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# BIOCHAR EFFECTS ON FERTILITY OF SALINE AND ALKALINE SOILS (NAVOIY REGION, UZBEKISTAN)

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## ABSTRACT

Alkaline and saline soils and their management are challenging issues in agricultural lands of arid and semi-arid regions and in other parts of the world as well. In order to maintain saline and alkaline soil fertility, understanding of the effects of organic amendments such as biochar is of interest. A short-term pot study was carried out to investigate the effect of biochar application on alkaline soil, its impact on soil properties, and to assess whether biochar has a positive or a negative effect on alkaline soils. In this study four soil treatments were investigated: soil only (control) and 20, 25, 30 g biochar per kg of soil, respectively.

The biochar used in this study was obtained from wood (apple tree woody waste) by pyrolysis at 450$^{o}$C, 4 hours. Total C, N, S, O, H, pH, ash, and moisture content of the biochar were measured in this study. The apple-wood biochar was alkaline (pH 8.67), with a high carbon content (75%) and low ash content (0.12%).

In the second part of the study, the influence of biochar on the soil physico-chemical properties was measured 8 months after application. The results showed a significant increase in total C content and organic matter (OM) content ($p< 0.01$) with an increasing biochar application rate. The C:N ratio increased in 25 and 30 g/kg applications. However, water retention ($p<0.01$), bulk density and cation exchange capacity (CEC) did not increase with biochar application within the study period.  All obtained results revealed that apple-wood biochar increased C and OM content, but soil alkalinity increased as well.

**Keywords:** Biochar, soil fertility, agriculture, alkaline and saline soils, dry and arid regions.

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# 1. INTRODUCTION

Soils that are alkaline and salt-affected are widely distributed throughout the world. About one-third of all soils in the arid and semiarid regions' agricultural lands are affected by some degree of salinity (Brady & Weil 2010). These soils are found in Australia, Latin America, Africa, and notably in Central Asia (Brady & Weil 2010). The economy of most regions located in arid and semi-arid regions is based on agriculture. However, the alkaline characteristics of these soils are highly adverse to the fertility of these lands. Understanding the process of alkalinisation and salinization therefore is important in the management of productivity and sustainability of agriculture.

"Alkalization" is the process of increasing concentrations of sodium ions on the exchange complex ions in soil (Magistad 1945). This process is accelerated by other soluble salts such as magnesium and chloride, and minerals such as gypsum are accumulated closer to the soil surface. Generally, saline and alkaline soil formation is related to geographical, geological and climatological conditions. Human activities such as irrigation, fertilization, poor drainage systems and mismanaged agriculture greatly contribute to accelerating this process. Most alkaline soils are located in flat areas that have the greatest capacity for agricultural because these lands are easy to irrigate and cultivate. The upper soil horizons in these areas of limited moisture and low rainfall are most vulnerable to salt formation and modification of soil pH. Thus soil salinity and alkalinity have been a problem in densely settled agricultural arid regions for many years. Year by year, the continuous salt effect on soil has led to soil organic matter depletion, crop productivity loss and soil degradation (Merry et al. 2002).

## 1.1 Fertility limitations of saline and alkaline soils

Alkaline or saline soils are usually described as infertile with low organic carbon (Brady & Weil 2010). High values of pH, exchangeable sodium and the sodium adsorption ratio are characteristic of alkaline soils. These affect the microbial activity and soil microbial biomass causing changes in soil respiration, especially when the soil is dry (Wong et al. 2008 ; Li et al. 2012; Mavi et al. 2012). Alkali conditions increase soil organic carbon mineralization and bulk density. Soil salinity and high soluble salt concentration can increase flocculation of aggregates and thus break down soil structure (Wong et al. 2010). Organic matter plays an important role in forming soil structure. In high alkali conditions, organic matter starts to decline and soil structure will be destroyed. When soil loses its coherence and cohesion it becomes more vulnerable to erosion and degradation. All the above factors undermine development of plant growth and reduce crop productivity. The ions increase pH and osmotic pressure and limit uptake of adequate nutrients from soil for plant growth. Albeit, there are some crops that have been observed to be dry and highly salt tolerant, for example: barley, cotton, olive, rye, and wheatgrass (at 8-12 dS $m^{-1}$) (Brady and Weil 2010; FAO 2007). They grow mainly in semi-arid regions. Furthermore, plant survival rate depends on the concentrations and type of salt ions. Nevertheless, there are some risks for all crops that grow in salty and alkaline conditions (Pearson 1967): 1) A high osmotic pressure due to increasing soil pH which makes water intake from soil by plants difficult; 2) Some valuable minerals unavailable for plants such as iron; and 3) A high ion concentration of minerals leading to nitrogen deficiency.

There is also the problem of low organic matter input due to less vegetative cover and lack of moisture in semi-arid region's soil. A high pH and high concentration of soluble salts can have adverse effects on plant growth and living organisms such as earthworms and microbes (Owojori & Reinecke 2009). All this leads to low soil fertility and reducing crop quality.

## 1.2 Fertility issues related to alkaline and saline soils in Uzbekistan

The Republic of Uzbekistan is located in Central Asia, with a total area of 448,900 km$^2$. Agricultural areas occupy a quarter of the total territory of Uzbekistan. The backbone of Uzbekistan's economy is agriculture; one-third of the annual GDP is obtained from this sector. The country ensures the demands of a rapidly growing population by growing crops such as cotton and wheat (Abdullaev et al. 2009). However trends within the field crop sector over the last decade indicate that the total irrigated area used in agriculture has declined 2.1% and total arable land has declined 15.7% from 2000 to 2007 (FAOSTAT 2009). For example, cotton and other crop productivity have declined over the past decade (CACILM 2006). Research has shown that under cotton monoculture without applying fertilizers the organic matter content has decreased by 30 - 40% and soil microflora are being depleted (Karajeh et al. 2002). The loss of fertility in irrigated lands has resulted in decreasing the productivity of the land and making it uncultivable. One the other hand, the population and demand for agriculture products have been growing fast. According to the World Bank (World Bank 2014), the population growth (annual %) in Uzbekistan was 2.69% in 2011. In order to produce more, a lot of effort has been made. For instance, in the irrigated lands of the republic, the 8-10 tonnes of manure applied per hectare are not nearly sufficient to provide a positive balance of organic matter in the soil (Karajeh et al. 2002). To maintain such a balance, it is necessary to apply at least 15 tonnes ha$^{-1}$ of organic fertilizer. Excessive application of mineral fertilizer to the soil leads to salt accumulation and fertility loss. The process of losing soil fertility will increase and create many problems unless sustainable approaches are carried out.

The main drivers of soil fertility depletion in this region include:

i. Waterlogging
ii. Salinization due to secondary salinization
iii. Water erosion
iv. Harsh climatic conditions
v. Insufficient input of organic fertilizers
vi. Mono-cropping of cotton and wheat (agricultural mismanagement)

Firstly, in about one third of the irrigated lands of Uzbekistan the groundwater table is less than 2 meters down (CACILM 2006). The groundwater table can easily rise up during the hot summer and rainy seasons and unsustainable agricultural practices could contribute to this fluctuation. Salt accumulation is observed in the soil pores while the groundwater rises and soil salinization is being accelerated during the hot summer. In order to remove the salty layer from the topsoil, washing with fresh water is usually carried out in agricultural lands and the salty water is then collected in drains. However, in poorly constructed drainage systems, the water can easily move to the groundwater. As a result of evaporation of the water, secondary salinization is been occurring in the area.

Secondly, water erosion causes topsoil loss in agricultural lands and has been increasing at the same rate as soil salinization. In Uzbekistan, severe soil erosion is estimated to describe a notable amount of irrigated croplands or 800,000 ha (Gintzburger et al. 2003).

Another factor accounting for the decreasing soil fertility is the geographic and harsh climatic conditions of the republic. More evaporation than precipitation and limited water resources have led to degradation (UNCCD 1999; Gintzburger et al. 2003). Climate, particularly temperature and precipitation, have been proposed as important factors in determining the rate of organic carbon decay as well. Around 60% of the carbon released from the soil is due to soil degradation (Lal 2007). Harvesting, intensive agriculture, irrigation, erosion, and deep percolation are some of the other factors by which soil loses its nutrients. A combination of the above factors leads to losses in soil fertility.

Nowadays, many new technologies have been applied in agricultural fields. At the same time prices of mineral fertilizers have been rising in Uzbekistan, and globally, over recent decades. Thus, it is necessary to develop more economically viable fertilizer means, including organic fertilizers made from animal and plant wastes. In particular, bone meal, animal manure and sludge are great source of nutrients. However, the efficiency of some of these fertilizers has not been sufficiently quantified and they may have environmental side effects. Moreover, excessive rates of mineral fertilizer application have gradually decreased organic matter in the soil (Abdullaev et al. 2009). Additionally, mineral fertilizer application efficiency is not high due to the hot climate and water limitation in arid and semi-arid regions. Researchers have investigated the high rates of $N_2$, $N_2O$ and NO emissions from irrigated cotton fields due to insufficient irrigation water (Scheer et al., 2009). An alternative fertilizer strategy is biochar application, which has recently been characterised as a multi-effective soil amendment. When biochar is applied with other fertilizers, research suggests that it works as a stimulator and increases the efficiency of mineral fertilizer application (Blackwell et al. 2010).

### 1.3 Biochar

Organic carbon (C) is an important component for soil and its formation. In the last few decades, biochar, an alternative source of organic carbon, has compelled the attention of many scientists with its benefits as a sustainable nutrient source for soil fertility maintenance and replenishment**.** Biochar is produced by the pyrolysis of agricultural waste materials such as wood, sewage, green waste, poultry litter, peanut hulls, pine chips, waste water sludge, rice husks, paper pulp and other organic wastes (Cao & Harris 2010; Hu et al. 2013). At first this term was used for soil that has variable quantities of highly stable organic black carbon waste (‘biochar’). This type of soil is mainly found within the Amazon-basin called “Terra preta” (Lehmann et al. 2003; Glaser et al. 2002). This soil is extremely productive and not similar to any other soil type. Since the recognition of “Terra preta”, the effect of biochar on crop yields and soil properties has been discovered over time (Major et al. 2010; Jeffery et al. 2011) but biochar is still not fully studied, for example, in alkaline soils.

Biochar alkalinity, particle size, and surface area are different depending on the pyrolysis methods and type of product used (Bruun et al. 2012; Yuan et al.2011). The highly porous structure and large surface area of biochar can provide “shelter” for soil micro-organisms such as microbes which live in the plant rhizosphere, and increase macro-nutrient availability, soil aeration and hydrology of the soils (Bohn et al. 2002; Downie et al. 2012; Hardie et al. 2014). Furthermore, biochar has been shown to increase cation exchange capacity (CEC) and organic carbon content, increase plant growth (Chan et al. 2008; Beesley et al. 2014; Carvalho et al. 2014), improve soil structure, reduce soil $N_2O$ emission, (Glaser et al. 2002; Yanai et al. 2007; Chan et al. 2008; Cao et al. 2011; Hu et al. 2013; Ahmad et al. 2014) and moderate nutrient leaching loss (Lehmann et al. 2003; Güereña et al. 2013) in the soil. Unlike other soil amendments, biochar can stay in the soil for many years and sequester carbon from the atmosphere because of its surface area (Kuzyakov et al. 2009).

Previous studies have shown that wood biochar application increased soil pH, K, Ca, Mg, Mn and nitrate in acidic soils (Asai et al. 2009; Major et al. 2009; Novak et al. 2009; Masulili & Utomo 2010; Carvalho et al. 2014; Criscuoli et al. 2014). Biochar application had improved soil aggregation and CEC (Cation Exchange Capacity), and an estimated increase in $CH_4$ flux and Karhu et al. (2011) also showed an 11% increase in water holding capacity and a significant effect on soil fertility by increasing water retention in biochar amended soil (Laird et al. 2010). Furthermore, biochar has a positive impact on soil biology (Kuzyakov et al. 2009; Verheijen et al. 2010). Soil-biochar interaction has been shown to enhance the accessibility of added C to microorganisms and enzymes and Chan et al. (2008) have shown that that it enhances earthworm and microbial biomass and stimulates root exudation by increasing nutrient availability for soil biota (Lehmann et al. 2011). The positive effects have mainly been attributed to biochar's ability to absorb plant nutrients (Glaser et al. 2002) and to increase soil water retention (Bruun et al. 2014; Hardie et al. 2014). All above mentioned researchers have studied the effects of biochar on tropical acidic soils.

In recent years, a few research studies have been carried out on the effect of biochar on alkaline and sandy soils (Shen et al. 2008; Blackwell et al. 2010; Xia et al. 2011; Liu & Zhang 2012; Song et al. 2014). Song et al. (2014) showed that low rates of biochar additions do not significantly impact the pH of the alkaline soil. Further, high CEC, increased by biochar application, might control the soil salinization process in agricultural lands (Liu & Zhang 2012). Some authors also found that biochar is a beneficial soil amendment which increases moisture retention and the effectiveness of fertilizer use and moderates drought stress at critical stages in arid environments (Blackwell et al. 2010; Van Zwieten et al. 2010).

Biochar application experiments have been carried out on different soil types and under varying conditions. For example, Ippolito et al. (2012) showed the immobilisation of mineral N in *Alfisol*, a typical agricultural soil with low organic matter, by applying additional nitrogen (100 kg N $ha^{-1}$). Novak et al. (2009) estimated that the application of biochar decreased S and Zn amounts in the acidic coastal soil of the southern United States. They also found that CEC was not affected by biochar in this type of soils.

The effect of biochar incorporation is also influenced by soil type and other environmental conditions. Biochar can be applied to a multitude of soils within various climates and agricultural systems but may improve nutrient retention and crop yields in one particular system. It is therefore noticeable that the literature reports both the potential benefits and also drawbacks of applying biochar. For example, the decreasing of the soil surface albedo has been estimated by increasing the application rate of biochar (even the lowest application) by Verheijen et al. (2013). This means that the soil temperature will increase. As a result of the condition, might soil microbes will increase or vice versa.

The following are concerns about the application of biochar in alkaline soils:

i. High pH makes minerals unavailable for plants (Brady & Weil 2010).
ii. Increasing alkalinity and nitrification (DeLuca et al. 2009)
iii. High alkalinity might decrease fertilizer (nitrate) efficiency (Song et al.2014).
iv. Dark coloured biochar might increase soil temperature (Meyer et al. 2012; Verheijen et al. 2013).

v. Biochar dust particles can cause explosions when the weather is hot, because of the quick oxygen and moisture exothermic absorption process (Blackwell et al. 2009).

Some studies show that biochar alkalinity depends on the temperature of pyrolysis and feedstock and the alkalinity of the biochar increases by increasing the temperature of pyrolysis (Yuan et al. 2011) as shown in Table 1.

**Table 1.** pH of biochar produced from various feedstock sources under different production temperatures

| Biochar feedstock | pH ( $H_2O$ ) | Production (°C) | Information source |
|---|---|---|---|
| Oak wood (*Quercus spp.*) | 4.8 | 350 | Nguyen & Lehmann 2009 |
| Oak wood (*Quercus spp.*) | 4.9 | 600 | Nguyen & Lehmann 2009 |
| Corn stover residue (*Zea mays L.*) | 5.9 | 350 | Nguyen & Lehmann 2009 |
| Corn stover residue (*Zea mays L.*) | 6.7 | 600 | Nguyen & Lehmann 2009 |
| Green waste | 6.2 | 450 | Chan et al. 2007 |
| Pea straw | 6.3 | 350 | Yuan et al. 2011 |
| Soybean straw | 6.3 | 350 | Yuan et al. 2011 |
| Canola straw | 6.3 | 350 | Yuan et al. 2011 |
| Wood (*Ponderosa pine spp.*) | 6.7 | 350 | DeLuca et al. 2009 |
| Rice straw | 6.8 | 350 | Yuan et al. 2011 |
| Beech wood (*Fagus spp.*) | 6.9 | 475 | Borchard et al. 2012 |
| Wood (*Eucalyptus deglupta Blume spp.*) | 7.0 | 350 | Rondon et al. 2007 |
| Bark (*Acacia mangium spp.*) | 7.4 | 260–360 | Yamato et al. 2006 |
| Pine chips | 7.5 | 400 | Gaskin et al. 2010 |
| Pecan shells | 7.6 | 700 | Novak et al. 2009 |
| Wood (*Mulga, Acacia aneur spp.*) | 7.6 - 7.8 | 700 | Zimmermann et al. 2012 |
| Peanut shells | 8.2 | 430 | Warnock et al. 2010 |
| Mixed softwood | 8.3 | 400 | Cornelissen et al. 2013 |
| Peanut shells | 8.3 | 360 | Warnock et al. 2010 |
| Peanut shells | 8.3 | 400 | Warnock et al. 2010 |

*Biochar in Uzbekistan*

Biochar application on Uzbek soils has not been studied yet. It is important to study the chemical and physical and biological effects of biochar soil amendments in alkaline soil conditions and also managing wastes. Some studies have showed biochar’s ecological benefits (Navia & Crowley 2010; Hossain et al. 2011) when made from sawdust, sewage sludge, animal manure, straw, hulls, chicken feathers, wastewater sludge and yard waste and other materials. In Uzbekistan a lot of agricultural organic wastes are produced every year. Especially, tree residue abundance occurs in the autumn. There is enough feedstock to produce biochar and prevent from using the dried stem of trees for fire by local people out of their needs. By using the organic wastes for biochar making would decrease methane and carbon dioxide emission from burning the waste materials in Uzbekistan.

### 1.4 Aims and objectives of the study

The purpose of this study was to investigate the effect of biochar application on alkaline soils and its impact on soil properties. The purpose of this research was to obtain a deeper understanding of the working mechanism of biochar in alkaline soils and to investigate the effect of biochar application on alkaline soils and its impact on soil properties. The following objectives were set up:

- To learn how to plan and carry out a biochar feasibility study
- To assess the effects of biochar application on the physical and chemical properties of alkaline soil.
- To characterize selected physical and chemical properties of the biochar

## 2. METHODS

### 2.1 Study site

Soil samples were collected 100 km from the airport in the Navoi region, Western Uzbekistan. The site is located in the central desert, the central channel of the Zarafshan River in the Kyzilkum Desert (40°5'55.87"N and 65°11'6.92"E). The total area of the region is 110.8 thousand square kilometres: 10.1 million hectares of agricultural lands with 10 million hectares of pasture lands and 91.6 thousand hectares of irrigated areas (Ahmedov 1999). There are more than 7500 farm enterprises in the province. The region has a flat topography from 300 to 400 m above sea level. The main agricultural sectors are cotton, grains, vegetable and melon production, and sheep and silkworm breeding.

#### *2.1.1 Climate of study area*

The climate of the region is continental and semiarid. Summers are dry and hot. The mean annual air temperature is 34°C and the mean minimum temperature -3.3°C in winter. The lowest temperature occurs in January. The annual precipitation ranges from 250 to 350 mm. (Akhmedov 1999).

#### *2.1.2 Soils of study area*

The soils of the sampling site were Calcic Yermosols (FAO 2003) with low organic matter content (<1.1-1.2%). This soil type is found on the high and flat zones within the region and it is the most common soil type in the Navoi region, although natural climate conditions may lead to formation of different soil types, as shown in Fig. 1.

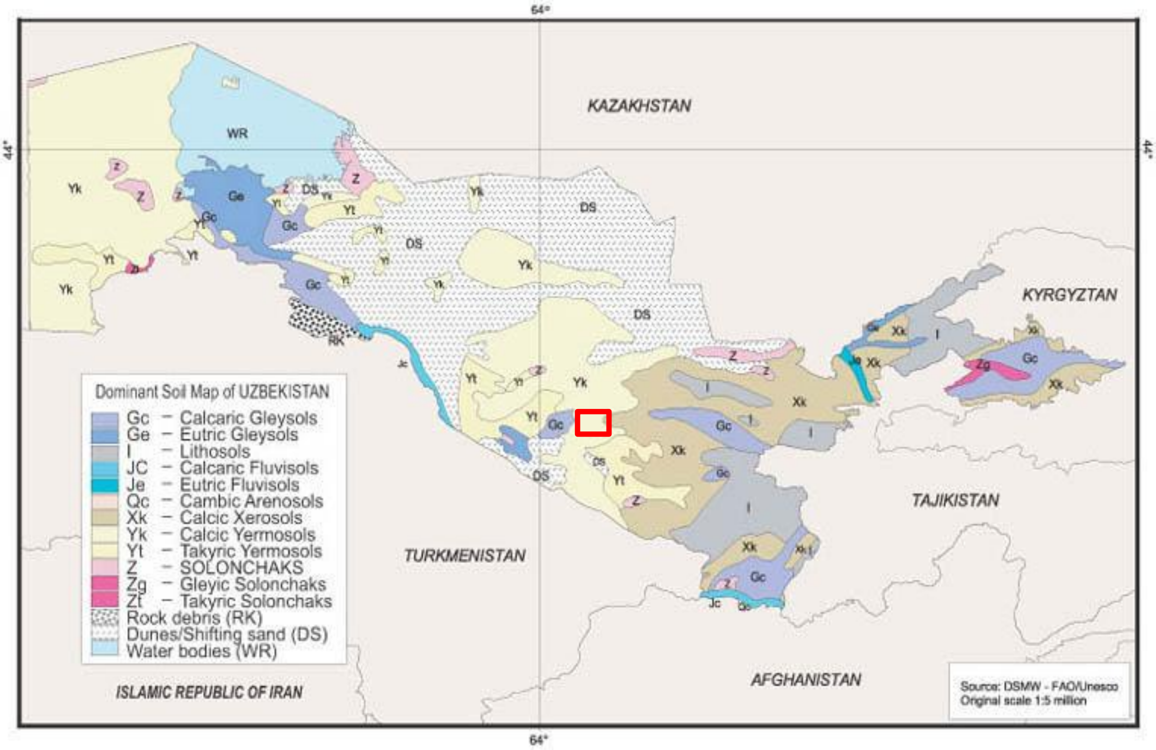
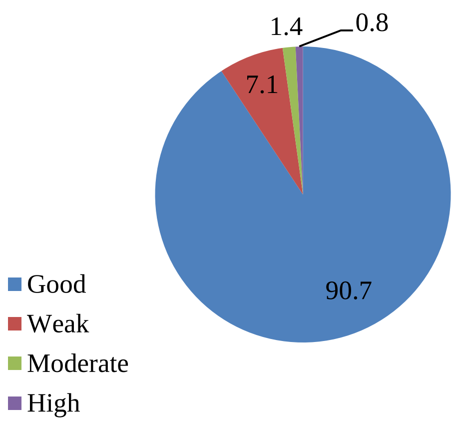
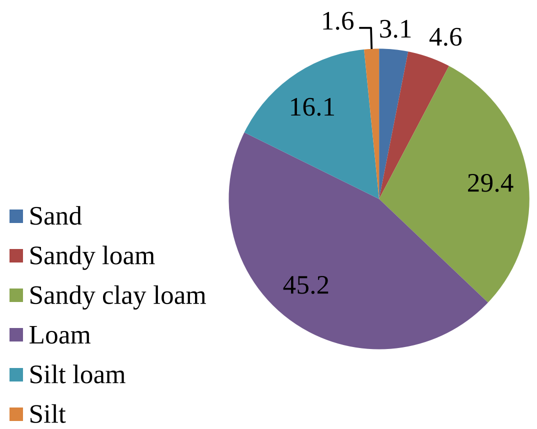



Figure 1. Dominant soil map of Uzbekistan. Sampling location is outlined by a rectangle. (DSMW-FAO & UNESCO 2003)

The majority (74.6 %) of the region's soils are silty loam and sandy clay loam (Fig. 2). The soils of the agricultural lands are more prone to erosion, including water erosion which mostly occurs on sloping sites. Most of the arable land in this region is affected by erosion: slightly eroded (43.8 %), moderately eroded (40.0%) and highly eroded (16.2%). The formation of gypsum is rapid in the irrigated lands of this region and it negatively affects water circulation in the soil.

<table>
<tr><th>Erosion in irrigated lands, %</th><th>Mechanic properties of irrigated lands, %</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Salinization ratio in irrigated lands, %</td><td>Quality and productivity of irrigated lands, %</td></tr>
</table>

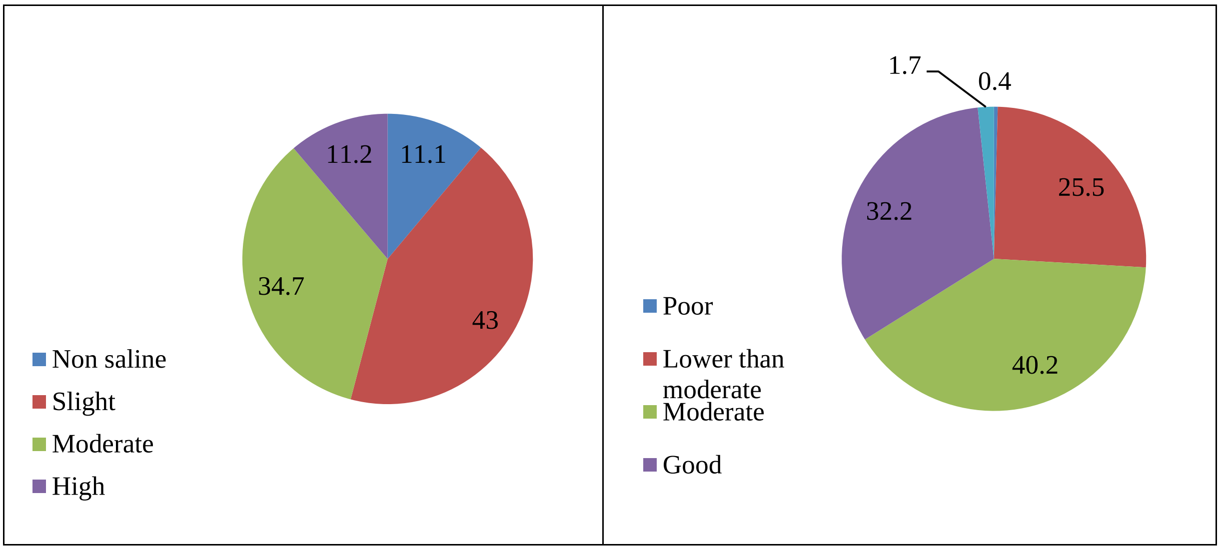



Figure 2. The condition and quality of irrigated lands of the Navoi region (Ministry of the Environment and Natural Resources of Uzbekistan, 2012)

## 2.2 Design of the experiment

The experimental soil was collected from the arable layer (0–25 cm). The soil was then used to establish a pot experiment on October 5, 2013, at the National University of Uzbekistan. One kilogramme soil was placed in each of four pots and a different amount of biochar (from apple-wood feedstock, see below) was added to each, corresponding to 3 biochar application rates and a control:

1. (C) = Control - soil only, no biochar
2. (SB-20) = 20 g biochar per kg of soil
3. (SB-25) = 25 g of biochar per kg of soil
4. (SB-30) = 30 g of biochar per kg of soil

The treatments were kept in room temperature and watered once a week. On March 7, 2014, half of the soil from each pot was brought to Iceland and the experiment was continued there in 500-mL plastic containers containing 500 g of soil. The samples were first kept at room temperature for two weeks, then at +11°C for a month and finally at +4°C and watered once a week. Permission was obtained from the Icelandic Ministry of Industries and Innovation (Atvinnuvega og nýsköpunarráðuneytið) for conducting analyses at the Agricultural University of Iceland and at the Soil Conservation Service of Iceland.

To produce the biochar, 2 kg of apple tree wood were chopped into 10 cm pieces and heated at 450ºC for 4 h in a beaker covered with a metal lid in a well-ventilated area.  The cover was used to create an oxygen-reduced condition. After pyrolysis, the biochar yield was left standing at room temperature overnight. Then the biochar was removed from the beaker and crushed using a broad hoe.

### *2.2.1 Soil analysis*

Samples for bulk density were taken from each pot using an auger and then analysed as outlined in Burt, 2004. The rest of the soil was divided into two parts, air-dried and field moist, for specific soil analyses. One part was air-dried at 30$^o$C and then sieved (2 mm) and the <2mm portion was collected for soil analyses. The other part, the field moist portion, was sieved and used to determine water holding capacity.

Soil water holding capacity was identified by the pressure plate method at 33 kPa, 100 kPa and 1500 kPa (Burt 2004; Pressure Plate Extractor).

The soil pH (water) method was adapted from Blakemore et al. (1987); air-dried soil (<2mm) was used. Organic matter (OM) was determined by loss-on-ignition. For each treatment, 3 g air-dried soil were dried at 105$^o$C overnight and then burned in a furnace at 500$^o$C. This was done in triplicate for each soil sample.

Soil (<2mm) was ball milled then used for total C, N and CEC analyses. Total C and N was determined by combustion at 900°C using a vario MAX CN analyser (Elementar Analysensysteme GmbH). CEC was determined by the ammonium acetate extraction method at pH 7 (Blakemore et al. 1987).

### *2.2.2 Characterization of biochar*

Biochar pH was measured according to Ahmedna et al. (1998). The method consisted of preparing a 1% suspension of biochar in deionized water. The suspension was heated to approximately 90ºC and stirred for 20 min to allow dissolution of the soluble biochar components. After cooling to room temperature, the pH of the biochar suspension was measured using a pH meter.

Moisture and ash content of the biochar were measured using a gravimetric method (Novak et al. 2009). First, 1 g of biochar was dried overnight at 105°C then transferred to a muffle furnace and combusted at 760°C for 6 h.

The C, N, O, S and H content were analysed by thermal combustion and elemental analysis (Thermo Scientific EA Flash, Thermo Fisher Scientific, Milan, Italy).

### *2.2.3 Data analysis*

The data were analysed by Analysis of variance (ANOVA) with Tukey’s studentized range test (HSD) using the SAS program to determine the significance of differences between treatments. A p-value less than 0.01 was considered significant and less than 0.001 as highly significant.

# 3. RESULTS

## 3.1 Biochar properties

The results showed that the apple wood biochar was alkaline and had a high carbon content and low ash content (Table 2). The atomic ratios of O/C, H/C and (O+N)/C were calculated from the biochar analytical data and are also shown in Table 2.

**Table 2.** Chemical and physical properties of apple wood biochar and atomic ratios were used in the experiments. Mean values with the standard deviation (SD) are presented.

| **Properties** | **Results** | **SD** | **Analytical procedure** |
|---|---|---|---|
| pH ($H_2O$) | 8.67 | 0.01 | 1: 100 hot water suspension, 90 $^oC$ |
| Ash (g/g) | 0.118 | 0.001 | Muffle furnace, 760 $^oC$, 6 h |
| Moisture (g/g) | 0.0053 | 0.0190 | Gravimetry 105 $^oC$, 24 h |
| C (%) | 74.96 | 0.007 | Combustion, 950°C, elemental analysis |
| N (%) | 0.57 | 0.11 | Combustion, 950°C, elemental analysis |
| S (%) | 0.09 | 0.03 | Combustion, 950°C, elemental analysis |
| O (%) | 14.97 | 0.15 | Combustion, 1060°C (Oxygen configuration), elemental analysis |
| H (%) | 2.83 | 0.08 | Combustion, 950°C, elemental analysis |
| O/C | 0.14 | 0 | Calculated value |
| H/C | 0.45 | 0 | Calculated value |
| (O+N)/C | 0.16 | 0 | Calculated value |

## 3.2 Soil properties

The OM content increased with the increasing biochar application rate compared to the control and the application rate of 30 g per kg of soil gave the highest OM value (Table 3). The increasing biochar application rate was also associated with increasing pH but when the mean values were compared individually, only the 25 g biochar per kg addition showed a significant pH increase ($p<0.01$) compared to the control (Table 3). The total C value was significantly different in biochar-amended samples compared to the control. The total N input by biochar was not observed in this study (Table 3). Soil bulk density was not influenced by biochar within this study period.

**Table 3.** Physical and chemical properties of soils treated with apple-wood biochar (450$^o$C) used in a pot experiment $p< 0.01$ pH (mean with standard deviation)

| **Physic and chemical properties** | **C** | **SB - 20** | **SB – 25** | **SB - 30** |
|---|---|---|---|---|
| pH | 8.075 ± 0.005 | 8.26 ± 0.03 | 8.375 ± 0.005 | 8.15 ± 0.02 |
| C (%) | 3.6 | 4.2 | 4.7 | 5.0 |
| C, calc.,without biochar, (% C ) | 3.6 | 3.5 | 3.1 | 3.4 |
| N (%) | 0.108 | 0.111 | 0.113 | 0.121 |
| C/N | 25.61 | 25.72 | 29.72 | 31.75 |
| OM (%) | 1.18 ± 0.08 | 1.49 ± 0.05 | 1.50 ± 0.11 | 1.58 ± 0.08 |
| Bulk density (g cm-3) | 1.71 | 1.60 | 1.64 | 1.74 |
| CEC (cmol/kg) | 15.7 | 11.5 | 13.2 | 11.4 |
| AWC (%) | 18.51 | 18.77 | 20.21 | 19.36 |

The CN ratio increased in the SB-25 and SB-30 samples by 4.11 and 6.14, respectively compared to the control (Table 3). The CEC of the soil did not change at all rates of biochar in this study. There was no significant difference in water holding capacity between the treatments (Fig. 3). Based on the water holding capacity the results for available water content (AWC) were calculated (Table 3). .

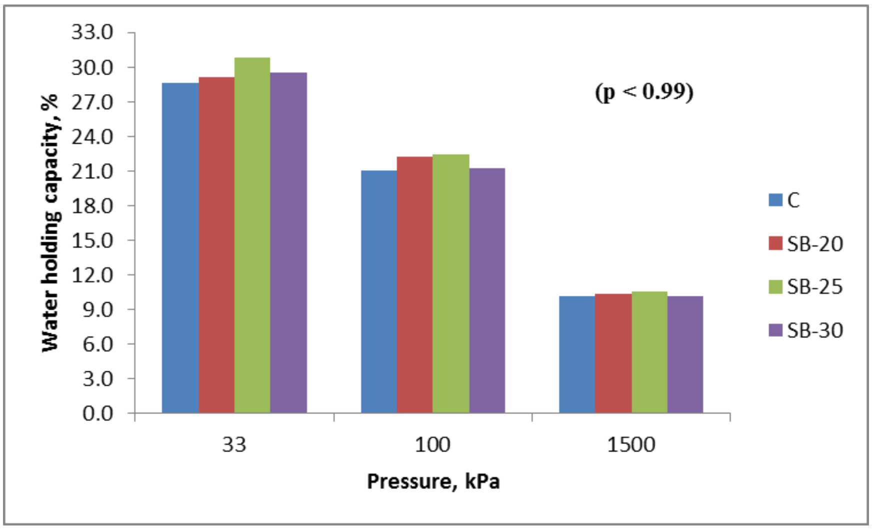



Figure 3. Water holding capacity of soils treated with biochar: SB- 20-soil (20 g biochar per kg soil), SB -25 (25 g biochar per kg soil), SB-30 (30g biochar per kg soil) and C (control).

# 4. DISCUSSION

## 4.1 Biochar characterization

The purpose of this study was to investigate the effect of biochar application on the physical and chemical properties of alkaline soils. The apple-wood biochar used for this study had a high C content (75%) and low ash content (11.8%) (Table 2). A few studies have shown that biochar produced from wood has a high C content (Lehmann et al. 2003; Atkinson et al. 2010). The biochar had a high C content, which is likely to have been due to its slow pyrolysis temperature and feedstock. A slow pyrolysis (lower temperature for a longer time) also results in higher biochar yields compared to biochar that is pyrolysed under high temperature (Bruun et al. 2011). Chaterene et al. (2011) showed that properties of biochar depend on feedstock. For example, wood biochars contain 62–79% carbon and 4–23 wt.% ash while switch grass and corn stover biochars contain low carbon (22–43%) and high ash contents (44–73 wt.%) at the same temperature. Recent research studies reveal that during the pyrolysis process biochar may be contaminated by by-products (organic and metal contaminants) and ash (Lucchini et al. 2014). If biochar is highly polluted with by-products this may lead to different heavy metals accumulation in the soil and increase its bioavailability. The results of this study showed that the ash content of the apple-wood biochar was 11.8% (0.118 gram ash per gram biochar), which is very low (Table 1). In this study, the biochar pH was high (8.67) (Table 2), or similar to the reported values of other biochars produced at 400$^{o}$C and higher pyrolysis temperatures (Gaskin et al. 2008; Gaskin et al.2010; Zwieten et al. 2010). Trends in the literature suggest that higher pyrolysis temperatures may produce biochars with a higher pH (Table 1). Low pH biochar application might be needed to stabilize the pH of the alkaline soils.

Criteria to assess biochar properties and qualities have been proposed by the European Biochar Certificate (EBC) (Glaser 2013) but are not yet accepted by any national legislation as official methods within the EU. The EBC defines some elemental limits, such as a total organic carbon content >50% and O/C and H/C ratios <0.4 and 0.6, respectively. The results obtained from the present study can be compared with EBC criteria: O/C, (O+N)/C and H/C ratios were low; 0.14, 0.16 and 0.45 respectively. Low O/C (<0.4) and H/C (<0.6) ratios indicate that the carbon is likely to be aromatic and therefore less easily decomposed (Krull et al. 2009). The molecular configuration of the carbon contained in biochar will affect its decomposition in the soil and how long it will be present in the soil (Lehmann, 2007). The low ratios indicate that the biochar carbon structure is very stable and likely to be recalcitrant (long-lasting) and has good carbon sequestration potential (Krull et al. 2009; Mankasingh et al., 2011). Slow decomposition leads to a decrease in $CO_2$ fluxes. Other studies showed that biochar, produced under lower pyrolysis temperature, is most polar with high O/C and O+N/C ratios (Novak et al. 2009), which may affect water holding capacity and movement of nutrients and some heavy metals (Pb, Cd, Zn) in the soil (Cao et al. 2009; Ahmad et al. 2012).

### 4.2 Biochar effect on soil properties

The results of this study gave an indication of the effect of biochar on alkaline soil. Organic matter and C (Table 3) appeared to increase with an increasing biochar rate but the C content of treated soils minus added biochar (calculated C content, % C, Table 3) suggested that there is no overall net accumulation of carbon in the soil. During the period of study, no manure, mineral fertilizer or plant residues were added to these treatments; this means that there was no additional OM input. These results also indicated that application of biochar might have promoted microbial activity - this needs further study. Domene et al. (2014) also showed that the effect of different rates biochar increased OM and C content; both organic and inorganic C contents increased in semi-arid region soils (Fernandez et al. 2014). This was also observed in this study.

For soil health and fertility C and N content, and their proportions to each other, are the most important factors. The results of the CN analyses showed that there was an increase in total C, N and the CN ratio. The CN ratio only increased with application rates of 25 g and 30 g. because carbon content in soil was increased by biochar application. Other research results suggest that biochar is more effective when added with mineral fertilizers. Results from Zwieten et.al (2010) showed that the total carbon in Calcarosol (pH = 7.67) was significantly increased from 2.03% to 2.73% (without fertilizer), whereas Ferrosol (pH=4.20) did not significantly increase in total C (0.5%). Also, biochar with urea ($CO (NH_2)_2$) applied to the soil showed a lower pH than soils amended with only biochar (Chaterene et al. 2011); this could be explained by the process of nitrification of the urea.

Although, many studies show an increase in water holding capacity after biochar application (Karhu et al. 2011; Major et al. 2012; Tammeorg et al. 2014), this pot study showed no significant increase in water holding capacity after 8 months. While comparing results, it is easily noticed that an application rate, soil porosity and type of soil are play major role in changing water-holding capacity. According to Tammeorg et al. (2014) 5-20t $ha^{-1}$ biochar had not sufficient to improve the water-holding capacity of soil. Also, many experiments conducted in a field with plant growing condition (Karhu et al. 2011) as it is known that plants are important for soil moisture.

In this study a slight fall in CEC was reported. The result could be connected to some factors such as the fact that the soil type used for analysis was rich in sulphate ($SO_4^-$) and chloride ($Cl^-$) anions. Therefore the CEC might have been decreased by the increasing application rate. Further, biochar had increased the pH of all treatments, so that CEC was decreased. Nevertheless, Liang et al. (2006) reported that biochar increased the CEC of Anthrosols with increasing OM. In this study OM was not high enough to raise the CEC.

The effect of biochar on biota was not investigated in the present study, but Gomez et al. (2013) studied soil microorganisms with biochar amendment under similar soil conditions (pH 8.3-8.7) to those of this study and they found a positive stimulation of biochar to microbial activity and plant growth. It also helps to know about the C decomposition rate.

Biochar price and efficiency must be assessed, because if large scale farmers want to use biochar on their farms a great deal of biochar is needed, which would be expensive for them. However, farmers could produce their own biochar because the benefits of biochar applications overweigh the high price. Biochar is not approved as a fertilizer for field application, although some farmers are using it in their gardens in some parts of the world, e.g. the United Kingdom, where it is sold as a commercial fertiliser in garden shops for use in horticulture, home gardens and greenhouses.

# 5. CONCLUSIONS AND RECOMMENDATIONS

Biochar derived from apple-wood and obtained by slow pyrolysis was alkaline (pH 8.67) and contained 75% C and 12% of ash content. The ratios of O/C, (O+N)/C and H/C were all low, indicating that the biochar decomposition rate is not high and therefore this biochar is likely to be rather stable in the soil. Soil organic matter increased with increasing biochar application rates. Short term biochar application (8 months) did not have an effect on the water holding capacity and CEC of the alkaline soils in this study. Application of alkaline biochar to alkaline soils in this study resulted in the soils becoming slightly more alkaline, so application rates of alkaline biochar alkaline soils should lower.

The results presented above suggest that biochar temperature and feedstock should be chosen according to soil type because the pH of the biochar is dependent on those factors. Low pH biochar should be obtained for application to alkaline soils. Wheat straw and green waste could be the best feedstock for Uzbekistan conditions because they can be used to make acidic biochar (pH 5-6) and there is enough of this feedstock in the country.

Many articles have pointed out that biochar has a positive impact on soil microbial activity. Therefore, the effect of biochar on alkaline soil biology must be identified. Measuring microbial activity such as microbial respiration will help to identify the $CO_2$ emission rate and the total C fluctuation in the soil.

It can also be recommended that a larger number of replicates are needed for such a study as this will give more reliable results with greater statistical confidence than in this study. Furthermore, a study period longer than 8 months might give different results than this study because the process of C turnover into soil carbon and soil physical property improvement takes a longer time (Brady & Weil 2010).

The optimum biochar application rate should be identified. Based on the present study, a biochar application at rate of 25 g $kg^{-1}$ would be recommended as the starting application for any further studies in using biochar to improve soil properties in alkaline soils. Future studies should also focus on application of mineral and organic fertilizers in combination with biochar.

Biochar price and efficiency must be assessed, because if large scale farmers want to use biochar on their farms a great deal of biochar is needed and this could be expensive for them. However, farmers could produce their own biochar using small-scale low cost units, as the benefits of biochar application overweigh the high price.

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