that using organic amendments in saline or sodic soils facilitates the leaching of sodium and other salts, decreasing the ESP and, and improving infiltration rate, water retention, and stability of aggregates.(El-Shakweer et al., 1998). Organic amendments have been very effective in decreasing the adverse impacts of sodium on soil properties. Several studies have reported the effectiveness of organic amendments including biochar and compost in enhancing the properties of soil such as saturated hydraulic conductivity, structural stability, water holding capacity, and other chemical and biological properties(Chaganti et al., 2015; Wahid et al., 1998; Zhang et al., 2020). This chemically stable organic material possesses high CEC which thus adsorbs the soluble salts, decreases pH, and EC, and promotes aggregation(Mahdy, 2011).

Biochar is a carbon-rich byproduct of pyrolysis of organic material which has been commonly used as soil amendment. Biochar has recently received a lot of attention as a soil amendment for increasing agriculture productivity and sustainability. However, there are only a few studies on biochar as an amendment in reclaiming saline or sodic soil. The use of biochar improves salt-affected soils by increasing organic carbon and nutrient accessibility, increasing CEC and structural stability, improving physical properties due to balanced water content and air porosity, and higher retention of polyvalent cations (Zheng et al., 2018). According to studies, applying biochar to fields can improve the hydro-physical characteristics of soil by boosting macro-aggregates, enhancing aggregate stability, and increasing water retention. Furthermore, it increases the plant's available water and facilitates the development of new pores through the alteration of the soil particle configuration(Yang & Lu, 2021). Biochar used as a soil conditioner in sodic soil improves the overall health of the degraded soil by raising the cation exchange

capacity (CEC), soil organic matter (SOM) content, and soil surface area, as well as increasing macronutrient concentration in soil.

Compost is a stable, mature biological product that has been produced through a controlled thermophilic (higher temperature), aerobic biological transformation. Compost is widely used for effective soil amendment all over the world and plays a significant role in maintaining soil quality and crop yield. Compost produced from crop wastes, leaves, grass clippings, crop twigs, grape skins, weeds, twigs, and branches is a great alternative to synthetic fertilizers, which are known to be a more effective and sustainable method of soil management (Sarwar et al., 2011). Compost can be effectively used in restoring salt-affected soils to their original potential, as well as substantially enhancing the physical environment in soil. Compost plays a crucial role in salt-affected soils because the organic source enhances the properties of such soils, which have been degraded to the point where water and air passage become quite difficult. Compost addition lowers the amount of Na^+ in the soil and enhances the amount of organic matter and macro nutrients K, N, and P (Diacono & Montemurro, 2010; Gondek, M.D., Thiel, T., Kleinheink, 2018). The addition of compost to salt-affected soil supplies the micro- and macro-nutrient elements (such as N and P and K), eliminating nutrient deficiency (Lakhdar et al., 2008) and also restoring soil's physicochemical properties and biological activity (Hanay et al., 2013). Compost is enriched with exchangeable Ca^{2+} and Mg^{2+} , thus helping in lowering the concentration of exchangeable sodium thereby improving the physical condition of salt-affected soils (Walker & Bernal, 2008a). Compost used as amendments help to speed up sodium leaching and decrease EC, thereby increasing aggregate stability and water-holding capacity of saline or sodic soil (Tejada, Garcia, Gonzalez, & Hernandez, 2006). Thus, compost possesses huge potential in restoring the overall soil properties of degraded salt-affected soil.

Several research studies have shown that biochar can be combined successfully with organic or chemical fertilizers, compost, vermicompost, animal waste, and chicken manure to improve the structure of the soil, soil fertility and quality as well as the growth of the plant and their productivity (Alkharabsheh et al., 2021; Zhu et al., 2017). The findings of Liu et al., (2012) study, reported that the combined application of compost and biochar in the field resulted in a favorable synergistic effect on nutrients of the soil, their structure, and the water retention capacity. However, in

saline or sodic conditions, there is little information regarding the interactive effects of the combination of biochar and compost on reclaiming the soil properties and quality of this degraded soil.

Based on various studies regarding the potential of biochar and compost in restoring salt-affected soil and their positive effect on soil hydro physical properties, we made a hypothesis that the application of biochar and compost as soil amendments to the salt-affected soil could:

- 1) Lower the pH, EC, ESP, and SAR of soil
- 2) Increase soil organic carbon
- 3) Increase Aggregate stability and structural stability index
- 4) Decrease Dispersion ratio
- 5) Increase hydraulic conductivity and water retention.

The objectives of this study were to investigate:

- 1) To observe the changes in soil hydro-physical properties and salt dynamics in different salt-affected soils.
- 2) To compare the effects of Biochar and compost application on hydro physical properties of saline, saline-sodic and sodic soils.
- 3) To compare the individual effect of Biochar and compost and combined application of biochar and compost on soil hydro physical properties of salt-affected soils.
- 4) To identify the key soil hydro-physical parameters in response to the use of woodchip biochar and tea waste compost that could mitigate the negative effects of salinity

2. LITERATURE REVIEW

2.1. Overview of Saline and Sodic/Alkaline

The term "salt-affected soil" has no rigid international quantitative definitions. Based on the total soluble salts of soil (electrical conductivity of the soil-saturation paste extract (EC), exchangeable sodium percentage (ESP) or sodium adsorption ratio (SAR) and pH, salt-affected soil are categorized into 3 groups namely saline, saline-alkali, and alkaline soil.

Table 2.1 : Classes of Salt -affected soil

Class	pH	EC (dS/m)	SAR	ESP
Saline soil	Less than 8.5	Greater than 4	Less than 13	Less than 15
Saline sodic soil	Less than 8.5	Greater than 4	Greater than 13	Greater than 15
Sodic (alkali) soil	8.5 to 10	Less than 4	Greater than 13	Greater than 15
Non-saline non-sodic	About neutral	Less than 4	Less than 15	Less than 15

Note: EC- Electrical conductivity, SAR- Sodium Adsorption Ratio, and ESP

Exchangeable Sodium Percentage(USSLS, 1954).

Saline and Sodic soils, not only differ chemically but also physically, biologically, and also geographically. Sodic soils undergo the process of sodification or alkalization which refers to the process of substantially increasing the Na saturation on the exchange complex of soil(Choudhary & Kharche, 2018). Under salt-affected soils, Na^+ , Ca^{2+} , Mg^{2+} , Cl^- , and SO_4^{2-} are abundant, while K^+ , NH_4^+ , CO_3^{2-} , HCO_3^- , and NO_3^- are present in lower concentration. A part of CaCO_3 , MgCO_3 , CaSO_4 , and MgSiO_3 precipitate from a part of Ca^{2+} and Mg^{2+} when soil levels of salt are high which causes the saline soil to be sodic by increasing the concentration of exchangeable sodium in the soil solution(Zia-ur-rehman et al., 2017). Thus, Sodidity could be an adverse outcome of salinity in clay soils, in which soluble salts are removed by leaching washed into the subsoil leaving the sodium in the exchange complex of clay(Leogrande & Vitti, 2019). The high salinity possesses a severe toxic effect on the plants like osmotic stress causing a great impact on plant production. On the other hand, sodicity or alkalinity hinders crop germination, crop growth, and

productivity by its huge impact on soil structure and the properties of soil. Sodium salt therefore acts as a dispersive agent leading to the destruction of soil aggregates and soil structure thus impacting the overall physical and hydraulic properties of soil.

In the event that a saline-sodic soil undergoes extensive leaching in the absence of any calcium or magnesium sources, some of the exchangeable sodium is gradually replaced by hydrogen. Such soil might have a mildly acidic pH, but it might also have a sufficient amount of sodium to give it an unstable structure. Such soil is referred to as degraded sodic soil, previously known as degraded alkali soil (Choudhary & Kharche, 2018).

2.2. Sources of Salts and Causes of Salinization

Saline and sodic soil are mostly prevalent in arid and semi-arid parts of the world where evaporation is more predominant than precipitation and concentrates salts in the soil. They occur in dry regions, having high groundwater levels, waterlogged conditions, and coastal areas. Sodic soils form in areas with characteristics comprising low saline groundwater, suspended water tables within one meter of the soil surface, restricted flow and drainage, weak slope gradients, and textural irregularities in the course of the deposition of sediments like glacial, or fluvial materials. Causes of Salinity or sodicity can be grouped into natural and anthropogenic or human-induced salinization which can also be said as primary salinization (natural) and secondary (human-induced) i.e. The buildup of salts in soil can be attributed to both human-related and natural influences (A. Hassani et al., 2020). The salinity of soil gets affected by climate, soil ecosystem, irrigation, groundwater depth, and salinity of water sources, also to land management procedures (Shaygan & Baumgartl, 2022). Several geological, hydrological, and pedological processes may contribute as natural causes of saline or sodic soil. For instance, Parent material and weathering of rocks and minerals with time is one of the natural causes of salinity in soil which involves the accumulation of physically transported salts and salts released during weathering along with parent material (PM) such as NaCl and CaSO₄. Primary minerals and exposed rocks found on the surface of the earth are the primary sources of salt in the soil. Another source of salt may be the addition of salts from rainfall and salts in groundwater, which are mostly brackish in arid regions (Rengasamy & Walters, 1994). Likewise, Seawater intrusion and seawater sprays contribute large amounts of salts

along the coastal areas. Marine, Lacustrine, and wind deposits are also responsible for the buildup of salts in the soil. Secondary salinization is the result of human activities and undesirable practices in the environment. The undesirable human activities leading to the saline and/or sodic condition of soil include: deforestation, industrial emissions, municipal wastewater, sewage sludge, using low-quality irrigation water i.e., improper irrigation management, poor soil internal drainage and land clearing(Munns, 2005)Saline, and sodic soil mostly occur in arid and semi-arid regions of the world where evaporation is more predominant than precipitation and concentrates salts in the root zone. They occur in the areas like dry regions, with high groundwater levels, waterlogged conditions, and coastal areas. Sodic soils form in areas with characteristics comprising low saline groundwater, suspended water tables within 1 m of the soil surface, restricted drainage, low slope gradients, and textural irregularities during the deposition of sediments like eolian, glacial, or alluvial materials. Causes of Salinity or sodicity can be grouped into natural and anthropogenic or human-induced salinization which can also be said as primary salinization(natural) and secondary(human-induced) i.e. The buildup of salts in soil can be attributed to both human-related and natural influences(A. Hassani et al., 2020). The salinity of soil is influenced by climate, environment type of soil, irrigation, groundwater depth, and salinity of water sources, also to land management procedures(Shaygan & Baumgartl, 2022). Several geological, hydrological, and pedological processes may contribute as natural causes of saline or sodic soil. For instance, Parent material and weathering of rocks and minerals with time is one of the natural causes of salinity in soil which involves the accumulation of physically transported salts and salts released during weathering along with parent material (PM) such as NaCl and CaSO₄. Primary minerals and exposed rocks found in the earth's crust are the direct source of salt in the soil. Another source of salt may be the addition of salts from rainfall and salts in groundwater, which are mostly brackish in arid regions(Rengasamy & Walters, 1994). Likewise, Seawater intrusion and seawater sprays contribute large amounts of salts along the coastal areas. Marine, Lacustrine, and wind deposits are also responsible for salt accumulation in the soil. Secondary salinization is the result of human activities and undesirable practices in the environment. The undesirable human activities leading to the saline and/or sodic condition of soil include deforestation, industrial emissions, municipal wastewater, sewage sludge, using low-quality irrigation water i.e., improper irrigation management, poor soil internal drainage, and land clearing(Munns, 2005).

2.3. Influence of Sodium and other salts on hydro physical properties of soil

Saline soils are characterized by an excessive buildup of soluble salts within the root zone, which hinders the growth of plants to their full potential. In contrast, Sodic soils are primarily distinguished by the excessive buildup of sodium salts relative to other exchangeable cations. Salinity possesses a great effect on the soil pH by increasing the pH above the desirable range thereby leading to the deficiency of nutrients. A high level of soluble salts in the soil solution induces an environment that is challenging for crop growth, leading to diminished yields and, in severe cases, total crop failure. Sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and chloride (Cl^-) are the primary ions present in the soil for salinization. Much of the influence on soils is induced by relatively high exchangeable sodium levels (ESP), which alter soil physical properties such as bulk density, water retention, and hydraulic conductivity. Excessive buildup of sodium salts in the soil possesses profound impacts on physiochemical properties, biological processes, and eventually on crop production and yield (Parvaiz & Satyawati, 2008). Sodicty is a specific salinity problem associated with poor structure as well as poor hydro physical properties of soil. A high level of salt in soil suppresses microbial population and activity due to osmotic stress, which impacts soil organic matter breakdown. According to Quirk, (2001), Sodicty acts on the soil at the level of the clay fraction, defined as particles less than 2 mm in diameter which is important in the soil matrix. Sodium present in the sodic soil acts as a highly disruptive agent causing the breakdown of aggregates thus leading to the degradation of soil which involves several unique degradation processes (Leogrande & Vitti, 2019; J. Quirk, 2001). The single electric charge and hydrated sodium and the comparatively larger size are responsible for the separation of soil particles leading to dispersion (Warrence et al., 2003). This dispersion caused by sodium may manifest undesirable physical and hydrological properties of soil. The adverse impacts of sodicty on soils are attributed to three interrelated phenomena, that is swelling, slaking, and dispersion (Shainberg & Letey, 1984). The dominant monovalent cation, Na^+ present in the sodium-affected soil increases the thickness of the double diffuse layer which thus greatly activates the electric repulsion force leading to the swelling of clay. This mechanism is thoroughly explained by Qadir et al., (2007). Generally, hydration of sodic soil causes slaking and swelling. In dry soil, while wetting, the attraction between the clay particles is reduced increasing the repulsive force between the clay particles which then negatively impacts the soil aggregate and structural

stability(Rengasamy & Sumner, 1998). Slaking refers to the breakdown of larger aggregates of soil and the destruction of macro pores, whereas dispersion refers to the separation of particles of clay individually from the soil aggregates(Abu-Sharar et al., 1987; Cass & Sumner, 1966; Qadir et al., 2006). Clay swelling leads to the reduction of the pore size and consequently decreases the saturated hydraulic conductivity or water flow in soil(Quirk & Schofield, 1955). The process of aggregate slaking and its resultant alteration of pore size distribution has the potential to reduce hydraulic conductivity, and flow rate, and consequently lead to the occurrence of erosion and runoff. Slaking decreases the permeability of soil by reducing the proportion of macropores and dispersion results in clogging the pores in the soil(Shainberg et al., 1980). Thus, the process of slaking and dispersion leads to the destruction of soil structure while wetting and thus leads to the disruption of hydraulic properties of soil as it hinders the water flow and water infiltration. The alteration of soil hydraulic properties has two primary outcomes. First is low water infiltration and hence less plant available water, especially at deeper levels. And second, there may be more runoff, which means more water loss and soil erosion. The potential impact of exchangeable sodium on accelerating the aggregate breakdown may be attributed to the potential weakening of covalent bonds between soil minerals and organic materials, as well as the possible increase of osmotic and hydration forces that can lead to particle repulsion during wetting(Levy & Nachshon, 2022). Furthermore, another degradation process occurs during drying while rearranging the soil particles on the surface which leads to the formation of soil crust or seal on the surface which is a densely packed thin soil layer with high shear strength(McIntyre, 1958). Even though some crusting may be naturally induced by the physical impact of the coming water, particularly rainfall, the dispersive effects caused by sodium might be greater than those of rainfall or irrigation. (Hardy et al., 1983) This crust on the surface hinders seed germination and also leads to poor crop stand. Hard setting is one of the other soil degradation processes in sodic environments, which refers to the huge, compact, and hard conditions in the upper layer of soil. It is similar to sealing. The only difference is that sealing affects only the top 0.1 to 0.5 mm of the soil whereas hard setting causes total aggregate destruction and clay migration often across the whole plowing zone(Mullins et al., 1990). Depending on the amount of sodium and clay type, frequent soaking and drying and eventual dispersion cause soils to reshape and solidify to a nearly cemented soil without structure or limited structure(Buckman & Brady., 1967;

Frenkel et al., 1978). This compactness caused by sodicity hinders the proliferation of plant root and thus prevent salt leaching. In addition, a number of processes, such as rapid absorption of water, the release of trapped air, and the mechanical force and stirring action induced by flowing water introduced through irrigation or precipitation increase the surface soil's vulnerability to the process of degradation(Oster & Jayawardene, 1998). This process has a huge implication on the structural stability and hydraulic conductivity of soil reducing the water infiltration, soil drainage and causing water logging, erosion and flooding in sodic soil. The poor structure of salt affected hinders the drainage and salt leaching. Consequently, the growth and yield of crops is affected by the sodic soil through its adverse impacts on the soil's physical properties. Sodic soils have low productivity because of their poor physical properties resulting in inadequate aeration, limiting root growth, and amplifying root infections.

A number of scholarly reviews, including those by Bresler et al., (2012), and Hopmans et al., (2021) have evaluated the impacts on the elevated levels of exchangeable sodium percentage (ESP) on soil structural degradation. In the study conducted by Mckenzie and So,(1989) where gypsum treatment was utilized to prevent the dispersion from a sodic Vertisol, the adverse effect of sodium salt on the processes of soil water redistribution and evaporation is discussed. An increase in exchangeable sodium content in the soil subsequently leads to a decrease in the hydraulic conductivity of the soil due to clay swelling and dispersion(Ben-Hur et al., 2009). Dispersion in the sodic soil blocks the soil pores with fine clay particles which then decreases the infiltration rate and hydraulic conductivity of the soil(So & Aylmore, 1993). The physical characteristics of alkaline soils deteriorate as pH and exchangeable Na levels rise(I. P. Abrol et al., 1988). Shainberg and Letey, (1984)have indicated that the impact of sodicity is influenced by numerous soil properties such as the texture of the soil, clay mineralogy, free sesquioxide, and soil density. Compared to silts and sands, clays are naturally more prone to dispersion(Warrence et al., 2003). Firstly, in contrast to sandy soils, clay soils will accumulate more salts, particularly sodium, since clay possesses a lower leaching fraction and a more exposed soil surface. Second, clay soils are more likely to have sodium permeability issues due to their structure. Third, the higher the clay concentration, the longer it takes to rectify sodium accumulation.

According to Ayers and Westcot., (1976) findings, the decrease in permeability caused by sodium is higher in soils that are predominantly composed of montmorillonite clays

compared to soils with illite-vermiculite clays. Furthermore, the reduction is significantly higher in soils with montmorillonite clays compared to those with kaolinite-sesquioxide clays, which exhibit the least amount of reduction. This is because of the highest cation exchange capacity of montmorillonite clays followed by illite, and then kaolinite.

Therefore, numerous scholarly works exist that effectively demonstrate the impact of sodicity and/or alkalinity on diverse soil characteristics.

2.4. Role of Organic amendments on reclaiming the hydro physical properties of soil influenced by sodium and other salts

The remediation of sodium-affected soil involves the supply of an easily accessible supply of calcium that can replace the excess exchangeable sodium from the soil. The basic idea of recovering sodic soil is centered on either eliminating or replacing the exchangeable sodium, modifying the soil's ionic structure using various additions in the soil, and also leaching out Na^+ from soil (Chhabra, 1994; Mahdy, 2011). Chemical amendments like gypsum, sulfuric acid, etc are commonly used in reclaiming the sodic or sal-affected soil which is the source of calcium providing Ca^{2+} required to offset Na^+ on the exchange site (Alcívar et al., 2018; Gupta et al., 2016). These chemical amendments help to replace the excess Na^+ on the exchange complex by supplying Ca^{2+} and also help in solubilization of CaCO_3 releasing Ca^{2+} in soil. Besides this, expensive, low-quality amendments with a significant amount of impurities and limited accessibility of amendments are the limitations associated with the chemical remediation of sodic soil (Qadir et al., 2007). In contrast, organic amendments can be utilized in place of chemical amendments as an option that is not only more cost-effective but also less expensive and a much more effective and sustainable sodic soil reclamation option. Organic amendments provide an adequate number of exchangeable cations like Ca, Mg, K, etc. thereby significantly enhancing cation exchange capacity (Oorts et al., 2003). The structural stability of soil aggregates is significantly enhanced by the use of organic amendments as these organic additions lead to the formation of an organo-mineral complex by integrating the mineral and organic components (Leogrande & Vitti, 2019). Sodic and/or alkaline soils contain low organic carbon therefore, adding organic amendments enhances the soil's microbial activity and increases the amount of organic matter, which helps restore the soil properties. As a result, enhanced microbial activity in the soil improves the

structure of the soil through the production of compounds like exo-polysaccharides, which reduce bulk density and improve porosity and soil hydraulic characteristics (Abiven, S. et al., 2009). Similar to this, the addition of organic amendments accelerates the leaching of salts, reduces erosion, and therefore maintains the ideal balance between the pores, i.e., small and larger pores thereby positively improving the soil properties (Grigg, A. H., Zhang, 2016). High organic matter content renders soils less prone to the deleterious impact of exchangeable Na (P. Nelson & Oades, 1998). Organic matter, which binds soil aggregates, improves water holding capacity, infiltration, water flow, and the soil pore system. Organic matter has the potential to prevent exchange reactions by binding aggregates or inducing hydrophobicity, thereby obstructing access to exchange sites, and thus helping in lowering the ESP and SAR of sodic soil. Organic amendments help to decrease the pH of soil by producing CO₂ and organic acids as they decompose, and the lower pH aids in the dissolution of calcium carbonate when present, raising electrical conductivity and substituting Na⁺ with Ca²⁺, lowering sodium concentration. The organic matter promotes the buildup of calcium, magnesium, and potassium cations while enhancing the leaching of Na⁺ from the soil profile. The decomposition of organic residues added in soil raises the carbon content and when dissolved in water liberates the H⁺ ion which then promotes the CaCO₃ breakdown releasing more Ca⁺ for exchange with sodium in the exchange site of soil (Amer et al., 2018). Zhang et al., (2007) have provided an in-depth understanding of the impact that organic waste has on the physicochemical properties, biological components, and aboveground plant biomass in saline soil. These academic attempts have successfully clarified the complex interaction between organic waste and the various characteristics of saline soil.

Compost, FYM, biochar, green manure, municipal solid waste, and other organic sources can be efficiently employed as soil amendments in regaining the qualities of deteriorated sodic or salt-affected soil.

Fernández-Gálvez et al., (2012) in their study showed the application of solid organic amendments was effective in increasing the hydro physical properties of soil including hydraulic conductivity and sorptivity. The physicochemical properties of saline-sodic soil were substantially improved with some organic amendments such as FYM and sodic soil reclamation was found to be effective using the various organic amendments

that lowered the ESP and bulk density significantly (Robbins, 1986). Shankar et al., (2022) from their study found that organic amendments like vermicompost, mushroom compost, farm yard manure, as well as green manure were effective in the amelioration of saline-sodic soils in India. Andrade Foronda, (2022) from his experiment suggested that cattle manure, biochar, or tropical peat are effective to reclaim the saline-sodic soil and also found cattle manure to be more effective in lowering ESP and EC and improving the soil structure and infiltration rate.

Biochar, compost, and a combination of biochar and compost were reported to have a positive impact on the soil properties like CEC, organic carbon, soil water as well as nutrient content and also increasing the peanut yield and nutrient status of plants on tropical ferrosols of Australia (Agegnehu et al., 2015). Organic amendments like Azolla fertilizer and vermicompost were successful in reducing the electrical conductivity and SAR of saline-sodic soil and thus can be suitable for reclaiming soil affected by salts (Sharifi et al., 2021).

2.5. Basic overview of biochar

Biochar, a byproduct of the pyrolysis of biomass of crop residues or wood, is becoming more widely recognized as an organic soil amendment. It is organic matter that is carbonized through pyrolysis in an environment without oxygen. About half of the carbon in the biomass is preserved in the biochar after pyrolysis, however, recovery rates vary greatly depending on the pyrolysis method used (Baldock & Smernik, 2002; Laird, 2008). Raw ingredients for the synthesis of biochar involve an array of organic materials which includes the waste from farms and forests such as rice husk, straw, wood chips, tree bark, nut shells, etc., waste from cities i.e., municipal waste, animal manures, etc. Biochar management promotes more efficient and sustainable use of current resources that provides a unique opportunity to sustainably utilize locally accessible and renewable resources to boost soil fertility and increase nutrient usage efficiency (Downie et al., 2009). Biochar being a carbon-based product contains a variety of other chemical groups like polycyclic aromatic hydrocarbons (Krull et al., 2009). This property of biochar is mostly related to its physical characteristics, like its high porosity, vast surface area, low bulk density, and strong adsorption capacity (Głab et al., 2016). It plays a fundamental role in improving nutrient retention and availability by binding the cations and anions to its surfaces. Biochar has the potential to enhance

the soil porosity, and soil's water retention capacity, increase the availability of water content for plants, modify soil hydrophobicity, and enhance hydraulic conductivity. In addition, biochar particles additionally contain intrapore space (space within the particles) that can be utilized to retain or store more water. The application of biochar to the soil influences water movement into the soil. Certain biochar has considerable quantities of extractable humic and fluvic acids, and their molecular structures exhibit high levels of chemical and microbiological stability and a millennia-long environment-dependent cycle(Trompowsky et al., 2005). Biochar is often characterized as a diverse material that exhibits variability in both physical and chemical characteristics(Atkinson et al., 2010). Due to their variable composition, biochar surfaces may possess hydrophilic, hydrophobic, acidic, and basic characteristics, all of which have an impact on the way they interact with constituents in soil solution. The observed variation can be attributed to the combined influence of the pyrolysis parameters, oxygen availability, and the source materials used in the production of biochar(Amonette & Joseph, 2009). Biochar exhibits better resistance to breakdown than fresh organic matter or compost, making it an appropriate choice for long-term carbon storage.

2.5.1. Effect of biochar application on properties of salt-affected soil

Biochar has beneficial effects on crop productivity, soil quality, nutrient cycling, and carbon sequestration, making it a highly valuable soil conditioner. Biochar as a soil amendment in reclaiming salt-affected soil is effective and has gained considerable attention globally. Several studies have also confirmed that biochar can successfully restore salt-affected soil. Biochar addition in saline or saline-sodic soil increases the concentration of K^+ , Ca^{+2} , Mg^{+2} , Zn^{+2} , and Mn^{+2} which is because of the simultaneous rise in the cation exchange capacity, total porosity, soil structural stability, surface area, and stability of organic materials(Alkharabsheh et al., 2021). The introduction of biochar alters the physical properties of the soil, leading to an increase in soil porosity and a decrease in soil density. This modification thus helps in the proper build-up of stable aggregates improving the soil structure. Biochar may raise the CEC of soil, raise the pH of acidic soils, and rapidly increase the organic matter and soil organic carbon (Yan et al., 2021). It can provide an ample amount of Ca^{2+} and Mg^{2+} ions and thus helps in lowering the exchangeable Na^+ by substituting it with exchangeable Ca^{2+} and Mg^{2+} (Cao & Harris, 2010). Additionally, biochar

application could create a soil structure more favorable for the leaching of sodium salt. Numerous studies have demonstrated that adding biochar to the soil enhances its physiochemical and biological properties, thereby boosting soil productivity and climate change resistance. Furthermore, biochar is crucial in combating climate change by functioning as a carbon sink and reducing greenhouse gas emissions (IPCC, 2019). Yang and Lu, (2021) in their field experiment used five different types of biochar and found all the biochar was effective in improving aggregate stability, mechanical properties, increasing water holding capacity, and available water of paddy soil. In a greenhouse experiment, Akhtar et al., (2015) demonstrated that adding biochar to soils with varying salinity levels can help wheat crops withstand the negative effects of salt stress. This is made possible by the high adsorption capacity of biochar, which lowers the amount of sodium that plants take up while increasing soil moisture and releasing minerals and nutrients into the soil solution to minimize osmotic stress and promote better crop development in salt-stressed environments. Zhang et al., (2020) have shown that biochar can greatly lower the pH, EC, ESP, and SAR thereby increasing the hydraulic conductivity and other hydraulic properties of saline-alkali soil.

2.6. Basic overview of compost

Compost refers to organic matter that has undergone decomposition through the process of composting which is a biodegradation process facilitated by microbial activity that operates at a low cost and does not necessitate energy or labor. During this procedure, a diverse range of microorganisms, facilitate the decomposition of organic matter into less complex compounds (Godishala & Kumari, 2019). The essential components for composting microorganisms include oxygen, carbon, nitrogen, and moisture. This natural process serves as a means of recycling solid waste, thereby reducing the threat to the environment. It is a valuable source of nutrients, containing a significant quantity of organic matter, nitrogen, phosphorous, potassium, and carbon. Its application can improve the organic matter status of soil, thereby reducing the reliance on chemical fertilizers. Compost is a humified organic product obtained through an oxidative procedure under controlled temperature, humidity, and aeration. Raw materials used for making compost can either be green wastes, crop residues, or manures. In addition, composts made from green materials have superior qualities than those made from other types of waste since they have fewer

contaminants, such as fecal coliforms, heavy metals, and pollutants (González-Hernández et al., 2022). One potential application for large volumes of agricultural residue is the conversion of such material into compost that has been enriched with nutrients which then can be employed as an organic amendment, thereby promoting resilient and sustainable agriculture (Meena & Biswas, 2013). It is a commonly used soil amendment that contains about 90-95% organic content. The impact of compost on soil quality and plant growth depends on its physical, chemical, and biological properties. The quality control measures during compost production determine its properties and also its degree of stability and maturity (Khater, 2012).

2.6.1. Effect of compost application on properties of salt-affected soil

The organic material obtained from compost is composed of significant quantities of carbon, as well as macro- and micro-nutrients. Compost is rich in nutrients and provides an array of benefits for the soil, including soil amendment, enhancement of the fertility of the soil, providing a source of essential humus, functioning as an organic and natural soil pesticide, and facilitating plant growth and productivity. Compost has the ability to serve as a beneficial organic addition to restore salt-affected soils. Compost helps in dissolving the insoluble calcium compounds present in the sodium-affected soil. Composts with a high EC content help in the restoration of saline-sodic soils by raising CEC, and facilitating the leaching of exchangeable sodium.

Termorshuizen et al., (2004) discovered that compost is one of the most stable sources of organic matter when considering the various organic amendments which help in the accumulation of organic matter in the long term. Tejada et al. (2006) found that adding cotton gin crushed compost and poultry manure to a saline clay-loam soil improved soil bulk density and structural stability whereas compost showed the better result because of higher humic acid content (Tejada, Garcia, Gonzalez, & Hernandez, 2006). Compost possesses a beneficial effect on the structure of the soil as it decreases bulk density and increases the total porosity of soil due to being significantly lesser weight compared to a mineral fraction of soil (El-Shaieny et al., 2022). The utilization of compost has a beneficial impact on soil salinity as a result of its enhancement of soil's physical characteristics. Consequently, it facilitates the flushing of Na^+ from the root zone and fosters the longevity of salt-affected soils due to its enduring ameliorative effects on soil properties and quality. A field study conducted by Meena

et al., (2022) reported that compost application greatly reduced the soil salinity with significant effects on soil OC, AS, retention of water, transmission properties, and pore size distribution. Ouni et al., (2013) found that compost (municipal solid waste and palm waste compost) was effective in improving the physiochemical properties, biological activity microbial biomass, and in saline soil. Cotton gin crushed compost used in the experiment conducted by Tejada et al., (2006) showed a positive effect on the physiochemical and biological parameters of saline soil. Ali et al., (2023) found that soil amendments like Trichocompost, tea waste compost, and Azolla compost were effective in ameliorating the soil salinity by lowering the soil pH, EC, and ESP thereby increasing the rice grain yield. Compost combined with gypsum and also applied solely were found to be effective in lowering pH, EC, ESP, and BD and also increasing hydraulic conductivity, porosity, and infiltration rate of saline-sodic soil(Amer et al., 2021). The green tea waste compost is composed of macronutrients (N, P, K) and tannins which supply the soil with useful nutrients and promote plant growth and yield(Gupta et al., 2020). It also promotes microbial activity which then oxygenates the soil, and improves the porosity and soil structure. In the short-term experiment, Lakhdar et al., (2011) concluded that solid waste compost could be the better option for reclaiming the salt-affected soil and improving crop growth. Fougaira et al., (2023) from their experiment found that compost can be an effective amendment in restoring the physio-chemical properties of salt-affected soil and subsequently improving the morphological features of grown plants. Compost application was found significantly effective in lowering the electrical conductivity and sodium adsorption ratio of saline soil thereby increasing the CEC, soil organic carbon, and rice and wheat yield(Amer et al., 2020). Walker and Bernal, (2008) from their research study reported that compost applied to saline soils raises CEC, soluble and exchangeable K^+ , and decreases Na^+ entry into the exchange complex, improving the soil chemical environment.

3. MATERIALS AND METHODS

3.1. Location and Soil Details

A pot experiment was conducted in a greenhouse at the agriculture faculty of Ondokuz Mayıs University, Samsun, Turkey from October 2022 to January 2023. Samsun is located on Turkey's northern Black Sea coast. The climate is average, with warm summers and mild winters. The mean temperature varies between 8°C (46°F) in the winter and 24°C (75°F) in the summer. It is one of the wetter regions in Turkey with an average annual precipitation of 900–1000 millimeters (35–39 inches). Samsun experiences comparatively high levels of humidity, particularly during the summer months, due to its coastal location. Sometimes, humidity can reach 80% or higher. The soil was collected from the agriculture experiment station of Ondokuz Mayıs University, Bafra, Samsun.

Collected soil was mixed artificially with the different salts and accordingly, three different soil types were made that is: 1) saline soil 2) saline-sodic soil, and 3) sodic soil. Saline soil was made by mixing the soil with the salts in the following ratio:

565.785g	MgCl ₂
410.07g	CaCl ₂
370.245g	NaHCO ₃
153.885g	KHCO ₃
1500g	Soil

Saline soil was made by mixing the 45 gm of above mixture of salts in 3 kg of oven dried soil while sodic soil was prepared by mixing 45 gm of NaCl salt in 3 kg of oven dried soil.

Saline-sodic soil was then made by mixing half saline soil and half sodic soil uniformly.

Table 3.1: Some properties of the soils used for the study

Properties	Saline soil	Saline-Na soil	Sodic soil
% sand	46.27	46.27	46.27
% clay	36.24	36.24	36.24
% silt	17.49	17.49	17.49
Texture	Loam	Loam	Loam
pH	7.3	7.45	7.89
Electrical conductivity (dS/m)	6.9	8.5	9.4
Organic carbon (%)	1.7	1.69	1.59
Organic matter (%)	3.06	2.92	2.74
CaCO ₃ (%)	15	15	15
Exchangeable Ca (meq/100gm)	40.67	22.08	17.08
Exchangeable Mg (meq/100gm)	19.03	10.98	9.09
Exchangeable Na (meq/100gm)	2.9	6.02	10.01
Exchangeable K (meq/100gm)	1.2	0.9	1.3
ESP (%)	4.54	15.06	26.70

*Values are based on oven-dried weight. ESP-Exchangeable sodium percentage

3.2. Design and Treatments of Experiment

A factorial randomized plot design was followed as the design of experiment with the three soils (Saline, Saline-Sodic soil, and Sodic soil) and four treatments 1) Control (without amendments) 2) Wood chip Biochar 3) Tea waste Compost and 4) Wood chip Biochar and Tea waste compost and replicated three times. Altogether 36 pots (Dimensions: Height of pot-14.3cm, upper diameter-16cm, lower diameter-10.2cm) were placed in this design and filled with 2 kg of soil and 44 gm of respective amendments (treatments) in each pot. About 12 seeds of wheat (*Triticum aestivum*) were sown in each pot and incubated in the greenhouse for about 3 months (October-December). Similarly, 24 soil columns were prepared with the same three soil and four treatments, and two replications. For this columnar study, PVC tubes of 5.5 cm diameter and 15 cm length were used and one end was covered using filter paper and wired mesh. The tube was then filled with about 250 gm of soil and 5 gm of respective amendments (treatments) in each column and sown with the two-wheat seed in each

column. The prepared soil column was kept in the same greenhouse under similar conditions to the pots. Proper irrigation was applied after planting with rainwater to maintain the moisture level at the field capacity. Also, for aftercare, fertilization was made at 1-month intervals after planting. Ammonium nitrate (33% N) (5 gm NH_4NO_3 for column, 50gm NH_4NO_3 for pot) was given at the rate of 10ml/pot and 20ml/column. Wood chip biochar and tea waste compost were used as organic amendments i.e., treatments in the experiment.

Table 3.2 Properties of wood chip biochar used in the study

Properties Analysed	Biochar
pH	9.42
EC (dS/m)	0.36
Organic carbon (%)	14.15
Exch. Ca (meq/100gm)	9.36
Exch. Mg (meq/100gm)	3.09
Exch. K (meq/100gm)	1.89
Fe (mg/kg)	77.54
Cu (mg/kg)	10.64
Mn (mg/kg)	95.57
Zn (mg/kg)	12.24

Table 3.3 Properties of tea waste compost used in the study

Properties Analysed	Compost
pH	7.02
EC (dS/m)	0.312
Organic matter (%)	89.9
Organic carbon (%)	14.15
Total N %	4.71
C/N	9.54
Total P (%)	0.25
Total K (%)	1.7
Total Ca (%)	0.5
Total Mg (%)	0.16
Total Na (%)	0.19
Total Fe (ppm)	3526.33
Total Cu (ppm)	11.13
Total Zn (ppm)	5420.63
Total Mn (ppm)	12.24

3.3. Soil Sample and Analysis

The soil particle size distribution was analyzed initially using the Bouyoucos hydrometer procedure with sodium hexametaphosphate as dispersing agent (Y. P. Kalra & Maynard, 1991). The soil was found to be loam with 46.27% sand, 36.24% silt, and 17.494% clay respectively. Soil texture was found to be uniform for all three types of soil. Soil pH and EC were measured by 1:2 soil: water suspension (Y. P. Kalra & Maynard, 1991; Rhoades, 1996). Lime content (CaCO_3) was determined using the Calcimeter method by reaction with dilute hydrochloric acid in Scheibler calcium and calculating the amount of CO_2 released from carbonates (Loeppert & Suarez, 1996). Soil organic carbon content was calculated by the Walkley-Black chromic acid wet oxidation method (Y. P. Kalra & Maynard, 1991). The ammonium acetate extraction method was used in the determination of exchangeable cations (Kacar, 1994).

After three months of incubation, wheat was harvested and then the soil was taken, air-dried, ground, sieved, and then subjected to analysis. The basic analysis was carried out again to determine the post-effect. Further analysis was made for hydro properties like Bulk density, Total porosity, Aggregate stability, Dispersion ratio, Stability index, Saturated hydraulic conductivity, and soil moisture constants.

3.3.1. Total Exchangeable Cations

Exchangeable cations (Ca^{2+} , Mg^{2+} , Na^+ , and K^+) were determined by ammonium acetate extraction method (Kacar, 1994). Total exchangeable cations were obtained by adding the concentration of all the exchangeable cations obtained.

3.3.2. Exchangeable Sodium Percentage (%ESP)

ESP was calculated by using the below formula:

$$ESP\% = \frac{\text{Exchangable Sodium (meq/100g)}}{\text{Ex. (Ca}^{+2}, \text{Mg}^{+2}, \text{Na}^+, \text{K}^+)(\text{meq/100g})} \times 100$$

3.3.3. Bulk Density (BD)

The core method (Blake, 1965) was used to determine the bulk density of the sample by diving the mass of oven-dried soil by the core volume. For the Pot and column sample, bulk density was calculated by dividing the mass of oven-dried soil by pot or soil column volume. Also, BD was assessed by packing the soil sample into the 10 cm length and 5 cm diameter cylinder using its volume and oven-dried soil sample.

$$\text{Bulk Density} = \frac{\text{Mass of Oven Dried Soil (gm)}}{\text{Volume of Core (cm}^3\text{)}}$$

3.3.4. Total Porosity (F)

To calculate the total porosity(F), data on bulk density and particle density were required. The below equation was used to determine the value of F (Hillel, 1982).

$$\text{Porosity} = 1 - \frac{\text{Soil Bulk Density (gm/cm}^3\text{)}}{\text{Soil Particle Density (gm/cm}^3\text{)}}$$

3.3.5. Aggregate stability (AS)

Aggregate stability was determined based on the wet sieving method using a Yoder type of wet sieving device. The procedure given by Kemper and Rosenau, (1986) was followed and the below equation was used for the calculation to obtain aggregate stability.

$$AS\% = \frac{\text{Stable Aggregate} - \text{Sand Correction for 0.25mm}}{\text{Oven Dry Sample} - \text{Sand Correction}} \times 100$$

3.3.6. Structural stability index (SSI)

To calculate SSI, the hydrometer method and the below equation were used (Leo, 1963).

$$SSI = \sum b \sum a$$

Where:

b: is clay fraction %

a: is silt+clay fraction %

3.3.7. Dispersion ratio (DR)

The dispersion ratio was calculated using the hydrometer readings and the following equation.

$$DR\% = \frac{a}{b} \times 100$$

Where:

a: Silt + Clay % in suspension

b: Silt + Clay % Dispersed in calgon solution

3.3.8. Saturated Hydraulic Conductivity (Ks)

The incubated soil columns were used for the analysis of Ks in an experiment. Ks was calculated by using the constant head method (US Salinity Lab. Staff 1954). Mariotte bottle was used for this method which was placed on a precision balance (± 0.01 g). For the calculation of Ks of the soil samples, the following Darcy equation was used

$$Ks \text{ (cm/hr)} = \frac{Q}{At} \left[\frac{S}{S + H} \right]$$

Where:

Q: is volume of outflow (cm^3)

A: cross sectional area of soil column (cm^2)

t: time (hour)

S: length of soil column (cm)

H: water head over the soil column (cm)

3.3.9. Soil moisture constants and water retention

For the determination of soil moisture constants and water retention, sand box and pressure plate apparatus were used to measure the water content at various suction pressure (Klute, 1986). Soil samples from each treatment were packed in a plastic cylinder of 5 cm height and 5 cm diameter with a consistent and uniform force. Packed samples were then left for full saturation by placing them in the flat round bowl with water. After saturation, the samples were kept in ceramic plates and placed inside the sand box. The soil sample weights were recorded at matric potentials: -0.25, -0.5, -0.75, -1.0, 1.75, -3.15, -4.0, -5.0, -6.3, -9.84 kPa respectively. Later the soil samples were shifted to pressure plate apparatus to record the moisture content at higher matric potentials: -33, -70, -100, -300, -600, -900, -1200, and -1500 kPa. After the last matric potential i.e. -1500 kPa, soil samples were oven dried at 105 °C for 24 h and the oven-dried weight of each sample was recorded which was used to calculate the gravimetric water content at each matric potential. Bulk density was also determined by using the oven-dried weight and volume of a cylinder. Thus, volumetric water content at each matric potential was calculated by multiplying gravimetric water content and bulk density.

3.3.9.1. Field capacity (FC)

The volumetric water content obtained at -33 kPa for each sample was recorded as field capacity.

3.3.9.2. Permanent wilting point (PWP)

The volumetric water content obtained at -1500 kPa for each sample was recorded as the permanent wilting point.

3.3.9.3. Plant Available Water (PAW)

Plant available water is the amount of water that is accessible to plants. It was determined as the difference between moisture content at field capacity and moisture content at permanent wilting point.

$$PAW = FC - PWP$$

Where:

PAW: Plant available water

FC: Field Capacity

PWP: Permanent Wilting Point

3.4. Statistical Analysis

All the data were analyzed using the statistical package for the social science software (SPSS, 17) and also Microsoft excel. Data were tested according to factorial experimental design (three different soil and four amendments) with ANOVA in order to determine main and interaction effects and to compare the means of different amendments applied under three types of soil. Duncan tests were used to differentiate the significance of individual treatment means ($p < 0.01$, $p < 0.05$).

4. RESULTS AND DISCUSSION

4.1. pH

The effect of biochar and compost on the pH of three soils with different salts used in the experiment is presented in figure 1 below. pH of the soil was found to be significantly ($p < 0.01$) affected under three soils with different salts and the organic amendments (biochar and compost) used in the study. Based on the result obtained, saline soil recorded the highest average value of pH (7.67) followed by sodic (7.53) and saline-sodic (7.49) soil respectively (Table 4.1).

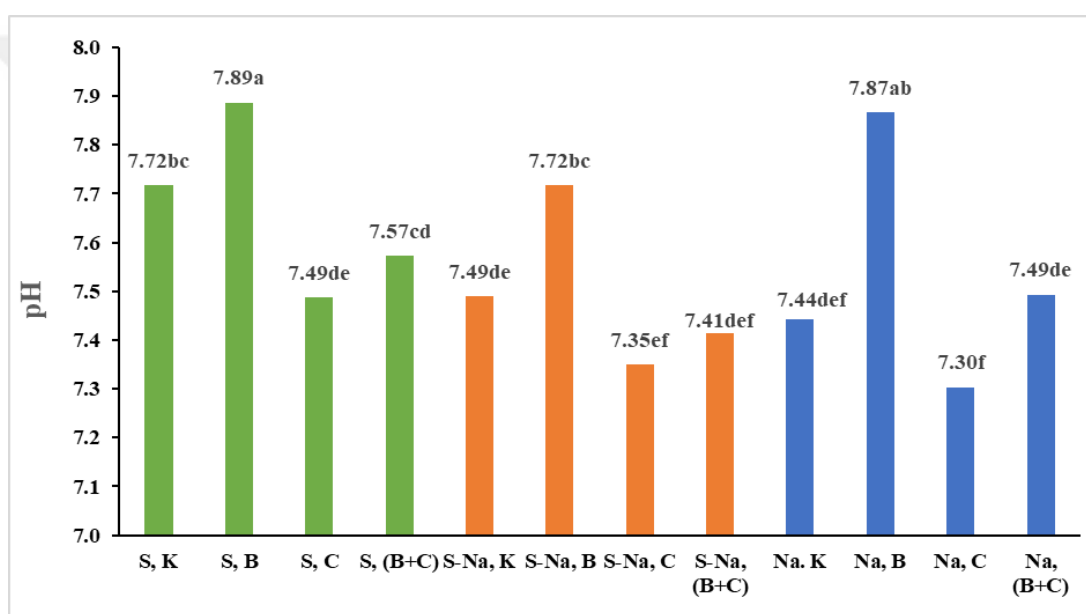


Figure 4.1: Effect of treatments on pH showing the interaction and mean values of each treatment.

Note: S = saline soil, S-Na= saline-sodic soil and Na = sodic soil, K = Control (without amendments), B = Biochar, C=Compost, and B+C= Biochar and compost. The similar color resembles the similar soil type. F value= 2.70**

The pH was in the range of 7.49-7.67 which is a small range. The slightly high pH of saline soil may be due to its higher CEC compared to other soils. Higher CEC in saline soil may have a greater concentration of cations including H^+ cation. Thus, the H^+ cations are then replaced by alkaline cations like Ca^{2+} and Mg^{2+} increasing the pH of the saline soil. While the lower CEC in sodic and saline-sodic soil may have resulted, in lower pH compared to saline soil.

It is clear that a significant reduction in pH value was obtained in compost-treated soils as shown in Figure 4.1 while the biochar treatment significantly increased

the pH value in all three salt-affected soils. The mean comparisons of amendments on soil pH can be arranged as: compost (7.38) < B+C (7.49) < control (7.55) and biochar (7.82) (Table 4.4). In general, biochar has higher pH compared to compost(Siedt et al., 2021) which may be one of the causes of higher pH in biochar-treated soils. The rise in pH may be attributed to the presence of organic anions and inorganic carbonates in the applied biochar and the adsorption of H⁺ ions on the exchangeable negative sites on the exterior surface of biochar(Atkinson et al., 2010; Yuan et al., 2011). Schulz and Glaser, (2012) in their experiment also found that the addition of biochar significantly increased the pH of soil. The drop in the soil pH by compost application in the salt-affected soil must be due to the organic acids formed during its decomposition process in soil (direct effect) and also due to the decreased sodium (indirect effect)(Abdel-Fattah, 2012; Trivedi et al., 2017). Compost addition on saline and alkaline soil could serve as a chelating agent that chelates the calcium, increases the CaCO₃ solubility, and thus reduces the soil pH(Avnimelech et al., 1994). However, the findings obtained by Sappor et al.,(2017) contradict our result which found a decrease in pH with biochar addition. So, the effect of amendments on pH may depend on the materials that are used to prepare it.

4.2. Electricity Conductivity (EC)

The below figure 4.2 represents the treatment effects on the electrical conductivity of three different soils used in the experiment. Both the salt treatments i.e., the three different soils and the amendments had significantly ($p < 0.01$) affected the electrical conductivity (EC) of soils.

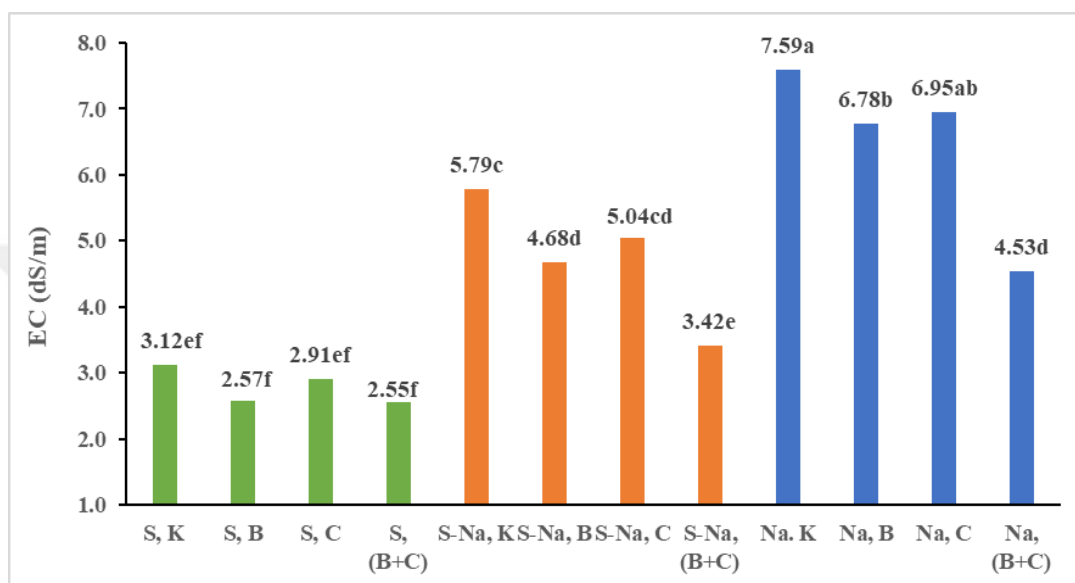


Figure 4.2: Effect of treatments on Electrical conductivity (EC) showing the interaction and mean values of each treatment.

Note: S = saline soil, S-Na= saline-sodic soil and Na= sodic soil, K= Control (without amendments), B= Biochar, C=Compost and B+C= Biochar and compost. The similar color resembles the similar soil type. F value= 9.523**

The mean values obtained for the three soils in the study were found to be significantly ($p < 0.01$) different from each other with the highest value for sodic soil (6.46 dS/m) followed by saline-sodic (4.73 dS/m) and saline (2.78 dS/m) respectively (Table 4.1). As Ca and Mg carbonates are relatively insoluble salts that do not increase the EC levels (McCauley & Jones, 2005) this might be the cause of low EC values in saline soil which is dominated by Ca and Mg salts. The addition of NaCl in the saline-sodic and sodic soil significantly raised the EC of the soils. The higher concentration of NaCl in sodic soil reported higher EC. This may be due to the higher solubility of NaCl salt and greater adsorption of other total soluble salts by higher NaCl salt. A similar finding was observed by Wasim et al., (2021) where the EC was raised significantly with increasing the NaCl concentration.

The results obtained showed that all the organic amendments used were

significantly effective in reducing the EC values as compared to control as shown in the figure 4.2. While comparing the mean values of organic amendments used, with the significant ($p < 0.01$) reduction in the combination of biochar and compost (3.50 dS/m) followed by biochar (4.68 dS/m), compost (4.97 dS/m) and control (5.49 dS/m) respectively (Table 4.1). The possible reasons may be the improvement of soil structure, porosity, and hydraulic conductivity by the organic amendments thereby facilitating the leaching of salts. Similarly, a reduction in EC values might also be due to the organic acids formed during the decomposition of organic amendments used that enhances the leaching of salts. Similar results and explanations were also stated by (Prapagra & Indraratne, 2014; Rahman et al., 1996), where organic amendments used were effective in lowering the EC of the saline-sodic soil. Organic amendments used worked as chelating agents which lowered the Na concentration by replacing the Na with Ca and Mg lowering the EC of salt-affected soil (Negim & Mustafa, 2016). Ippolito et al. (2014) found that increased dosages of the hardwood biochar resulted in a drop in EC due to the adsorption of salts on the biochar surfaces. Application of biochar and compost showed a significant reduction in the electrical conductivity in saline-sodic soils by supplying Ca^{2+} which then displaces the sodium salt from the exchange complex of soil (Chaganti & Crohn, 2015). A number of studies have found similar drops in soil E_{Ce} when various organic additions were used to recover salt-affected (Hanay et al., 2013; Tejada, Garcia, Gonzalez, & Hernandez, 2006).

4.3. Organic Carbon

Changes in the organic carbon showed a significant difference ($p<0.01$) among the control (without amendments) compared to other treatments in all three soils. Also, the interaction effect among the soil and amendments was found to be significant ($p<0.01$) as shown in Figure 4.3.

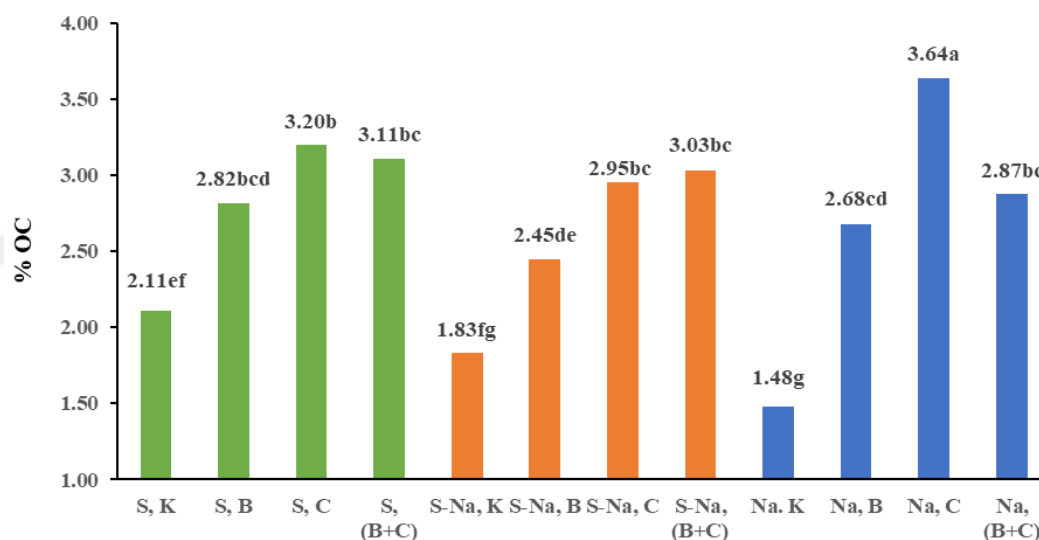


Figure 4.3: Effect of treatments on organic carbon (OC) showing the interaction and mean values of each treatment

Note: S = saline soil, S-Na= saline-sodic soil and Na= sodic soil, K= Control (without amendments), B= Biochar, C=Compost and B+C= Biochar and compost. The similar color resembles the similar soil type. F value= 9.523**

The lowest OC value was recorded in sodic soil without amendments (1.48%) followed by saline-sodic (1.83%) and saline soil (2.11%) without amendments. This is because high levels of sodium in sodic and saline-sodic soil hinder the microbial and enzymatic processes involved in OM decomposition leading to a slower decomposition rate and low accumulation of organic carbon in the soil. It is found that NaCl salt showed greater inhibition in microbial and enzymatic activities than other salts like CaCl₂ (Frankenberger & Bingham, 1982). For instance, according to the study of Laura, (1974) with the increase in salinity level from 0.1% to 5.1% NaCl, decomposition of organic materials from the added green manure was hindered. Higher concentration of Ca²⁺ in the saline soil may have been attributed to the higher organic carbon as Ca²⁺ helps to stabilize the humified organic material as well as undecomposed plant materials thereby controlling the decomposition of organic matter in the degraded soil (Golchin et al., 1994). The poor soil structure and the dispersion

associated with sodic and saline-sodic soil may also lead to the loss of organic carbon through leaching, runoff, and sedimentation. The dispersion caused by Na⁺ in sodic and saline-sodic soil may also speed up C loss by making earlier preserved SOM more easily available(Wong et al., 2006).

All three soils without amendments exhibit lower organic contents as compared to amended soil. Poor soil structure and poor plant growth may have led to the low inputs of organic matter and low organic carbon in the soil. This is because of the degradation of soil's physical and chemical properties by the sodium salt, also due to the toxic effect of salt and harmful osmotic stress (Wong et al., 2006). Soil organic carbon was then significantly increased by all the organic amendments applied with the highest mean value of compost (3.26%) followed by Biochar + Compost (3.00%) and biochar (2.65%) (Table 4.4). All the organic amendments were effective in increasing the organic carbon content while compost showed a more pronounced effect compared to other treatments. The presence of labile carbon i.e., easily decomposable organic matter in compost(A. Kalra et al., 2010) may have contributed the highest increase in organic carbon while, lower OC values in biochar may be due to the fact that biochar contains a highly stable form of carbon that undergoes minimal decomposition over time Brassard et al., (2016). And also, the recalcitrant nature of biochar limits microbial activity and subsequent accumulation of OC in the soil(Zimmerman, (2010). In contrast, Cui et al., (2021) reported that biochar can promote microbial activity in soil which can accelerate the organic matter decomposition and increase organic carbon content in saline-alkaline soil. Sánchez et al., (2022) also found that different types of biochar significantly improved the organic matter and organic carbon content in the saline-alkaline soil. (Bhaduri et al., 2016) also found that adding Biochar to saline soil altered the growth of microbes and that improving carbon use efficiency resulted in an increase in microbial biomass and the organic carbon in the soil. Similar results were found by (Zahra et al., 2021) where both biochar and compost showed an effective increase in organic carbon compared to the control, and also combined application of biochar and compost showed a greater increase in organic carbon relative to their sole application. Also, the results we obtained are in agreement with Sánchez et al., (2022) where both biochar and compost were effective in enhancing OC content in alkaline sandy loam soil however the compost-treated soil yielded the highest organic carbon content. The organic

amendments added promoted better soil aggregation which may have led to increased soil carbon storage Wang et al., (2022). Organic amendments enhance the organic matter and organic carbon concentration by promoting Ca^{2+} bridging with organic matter (Fernandez-Ugalde, et al., 2014). Nobile et al., (2022) in their experiment also concluded the combination of biochar and compost as organic amendments is effective in improving the organic carbon content in soil.

4.4. Cation Exchange of Capacity (CEC)

Figure 4.4 presents the effect of various treatments used in the experiment and their interaction effect on the CEC of the three soils with different salts. CEC among the three soils in the experiment were also found to be statistically different ($p < 0.01$) where saline soil recorded the maximum average CEC value (83.27 meq/100gm) followed by Saline sodic (61.87 meq/100gm) and sodic soil (60.02 meq/100gm) respectively (Table 4.1). The maximum CEC in saline soil is because of the presence of a high amount of exchangeable cations (Ca^{2+} , Mg^{2+} , K^{+}) and less amount of Na compared to saline-sodic and sodic soil. Similarly, High sodium content in sodic and saline-sodic soil replaces the Ca and Mg in the exchange complex, which may be the reason for to reduce overall CEC, and as well as the dispersion caused by the sodium in the soil may reduce the soil cation retention ability leading to the lower CEC value.

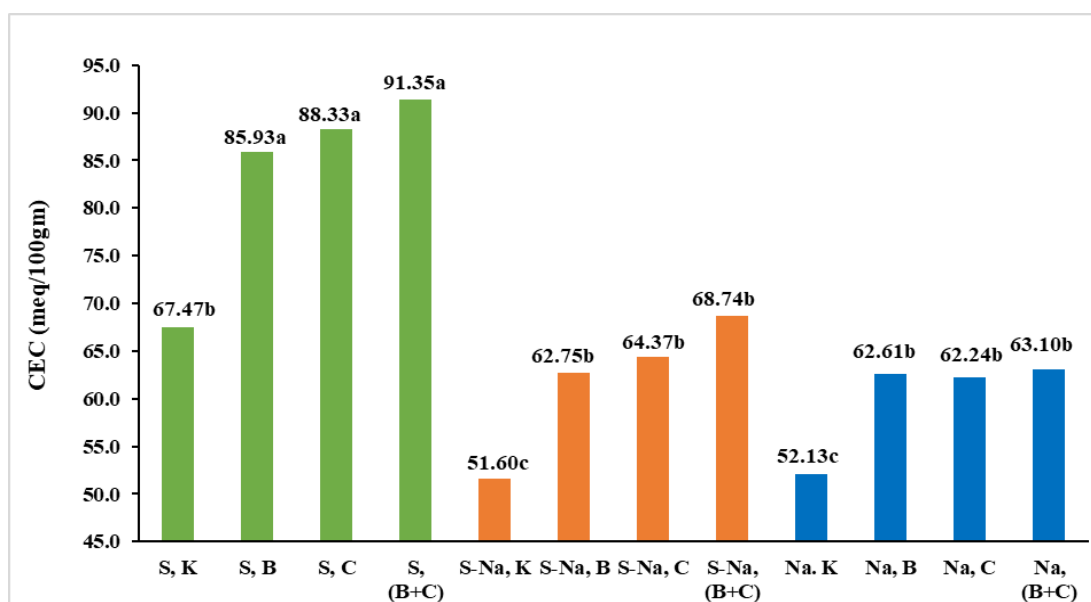


Figure 4.4: Effect of treatments on Cation Exchange Capacity (CEC) showing the interaction and mean values of each treatment.

Note: S = saline soil, S-Na= saline-sodic soil and Na= sodic soil, K= Control (without amendments), B= Biochar, C=Compost, and B+C= Biochar and compost. The similar color resembles the similar soil type. F value= 3.64*

Figure 4.4 clearly showed significantly higher CEC ($p < 0.01$) in the biochar, compost, and biochar + compost treated pots compared with the control (without any amendments) in all three soils used in the experiment. The increase was more pronounced in the combined application of biochar and compost (74.39 meq/100gm) followed by compost (71.65 meq/100gm), biochar (70.43 meq/100gm), and control (57.07) respectively (Table 4.4). The decomposition process of organic amendments added to the soil generates the cations like Ca^{2+} , Mg^{2+} , and K^{+} which contribute in increasing the CEC of soil (Abdel-Fattah, 2012; Brady & Weil, 2005). The increase in soil organic carbon of the soil by the application of biochar and compost promotes microbial activity which helps in releasing more cations and improves the soil granulation and retention power of soil thereby contributing to elevating the CEC value of soil (Mahmoud et al., 2018; Oram et al., 2014). Tomczyk et al., (2020) found that the addition of woody biochar significantly enhanced the CEC of the manufactured soil by 190% compared to unamended soil. The combined application of biochar and compost increased the CEC of soil significantly compared to the sole application of biochar and compost (J. Liu et al., 2012a). Other consistent results were found regarding the combination of biochar with compost or other organic amendments which showed significant improvement in OC and CEC of the soil (Agegnehu et al., 2016; Carter et al., 2013). An increase in CEC may be attributed to the presence of cation exchange sites on the surface of biochar (Sohi et al., 2010; Trupiano et al., 2017). Getahun et al., (2020) in their experiment showed that organic amendments (biochar, compost, manure, and mixed) increased the OC, OM, and CEC of the soil in a highly degraded habitat and also reported the synergistic role of organic amendments in improving the soil properties.

4.5. Exchangeable Sodium Percentage (ESP)

The effect of three soil with different salts and the organic amendments (biochar and compost) on exchangeable sodium percentage is shown in Figure 4.5 below. The mean values of ESP were found to be significantly different among the treatments. Also, the result from Anova and Duncan shows that both the soil type (saline, saline-sodic and sodic soil) and the amendments (biochar, compost, and biochar + compost) show a significant impact ($p < 0.01$) on the ESP of soil (Table 4.2 and 4.5). The mean values obtained for saline, saline-sodic and sodic soil were 3.28, 10.50, and 16.99%

respectively which shows that the soil affected with sodium has the highest ESP followed by saline-sodic and sodic soil respectively (Table 4.2). Also, figure 4.5. shows that the highest ESP i.e., 23.31% was found to be in the sodic soil without amendments (Na-K). So, from this result, we can be clear that the type of salt in the soil can influence the ESP significantly. The increase in ESP in sodic soil and saline-sodic may be due to the increase in the concentration of exchangeable sodium and the decrease in the concentration of exchangeable Ca and Mg as compared to saline soil (Table 4). Higher Ca^{2+} and Mg^{2+} concentrations, inhibit the capacity of sodium to occupy the soil exchange complex, resulting in a reduction in the amount of exchangeable sodium (Hanson, Grattan, & Fulton, 1999). Also, the significant decrease in CEC of sodic and saline-sodic soil may be one of the convincing reasons for the increment of ESP of sodic and saline-sodic soil. A high concentration of Na salt in sodic and saline-sodic soil compared to saline soil resulted in a higher ESP in sodic and saline-sodic soil.

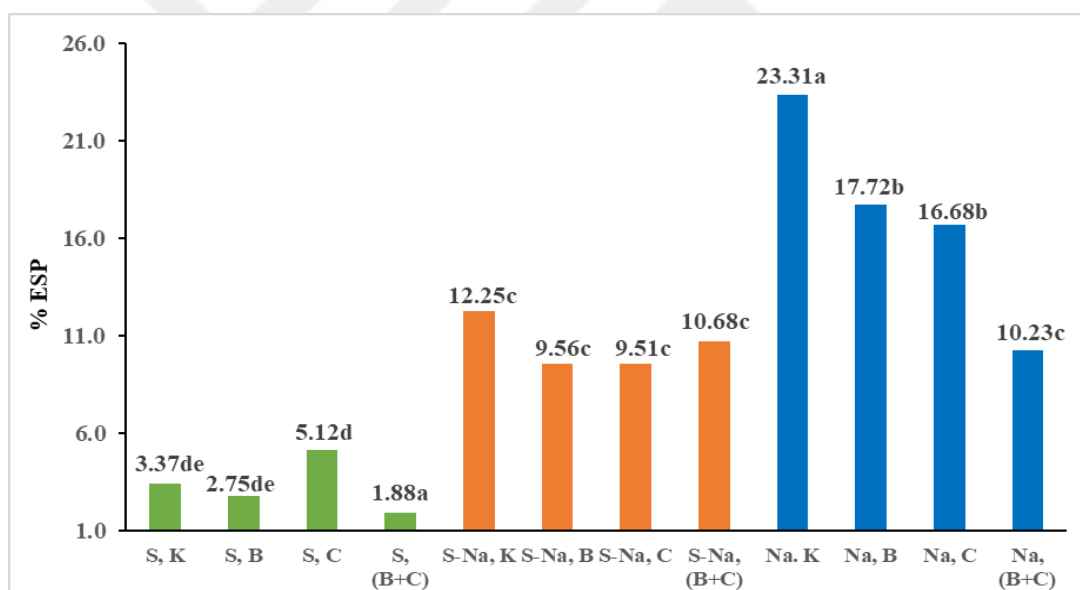


Figure 4.5: Effect of treatments on exchangeable sodium percentage (ESP) showing the interaction and mean values of each treatment

Note: S = saline soil, S-Na= saline-sodic soil and Na= sodic soil, K= Control (without amendments), B= Biochar, C=Compost and B+C= Biochar and compost. The similar color resembles the similar soil type. F value= 20.374**

The application of biochar and compost in these three different soils showed a significant impact in lowering the ESP in all three types of soil except the compost treatment in saline soil (S-C) which increased the ESP compared to control. In saline and sodic soil, combined application of biochar and compost showed maximum reduction in ESP values of soil while in saline soil, sole application of biochar and

compost showed maximum reduction in ESP compared to control. The mean values of all the treatments i.e., control (12.89%), Biochar (10.01%), compost (10.43%), and biochar + compost (7.60%) showed that combined application of biochar and compost were more effective in decreasing the ESP of soil compared to other treatments ($p < 0.01$) (Table 4.5). In sodic soil, the combined application of biochar and compost showed a greater reduction of ESP compared to control and other soils. Biochar and compost significantly ($P < 0.01$) increased the exchangeable Ca and Mg in the soil as compared to the control (Table 4.5). Also, cation exchange capacity was significantly raised with the application of biochar and compost in the soil. Thus, the decrease in ESP can be attributed to the capacity of these organic amendments, biochar, and compost in supplying more Ca and Mg in the exchange complex displacing the Na from the soil and also facilitating the Na leaching from the soil (Cao & Harris, 2010; Shaygan & Baumgartl, 2022; Tejada, Garcia, Gonzalez, & Hernandez, 2006). The findings are consistent with other similar studies. For instance, Akhtar et al., (2015) found that the application of biochar to salt-affected soil increased the concentration of exchangeable Ca and Mg and decreased the Na^+ from the exchange complex. Likewise, ESP was found to be significantly reduced with the use of compost as an amendment in the sodic and saline-sodic soil (Hanay et al., 2004; Trivedi et al., 2017). Agegnehu et al., (2015) and Izilan et al. (2022) also concluded a similar finding that the combined application of biochar and compost was found more effective in elevating the concentration of exchangeable Ca, Mg, and K in the soil. In sodic soil, the use of organic amendments such as green manure, rice husk, and wheat straw also showed a significant reduction in ESP with the increase in exchangeable Ca and Mg concentration (Swarup, 1992). Biochar-Compost exhibits a high salt sorption capacity and can serve as a primary source of Ca and Mg decreasing sodium salt from soil exchange complexes (J.-F. Liang et al., 2021; Saifullah et al., 2018).

4.6. Bulk Density (BD)

The changes in the bulk density (BD) under different soils having different salts and organic amendment treatments are shown in figure 4.6. The obtained result showed that the BD values were not significantly different among the soils used in the experiment.

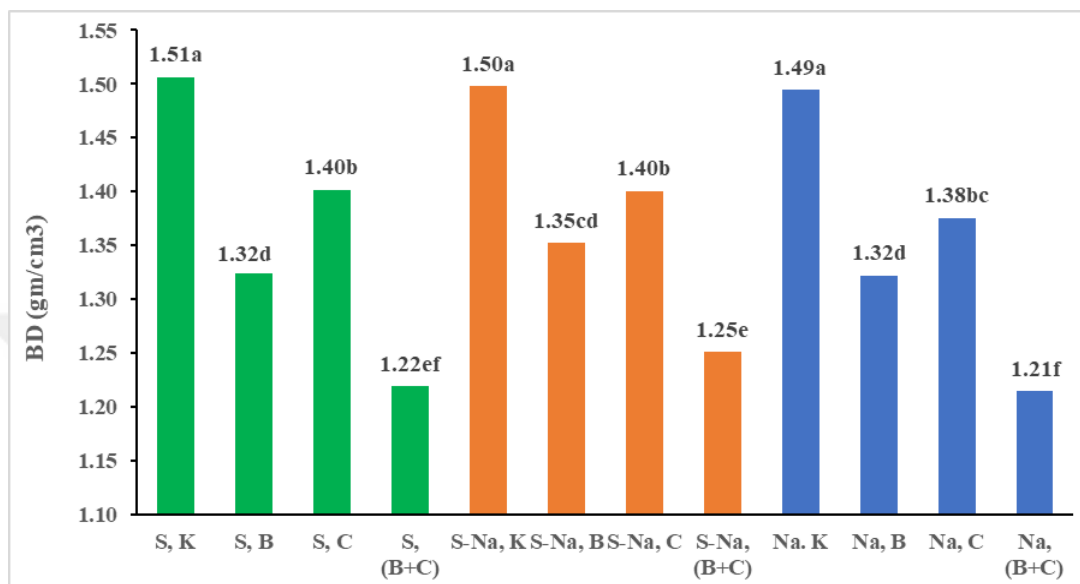


Figure 4.6: Effect of treatments on Bulk Density (BD) showing the interaction and mean values of each treatment

Note: S = saline soil, S-Na= saline-sodic soil and Na= sodic soil, K= Control (without amendments), B= Biochar, C=Compost, and B+C= Biochar and compost. The similar color resembles the similar soil type. F value= 1.668ns

The mean values obtained for three soils were 1.37 gm/cm³, 1.36gm/cm³, and 1.35 g/cm³ for saline-sodic, saline, and sodic soils respectively (Table 4.1). These values were statistically at par with each other. Also, the control treatment (without amendment) of all three soil showed the BD values statistically similar to each other. Though the organic carbon content, CEC, and ESP of these soils were different from each other, the similar BD values obtained may be attributed to their similar textural characteristics, mineral composition (sand, silt, and clay), and particle packing characteristics. Also, maybe the different soils experienced similar compaction levels which led to similar BD values.

However, a significant difference ($p < 0.01$) in the bulk density was obtained among the different amendments used during the study. Compared to the control i.e., without amendments (1.50 gm/cm³), a significant reduction in the BD values was reported for all the amendments used with the highest reduction in the combined

application of biochar and compost (1.23 gm/cm³) followed by biochar (1.33gm/cm³) and compost (1.39 gm/cm³) (Table 4.4). Although bulk density depends on several factors, it is strongly correlated with organic matter and organic carbon content(Leifeld et al., 2005). The organic matter may have increased the pore spaces lowering the bulk density as organic matter have a lower density than the mineral fraction of soil. This phenomenon is described as the “fluff” effect on bulk density(Kranz et al., 2020; Layman et al., 2010). So, the decrease in bulk density may be due to the increase in organic carbon content that was found after the application of biochar and compost. Similarly, the use of organic amendments promoted the soil structure improving the aggregated stability, and porosity, and reducing the dispersion thereby lowering the bulk density. Özdemir Et Al., (2022) reported that an increase in aggregation improves the porosity which then lowers the BD of soil. According to Oo et al.(2013) and Qadir & Oster. (2004), combining organic amendments caused significant flocculation and the development of stable soil aggregates which then lowers the BD values. Elazazi et al., (2017) while studying the effect of amendments on saline-sodic soils found that the organic amendments significantly lower the bulk density compared to soil without amendments. Biochar being highly porous, having a high surface area and an enormous number of micropores(Jaafar et al., 2015; Mukherjee et al., 2011) may have attributed to the improvement of bulk density of soil(Mwadalu et al., 2021; Y. Zheng et al., 2019). Several other studies (V. Abrol et al., 2016; Blanco-Canqui, 2017; Herath et al., 2013; Omondi et al., 2016)also reported a decrease in bulk density with the use of biochar. The high organic matter present in the compost may have lowered the BD values of the soil by enhancing the organic carbon content, enhancing the microbial activities, and promoting the stabilized soil structure. Since biochar is more porous than compost, when coupled with compost, it created a favorable synergy that resulted in a considerable drop in the bulk density of all three soils. The findings were consistent with the study of Phares and Akaba, (2022) where the compost alone or with biochar showed a significant reduction by 15 and 17.7%, respectively, relative to the control. Biochar serves as a habitat for a variety of soil-borne microorganisms that enhances the physical properties thus improving air porosity in soil(Amini et al., 2016; Vasconcelos, 2020).

4.7. Total Porosity (F)

The data on the effect of different amendments on the total porosity (F) of the three soils with the different salts used in the experiment are presented in figure 4.7. All three soils without amendments showed the lowest porosity values compared to other treatments and the values obtained were statistically similar to each other.

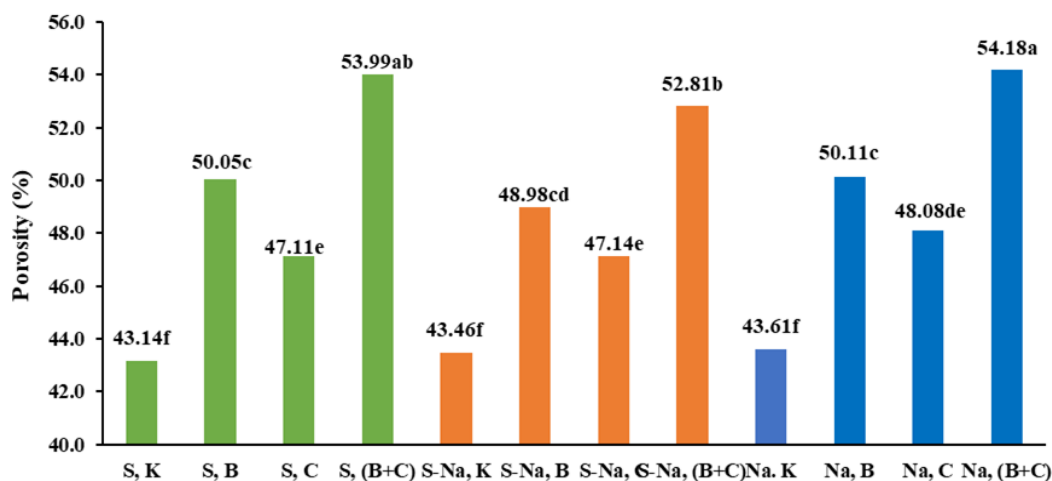


Figure 4.7: Effect of treatments on Total Porosity (F) showing the interaction and mean values of each treatment.

Note: S = saline soil, S-Na= saline-sodic soil and Na= sodic soil, K= Control (without amendments), B= Biochar, C=Compost, and B+C= Biochar and compost. The similar color resembles the similar soil type. F value= 0.608ns

Likewise, while comparing the mean values of three soils with Duncan, the highest porosity value was obtained for sodic soil (49%) followed by saline (48.58%) and saline-sodic soil (48.09%) (Table 4.1). The porosity values of the three soils were statistically similar to each other. The mean value of the combined application of biochar and compost in sodic soil showed the highest porosity (54.18%). The B+C treatment in saline soil was statistically at par with the sodic soil, B+C treatment with a porosity value of 53.99% and the B+C in saline-sodic soil was also statistically at par with the saline soil, B+C treatment (52.81%). Likewise, in all three soils used for the study, biochar, and compost showed significantly higher porosity values compared to control. Likewise, while comparing the mean values of amendments, combined application of biochar and compost showed the highest porosity (53.66%) followed by biochar (49.72%), compost (47.45%), and control (43.41%) respectively (Table 4.4).

Porosity is derived from the bulk density and particle density of soil and thus inverse relationship exists between bulk density and porosity. Therefore, a decrease in bulk density increases the porosity. So, the Low BD values of soil by the organic

amendments found in our study resulted in an increment in the total porosity of the three soils used in the experiment. The results obtained were consistent with the findings of Hassani et al., (2021) where compost and biochar were capable of significantly lowering the BD thereby improving the total porosity of saline-sodic soil used for the study. Likewise, the decrease in ESP of soil by the organic amendments used also favored better soil aggregation and thus improving the soil structure and porosity of the soils. Biochar can serve as the habitat for soil microorganisms and enzyme activities which promotes good soil structure and thus decrease the soil bulk density and increase the soil porosity(Amini et al., 2016; Y. Zheng et al., 2019). The combined application of biochar and compost reported a significant improvement in soil aggregation and total soil porosity of soil under saline conditions(D. Liu et al., 2021).

4.8. Aggregate Stability (AS)

Figure 8 illustrates the results for the impact of different treatments on Aggregate Stability (AS), including the interaction and mean values for each treatment group. The interaction between soil $\times$ amendment was not significant (figure 4.8) while the soil types and amendments used in the experiment showed a significant result.

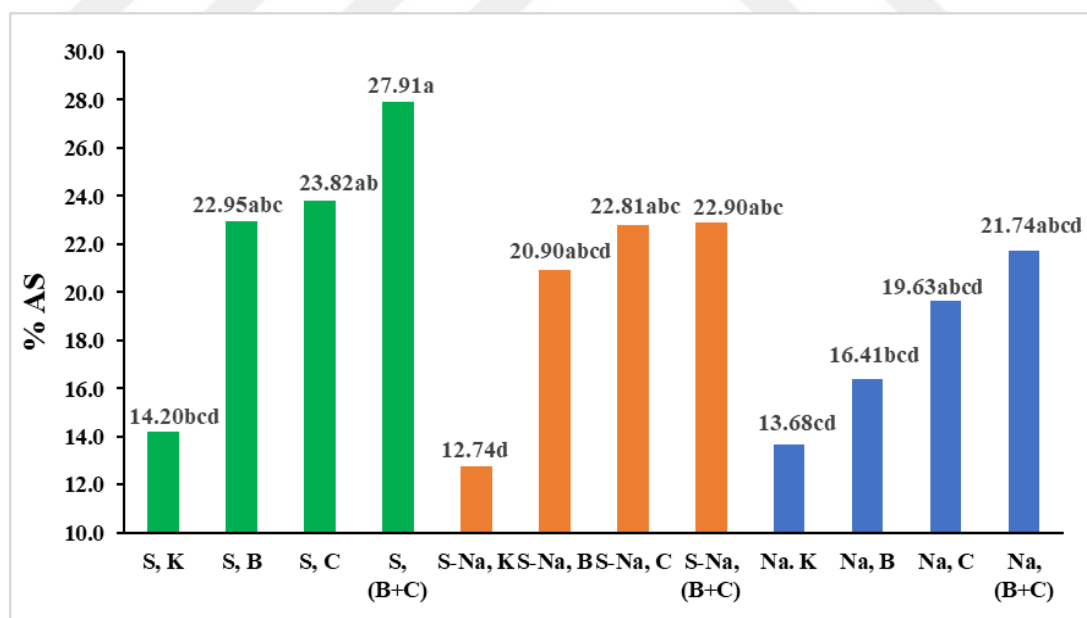


Figure 4.7: Effect of treatments on Aggregate Stability (AS) showing the interaction and mean values of each treatment.

Note: S = saline soil, S-Na= saline-sodic soil and Na= sodic soil, K= Control (without amendments), B= Biochar, C=Compost, and B+C= Biochar and compost. The similar color resembles the similar soil type. F value= 0.721ns

The Aggregate stability values ranged from 12.74 to 27.91%. The highest AS value was observed for the treatment where both biochar and compost were applied in saline soil (S, (B+C)) with a value of 27.91%. Saline sodic soil without amendments recorded the lowest aggregate stability value (12.47%) followed by sodic, control (13.68%), and saline soil without amendments (14.20%). Furthermore, the ANOVA and Duncan's test revealed a significant difference ($p < 0.05$) in aggregate stability among the soil types used in the experiment (Table 4.3). The saline soil exhibited the highest aggregate stability (22.22%) followed by saline-sodic (19.83%) and sodic soil (17.86%). These findings suggest that saline soil had a more favorable soil structure and the highest aggregate stability compared to other soil types. The high concentration of sodium in sodic and saline-sodic soil may have led to the disruption in the soil structure lowering aggregate stability. Sodium salt acts as a highly dispersive agent leading to the breakdown of aggregates through unique degradation processes like slaking, swelling, and dispersion (Leogrande & Vitti, 2019; J. Quirk, 2001; Shainberg & Letey, 1984). On the other hand, Calcium and Magnesium generally have a positive impact on the soil structure as they keep the soil flocculated and improve the soil aggregation (Agass et al., 1981; Ayers & Westcot., 1976a; Miller & Donahue., 1995). Therefore, in saline soil high concentrations of calcium and magnesium lowered the quantity of sodium by competing with sodium for the exchange sites which then improved the soil aggregation (Hanson, Grattan, & Fulton., 1999).

In addition to the soil types, the amendments used in the experiment showed a significant increment ($p < 0.01$) in aggregate stability in all three soils compared to the control. The combined application of biochar and compost showed the highest AS (24.18%) followed by compost (22.08), biochar (20.08%), and control (13.54%) (Table 4.6). The results indicated that all the organic amendments were effective in improving the aggregate stability of soil while the combined biochar and compost treatment had the most pronounced effect. The amount of organic matter and organic carbon in the soil, as well as the amount of calcium and magnesium, were all significantly increased with the application of biochar and compost. Thus, biochar and compost acted as soil binding agents, enhancing the aggregate stability of all soils used for the study. Angst et al., (2017) reported that the addition of organic matter in the soil increases the microbial activity and decomposition process which in turn releases the binding agents for the soil aggregates. The organic molecules facilitate the binding

of polyvalent cations and clay particles to enhance aggregation in deteriorated salt-affected soils(Amini et al., 2016). Compared to other readily degradable organic inputs, Biochar enhances the stability of organic molecules and helps to bind the soil aggregates for a long period of time improving the aggregate stability of the soil(Yeboah et al., 2009). Biochar addition increased the soil organic carbon and promoted soil aggregation in saline-sodic soil(Che et al., 2021). Annabi et al., (2007) concluded that the presence of larger labile carbon in compost promotes microbial activity when added to soil which enhanced aggregate stability increasing water repellency and slaking resistance. The findings we obtained correspond with those of numerous previous research which explain that the addition of compost, biochar, and the combination of biochar and compost aggregate stability of soil(Amlinger et al., 2007; Ibrahim et al., 2021; Ouyang et al., 2013). The positive impact of biochar and compost application on soil organic carbon, bulk density, and porosity also leads to better soil aggregation and aggregate stability of saline-sodic soils. (F. Hassani et al., 2021). Chaganti et al., (2015) also showed that the application of organic amendments like biochar, biosolids co-compost, and green waste compost increased the aggregate stability of saline-sodic soil compared to control. Compost showed a greater increase in aggregate stability compared to other amendments.

4.9. Dispersion ratio (DR)

Dispersion ratio (DR) as affected by the different amendments and the soils with the different salts used during the experiment is presented in the figure 4.9. Significant differences ($p < 0.01$) were obtained for both the amendments and the three soils employed for the study. Sodic soil without amendments showed the highest dispersion ratio (62.69%) which was statistically similar to the saline-sodic soil without amendments (60.14%). While comparing the mean values of soil types, the dispersion ratio values of three soils showed statistically significant differences ($p < 0.05$) among each other with the highest dispersion in sodic soil (51.56%) followed by saline-sodic (49.20%) and saline soil (47.88%) (Table 4.3). This may be attributed to the fact that high sodium concentration in the sodic soil led to the degradation of soil structure through dispersion. Sodium has a greater tendency to disperse the soil particles due to its comparatively large size, single electric charge, and its hydration status while the Ca and Mg are smaller, non-hydrated, and divalent cations, they do not have the same

effect as sodium instead they flocculate the soil particles(Warrence et al., 2003).

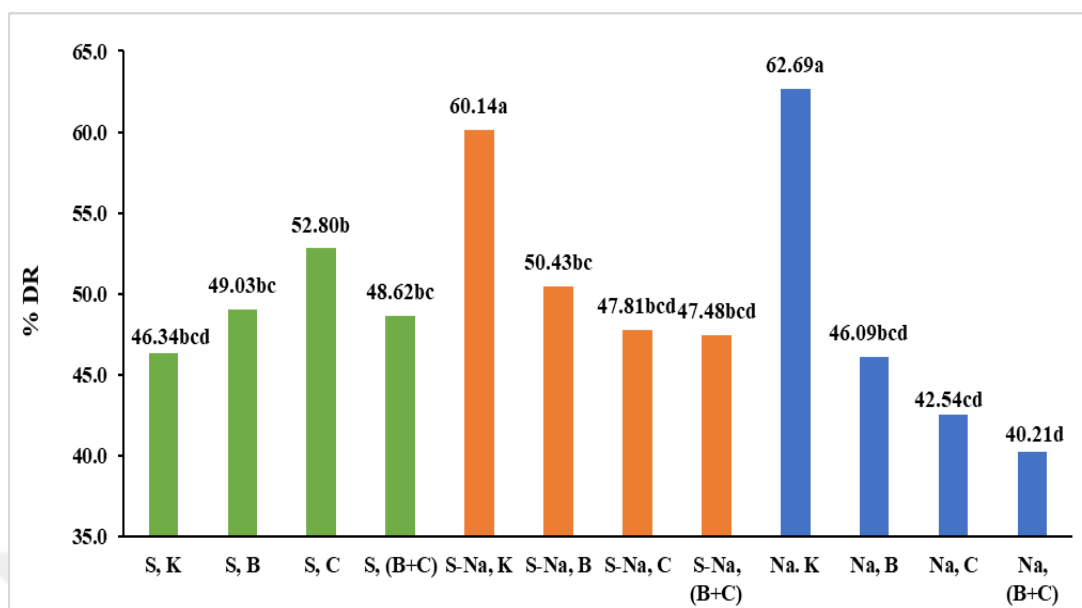


Figure 4.8: Effect of treatments on Dispersion ratio (DR) showing the interaction and mean values of each treatment.

Note: S = saline soil, S-Na= saline-sodic soil and Na= sodic soil, K= Control (without amendments), B= Biochar, C=Compost, and B+C= Biochar and compost. The similar color resembles the similar soil type.

Soils having high ESP led to greater dispersion of soil sand and poor soil structure(Agass et al., 1981). The presence of exchangeable Na⁺ in the soil solution and at exchange sites creates repulsive charges that disperse soil particles(Bronick & Lal, 2005).

From Figure 9, it can be noted that compared to the control application of biochar and compost showed a significant reduction in dispersion ratio in the saline-sodic and sodic soil while in saline-soil the amendments showed an increment in the dispersion ratio with the highest in compost treated saline soil. A more pronounced reduction of dispersion ratios by organic amendments used was found in sodic soil with the highest reduction in combined biochar and compost followed by compost and biochar respectively. This result suggests that the effect of organic amendments on dispersion ratios can vary depending on the soil type and its properties. Comparison of mean values also showed the lowest dispersion ratio values in the combined application of biochar and compost (45.53%) followed by compost (47.71%), biochar (48.52%), and control (56.39%) respectively (Table 4.6). Thus, the result suggests all the organic amendments used either solely or combined were capable of lowering the dispersion ratio values while the combined use of biochar and compost was found more effective

indicating the synergistic effect of amendments. The decrease in the ESP and increase in the organic carbon, concentration of Ca and Mg by the addition of amendments may have been attributed to the lower dispersion ratio in the amended soil. Agbede, (2021) found that biochar and manure were effective in lowering the dispersion ratio of the soil compared to the soil without amendments and suggested that organic matter supplied through amendments protected the soil from degradation and improved the stability of soil.



4.10. Structural Stability Index (SSI)

The mean values of SSI associated with different combinations of treatments are presented in Figure 4.10. It demonstrates the significant influence of amendments and soils with varying salt type on the structural stability index of soil. Saline-sodic and sodic soil without amendments showed comparatively lower values of SSI compared to amended soils. While comparing the mean values of unamended soils, the lowest value of SSI was observed in saline-sodic soil (17.70%) followed by sodic soil (21.26%) and saline soil (25.48%) respectively (Table 4.3). The lower SSI values in unamended saline-sodic and sodic soil may be due to the high concentration of sodium which led to more dispersion ratio and less aggregation of soil. The High ESP and low organic carbon also led to the low SSI values of unamended saline-sodic and sodic soil.

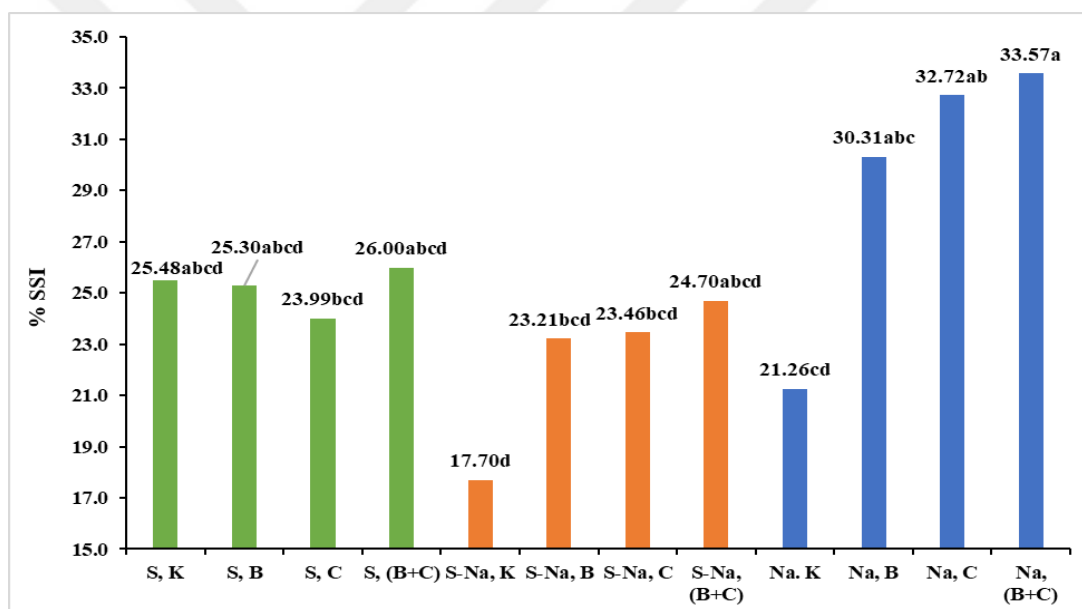


Figure 4.9: Effect of treatments on Structural Stability Index (SSI) showing the interaction and mean values of each treatment.

Note: S = saline soil, S-Na= saline-sodic soil and Na= sodic soil, K= Control (without amendments), B= Biochar, C=Compost, and B+C= Biochar and compost. The similar color resembles the similar soil type. F value= 3.076ns

Comparing the effect of amendments (biochar and compost), the application of biochar and compost either sole or combined showed a significant improvement in saline-sodic and sodic soils while in saline soil, there were no observed differences among the treatments. In sodic soil, treatments showed a greater increase in SSI values compared to the control which showed that the effect of amendments depends on the

soil properties and the type of salt and salt concentration. The result of the mean separation of the amendments showed the highest SSI values in a combination of biochar and compost (25.66%) followed by compost (22.62%), biochar (21.63%), and control (19.87%) (Table 4.6) suggesting the combination of biochar and compost most effective in improving the structural stability index of soil. The lower dispersion ratio, bulk density, and increased porosity, aggregate stability with the application of amendments may have led to the greater SSI values in the amended soils. The result obtained is consistent with the findings of Spaccini et al., (2004), (Tejada & Gonzalez, (2006) and, (Tejada, Garcia, Gonzalez, & Hernández, 2006) who discovered that organic matter works as a cementing agent, allowing flocculated soil particles to create stable aggregate. Tejada et al., (2008) found that compost significantly increased the structural stability index of soil compared to control. They proposed that this improvement could be attributed to the formation of clay-organic complexes facilitated by the presence of humic acids that arise during compost decomposition leading to the formation of stable aggregates. The incorporation of biochar in the soil led to the formation of macroaggregates by binding the micro aggregates which increases the diameter of soil aggregates therefore improving the structural stability of soil (C.-H. Cheng et al., 2006). The mineralization of biochar increases the amount of oxidized functional groups like hydroxyl groups and carboxylic groups which then promotes the flocculation of both the soil particles and biochar improving the stability index of soil (Jien & Wang, 2013; Wang et al., 2017). Likewise, a synergistic positive effect of biochar and compost was noted on the stability index of soil in the study by (Sharma, Abrol, Sharma, Chaddha, Srinivasa Rao, et al., 2021).

4.11. Saturated Hydraulic Conductivity

The data presented in Figure 4.11 revealed that both the soil type with different salt contents and the organic amendments used significantly affected the saturated hydraulic conductivity. The K_s values were obtained in the range of 0.42-4.61 cm/hr. Unamended sodic soil recorded the lowest K_s value (0.42 cm/hr) followed by unamended saline-sodic (0.76 cm/hr) and saline soil (2.03 cm/hr) respectively.

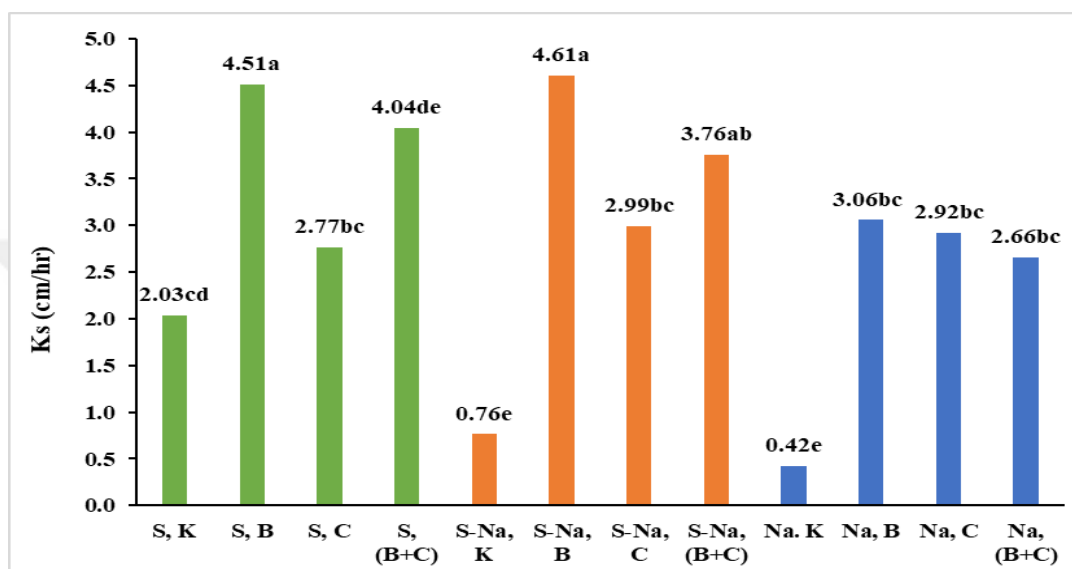


Figure 4.10: Effect of treatments on Saturated Hydraulic Conductivity (K_s) showing the interaction and mean values of each treatment.

(S = saline soil, S-Na= saline-sodic soil and Na= sodic soil, K= Control (without amendments), B= Biochar, C=Compost, and B+C= Biochar and compost. The similar color resembles the similar soil type. F value= 2.45*)

Moreover, a comparison of mean values of the soils used also showed significant differences ($p < 0.01$) among the soils used lowest K_s value in a sodic soil with the value of 2.26cm/hr followed by saline-sodic (3.02cm/hr) and sodic soil (3.34cm/hr.) respectively (Table 4.3). These findings suggest that the soil type and salt contents greatly influenced the saturated hydraulic conductivity. The high sodium concentration in sodic and saline-sodic soils likely contributed to the reduced hydraulic conductivity. High sodicity reduces hydraulic conductivity considerably due to the swelling and dispersion caused by sodium, leading to the breakdown of soil aggregates (J. P. Quirk & Schofield, 1955) (McNeal et al., 1968) Dispersion causes the clogging of soil pores and may lead to the permanent blockage of water navigating pores reducing the hydraulic conductivity significantly (Sumner, 1993). In contrast, high concentrations of Ca and Mg in the saline soil may have promoted better

aggregation and led to better conductivity compared to sodic and saline-sodic soils.

Considering the amendments used in the experiment, a significant difference ($p < 0.01$) was observed among the amendments in all three soils. All the amendments showed significant improvement in hydraulic conductivity as compared to control. The highest K_s value was obtained for biochar-amended saline-sodic soil (4.61cm/hr) which was statistically similar to the biochar-amended saline soil (4.51cm/hr). The result of ANOVA and Duncan test also revealed that biochar and compost application significantly increased the K_s values compared to the soils without amendments. The highest K_s value was recorded for Biochar (4.06cm/hr) followed by Biochar + Compost (3.49cm/hr), Compost (2.89cm/hr), and Control (1.07cm/hr) respectively (Table 4.6). The high porosity of biochar helps to retain the water with the capillary forces which improves the water-holding capacity of soil when used as an amendment (Karhu et al., 2011; Pietikäinen et al., 2000; Tryon, 1948). The application of organic amendments in all the soils reduces the concentration of exchangeable Na^+ concentration and EC by leaching the salts and NaCl which then led to a reduction of bulk density improving the porosity and hydraulic conductivity of salt-affected soil (Diacono & Montemurro, 2015; Lakhdar et al., 2010). Biochar promoted biological activity and led to the formation of stable aggregates and improved hydraulic conductivity of soil as compared to unamended soil (Herath et al., 2013). Application of biochar showed a significant reduction in bulk density and then improvement of porosity and saturated hydraulic conductivity (K_s) of the highly saline-sodic soil. Several studies concluded that combined application of biochar and compost has a positive impact on water retention and saturated hydraulic conductivity of soil (Al-Omran et al., 2019; Sharma, Abrol, Sharma, Chaddha, Ch, et al., 2021). Abd El-Mageed et al., (2021) found that co-composted poultry litter biochar had a positive impact on the hydraulic conductivity of the soil. Chaganti et al., (2015) discovered that both biochar and compost were effective in improving the hydraulic conductivity of saline-sodic soil where they found that amended soil had a higher K_s value compared to the control soil.

4.12. Field Capacity (FC), Permanent Wilting Point (PWP), and Plant Available Water (PAW)

Figure 4.12. presents the effect of treatments (biochar, compost, biochar + compost, and control i.e. without amendments) on the Field capacity (FC), Permanent Wilting Point (PWP), and Plant Available Water (PAW) content in all three soils used in the experiment. The results of the mean values for FC, PWP, and PAW in different treatments for saline, saline-sodic, and sodic soils indicate the effects of these amendments on water-holding capacity. Compared to the control, significant increments in the mean values of FC, PWP, and PAW were obtained for all the amendments used. In terms of FC, biochar, and biochar+compost treatments consistently showed higher values compared to the control in all soil types (saline, saline-sodic, and sodic). The compost treatment also showed some improvements in FC, although to a lesser extent than biochar. This suggests that these amendments have the potential to enhance the soil's ability to retain water. Regarding PWP, all the treatments showed significantly higher PWP values as compared to the control in all three soils. This suggests that the organic amendments can help plants withstand water stress by providing a greater buffer before reaching the critical moisture level.

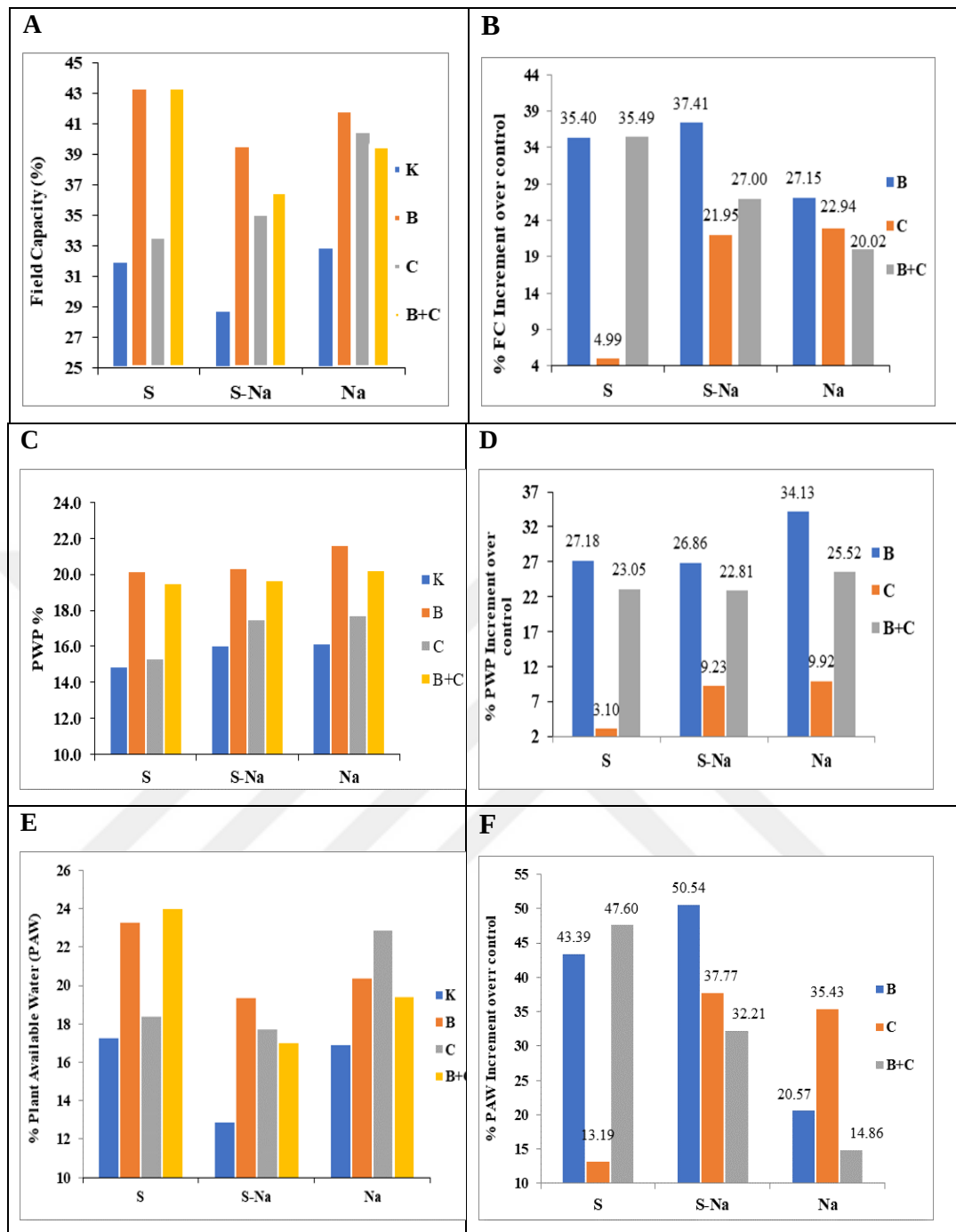


Figure 4.11: Treatment effect on (A) Field Capacity (FC), (C) Permanent Wilting Point (PWP), and (E) Plant Available Water (PAW) on the three soils used in the experiment presenting their mean values. (B) FC increment over control (without amendments) in percentage, (D) PWP increment over control in %, and (F) PAW increment over control in %.

Furthermore, the application of biochar, compost, and biochar + compost generally resulted in higher PAW values relative to the soils without amendments. This result indicates that organic amendments help to retain the water and increase the water availability for plant uptake. Overall, these results demonstrate the potential of biochar, compost, and biochar + compost amendments to positively influence soil water

dynamics and availability. They offer promising solutions for mitigating water stress and improving plant performance in saline, saline-sodic, and sodic soils, which are often challenging for agricultural productivity. The positive effect on soil moisture may be attributed to the increase in porosity and improved pore size distribution which led to the increase in micropores i.e., water-holding or water-storage pores. Also, the improvement in the soil aggregate stability and soil structure led to the improvement of the water holding capacity of soil which then improved the Field capacity, permanent wilting point, and then increased availability of water to plant.

The high porosity of biochar helps to retain the water with the capillary forces which improves the water-holding capacity of soil when used as an amendment(Karhu et al., 2011; Pietikäinen et al., 2000; Tryon, 1948). Several studies recorded the improvement in water holding capacity and increase in plant-available water with the use of biochar(Baronti et al., 2014; Briggs et al., 2012; Kammann et al., 2011; Novak et al., 2012). The high microporosity of biochar increases the micropores in the soil as well as the small particle size of biochar can fill the pore space between the coarse particle size of soils which then reduces the pore size of the soil. This may lead to an increase in water retention of soil and increase the field capacity, PWP, and plant available water content in soil(Z. Liu et al., 2017). The significant increase in PWP and PAW by biochar application may be attributed to the hydrophilic surface and larger surface area of smaller biochar particles which increased the specific surface area of the soil thereby improving water retention(Razzaghi et al., 2020; Zhang et al., 2016). Zhang et al., (2020) in their experiment also found that biochar application significantly increased the Field capacity and saturated water content in saline-alkali soil. Biochar possesses intrapores within its particles, which can offer additional storage capacity for water, extending beyond the pore space found between particles (interpores)(Masiello et al., 2015). El-Sodany et al., (2018) reported that the application of compost positively affected the hydrophysical properties of soil resulting in a decrease in bulk density of soil while increasing the total porosity, hydraulic conductivity, and soil moisture constants i.e., field capacity, wilting point, and available water. A similar result was obtained by Haggag et al., (2022) where they found that application of biochar and/or compost was effective in improving water retention and increasing the field capacity, PWP, and available water in saline soil.

4.13. Effect of soil type and amendments on the soil properties analyzed.

The ANOVA and Duncan result of the soils and the amendments i.e. biochar, compost, and biochar + compost on the properties of soil analyzed in the experiment are summarized in the following tables.

Table 4.1: Effect of three different soil on pH, EC, OC, CEC, BD, and F

Soil	pH	EC (dS/m)	OC (%)	CEC (meq/100g)	BD (gm/cm ³)	F (%)
S	7.66a	2.79a	2.81a	83.27a	1.36ab	48.58ab
S-Na	7.49b	4.73b	2.56b	61.87b	1.37a	48.09b
Na	7.53b	6.46c	2.67ab	60.02b	1.35b	49.00a
F value	23.20**	0.37**	6.09**	273.03**	7.882*	7.865*

* and ** statistically significant at 0.01 level and 0.05 level

Table 1.2: Effect of three different soil on Exchangeable Ca, Mg, Na and K and ESP

Soil	Ex Ca (meq/100g)	Ex Mg (meq/100g)	Ex Na (meq/100g)	Ex K (meq/100g)	ESP(%)
S	49.43a	28.664a	2.72c	2.48a	3.28c
S-Na	30.41b	23.83b	6.44b	1.18b	10.50b
Na	28.90b	19.95c	10.01a	1.16b	16.99a
F value	623.96**	55.33**	380.02**	68.95**	432.29**

** statistically significant at 0.01 level

Table 4.3: Effect of three different soil on AS, DR, SSI and Ks

Soil	AS (%)	DR (%)	SSI (%)	Ks (cm/h)
S	22.22a	47.88b	25.60a	3.34 a
S-Na	19.84ab	49.20ab	22.17b	3.02 a
Na	17.87c	51.46a	19.56c	2.26 b
F value	4.20*	3.88*	26.25**	11.26**

* and ** statistically significant at 0.01 level and 0.05 level

Table 4.4: Effect of ammendments on soil pH, EC, OC, CEC, BD, and F

Ammendment	pH	EC (dS/m)	OC (%)	CEC (meq/100g)	BD (gm/cm ³)	F (%)
K	7.55b	5.50a	1.81d	57.07c	1.50a	43.41d
B	7.82a	4.68b	2.65c	70.43b	1.33c	49.72b
C	7.38c	5.0c	3.26a	71.65ab	1.39b	47.45c
B+C	7.49b	3.50d	3.00b	74.39a	1.23a	53.66a
F value	73.11**	0.059**	123.41**	73.136**	533.60**	534.86**

** statistically significant at 0.01 level

Table 4.5: Effect of ammendments on soil Exchangeable Ca, Mg, Na and K and ESP

Ammendment	Ex Ca (meq/100g)	Ex Mg (meq/100g)	Ex Na (meq/100g)	Ex K (meq/100g)	ESP(%)
K	29.98c	19.13b	6.9a	1.05c	12.98a
B	37.67b	24.68a	6.4a	1.60b	10.01b
C	37.01b	25.60a	7.00a	2.04a	10.44b
B+C	40.32a	27.15a	5.17b	1.75ab	7.60c
F value	69.65**	26.74**	15.23**	15.44**	33.51**

** statistically significant at 0.01 level

Table 4.6: Effect of ammendments on soil AS, DR, SSI and Ks

Ammendment	AS (%)	DR (%)	SSI (%)	Ks (cm/h)
K	13.54b	56.39a	19.87b	1.07c
B	20.09a	48.52b	21.63b	4.06a
C	22.09a	47.71b	22.62b	2.89b
B+C	24.18a	45.53b	25.66a	3.49ab
F value	14.02**	19.88**	12.63**	46.47**

** statistically significant at 0.01 level

5. CONCLUSION AND RECOMMENDATION

This study aimed to investigate the effect of biochar and/or compost on the hydro physical properties of soils affected by different salts. The objectives were to assess the impact of sodium and other salts on the various properties of soil and also to study the effectiveness of organic amendments in reclaiming the properties of salt-affected soils. The results obtained in this study provided valuable insights into the impact of sodium and other salts like Ca, and Mg on various properties of soil and also the effectiveness of biochar and/or compost in improving the soil properties and water availability in salt-affected soils and revealed the significant influences of different salt affected soils and amendments on the various soil properties measured.

Sodium salt was found to be a more harmful salt as compared to other calcium and magnesium salts as sodic and saline-sodic soil showed a negative impact on the soil properties. Sodic and saline-sodic soil was found to have higher EC, ESP, and lower OC, CEC, Aggregate stability, Structural stability index, and saturated hydraulic conductivity. A higher dispersion ratio was obtained for sodic and saline-sodic soil which was attributed to the high sodium concentration leading to dispersion.

The application of biochar and compost either solely or combined observed a significant positive impact on the overall soil properties measured. The application of biochar and compost led to notable changes in soil pH, with biochar increasing pH values and compost decreasing them. Organic amendments resulted in reduced EC levels, possibly due to improved soil structure and enhanced salt leaching. The organic carbon content, CEC of the soils was significantly increased by all amendments, indicating an enhanced capacity for nutrient retention and exchange. The amendments also played a crucial role in reducing ESP, with the combined biochar and compost treatment proving the most effective in lowering exchangeable sodium percentages.

Bulk density and Total Porosity were positively affected by the amendments, suggesting improved soil structure and reduced soil compaction enhancing water-holding capacity, and improved soil aeration. The amendments also reduced dispersion ratios, indicating improved soil stability and reduced susceptibility to erosion. Aggregate stability and structural stability index were positively influenced by the amendments indicating improved soil structure, with the combined biochar and compost treatment exhibiting the highest values. Saturated hydraulic conductivity

values were also improved by the biochar and compost, indicating enhanced water flow through the soil. Furthermore, the application of biochar and/or compost positively impacted field capacity, permanent wilting point, and plant available water, indicating improved water retention and availability for plant growth. Thus, biochar and compost were found to be effective organic amendments in reclaiming the hydro physical properties of salt-affected soil. The combination of biochar and compost also showed a positive synergistic effect on soil properties. Overall, the findings of this study demonstrate the substantial benefits of organic amendments in enhancing soil quality and water dynamics in salt-affected soils. These findings support the use of organic amendments as a sustainable approach to mitigate soil salinity issues and improve agricultural productivity in such environments.

It is important to consider the specific characteristics of each soil type and select appropriate amendments accordingly. Long-term monitoring and field-scale trials are recommended to assess the persistence and long-term effectiveness of these amendments. Additionally, further research is needed to explore the impact of organic amendments on other important soil properties and nutrient dynamics.

In conclusion, the knowledge gained from this study contributes to our understanding of sustainable soil management practices and provides practical implications for farmers and policymakers seeking to enhance soil fertility, water availability, and agricultural productivity in salt-affected areas. The findings of this study serve as a foundation for future research and have the potential to positively impact sustainable agriculture and soil management practices in salt-affected regions.

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CURRICULUM VITEA

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Publications :

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2. Begum, M; Gulser, C., and Parajuli, S. (2022). *How do salt stress affect the plant growth?* In R. Kızılkaya, C. Gulser, O. Dengiz (Eds.), *International Soil Science Symposium on Soil science and Plant Nutrition* (pp. 1-6). Samsun: FESS
3. Parajuli, S., Shrestha, B., Dulal, P.R., Sapkota, B., Gautam, S., and Pandey, S., (2020). Efficacy of Various Insecticides against Major Insect Pests of Summer Squash (*Cucurbita Pepo*) in Dhading District, Nepal. *Science Heritage Journal*, 4(1): 35-42.
4. Pandey, S., Parajuli, S., Oli, B., Dhungana, S., (2020). Effect of different doses of boron on growth and yield of offseason cauliflower (*Brassica oleracea* var. Botrytis) in Arghakhanchi, Nepal. *Reviews in Food and Agriculture (RFNA)* 1(1) (2020) 12-17
5. Sapkota, B., Tripathi, K. M., Parajuli, S., Gautam, S., Adhikari, G., Sharma, B., & Bhandari, S. (2020). Economic analysis and resource use efficiency of carrot production in Chitwan district, Nepal. *Journal of Agriculture and Natural Resources*, 3(2), 218-227.

6. Gautam, S., Tiwari, U., Sapkota, B., Sharma, B., Parajuli, S., Pandit, NR., Gahire, YK., Dhakal, K. (2022). Field evaluation of slow-release nitrogen fertilizers and real-time nitrogen management tools to improve grain yield and nitrogen use efficiency of spring maize in Nepal. *Heliyon*, Volume 8, Issue 6, 2022, article e09566.

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1. Erasmus Mundus Joint Master Degree Scholarship fully-funded by European Union (2020-2022). Merit Based Scholarship,
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